Long Term Ecological Research Network

20 Years of Research

* AND Andrews Forest LTER
* ARC Arctic Tundra LTER
* BES Baltimore Ecosystem Study LTER
* BNZ Bonanza Creek LTER
* CAP Central Arizona-Phoenix LTER
* CDR Cedar Creek LTER
* CWT Coweeta LTER
* HBR Hubbard Brook LTER
* HFR Harvard Forest LTER
* JRN Jornada LTER
* KBS Kellogg Biological Station LTER
* KNZ Konza Prairie LTER
* LUQ Luquillo LTER
* MCM McMurdo Dry Valleys LTER
* NTL North Temperate Lakes LTER
* NWT Niwot Ridge LTER
* PAL Palmer LTER
* PIE Plum Island Ecosystem LTER
* SBC Santa Barbara Coastal LTER
* SEV Sevilleta LTER
* SGS Shortgrass Steppe LTER
* VCR Virginia Coast Reserve LTER

AND Andrews L T E R

Riparian Zone Research

Riparian zones are important habitats for many economically important species. Restoration of these ecosystems, by adding logs, retaining tree cover, and other practices are key elements of a strategy to improve habitat for commercial fishes such as salmon. Members of the H. J. Andrews LTER have developed many of these new practices; studying the processes that control how forests and streams interact has lead to the discovery of the role of forest cover in controlling water temperatures, woody debris as a habitat, and the contribution of earthflows and floods to spawning habitat. Many of these findings ran counter to older management practices, such as the removal of in stream woody debris. New research is testing the effects of adding woody detritus to streams on salmon and trout rearing and spawning habitat. Insights from this work will tell managers which habitat structures work and why. This will help Pacific Northwest salmon recover and to be managed in a sustainable way that revives revenues of a multi-million dollar industry.

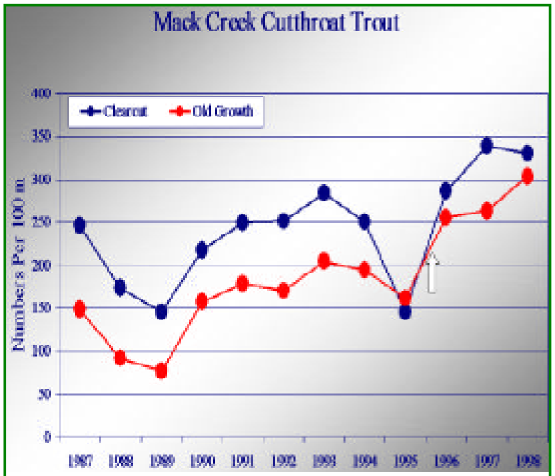

Figure 2. Annual variations in cutthroat trout from one of the longest time series of record in western USA

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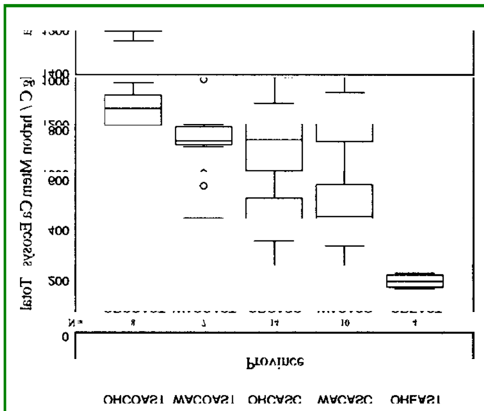
Carbon Dynamics Research

Concerns about increases in greenhouse gases and their potential effects on global climate have lead to an interest in both slowing down the release of fossil fuels and increasing the rates that natural ecosystems, such as forests, remove them. Recent work by the H. J. Andrews LTER has examined the role of Oregon's forests as a source/sink of carbon dioxide to the atmosphere. Combining field measurements, ecosystem models, and remote sensing these studies have indicated that forest practices have released a substantial amount of carbon dioxide into the atmosphere in the past 50 years. However, our research also indicates there is considerable potential to reverse this trend and make the region a significant national level carbon sink. By altering forest harvest practices, increasing the length of time between harvests, and reclaiming former forestlands these studies indicate current carbon stores could be almost doubled without reducing the volume removed for forest products. Even using low carbon credit values that have recently been discussed ($10 per metric ton stored), this doubling of the Pacific Northwest's forest carbon stores could generate up to $25-100 billion in the next 50 years.



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Natural Hazards Research

Natural hazards, especially landslides, floods, fire, windthrow, and insect outbreaks cause many millions of dollars in damage and civil litigation in Oregon. Is the frequency of these events increasing? Is there a positive side to these disturbances? Long-term observations of climate, streamflow, and landslides conducted by the H. J. Andrews Long-Term Ecological Research Program have allowed researchers to determine how often, where, and under what conditions natural hazards occur. For example, in the past 50 years three extreme floods with associated landslides have occurred in western Oregon. These were associated with warm rain falling on deep snowpacks, a combination that produces extreme floods and episodes of landsliding. As for increasing the frequency of floods and landslides, forest harvesting and road construction over the past 50 years appears to have increased the potential of large floods, although flood-protection dams have mitigated actual damage. Research has also shown that recently created clearcuts and roads have a higher rate of landsliding than undisturbed forests in western Oregon. This has obvious implications for the location of housing and roads so as to minimize human risk. While floods, landslides, fire, windthrow, and insect outbreaks are often characterized as "disasters" they are natural processes which have many ecological benefits, including adding large wood, rocks, and gravel to provide aquatic habitat in streams and creating patches of young vegetation which provide habitat for animals and birds.

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ARC Arctic LTER

Arctic LTER Terrestrial Component

Repeated observation and sampling of long-running experiments allows us to determine whether the initial magnitude and trajectory of ecosystem response to environmental change is sustained over the long term, and to examine interactions among slow- and fast-responding components of overall ecosystem change. Repeated observation also allows us to interpret long-term change in response to our manipulations in the context of long-term "normal" or "background" variation in ecosystem states and processes. For example, in the summer of 2000 we completed our fifth harvest of a 20-year old fertilizer experiment (the 6th harvest of control plots for this experiment). After 20 years it was clear that fertilized plots were distinctly different from control plots, not only in terms of their total production and biomass, but that they also differed functionally in terms of the relationships between productivity, leaf mass, and leaf area (Fig. 5). Remarkably, leaf mass in the fertilized plots was significantly lower than in the controls in both 1995 and 2000, while productivity in the fertilized plots was more than double that of controls. How is this possible? The main reason for this result is that the fertilized plots are not strongly dominated by dwarf birch, Betula nana, which has much thinner leaves (i.e., a much higher specific leaf area). Because birch has thin leaves, it can produce more than twice the leaf area of controls with a lower total leaf mass. This leads also to very different overall pattern of canopy and aboveground N allocation, with a much more efficient photosynthetic return per unit canopy N (Shaver et al. in press). It also allows much greater proportional allocation to woody stem growth, greatly increasing both the height of the canopy and the total aboveground biomass (Bret-Harte et al. 2001, submitted). This interpretation of the causes and implications of a change in plant functional type composition is radically different from earlier hypotheses (e.g., Chapin and Shaver 1985) and would not have been possible without long-term experimental evidence.

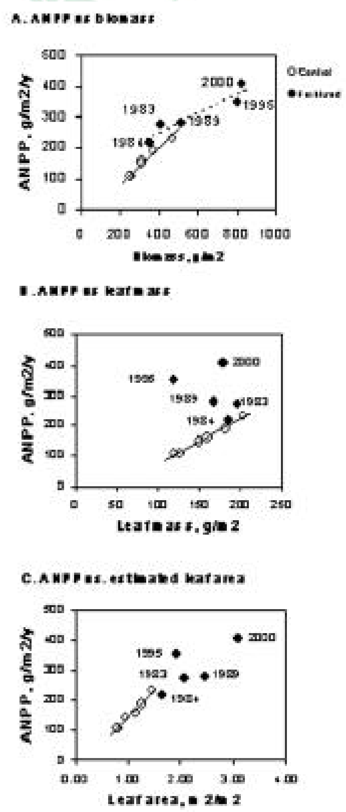

Fig. 5. Aboveground net primary production in fertilized and control plots in moist acidic tussock tundra at Toolik Lake, 1982-2000

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Arctic LTER Streams Component

In order to test the hypothesis that the low productivity of the Kuparuk was due to lack of nutrients rather than harsh winter conditions, cold temperatures and physical scouring of the rocky stream bottom, we started in 1983 a long-term experimental fertilization study of the Kuparuk River. Even in the first summer of the fertilization it was apparent that phosphorus addition during the summer stimulated biotic activity of all types in the river (Peterson et al.1985). Bacterial activity on both labile and refractory substrates was increased by phosphorus addition (Hullar and Vestal 1989). Diatoms on the rocks responded within a few days to the added phosphorus and within a few years insect abundance and fish growth were measurably affected by the addition (Peterson et al. 1993). Some insects such as black flies declined but others including Baetis and Brachycentrus increased (Hershey and Hiltner 1988, Hershey et al.1988), contributing to accelerated fish growth (Deegan and Peterson 1992).

After several more years of fertilization we debated stopping the experiment because we thought we might have already observed the full response. However we were wrong and to our surprise moss began to proliferate on rocks in riffles after 8 or 9 years of continuous summer fertilization (Bowden et al. 1992). Over the next several years a dense mat of the moss Hygrohypnum covered the majority of what had previously been bare rock habitat covered by a thin biofilm of bacteria and diatoms. Again the insect populations underwent dramatic changes with increases in chironomids and Ephemerella and declines in Orthocladius and Baetis. The effect of this recent transition in community structure on grayling is still unknown although surprisingly it does not yet appear to be large.

A second stream fertilization was performed in Oksrukuyik Creek starting in 1991. The pattern of response was similar to that observed in the Kuparuk with the exception that filamentous algae were more abundant in the fertilized reach than was observed in the Kuparuk (Harvey et al. 1998).

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Arctic LTER *Aquatic Research*

I. Far and away the longest monitored lake is Toolik Lake, which was first studied in 1975. (O'Brien et al. 1997). We have noted a variety of long-term trends in Toolik Lake. One is the warming of the mean July water temperature at 1 m for each year (Fig. 2); the overall trend is statically significant with the regression having a p value of 0.025. The "y" intercepts for 1975 versus 2000 indicate that, on average, the lake is 2(C warmer now than at the beginning of the study. (Hobbie et al. 1999). While even 25 years is too short a time to confirm arctic warming, these data are certainly consistent with such a warming trend. We have also noticed that the alkalinity of Toolik Lake water has increased (Fig. 3). This increase has not been linear but shows two spurts: one early in our study of the lake and then one much more recently with a cubic equation fitting the data with a remarkably low p value. Analysis of the precipitation chemistry shows that this increase is not due to increased salinity in the precipitation but is most likely coming out of the Toolik watershed, possibly due to deepening of the thaw layer above the permafrost. Another long-term trend in Toolik Lake we have noted is the reduction in size of lake trout. Early in the study in 1977, the median weight of lake trout was 578 g and by 1986 this was reduced to almost one-half (McDonald and Hershey 1989) of what it was (Fig. 4). By 1997 the median weight of lake trout was still 60% of the 1977 weight. This reduction in the size is doubtless due to the fairly heavy fishing pressure Toolik Lake has received and the very slow growth of lake trout. Our estimates of lake trout growth rate averages less than 5% increase yr-1 for adult fish.

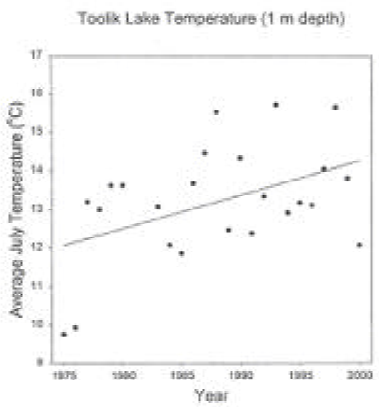

Figure. 2 July water temperature at 1 m for each year at Toolik Lake, Arctic LTER

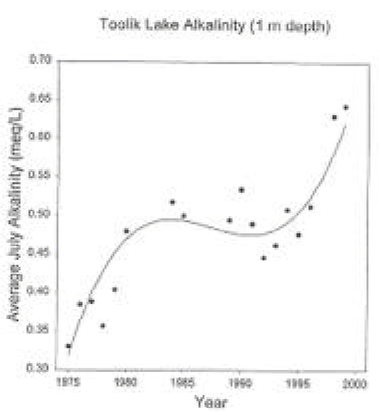

Figure 3. Non-linnear alkalinity increase of Toolik Lake water

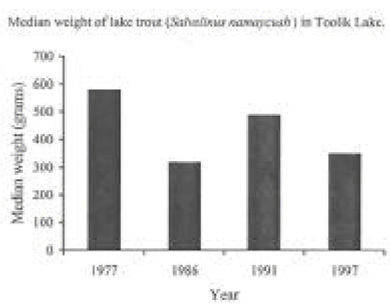

Figure 4.The reduction in size of lake trout in theToolik Lake study

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II. We have gained a great deal of understanding of the functioning of arctic lakes through a series of whole lake manipulations. One of the most successful experiments was dividing a lake with a polyethylene curtain and adding inorganic nitrogen and phosphorus for six summers to the down-stream sector of the lake (Hershey 1992). The nutrient loading levels were 2.91 mmols N m-2 day-1 and 0.23 mmols P m-2 day-1 which is five times the estimated nutrient loading of Toolik Lake (Fig. 5). The phytoplankton, as measured by chlorophyll a, responded positively to the nutrient addition, which began in 1985; each year the treated sector had significantly more phytoplankton than the reference sector. However, for the first four years of the experiment there was no carryover from one year to the next. That is, in the early summer both sectors looked the same and indeed had virtually identical chlorophyll levels even though the chlorophyll levels may have differed by as much as eight times at the end of the previous summer. The reason for this was that during the first four summers none of the added phosphorus was recycled from the sediments. This was verified through the use of benthic chambers, which can measure nutrient fluxes from the sediment. Some nitrogen did recycle early in the experiment but it was not until the fifth year of the experiment that any phosphorus was released from the sediment of the treated sector of lake N-2 (Fig. 6).

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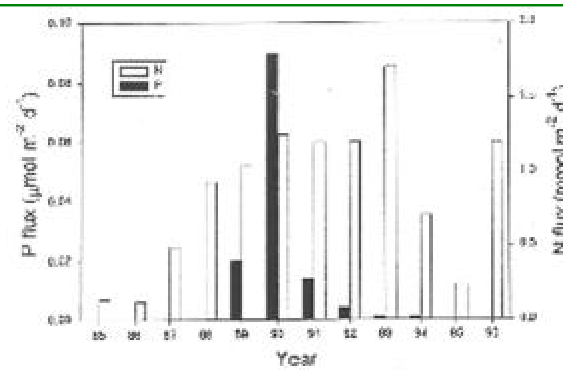

Fig. 5. The mean annual chlorophyll a density for the upper three meters of the sectored Lake N-2. The open bars represent the treated sector of the lake while the solid bars represent the reference sector of the lake. The asterisks under each year gives an indication of the level of significan difference between the treated and reference sector for that year.

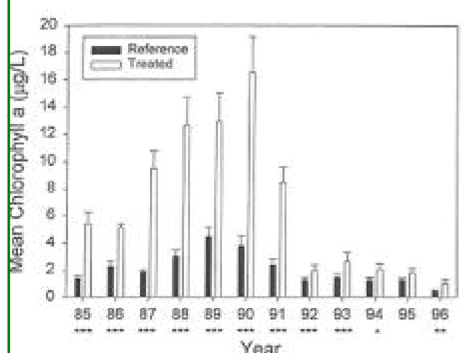

Fig. 6. Sediment flux of inorganic nitrogen and phosphorus from the treated sector of Lake N-2. The open bars represent the flux of nitrogen while the solid bars represent the flux of phosphorus.

BES
Baltimore Ecosystem Study LTER

Urbanization and Stream Chemistry: Temporal and Spatial Changes

The spread and intensification of urban land uses is among the most conspicuous of global changes. Because urban systems are so dynamic, long-term studies are crucial to understanding their ecological implications. The Baltimore Ecosystem Study - LTER has been under way for only a short time. But already the importance of long-term studies of effects and processes of urbanization are becoming clear.

Nowhere is this more apparent than in the loadings of pollutants in Baltimore's streams. We chose to study stream nutrient loading as one of the key aspects of urban ecosystems because streams integrate much of the complex interaction between biota, physical processes, socio-economic factors, and infrastructure. Our stream studies have focused so far on the 17,150 ha Gwynns Falls watershed.

The BES stream record spans two years, starting in 1998. Although this is just the beginning of a long-term record, some clear temporal and spatial trends are emerging. First, any site that supports urban or suburban development, or is managed by humans has higher nitrate and phosphate loading than the forested reference watershed. The small watersheds representing urban and suburban development have similar nitrate concentrations, while the highest nitrate loadings are from the agricultural watershed.

Comparing sites along the main stem of the Gwynns Falls stream showed that phosphate and nitrate were highest in the headwaters in suburban areas, but decreased downstream as the degree of urbanization increased. The very high levels of nutrient loading in the suburban site was unexpected, which prompted us to look not only at contemporary factors such as roads and lawn fertilization, but also to explore lags from prior agricultural land uses in areas that are now suburban. In addition, the pattern requires that the complex of factors that make up urbanization be examined through spatial comparisons of contrasting land covers, infrastructure, and human use, as well as measured into the future. This pattern is counter to conventional wisdom about urban streams and raises questions of infrastructural connections with the streams. Without long-term data, this pattern would not have appeared.

Retrospective studies are adding temporal depth to the two year stream quality data. Stream channel morphology is being measured and will be related to contemporary resampled biotic and chemical stream data from 23 sites in addition to those main stem and small watershed stations presented above. Although analysis of these data is not yet complete, the approach illustrates the power of long-term stream data to integrate urban ecosystem function.

This research has been conducted by a team of BES researchers representing several institutions:

Lawrence Band, University of North Carolina, Chapel Hill; Kenneth Belt, USDA Forest Service, Northeastern Research Station; Mark Colosimo, US Army Corps of Engineers; Gart Fisher, US Geological Survey;Peter Groffman, Institute of Ecosystem Studies

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BNZ
Bonanza Creek LTER

Fire-Permafrost Interactions in the Alaskan boreal forest Bonanza Creek LTER

Forest fires in the boreal forest produce an immediate effect on the surface energy and water budget by drastically altering the surface albedo, roughness, infiltration rates, and moisture absorption capacity in organic soils. This drastic change in land-cover initiates a long process of recovery and sometimes shifts in successional pathway, in which changes in permafrost play a key role. As transpiration decreases or ceases, soil moisture increases markedly throughout the year. The loss of the insulating organic layer during fires causes permafrost to thaw near the surface and warm to greater depths (Yoshikawa et al., In Press). Within a few years, it may thaw to the point where it no longer completely refreezse every winter, creating a permanently thawed layer in the soil called a talik. After formation of a talik, soils drain internally throughout the year (Hinzman et al., 2001), producing drier soils. The radical difference in soil moisture depending on presence or absence of permafrost influences successional trajectory. The wet soils found over shallow permafrost favor black spruce forests, whereas a deeper permafrost table (thicker active layer) favors birch or alder.

The discontinuous permafrost in interior Alaska is quite warm, -2 to 0°C. Permafrost is maintained by a negative radiation balance on north-facing slopes and by cold air drainage in valley bottoms. The surface organic layer is the most important factor controlling degradation or aggradation of permafrost. When the organic layer is removed, the albedo of the surface decreases from 0.35-0.5 to 0.10-0.25, and the soil thermal conductivity of the surface soil layer increases from about 0.2 to about 1.0 W m-1 °C-1. Removal of the surface organic layer initiates subsurface warming and sometimes thawing of permafrost. Removal of the organic layer above cold permafrost (-4°C average annual temperature) caused a 30% increase in active-layer thickness. The extent of permafrost warming depends on both the severity of surface disturbance and the time to re-establish the the organic mat, suggesting that fire severity and subsequent vegetation trajectory will strongly influence permafrost integrity in the zone of discontinuous permafrost.

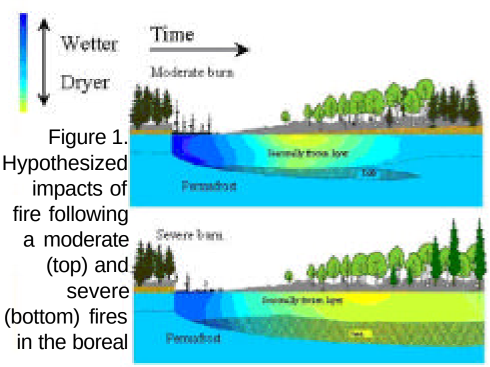

Figure 1. Hypothesized impacts of fire following a moderate (top) and severe (bottom) fires in the boreal

Permafrost distribution is even more sporadic than one would expect from thermal analyses. It appears that forest fires earlier in this century (probably those from 1920s) initiated a disturbance to the surface and caused substantial permafrost degradation in isolated occurrences. This has significant implications on the long-term impact of forest fires. If, under the existing climate, the surface disturbance caused by fire initiates wide-spread degradation of permafrost, then substantial changes to the boreal forest ecosystems will certainly follow. Additional research needs to verify if permafrost will continue to degrade after disturbance in this area, or if it will recover in time (Hinzman, 2000).

Bonanza Creek LTER—Plant species richness is greater in boreal forest disturbed by wildfire than by logging.

Fire and logging are the two major disturbances in upland boreal forests of North America, which is a largely disturbance-driven ecosystem. Fire has long played a crucial role in the ecology of the boreal forest of Interior Alaska represented by Bonanza Creek LTER, and many plants species depend upon this disturbance for their survival. On the other hand logging only started in interior Alaska about 1900. Forest managers need to know to what degree disturbance by logging does or does not create effects similar to fire. Studies of logging in the boreal forest of Scandinavia have documented major declines in a number of plant and animal species as the result of widespread, intensive timber production and the nearly complete suppression of wildfire.

Organic layer thickness was significantly greater on logged sites compared to burned sites overall and at each stage of early post-disturbance regeneration. Burned sites (all stages combined) supported more species (146) than logged sites (111), and more species at each stand development stage. Recently burned plots supported abundant cover of a few apparent fire specialist species that were present in only minor amounts on logged sites. Burned plots exhibited higher species turnover from stage to stage and among all stages than logged plots. Species dominant in young burned plots were nearly absent at later stages, while early dominants in logged sites were common mature forest species that increased in each subsequent stage

Greater soil organic layer depth in the boreal forest is associated with cooler soil temperatures, reduced nutrient availability, and lowered site productivity. Logged sites appear to begin and continue succession with a greater share of the original mature forest understory plants, while burned sites initiate succession with more distinctive and specialized plant species. Most of the species at risk of decline in abundance from logging compared to burning by wildland fire in central Alaska are associated with early successional conditions.

These results suggest that forest managers should consider broadcast burning of at least some logged sites. The benefits from this treatment would include sustained site productivity from soil warming rather than decreasing productivity from soil cooling, greater plant species richness, and greater abundance of fire-specialist species.

The Changing Role of Fire in Boreal Climate Feedbacks

In the boreal forest, the extent of wildfires is clearly linked to patterns of temperature and precipitation, with high-fire years associated with abnormally warm and dry conditions. The recent warming experienced throughout the North American boreal forest region has resulted in a doubling of the annual area burned at decadal scale between the 1960s and 1990s (Kasischke et al. 2000), with this trend most strongly developed in the most continental regions. During the past four decades, 55% of the total area burned occurred during six high fire years. Four of these high fire years have occurred since 1988.

Research at the Bonanza Creek LTER site demonstrates some of the ecosystem and climatic consequences of this dramatic change in fire regime. In most years, burning occurs prior to mid-July. However, during large fires years (e.g., 1997) fires continue to burn through August; these late-season fires account for 10% of the area burned. Late-season fires also consume a larger proportion of the soil organic mat, because soils are better drained later in the growing season when permafrost thaw depths are near their seasonal maximum (Kasischke et al. 2000). The greater depth of burning in late-season fires contributes to interannual variations in trace-gas emissions from the boreal forest region (French et al. in press) and strongly influences long-term soil carbon storage(Harden et al. 2000). High levels of organic mat consumption promote carbon loss due to both the direct consumption of organic matter and the warmer soil temperatures (Kasischke et al. 2000) and enhanced soil respiration that occurs for 10 to 25 years after the fire (O'Neill et al. in press).

Fire also influences regional climate through vegetation-mediated changes in water and energy exchange. Late-successional spruce forests have a lower albedo than post-fire deciduous shrublands and forests and transfer a larger proportion of this energy to the atmosphere as latent rather than sensible heat (Chapin et al. 2000). The net effect of these changes in energy exchange is that post-fire forests transfer less heat and more moisture to the atmosphere, leading to a cooler moister climate than if the vegetation change had not occurred. It also reduces convective heating and boundary layer development, which reduces the probability of thunderstorms that ignite fires. This climatic impact of fire-induced vegetation change is important because it is the only negative feedback to high-latitude warming that has yet been identified.

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Species Effects on Ecosystem Dynamics in the Boreal Forest

The Earth is in the midst of the sixth major extinction event in the history of life. Current extinction rates are estimated to be 100-1,000 times greater than pre-human rates. Climatic warming is occurring most rapidly in the boreal forest. This is almost certain to cause changes in species abundance, including both gains and losses of species (Chapin and Danell 2001). However, we have only a limited understanding of the impact of these future species changes on the functioning of ecosystems (Chapin et al. 2000).

Research at Bonanza Creek LTER demonstrates that the low diversity of boreal forests makes this system extremely vulnerable to species change. This is illustrated most dramatically through vegetation-induced changes in ecosystem processes through succession. Succession in interior Alaska is not a gradual linear change in ecosystem properties but is punctuated by a series of turning points initiated by changes in a single tree species and characterized by rapid changes in ecosystem controls (Van Cleve et al. 1991).

The shift from a physically dominated open shrub stage to a biologically regulated closed shrub stage is one of the most dramatic turning points in floodplain succession. The nitrogen that is fixed by alder at this time (Uliassi et al. in press) accounts for 60-70% of the total nitrogen that accumulates during the entire 200-year floodplain succession (Van Cleve et al. 1993). Later in succession, the shift from deciduous to conifer dominance allows the development of an insulating moss layer that cools the soil and reduces litter quality. The resulting decline in decomposition alters most soil physical and chemical properties in ways that promote the switch to conifer dominance. The processes that regulate the rate and pattern of succession are not unique to interior Alaska. However, the extreme physical environment and large expanses of areas that currently experience only modest levels of human impact provide a natural laboratory to explore the general principles that govern species effects on environment.

Species effects on fire regime further illustrate the importance of species effects on ecosystems. Early successional deciduous forests burn less readily than do spruce stands because the high water content of deciduous leaves in the canopy and understory vaporizes during fire and prevents temperatures from rising to a level that can sustain combustion and fire spread. Deciduous forests therefore act as a partial fire break until spruce becomes an important canopy component. Black spruce is born to burn. Its resin-rich, flammable needles and twigs have a high surface-to-volume ratio and provide ladder fuels that link the moss surface to the top of the canopy. The thick moss and organic mats that form beneath black spruce dry quickly during the warm, dry conditions that characterize the continental conditions of interior Alaska during mid-summer. Oxygen diffuses readily into the low-bulk-density moss mats during fires, promoting effective combustion. The combination of low-growing evergreen shrubs, mosses, and the underlying organic mat carry fire through black spruce forests. The semi-serotenous cones of black spruce open after fire, providing a regeneration capacity that is tightly tied to fire.

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Fine Root Dynamics and Whole-Stand Carbon Balance of Alaskan Black Spruce Ecosystems

Fine root growth typically constitutes more than half the annual net primary production of forested ecosystems. This proportion may be greater in high-latitude forests where low soil fertility and soil temperatures are the major factors limiting plant growth (Ruess et al. 1996, 1998). We recently combined minirhizotron estimates of fine root growth and dynamics (Ruess et al. 1998) with direct measures of root respiration (Burton et al., submitted) to estimate fine root contributions to whole stand carbon balance in black spruce stands along the Tanana River floodplain. Data from these black spruce stands, and other Alaskan forests we have investigated, show that mean life spans of fine roots in Alaskan boreal forests are not dissimilar from those reported for many temperate forests. Survival estimates of black spruce fine roots translate to mean life spans of 114 (4 days during growing season intervals, and very low survival over winter periods (0.47). Relative to other Tanana floodplain forest types, mean life span of black spruce fine roots is 20% greater than that of white spruce forests (MLS = 99 (2 days), and over 50% greater than that measured for early successional stands dominated by willows (MLS = 74 (3 days) (Ruess et al. 1998). So while variation in fine root longevity among Alaskan ecosystem types does not parallel the magnitude of differences in growth and phenological characteristics of aboveground tissues, there do appear to be significant differences in fine root life span that are correlated with other physiological/morphological growth traits.

We have also found that for fine roots decomposing during the growing season, those with longer life spans decomposed more slowly after death (see Figure). Our relationship shows that there was essentially no variation in decomposition rate among fine roots that lived less than a year, but that decomposition rate decreased appreciably after that. For example, roots that lived for 8 months decomposed 3 times as fast (50 days) as those that lived for 18 months (156 days).

Fine roots and bryophytes combined to account for 70% of total NPP (see Figure). Both soil (Q10 = 2.21) and fine root (Q10 = 2.30) respiration rates correlated positively with soil temperature, and roots conservatively accounted for approximately 57% of total soil CO_2 efflux. Rates of C and N flux through fine roots are several orders of magnitude faster than for AG tissues, emphasizing the importance of fine roots in element cycling in these systems.

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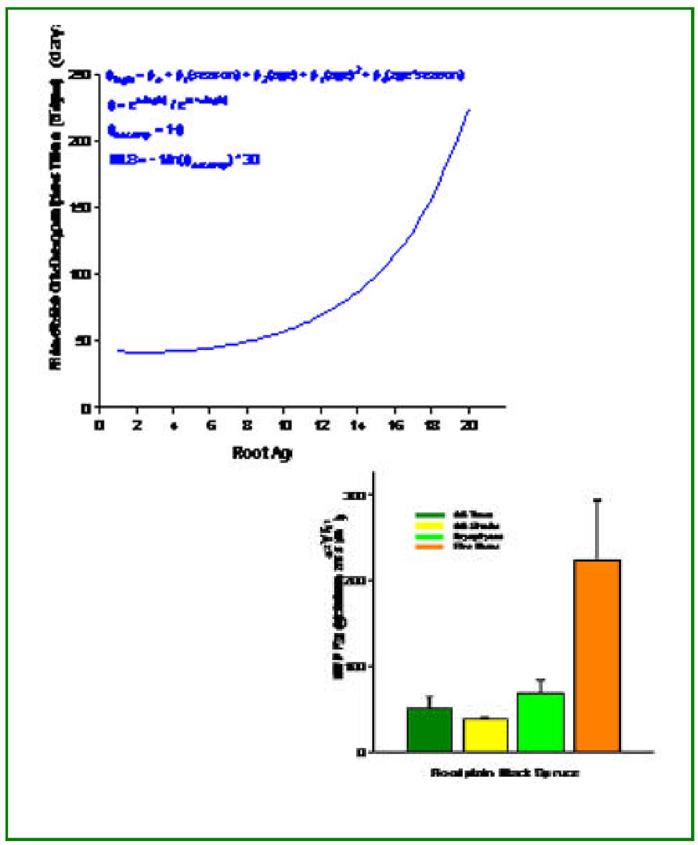

Bonanza Creek LTER—Recent High-Latitude Warming Reduces Forest Production.

The boreal forest is one of the world's largest biomes, totaling nearly 17% of the earth's land surface area. This cold northern region has warmed significantly in recent decades. Computer models of global climatic warming from greenhouse gasses project that some of the largest amounts of warming would occur in the boreal region. Nearly all models of climatic warming assume that tree growth, and thus uptake of the greenhouse gas carbon dioxide, will increase in the boreal forest under the warmer conditions.

White spruce is the dominant forest cover on about 25% of the Alaska boreal forest. Although white spruce occupies floodplains and cold treeline sites, much of this forest type in Alaska occurs on dry upland sites across low-elevation basins in the interior of the state. On upland sites in Interior Alaska, radial growth of white spruce is highly negatively related to summer temperature. In other words, it grows least in years with warm summers and most in years with cool summers. This is an unexpected finding, because treeline white spruce at the edge of the tundra have produced many important climate reconstructions based on the positive relationship between summer temperature and radial growth on those sites. The temperature control of white spruce growth in Interior Alaska is consistent throughout the entire period of Fairbanks climate record since 1906.

The negative relationship of radial growth to summer temperature is associated with temperature-induced drought stress as confirmed at Bonanza Creek LTER by three properties of tree-rings (1) ring-width, (2) 13C discrimination, and (3) maximum latewood density.
The period since the mid-1970s has been the longest sustained interval of warm summers in Interior Alaska, and lowest radial growth of white spruce. The mid 20th century was an usually favorable period of cool summers and high radial growth. Radial growth in the warm late 20th century is about half the level of the cool mid 20th century on a sustained basis. These results suggest that high-latitude warming and associated drying will not enhance carbon uptake and sequestration, in upland white spruce forests, as currently projected by global and regional models.

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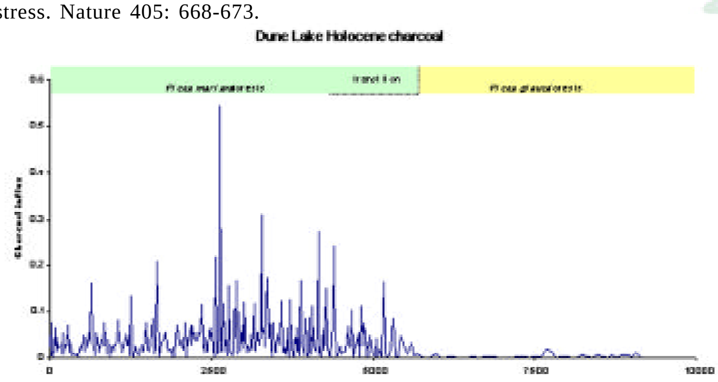

Charcoal influx at Dune Lake, Alaska. Data from J. Lynch.

Vegetation-Initiated Shifts in Holocene Fire Regime in Interior Alaska

Climate, disturbance, and vegetation composition have covaried throughout the Holocene. The causal relationships among those variables during periods of change have until recently remained unclear, however, because of the paucity of precisely dated high-resolution sediment records. However, simultaneous lake sediment records of lake level (an indicator of climate), charcoal, and vegetation have been obtained from Dune Lake in interior Alaska by the Bonanza Creek LTER, thus providing an opportunity to examine how these three variables have covaried during the Holocene. Sediment pollen records indicate that white spruce (*Picea glauca*) forests gave way to black spruce (*Picea mariana*) forests approximately 5,000 years ago. Bigelow (1997) found that lake levels began to rise immediately prior to the transition from white to black spruce, indicating that climate may have been the primary driver of the increased importance of black spruce in Alaska in the late Holocene. The shift to cooler, moister conditions would have been expected to favor low-intensity, infrequent fires. However, Lynch et al. (2001, in review) examined charcoal influx in Dune Lake, and showed that fire severity/frequency increased after the dominance of black spruce was established. In particular, they found that low influx in the early Holocene gave way to high influx from approximately 5000 years ago to present, and suggested that this indicated a change in fire regime from light, infrequent fires to frequent stand-replacing fires. Thus the change in vegetation to black spruce dominated forests seems to have initiated an increase in the importance of fire, despite a climatic change (towards moister, cooler conditions) that would have been expected to favor less frequent, less intense fires. These data demonstrate that vegetation is a more important determinant of fire regime in interior Alaska than is climate.

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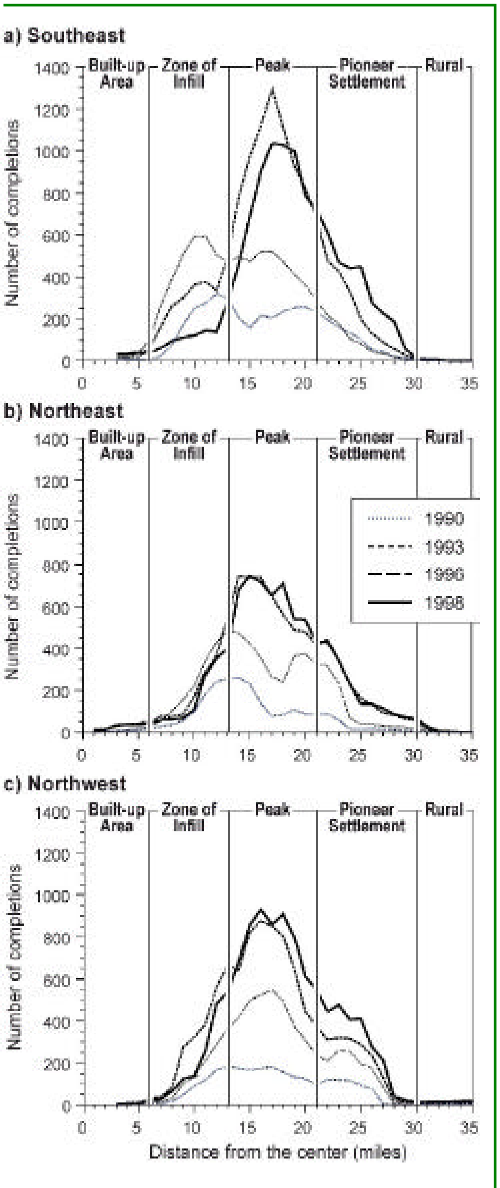
CAP
Central Arizona-Phoenix LTER

Among the significant discoveries resulting from the first three years of Central Arizona-Phoenix LTER studies, three stand out for their scientific generality and potential social relevance. In a comprehensive study of the nitrogen mass balance for the CAP ecosystem, it was found that anthropogenic sources far outstrip natural sources of N. More interestingly, the vegetation and soils in the city are likely sinks for retaining much of the enormous production of N from combustion-derived NOx production (Baker et al. in review). This detailed N mass balance is a first for an agro-urban ecosystem and is therefore a landmark effort. Such information can be used to help guide responsible use of commercial fertilizers by accounting for the use of high-nitrate content groundwater for irrigation.

A study of the growth of the Phoenix metropolitan area, determined that the spread of the city through the construction of new single-family houses at the periphery could be characterized by a "wave of advance" model (Fig. 1; Gober et al. 1998). Related studies are showing that this wave is instrumental in determining changes in key ecological variables such as microclimate, soils, and vegetation cover. The initial data for this came from county records but is now being supplemented by CAP LTER researchers who are using sequences of aerial photos to monitor land-use change in greater detail. At the same time our remote sensing team is developing a classification scheme to carry this study forward into the future in a more time efficient and comprehensive manner.

A third key study has looked at whether there is a systematic relationship between the distribution of environmental hazards and residential



location of minority groups or economically disadvantaged families. Examining both sources of toxic releases and patterning of air pollution, it is clear that ethnic minorities and the poor are exposed to greater environmental hazards (Fig. 2; Bolin et al. 2000). As the pattern of industry changes, however, this correlation may change as well. With the shift from traditional smokestack polluters to new economy chip manufacturers comes a greater tendency for polluters to be located in more affluent neighbor-hoods. Part of our study is looking at how local residents perceive these risks and the type of action they take to ameliorate the situation.

Due to the urban location of the CAP LTER, the results of these studies and many others are of immediate service to society. Understanding the ecological changes that accompany new housing and urban sprawl will allow for more rational city planning, while knowledge of nutrient sources and sinks in the urban environmental will lead to more efficient construction of infrastruc-ture. The insights we are gaining on the nature of environmental risks and how they are differentially borne by citizens will enhance city planning and possibly an enhanced quality of life. The CAP LTER project also offers a stimulating research and learning environment for a diversity of graduate students, postdoctoral associates, and K-12 schoolchildren. This year, we are expanding those opportunities through an IGERT graduate program focused on training professionals to work with issues of urban ecology. We have an extremely active K-12 program called "Ecology Explorers" that has worked with schoolteachers from throughout the urban area to enhance science and math education through inquiry-based, hands-on educational opportunities associated with our research project.

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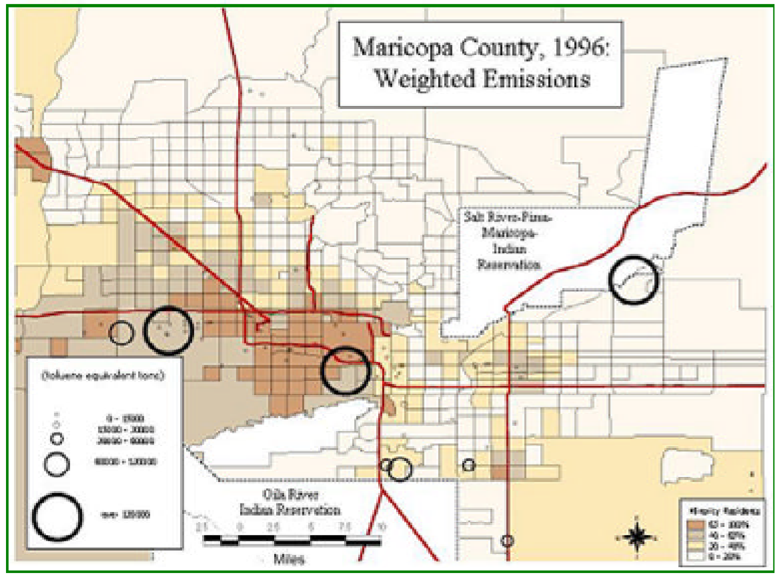

CDR
Cedar Creek LTER

Long-term research has been central to the major findings of the Cedar Creek LTER, including our work on biodiversity and ecosystem functioning. Our data on primary productivity and plant species abundances in 207 grassland plots, collected annually since 1982, provided the first well-replicated field data showing strong effects of biodiversity on ecosystem stability (Tilman and Downing 1994; Tilman 1996, 1999). These demonstrations that grasslands with greater plant biodiversity were both more stable when faced with a major drought and had less year-to-year variability in their productivity in response to normal year-to-year variation in climate (Figure 1) helped inspire a new wave of research on the potential effects of biodiversity on population, community and ecosystem processes.

This long-term result inspired two biodiversity experiments, now in their 8th year, in which we directly manipulated plant diversity in grassland plots (Tilman et al. 1996, 1997, 2001; Knops et al. 1999, Haddad et al. 2001, Naeem et al. 2001). These are the oldest and largest scale experimental studies of the population, community and ecosystem effects of diversity in existence. These experiments have shown that greater plant biodiversity leads to greater community biomass (Figure 2), to greater incidence of plant disease, to greater rates of invasion by other plant species, and to lowered insect diversity. These results and results of other studies have generated considerable debate concerning the mechanisms that might cause these relationships. In addition to the theories and mechanisms that have been suggested by many other investigators, we have developed several alternative mathematical theories relating biodiversity and species composition to stability (Lehman and Tilman 2000), and to productivity and resource use efficiency (Tilman 1999, Lehman and Tilman 2000). Our ongoing experiments are allowing us to test among these alternative hypotheses (e.g., Figure 2; Tilman et al. 2001).

In analyses of our most recent experiments, we have found that plant diversity and niche complementarity have had progressively stronger effects on ecosystem functioning with 16-species plots attaining 2.7 times greater biomass than monocultures by the 7th year of the experiment (Figure 2A, B). Diversity effects were neither transients nor explained solely by the presence of a few productive or unviable species. Rather, more than half of the higher-diversity plots outperformed even the single best monoculture plot (Figure 2C). These results help resolve debate over biodiversity and ecosystem functioning, show effects at higher than expected diversity levels, and demonstrate, for these ecosystems, that even the best-chosen monocultures cannot achieve greater productivity or carbon stores than higher-diversity sites.

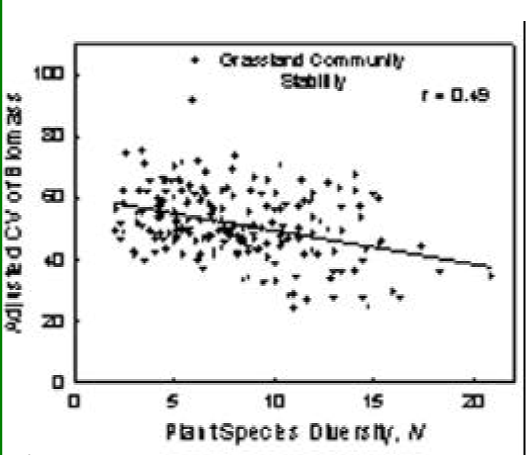

Figure 1.

In both our biodiversity experiment and in a study in native oak savannah we found that higher local plant diversity led to lower rates of invasion by exotic, non-native plant species (Knops et al. 1999). Analyses suggest that plant diversity had this effect because higher plant diversity lead to lower levels of limiting resources, and it was these lower resource levels that caused reduced invasion rates. We have also found that plant diversity has effects that ramify up the food web, influencing the diversity of herbivorous, predatory and parasitic arthropods (Haddad et al. 2001).

A second major theme of the Cedar Creek LTER is the effect of nitrogen, and nitrogen deposition, on grassland ecosystems (e.g., Wedin and Tilman 1996, Inouye and Tilman 1988). Long-term nitrogen addition experiments have shown that high diversity ecosystems dominated by native warm-season grasses shifted to low-diversity mixtures dominated by cool-season grasses within 15 years at all but the lowest rates of N deposition. This shift was associated with decreased biomass carbon C:N ratios, increased N mineralization, increased soil nitrate losses, and low C storage. Thus, grasslands with high N retention and C storage rates were the most vulnerable to species losses and major shifts in C and N cycling in response to elevated nitrogen deposition.

Figure 2. A

Figure 2. B

Figure 2. C

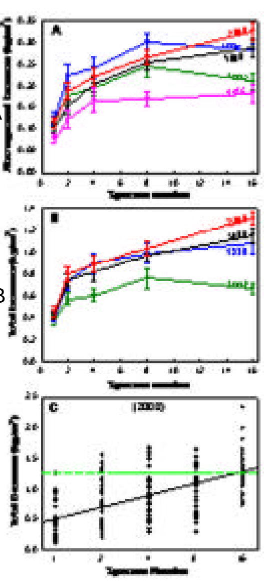
Figure 2.

Another major experiment combines our interests in the effects of biodiversity and of nitrogen deposition with an interest in the direct (non-climatic) effects of elevated atmospheric CO2. A major grassland field experiment, now in its fifth year, tests the hypothesis that plant diversity and composition influence the enhancement of biomass and carbon acquisition in ecosystems subjected to elevated atmospheric CO2 concentrations and nitrogen deposition. The study experimentally controls plant diversity (1, 4, 9 or 16 species), soil nitrogen (unamended versus deposition of 4 g of nitrogen per m2 per yr) and atmospheric CO2 concentrations using free-air CO2 enrichment (ambient, 368 ppm, versus elevated, 560 ppm) in a total of 360 field plots. We found (Figure 3) that the enhanced biomass accumulation in response to elevated levels of CO2 or nitrogen, or their combination, is less in species-poor than in species-rich assemblages (Reich et al. 2001).

In total, our on-going studies at Cedar Creek attempt to synthesize population, community and ecosystem processes to allow a more mechanistic understanding of the processes that determine the species compositions, dynamics, diversity and functioning of grassland and savannah ecosystems. Our work combines a highly experimental approach with long-term observations and with the on-going development of related theory and concepts.

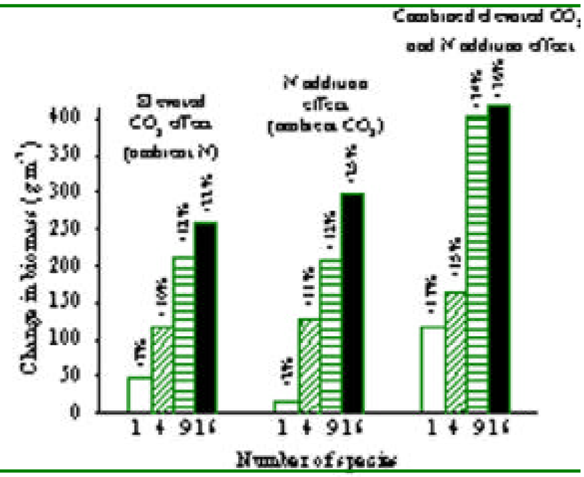

Figure 3.

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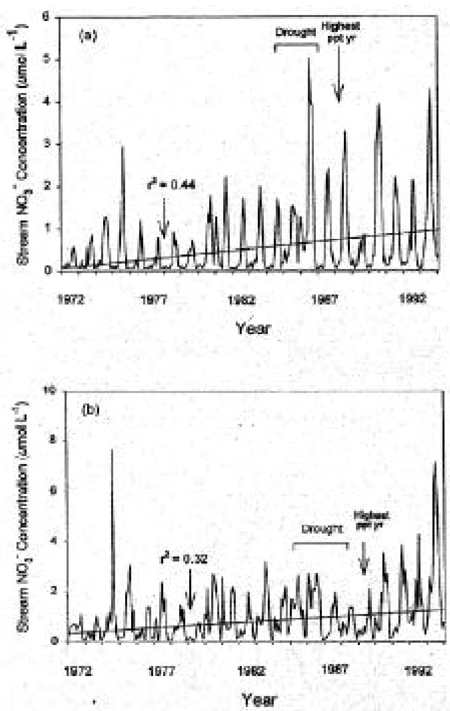
CWT
Coweeta LTER

We analyzed long-term data (23 years) of inorganic N deposition and loss for an extensive network of mature mixed hardwood covered watersheds in the southern Appalachians of North Carolina to assess trends and dynamics of N in baseline ecosystems. We also assessed watershed N saturation in the context of altered N cycles and stream inorganic N responses associated with management practices and with natural disturbances on reference watersheds. Reference watersheds were characterized as highly conservative of inorganic N with deposition <9.0 kg ha-1 yr-1 and stream water exports below 0.25 kg ha-1 yr-1. However, reference watersheds appeared to be in a transition phase between stage 0 and stage 1 of watershed N saturation as evidenced by significant time trend increases in annual flow- weighted concentrations of NO3- in stream water and increases in the seasonal amplitude and duration of NO3 concentrations during 1972-1994. These stream water chemistry trends were partially atributed to significant increases in NO3- and NH4+ concentrations in bulk precipitation over the same period and/or reduced biological demand due to forest maturation. Levels and annual patterns of stream NO3- concentrations and intra-annual seasonal patterns characteristic of latter phases of stages 1 and 2 of watershed N saturation were found for low-elevation and high-elevation clear-cut watersheds, respectively, and were related to the dynamics of microbial transformations of N and vegetation uptake. Evidence for stage 3 of N saturation, where the watershed is a net source of N rather than a N sink, was found for the most distributed watershed at Coweeta. Compared to other intensive management practices, prescribed burning had little effect on stream water NO3- concentrations, and stream NO3- losses associated with natural disturbances are small and short-lived.



Trends in stream water NO3- for (a) low- and (b) high-elevation (WS 36) watersheds. The regression line (p<0.01) was fit to annual means across the sampling period.

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Mean monthly concentrations (flow weighted) of NO3- in streamwater of WS7 and WS2 during calibration, treatment activities, and post-harvest periods, Coweeta Hydrologic Laboratory, Otto, NC.

Interpreting recruitment limitation in forests

Studies of tree recruitment are many, but they provide few general insights into the role of recruitment limitation for population dynamics. That role depends on the vital rates (transitions) from seed production to sapling stages and on overall population growth. To determine the state of our understanding of recruitment limitation we examined how well we can estimate parameters corresponding to these vital rates. Our two-part analysis consists of (1) a survey of published literature to determine the spatial and temporal scale of sampling that is basis for parameter estimates, and (2) an analysis of extensive data sets to evaluate sampling intensity found in the literature. We find that published studies focus on fine spatial scales, emphasizing large numbers of small samples within a single stand, and tend not to sample multiple stands or variability across landscapes. Where multiple stands are sampled, sampling is often inconsistent. Sampling of seed rain, seed banks, and seedlings typically span <1 yr and rarely last 5 yr. Most studies of seeding establishment and growth consider effects of a single variable and a single life history stage. By examining how parameter estimates are affected by the spatial and temporal extent of sampling we find that few published studies are sufficiently extensive to capture the variability in recruitment stages. Early recruitment stages are especially variable and require samples across multiple years and multiple stands. Ironically, the longest duration data sets are used to estimate mortality rates, which are less variable (in time) than are early life history stages. Because variables that affect recruitment rates interact, studies of these interactions are needed to assess their full impacts. We conclude that greater attention to spatially extensive and longer duration sampling for early life history stages is needed to assess the role of recruitment limitation in forests.

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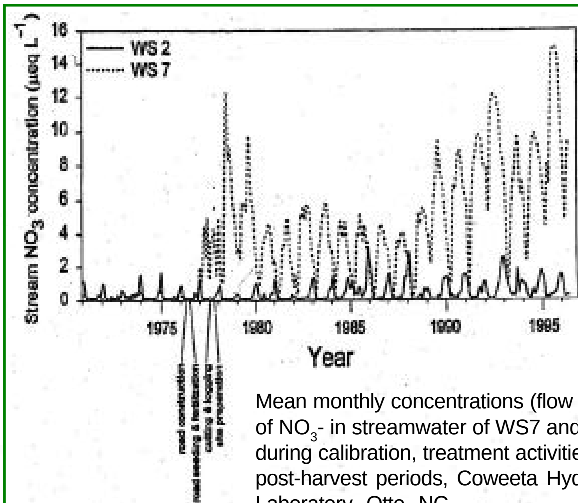
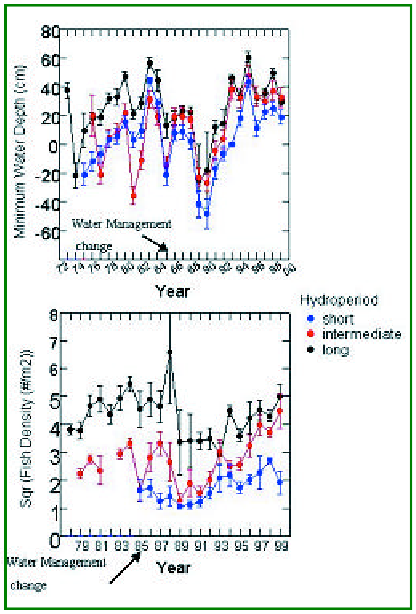


Mean monthly concentrations (flow weighted) of NO_3- in streamwater of WS7 and WS2 during calibration, treatment activities, and post-harvest periods, Coweeta Hydrologic Laboratory, Otto, NC.

FCE
Florida Coastal Everglades LTER

The wetlands of the Florida Everglades have been affected by human alterations of both the quantity and quality of water and are now the subject of a major restoration initiative. A challenge for managers is to predict how their various restoration options will affect the communities of aquatic plants and animals that live there in an effort to form a basis for choosing among alternative restoration plans. Accomplishing this requires knowledge of the linkage of aquatic communities to the environmental factors under the influence of environmental managers. For over 22 years, biologists from the Everglades National Park have collected data on fishes at three sites representative of different hydroperiods in the Everglades (Loftus and Eklund 1994). Hydroperiod is the length of time during the year when a site is inundated with water. One of the three study sites was subjected to a change in hydrological management in 1985, several years into the time series, switching it from a site that dried most years, to one that dried much less often (top figure). The other two sites were unaffected by this change, and can be considered "references" to evaluate its effect on fish communities. There was a system-wide drought soon after the management change (1989 - 1990) that obscured differences among the sites in hydroperiod. The drought was a "clock setting" event that pushed all the sites to a similar extreme community composition (Trexler et al., in press). There was a multi-year lag before the effects of the hydrological manipulation emerged. This lag arose because some species were slow to respond to the new hydrological condition... it took several generations for the effects to be manifest. The hydrological manipulation did lead to a change in fish density at the manipulated site, making it more like the long-hydroperiod reference than it was in the early 1980's (bottom figure), consistent with the goals of the management experiment. Results like these are encouraging that the aquatic community will respond in the desired direction as Everglades restoration proceeds and illustrate the usefulness of long-term ecological studies.



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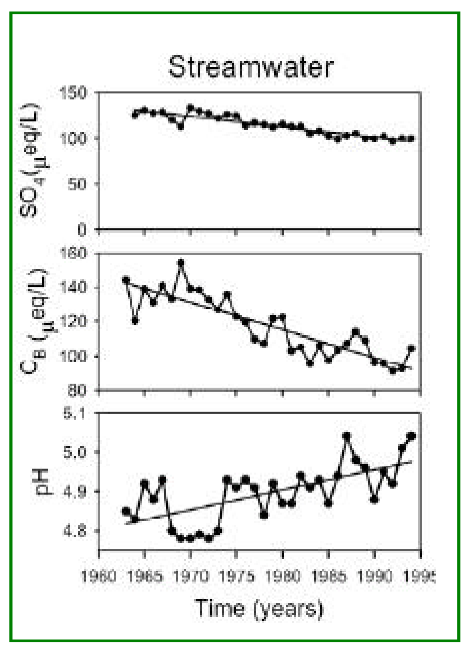
HBR
Hubbard Brook LTER

Many people believe that the problem of acid rain was solved with the passage of the 1990 Clean Air Act Amendments (CAAA). However, research from the Hubbard Brook Experimental Forest (HBEF) in New Hampshire and other study sites in the northeastern United States demonstrates that acid rain is still a significant problem. Acid deposition delivers acids and acidifying compounds to the Earth's surface, which then move through soil, vegetation, and surface waters and, in turn, set off a cascade of adverse ecological effects. Recent research shows that the ability of some ecosystems to neutralize acid deposition has diminished over time, delaying the recovery of forests, lakes, and streams. The alteration of soils by acid deposition has serious consequences for acid-sensitive ecosystems. Soils that are compromised by acid deposition are less able to neutralize additional amounts of acid deposition, provide poorer growing conditions for plants, and delay ecosystem recovery.

Stream data from the HBEF reveal a number of long-term trends (see Figure). Specifically, the concentration of sulfate in streams at the HBEF declined 20 percent between 1963-1994. The pH of streams consequently increased from 4.8 to 5.0. Although this represents an important improvement in water quality, streams at the HBEF remain acidic compared to background conditions, estimated to be above 6.0. Moreover, acid-neutralizing capacity - an important measure of a lake or stream's susceptibility to acid inputs - has not improved significantly at the HBEF over the past thirty years. Three factors account for the slow recovery in chemical water quality at the HBEF and across the Northeast, despite the decreased deposition of sulfur associated with the CAAA. First, acid-neutralizing base cations have been depleted from the soil due to acid deposition and, to a lesser extent, a reduction in atmospheric inputs of base cations. Second, inputs of nitric acid have acidified surface waters and elevated their concentration of nitrate in many regions of the Northeast. Finally, sulfur has accumulated in the soil and is now being released to surface waters as sulfate, even though sulfate deposition has decreased.



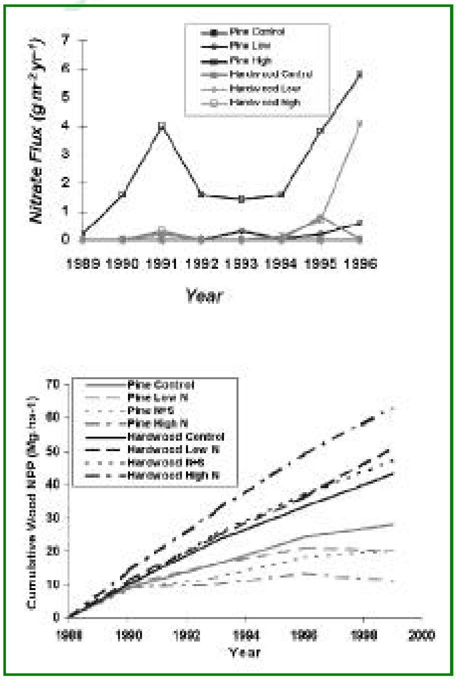
In sum, long term research suggests that deeper emissions cuts will lead to greater and faster recovery from acid deposition in the Northeast.

HFR
Havard Forest LTER

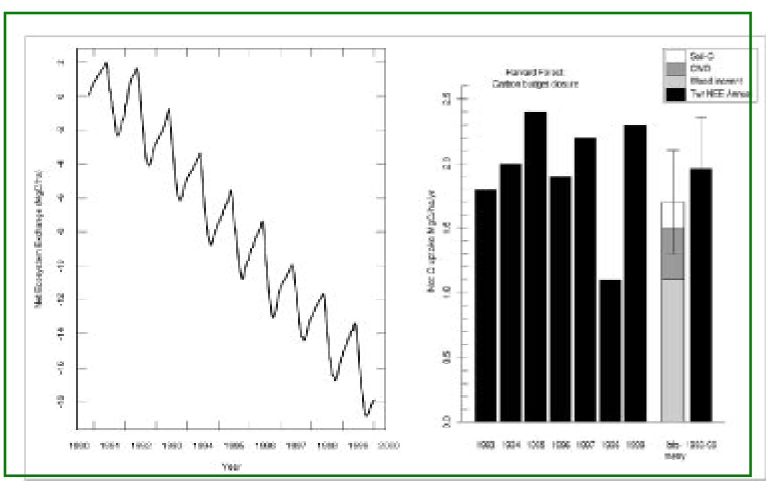
Nitrogen Saturation in Temperate Forest Ecosystems

Human activity has augmented the cycling of nitrogen through the biosphere more than any other element. As the pivotal element in amino acids, proteins, nucleic acid, chlorophyll and other biomolecules, nitrogen has profound effects on ecosystem function. As a component of nitric acid, nitrogen is a key element in the acidification of soils and streams due to acid deposition.

In 1989, the LTER group from the University of New Hampshire, led by John Aber, published a series of hypotheses concerning the expected responses of N limited forest ecosystems to chronically elevated N deposition. Central to these was the expectation of highly non-linear or threshold responses in the induction of nitrification and nitrate leaching. They also predicted that excess N deposition would eventually reduce tree growth and lead to forest decline. However, there was no real expectation that this would happen in a short period of time.



In 1998 John's group revisited these initial hypotheses. Two of the most important ones have been supported by the findings. It is indeed possible to induce nitrification and nitrate leaching with chronic N additions, although this took much longer in the very N-poor hardwood stand than we expected (Fig. 1). Mechanisms by which large amounts of added N are retained in these systems are now a key area of study. In addition, and rather surprisingly, the application of nitrogen did induce significant reductions in growth rates in the pine stand (Fig. 2). By the year 2001, the pine stand receiving the highest level of N deposition was effectively dead. To-date there has not been any growth declines in deciduous, broad-leaved stands. This result may assist us in interpreting historical episodes of forest decline and anticipating future trends in forest health in areas of high N deposition.



Carbon Sequestration by Temperate Forests

Northern mid-latitude forests appear to be important sinks for as much as 25% of the CO2 added to the atmosphere by fossil fuel burning since 1980. The net sink varies inter-annually by a factor of two or more, correlating with global-scale climate variations, and possibly accelerating in the 1990's. When the Harvard Forest LTER was initiated in 1989, the group from Harvard's Department of Earth and Planetary Sciences headed by Steve Wofsy set out to determine whether typical New England forests were a net sink for CO2, how large the sink was, and what processes controlled it. Various factors have been suggested: previous land use, fire and forest management are factors that are subject to deliberate modification; longer growing seasons due to climate warming, fertilization by elevated CO2 and N deposition are environmental influences not subject to direct manipulation.

Rates for Net Ecosystem Exchange (NEE) of CO2 at Harvard Forest have been measured by Steve's research group each hour since 1990, using the eddy covariance technique, along with extensive biometric measurements of species-specific changes in the C stored in live and dead wood. These long-term observations allow assessment of the accuracy of the C budget derived from hourly flux data, and quantitative analysis of the observed response of the ecosystem to environmental variation for time scales from instantaneous (hourly) to decadal.

The long-term record of NEE (Fig. 1a) shows average net uptake of 2.0(0.4 Mg C ha-1yr-1, with inter-annual variations exceeding 50%. Cumulative uptake compared well with biometric data that indicated storage of 1.6(0.4 Mg C ha-1 yr-1 over 8 years, 60% in live biomass and the balance in coarse woody debris and soils (Fig. 1b). Very different processes control carbon uptake on long and short time scales. Ecosystem responses to weather and climate (e.g., variations in growing season length or cloudiness) regulated seasonal and annual fluctuations. Legacies of prior disturbance and land use, especially stand age and composition, dominated longer time scales. Thus short-term variations of NEE at Harvard Forest reflect prompt forest response to environmental influences, while inter-annual variations reflect interactions of climate variations with ecosystem properties on annual time scales, affecting tree mortality, respiration rates, length of the growing season, and available light. Since seasonal and annual climatic anomalies are often coherent over large spatial scales, the processes described here are significant in mediating inter-annual variations of the rate of increase of atmospheric CO2. The long-term carbon budget at Harvard Forest reflects the slowest-changing ecosystem properties: stand age and composition, soil fertility, coarse woody debris. The enormous areas occupied by mid-successional forests (30-100 yrs old) in the U.S. have been cited as the major factor in present terrestrial uptake of carbon, for which these studies provide strong quantitative support and mechanistic understanding.

JRN

Jornada Basin LTER

Desertification, the degradation of terrestrial ecosystems to the point where structure and function resemble those of arid lands, is a problem of global significance. A third of the earth's land surface is classified as semiarid or arid, and a substantial portion of the human population relies on those lands for subsistence. Semiarid ecosystems are vulnerable to climatic fluctuation, to the loss of vegetation and/or functioning soils due to overgrazing or physical disturbance, and to degradation due to the over-exploitation of woody plants (Huenneke and Noble 1995). Increasing human populations and intensification of human use suggest that desertification will remain a significant problem over the next century. However, both the time scale of land degradation processes, and the large spatial scale necessary for studying the variable and sparse ecosystem elements of semiarid systems, mean that long-term research efforts such as the Jornada Basin LTER are essential for understanding the problems.

In the southwestern USA and northern Mexico, desertification has resulted in the loss of extensive perennial grasslands and their replacement by desert scrub — shrublands dominated by mesquite (*Prosopis glandulosa*) and creosotebush (*Larrea tridentata*). The Jornada Basin of southern New Mexico has long been a major site for research relevant to desertification processes and their consequences. Given the long response time of many elements of the system, the existence of this long-term site has been crucial to documenting changes in ecosystem structure and responses to human activities in the landscape (Buffington and Herbel 1965).

The resource redistribution/increasing heterogeneity model of desertification (highlighted by Schlesinger et al. 1990, 1996) has served as a key conceptual model for researchers in semi-arid ecosystems around the world. The model has focused attention on the concentration of soil resources beneath shrubs, and the formation of open or bare inter-plant spaces, as the crucial step increasing the impact of abiotic factors (e.g., agents of erosion). Productivity in semi-arid systems is so patchy and variable in time that it is impossible to assess the degree to which desertified systems actually have decreased in primary production without long-term data (Huenneke et al., 2001). Intensive sampling at 15 sites in the Jornada Basin over 10 years demonstrated that in fact relict grasslands tend to have significantly higher aboveground NPP than do desertified shrublands (Huenneke et al., in press).

The resource redistribution model has found a number of applications to management, monitoring, and remediation in semi-arid rangelands (De Soyza et al. 2000). Long-term ecological and management records from the Jornada Experimental Range and LTER created the unique opportunity to test the use of higher-resolution remote sensing data in the challenging environment of dryland systems (e.g., Privette et al. 2000, Goslee et al. 2000). The same long-term history of manipulations and archival of methods and data from the Jornada Basin (e.g., Rango et al. in press) is proving essential to efforts ranging from evaluating potential for soil carbon sequestration in rangelands (Bird et al. 2001) to modeling potential response of semi-arid systems to climate change (Peters and Herrick, in press).

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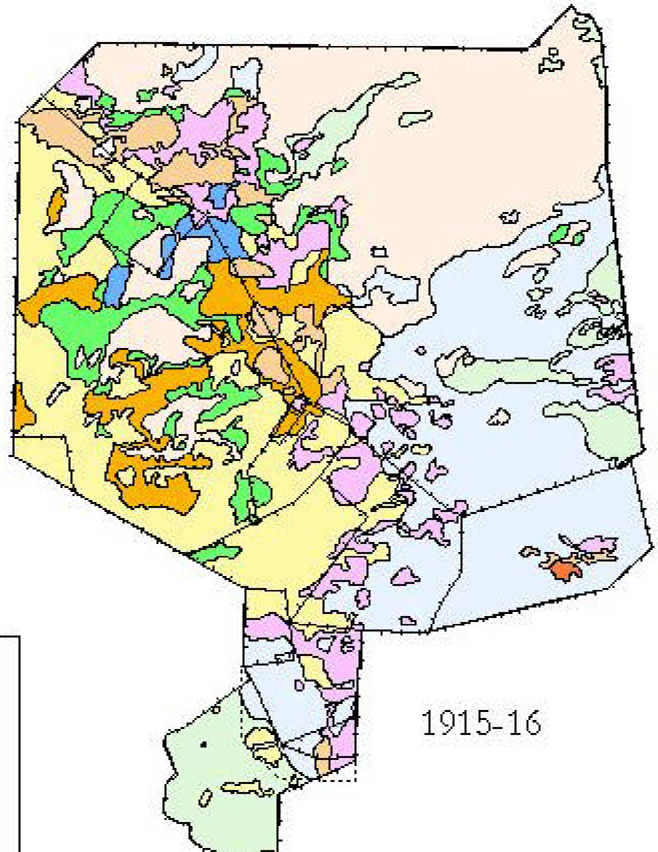
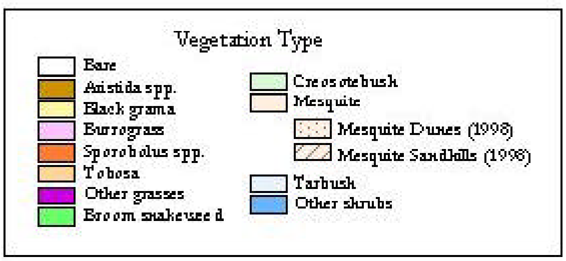
Temporal Changes in Plant Communities on the Jornada Experimental Range

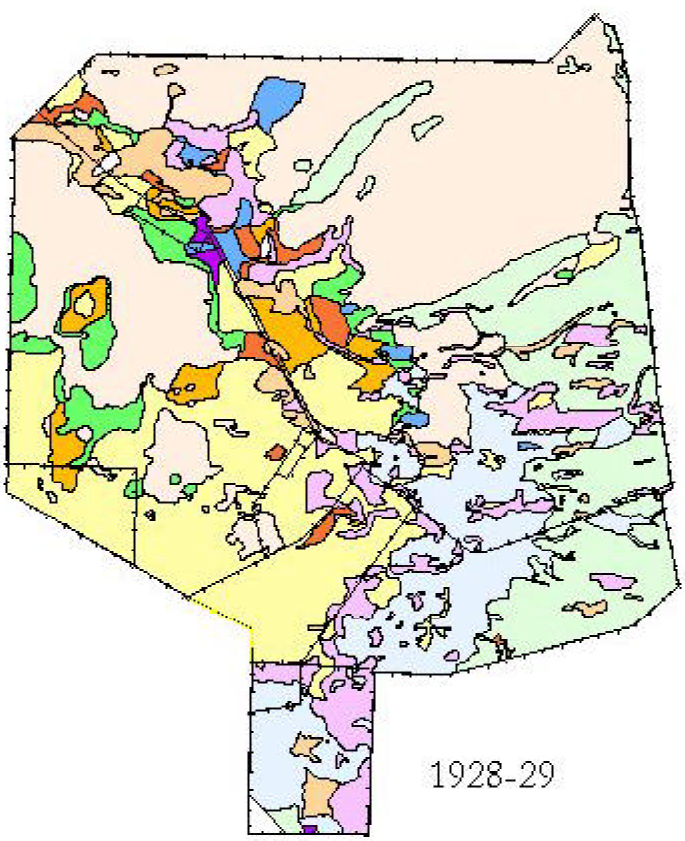
Reconnaissance surveys were made by the Forest Service to determine the number of forage acres on the plains portion of the Jornada Experimental Range in 1915-16 and 1928-29. Vegetation type maps were prepared from the surveys and these maps have been digitized so that they may be compared to a vegetation type map made utilizing aerial photographs and field reconnaissance in 1998. More area was fenced in 1915-16 than at present but only area shown by dotted lines and conforming to present boundaries was used in computing the areas for the various vegetation types shown in table. Only the primary dominants given in the 1915-16 survey are shown. The areas dominated by mesquite in 1998 were categorized as mesquite (soil accumulations at base of plants 20 cm or less), mesquite dunes (20 cm to about 3 m in height), or mesquite sandhills (greater than 3 m in height, sometimes 6 m or more).



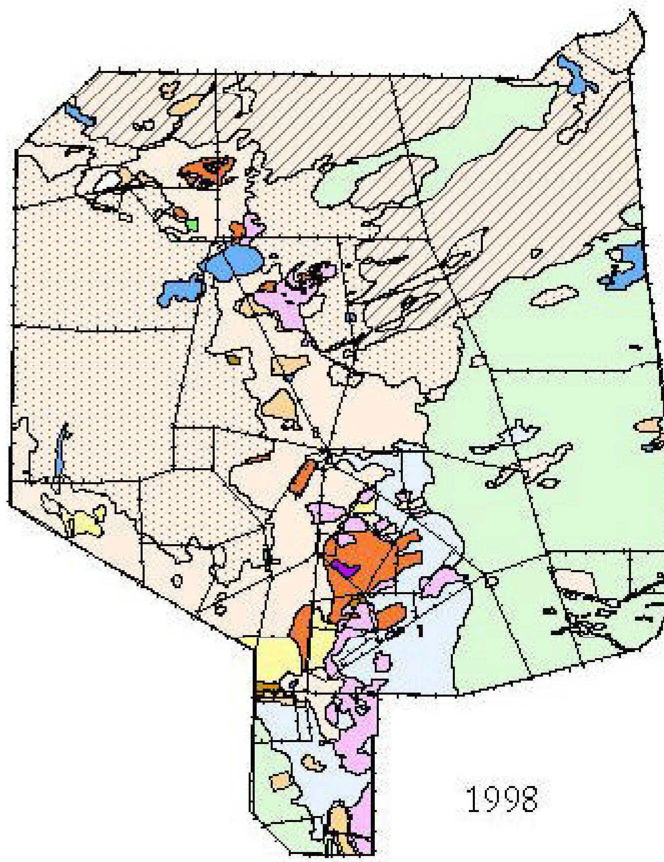
1915-16

Vegetation Type	1915-16	1928-29	1998	1915-16	1928-29	1998
		hectares			percent	
Bare	60	61	67	0.1	0.1	0.1
Aristida spp	3,344	1,601	70	5.7	2.8	0.1
Black grama	11,126	11,235	699	19.0	19.3	1.2
Burrograss	4,706	4,598	1,778	8.0	7.8	3.0
Sporobolus spp	68	946	1,224	0.1	1.6	2.1
Tobosa	2,415	2,401	844	4.0	4.2	1.4
Other grasses	0	167	39	0	0.3	0.1
Broom snakeweed	3,568	2,209	34	6.1	3.8	0.1
Creosotebush	2,605	8,221	14,485	4.5	14.1	24.9
Mesquite	12,275	19,558	34,387	26.1	33.5	59.1
Tarbush	14,812	6,519	3,826	25.3	11.2	6.6
Other shrubs	621	772	739	1.1	1.3	1.3
Total hectares	58,600	58,288	58,192			





1928-29



1998

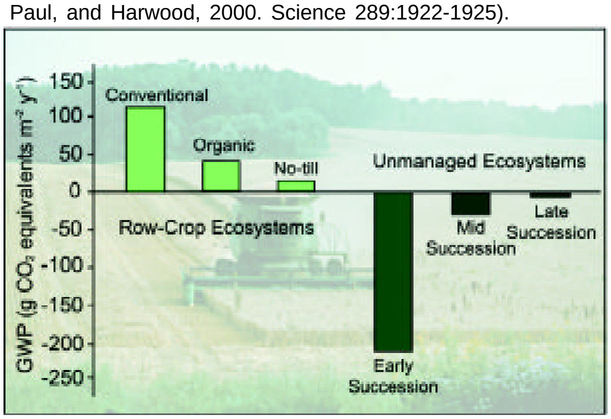
KBS
Kellogg Biological Station LTER

Agriculture's Impact on Global Warming and Potentials for Greenhouse Gas Mitigation

Over half of the conterminous U.S. land base is used for agriculture. The impact of changes in agricultural management on the regional environment can be correspondingly huge: a relatively minor change in soil carbon storage or greenhouse gas production, for example, can have enormous impact when played out over millions of hectares. But without careful measurement of these changes and insightful analyses of their causes and interactions, the impacts of changes can go unrecognized or under-appreciated. This is why long-term ecological research in these systems is needed, and how it can pay off.

For the past ten years scientists at the KBS LTER site have studied fluxes of the major, naturally occurring greenhouse gases - CO2, methane, and nitrous oxide -in a variety of cropped and natural ecosystems. A Science report last fall showed that different cropping strategies can have markedly different global warming potentials. Ten years of research showed that on average, conventional cropping methods had an annual global warming potential (GWP) of 114 CO2-equivalents m-2. Careful analysis showed that nitrous oxide production was responsible for more than half of this potential, with the remaining half the net effect of commercial fertilizer, lime, and fuel use.

The net global warming potential (GWP) of different types of cropped and successional ecosystems (Source: Robertson, Paul, and Harwood, 2000. Science 289:1922-1925).



The KBS analysis also showed that almost all of the GWP impact of these activities could be mitigated substantially by various management strategies. No-till cultivation led to soil carbon storage almost equal to the total GWP cost of other activities. Planting leguminous cover crops to reduce the need for nitrogen fertilizer and agricultural lime also substantially reduced cropping system GWP. Taken together, analysis suggests that not only could row-crop agriculture be GWP-neutral, but crop production could help to mitigate greenhouse gas production in general - sufficient even to offset the annual increase in U.S. GWP from the emission of fossil fuel CO2.

Comparison of cropland to natural communities at KBS showed further that early and mid-successional communities - ecosystems that had been abandoned from agriculture 10-50 years previously - had a higher mitigation potential (a more negative GWP) than any of the cropping systems and greater even than late successional forest. Putting marginal cropland into conservation easements could thus be an additional strategy for mitigating greenhouse gas production elsewhere in the economy.

Why was LTER instrumental for this analysis? First, because many of the processes that were measured change slowly, with annual increments hard to detect. Soil carbon, for example, accumulates under no-till crops at an annual rate of about 30 g m-2 - a quantity that is very difficult to differentiate from background soil concentrations that are greater by more than two orders of magnitude. Detection of soil carbon change over time intervals of less than a decade are thus very hard to detect. Changes in the annual fluxes of nitrous oxide and methane are equally difficult to detect reliably, in this case because of year-to-year climatic variability.

The second reason LTER was crucial for this analysis has to do with the ecosystem approach of LTER. The KBS study was in part serendipitous - GWP analysis was not anticipated when the measurements were first initiated. But an ecosystem approach to taking measurements and a commitment to long-term sampling meant that when crucial measurements were needed for complete GWP analysis - measurements of fuel use and soil nitrogen levels, for example - they were available. Detection of such trends at an LTER site means also that experimentation can be initiated in the context of continuing long-term measurements.

LUQ
Luquillo LTER

Water supply management

The long-term ecological information needed to evaluate and manage natural resources is commonly not available to local regulatory agencies. This is especially true for water diversions that are designed for decades of service. At the Luquillo site, LTER data has been used to assess the impacts of water diversions on aquatic organisms and help local and Federal environmental regulatory agencies develop plans to mitigate adverse impacts. When it became apparent to the regulatory agencies that these water diversions are often over designed and can reduce the abundance and biodiversity of aquatic organisms, long-term ecological studies from the Luquillo site were consulted. Specifically, LTER-data has been used by engineers to develop long-term hydrologic budgets and determine the frequency and impacts of droughts and floods on specific projects, including a 60 million dollar dam and several 10 million dollar water intakes. Data from the long-term monitoring of the dominant aquatic species and life history information collected by LTER graduate students were also used in a collaborative effort of LTER scientists, the local water authority, and US Forest Service and US Fish and Wildlife Service managers to determine the stream flows and habitat requirements to needed to maintain their populations. As a direct result of these efforts, the Puerto Rican Water company and local and Federal environmental regulatory agencies now use instream flows standards based on Luquillo LTER data. LTER collected data on the migration of aquatic organisms has also been used to design new water intakes and develop water extraction schedules that reduce impacts in existing water intakes. Using this basic ecological information, the mortality of larval organisms that migrate past these intakes can be reduced from 70% or more to less than 20% with a cost of less than a 5% in extracted water.

K N Z
Konza Prairie L T E R

The Importance of Long-Term Studies for Understanding the Effects of Fire in Humid Grasslands

Long-term record of responses in plant species richness to different fire frequencies at Konza Prairie. Long-term annual burning significantly reduces plant species richness, while the short-term effects of fire are variable and inconsistent (Inset)

Long-term studies on Konza Prairie address the ecological consequences of different fire frequencies in tallgrass prairie ecosystems. These studies include comparisons of ecosystem processes and plant species richness on watersheds subjected to different fire frequencies for more than 20 years. A recent assessment of this long-term dataset revealed the long-term consequences of different fire regimes could not be predicted by short-term responses to individual fires (Knapp et al. 1998). For example, comparisons of pre- and post-fire data on plant species composition indicated that individual fires do not significantly alter plant species richness. However, the long-term record clearly indicates that repeated frequent fires decrease species richness, while infrequent burning may enhance the number of plant species present. Likewise, the long-term record of aboveground net primary productivity (ANPP) demonstrates the importance of long-term studies to adequately assess the effects of fire on plant productivity. Splitting the long-term record into a series of “short-term” studies of 1-3 consecutive years yielded results indicating that fire increases, decreases, or does not affect plant productivity. However, analysis of data from any 10-year (or longer) consecutive period clearly demonstrates that fire stimulates ANPP in tallgrass prairie. Fire also increases the relative responsiveness of prairie to interannual variation in precipitation. However, a dataset >18 years in duration was required to show a statistically significant relationship between annual plant productivity and annual precipitation. Long-term fire treatments have also been important for understanding the influence of fire on N availability and plant responses. Studies of sites that are burned relatively infrequently indicate that N limitation is not affected by fire, while studies of sites with different long-term fire treatments clearly indicates that repeated fires lead to decreased N availability. These observations have been important in providing a mechanistic understanding for post-fire increases in ANPP associated with different fire return intervals (Seastedt and Knapp 1993, Blair 1997). In total, these studies clearly demonstrate the importance of long-term studies for understanding patterns and controls of ecological processes in tallgrass prairie.

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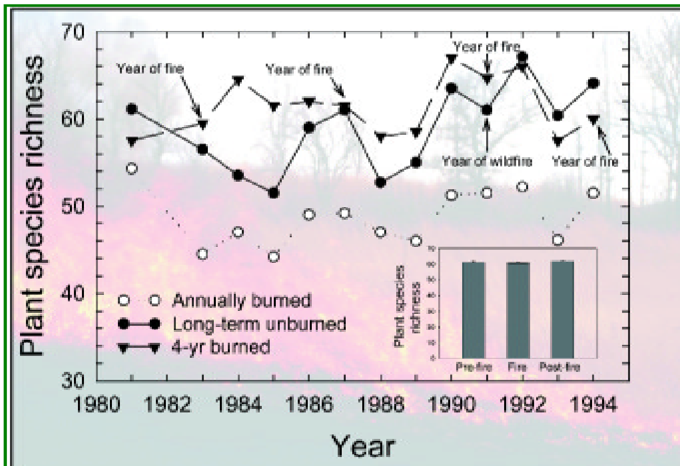


M C M
McMurdo L T E R

Temperature Trends in Antarctic Lakes

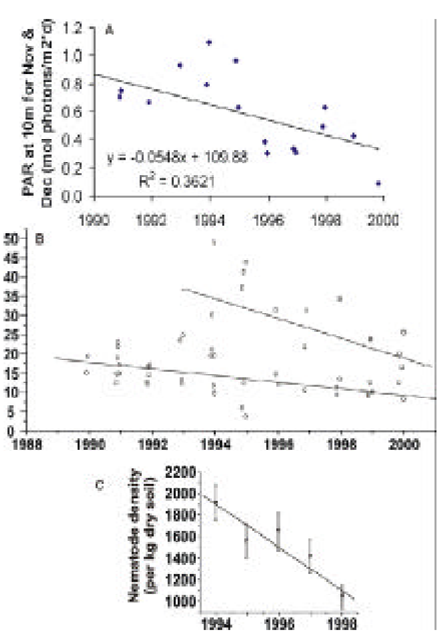
One of the key questions concerning the future of all ecosystems on our planet is how they will respond to natural and anthropogenically induced climate change. The McMurdo Dry Valleys (MCM) represent the largest ice-free area in Antarctica and are among the coldest and driest terrestrial environments on the planet. They contain a number of ice-covered, closed-basin lakes. Lake level records collected primarily by New Zealand scientists indicated that the MCM region had been warming in the 1970s into the 1980s. Our meteorological data from Lake Hoare in Taylor Valley represent the longest continuous climate record on the Antarctic continent. Long-term studies at the MCM-LTER site have documented a cooling trend in this portion of Antarctica over the past decade. Seasonally averaged surface temperature has decreased by 0.56°C per decade over a 14-year period.

This environment has long been viewed as extremely sensitive to small changes in climate. As the climate has cooled, MCM-LTER scientists have documented an increase in ice thickness on the lakes, as well as a decrease in lake levels. In addition to these physical changes, we have observed an increase in lake salinity, a decrease in primary production, and dramatic changes in phytoplankton composition within the lakes over this time period. The increase in thickness and reduced underwater irradiance has led to a primary production decrease of 5% per year from 1989 to 2000. Declining populations of nematodes in the soils and changes in algal mat types in the streams have also been observed. Without continuous, long-term monitoring these changes in the ecosystem of the McMurdo Dry Valleys could not have been linked directly to the physical forcing.

A) PAR at 10m for Nov and Dec (mol photons m-2d-1)

B) Primary Productivity (mg C m-2d-1)

C) Nematode density (per kg dry soil)



NTL
North Temperate Lakes
LTER

Long-term dynamics of yellow perch in Crystal Lake

One of the most intriguing types of population fluctuation is that of regular cyclical change. Recurrent oscillations in natural populations have generated considerable interest both in their occurrence and in their cause. Theoretical models of populations suggest that these oscillations can result from a number of factors including combinations of fertility and survival rates, intraspecific competition and cannibalism, and predator-prey dynamics. Cyclic patterns of abundance have been observed in freshwater fishes, although the ability to detect such cycles is often obscured by the influence of environmental factors and the lack of long-term observations. Understanding the causes of these repeated oscillations in fish populations is an important challenge.

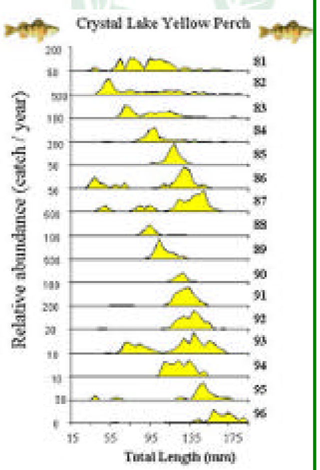


Figure 1. Relative abundance (CPUE) of yellow perch (Perca Flavescens) in Crystal Lake as a function of size for years 1981-1996.

At the North Temperate Lakes LTER site, we have observed cyclic dynamics in a population of yellow perch in oligotrophic Crystal Lake over the past 20 years. Since 1981, three sequential cases of cohort dominance have occurred in which similarly-aged fish dominated the population for roughly 5 years (Figure 1, Sanderson et al. 1999).

What caused these cycles? Clues come from long-term observation and modeling. The presence of young-of-the-year fish was observed to be negatively related to juvenile perch abundance and positively related to adult perch abundance. Modeling results suggest that oscillations in young-of-the-year perch abundance were driven by the positive effect of adult perch reproduction and the negative effect of juvenile perch via cannibalism and competition. Young-of-the-year fish were abundant primarily in years when reproductively mature fish were in the lake suggesting that the cycles are driven predominantly by pulses of abundant reproductive adult perch. As these young perch grow to juveniles, they exclude the possibility of survival by younger cohorts through cannibalistic and competitive interactions. This exclusion occurs until they themselves become reproductively mature and the cycle then repeats. The long-term pattern in Crystal Lake is an exceptional example of cyclic dynamics generated by intraspecific interactions

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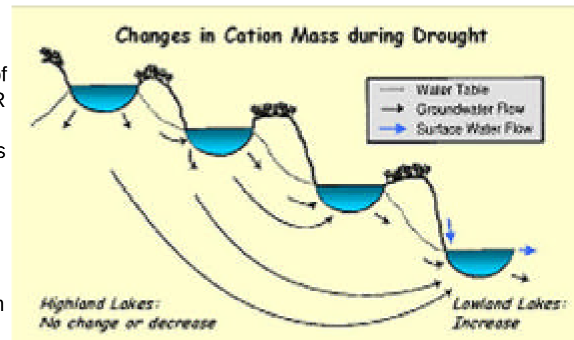
Groundwater, Lake Chemistry and Climate

Long-term research at the NTL-LTER site, which was established in 1981, provided unexpected insights into the effect of climate shifts on lake-groundwater interactions. Five years after the site was established, the region experienced a severe 4-year drought. The availability of continuous, long-term data before, during, and after the drought allowed Anderson et al. (1993) to show that local flowpaths of groundwater to lakes were much more dynamic and transient than previously thought. Crystal Lake, an NTL-LTER seepage lake located high in the landscape received up to 10% of it's water inputs from groundwater during wet periods, but became totally isolated from groundwater inputs during the drought. These switches in groundwater inputs have important implications for lake chemistry and biological communities. In the Northern Highland Lake District, groundwater is the major source of materials that support aquatic life (such as the calcium needed by snails to build shells) and buffer lakes from damage by acid rain. Long term data on lake chemistry from the NTL-LTER program demonstrated that lakes moderately high in the landscape, where reversals in groundwater inflow are likely, lose cation mass during drought (Webster et al. 1996). Under the more sustained switch to warmer and drier conditions predicted by climate change models, the concentration of biologically important cations and acid neutralizing substances could substantially decline (Kratz et al. 1997). No change was observed in lakes that are always hydraulically mounded. Lakes low in the landscape, however, accumulated cations during the drought because their groundwater inputs are dominated by regional flowpaths, which are less temporally responsive to climate shifts.

Without the long-term data record on chemistry and hydrology from a set of lakes ranging across the landscape, these insights into the dynamic nature of lake-groundwater interactions and resultant implications for lake chemistry and biology would have been missed. Further, because of long-term studies at NTL-LTER, we were able to take advantage of a "natural" experiment-the sustained drought - allowing us to better understand differential lake responses to regional climatic events.

Figure 1. Changes in cation mass of the NTL-LTER lakes during drought. Lakes are arranged along the landscape position gradient. (Adapted from Webster et al. 1996).



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Ice freeze and breakup quantifies long-term global responses of lakes and rivers to climate change and variability

Each year lakes and rivers at northern latitudes freeze over in autumn and breakup in spring. Taken as single points in space and time, these events lack context and reveal little to the observer. Yet generations of observers have recorded such events at sufficient regularity since the middle of the last century that long-term global changes can be analyzed and significant inferences drawn of change around the Northern Hemisphere.

What do such long-term records tell us (Magnuson et al. in press)? First they tell us that at the North Temperate lakes LTER site, the ice duration on Lake Mendota in the winter of 1997-98 was the shortest over the period of record beginning in the 1850s. Also, the average duration of ice cover has declined from about 4 to 3 months or by 25%. Step changes occurred that correspond to the end of the "little ice age" and to interdecadal changes in the strength of the Aleutian low. Springs with the earliest breakups occurred in the year following the onset of an El Niño. The long-term trend corresponds to a warming of

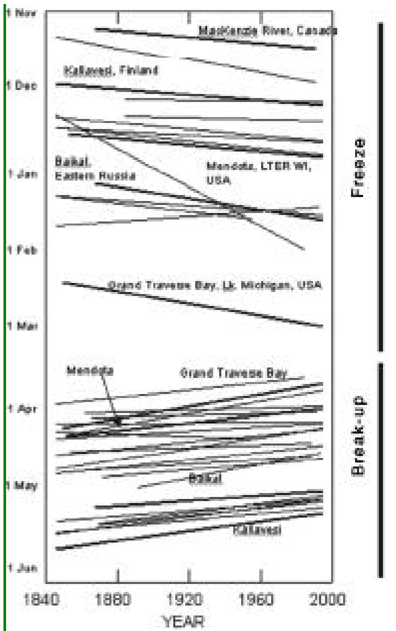

Figure: Historical trends in freeze and breakup dates of lakes and rivers in the Northern Hemisphere, 37 of the 39 trend slopes are in the direction of warming (modified from Fig. 1 and Table 1 in Magnuson et. al. (2000)).

about 1°C in 100 years. These dynamics in the timing of ice breakup and freezing are driven by climate drivers, originating far distant from Wisconsin in the Southern and Northern Pacific, and in the case of the long-term warming trend from the globally dispersed drivers behind that warming.

The Lake Mendota patterns above are observable around the Northern Hemisphere with some variation in pattern (Magnuson et al. 2000). The ability to infer long-term and regional pattern from these events, puts the observations at one site in one year in a context more useful and meaningful to us as we attempt to deal with global change. The particular events have been moved from behind the mask of the "invisible present" (Magnuson 1990) and the "invisible place" and as a result can be used to understand and respond more appropriately to the changes in the world around us.

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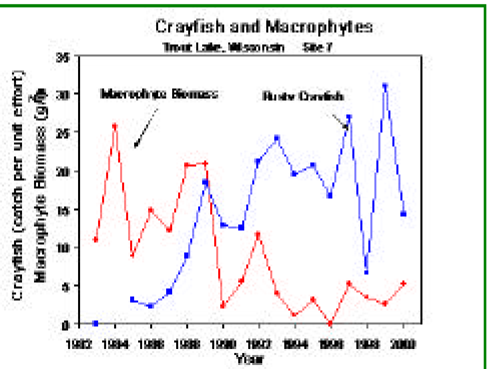

Figure 1. Rusty crayfish abundance and macrophyte biomass at site 7 in Trout Lake from 1983-2000. Crayfish abundance is in units of numbers caught per trap set divided by two .

Long-term relationships between rusty crayfish and macrophytes in lakes

The rusty crayfish (Orconectes rusticus), a species native to Ohio and Indiana, has been invading lakes throughout northern Wisconsin for the past several decades (Hobbs et al. 1989). This exotic species has the ability to outcompete native crayfish species (Hill and Lodge 1999) and often replaces native crayfish species in the lakes it invades (Olsen et al. 1991). In addition, the rusty crayfish often occurs at higher population densities than the native species and has been associated with reductions in macrophyte biomass. Because macrophytes provide important foraging and reproductive habitat to fish and other aquatic organisms, the relationship between rusty crayfish abundance and macrophyte biomass has been of interest to scientists, lake managers, anglers, and the general public. Long-term observations of rusty crayfish abundance and macrophyte biomass in Trout Lake, one of the North Temperate Lakes LTER program's primary study lakes, have shown an inverse relationship over the past 18 years (Figure1). Interestingly, in the first seven years of record (1983-1989), when rusty crayfish abundance was increasing rapidly at this site in the lake, there was no evident decline in macrophyte biomass. The inverse relationship between rusty crayfish and macrophyte biomass, which has also been established experimentally (Lodge and Lorman 1987), was only apparent after 12-15 years of record, indicating the importance of long-term data in these lakes.

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Predicting Blue-Green Algal Blooms in Lakes using Long-Term Data

Excessive inputs of phosphorus (P) have long been known to cause excessive blue-green algal blooms and other eutrophication symptoms in lakes. To predict how an individual lake would respond to changes in P inputs, scientists frequently have relied on models that link P inputs to in-lake P concentrations, which can be linked to summer algal densities or chlorophyll (Chl) concentrations. These models were derived from cross-sectional analyses of many lakes and predict average concentrations of P or Chl at steady state conditions of P inputs - a condition that rarely occurs due to variability in runoff and other drivers. Large prediction uncertainties exist when the models are applied to any one lake thus making model predictions difficult to interpret. In addition, summer blue-green algal blooms are extreme and highly stochastic events whose occurrence can be masked in average conditions. Unfortunately, few lakes have the necessary long-term data available to accurately predict algal bloom responses to stochastic watershed P input rates under a different set of land management practices.

To illustrate the value of long-term data for lake diagnostic studies, the probabilities of summer blue-green algae exceeding bloom concentrations of >2 and >5 mg L-1 were predicted for P input loading rates for Lake Mendota, one of the North Temperate Lakes LTER study lakes (modified from Fig. 5, Lathrop et al. 1998). These analyses were possible because of a 21-year record for P input loadings, in-lake P concentrations, and blue-green algal concentrations in the lake. These analyses were conducted by a collaboration of LTER and state agency researchers and were used to justify the recommended 50% P input reduction as a target for the Lake

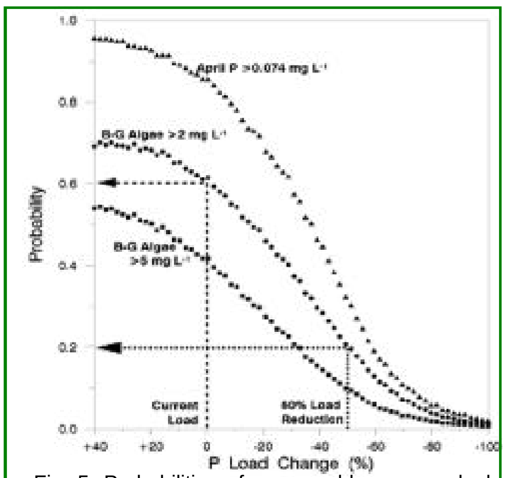


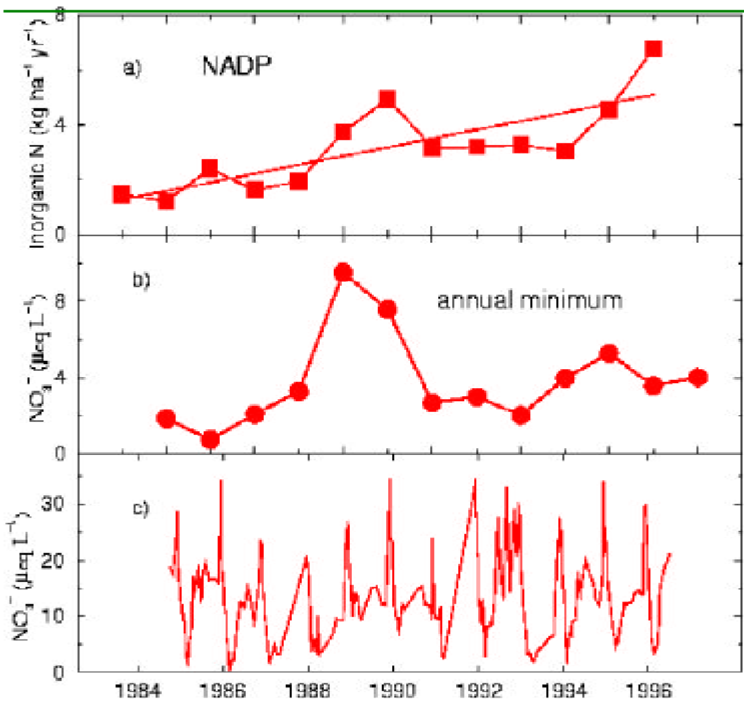
Fig. 5. Probabilities of summer blue-green algal bloom concentrations >2 and >5 mg L-1 and spring P concentrations >0.074 mg L-1 vs. current P loading rates (0% P load change) and a proposed 50% reduction in P loading rates for Lake Mendota.

NWT Niwot LTER

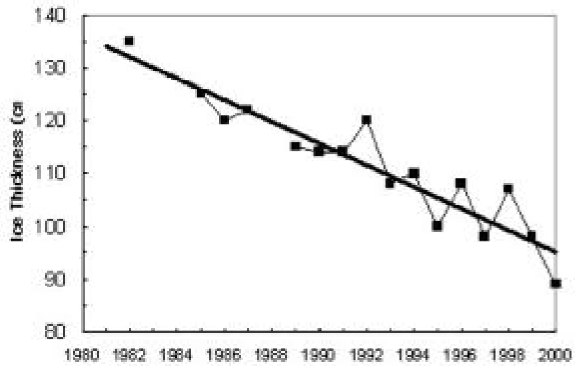
Critical Loads for Inorganic Nitrogen Deposition in the Colorado Front Range

Increases in atmospheric deposition of inorganic nitrogen (N) in wetfall to the Colorado Rockies have crossed a threshold such that high-elevation areas are switching from N-limited to N-saturated ecosystems. We use both intensive data collected at the Niwot Ridge LTER site and extensive data collected throughout the Colorado Plateau to identify the amount of inorganic N in wetfall that may cause this biological switch.

Results from the NADP site located at the Niwot Ridge in the Colorado Front Range shows a significant increase in deposition of inorganic N in wetfall at the rate of of 0.32 kg/ha/yr over the 13 years of record to about 4 kg/ha/yr ($r2 = 0.62$; $p < 0.001$, $n = 13$). In turn, the increasing amount of inorganic N in wetfall is causing episodic acidification in headwater catchments of the Green Lakes Valley in the Colorado Front Range. Episodic values of ANC are now below 0 ueq/L in surface waters during snowmelt runoff at 9-ha and 42-ha sampling sites, whereas a decade ago the ANC values were never below 0 ueq/L. Aquatic and terrestrial changes are now occurring in these high elevation areas as a result of the switch from N-limited to N-saturated ecosystems. Results from NADP sites throughout the Colorado Plateau show that N deposition was significantly greater at elevations above 2,500 meters because of higher amounts of precipitation. A synoptic survey of nitrate concentrations from 91 high-elevation lakes in the central Rocky Mountains shows that N saturation is now starting to occur throughout the Colorado Front Range but not in other portions of the Colorado Plateau. These various data sets suggest we have crossed a biological threshold that puts the region of the Colorado Front Range on a slippery slope towards dead fish and dead trees. We make a conservative recommendation that critical loads of inorganic N in wetfall to Class 1 areas in the central Rocky Mountains be set at 4 kg/ha/yr.



A time series of a) annual inorganic N in wet deposition as measured at the NADP site on Niwot Ridge; b) annual minimum concentrations of nitrate at the outlet of Green Lake 4; and c) nitrate concentrations from Green Lake 4 outlet. As loading of inorganic N in wetfall increases with time, there is an increase in the amount of nitrate during the growing season.



Ice thickness measurements have been made between March 20 and 31 in all years except 1982 when it occurred on March 10. At this time, ice thickness is close to its seasonal maximum. The decline in thickness over the period of LTER records corresponds to a thinning at 2.0 cm/yr ($r = -0.931$; $p < 0.01$).

Increasing precipitation produces a “climate warming signal” in the alpine.

The fifty-year climate record from the alpine of Niwot Ridge indicates that the site is becoming wetter but not colder. These climate records are now supported by ice depth, ice duration, and water storage estimates from the Green Lakes watershed. Data collected for the last 20 years by Nel Caine indicates that ice thickness in an alpine lake has declined 25%, in spite of no significant change in temperatures or changes in the duration of ice on this lake. Instead, this change is related to greater thermal inertia of an enhanced volume of water. These findings show that an apparent warming signal can be generated by changes in precipitation rather than temperature.

Ice Thickness in Late-March on Green Lake 4

This trend is not associated with any change in the dates of lake ice inception and decay or in the duration of ice on the lake which remained constant at about 9 months/year over the last 20 years. Nor is there any evidence of a trend in air temperatures and solar radiation receipts during this period. On the other hand, the last 20 years have experienced an increase in winter precipitation (about 12 mm/yr) in the Niwot Ridge area and this has been accompanied with an increase in late season water storage in Green Lakes Valley. When the effects of increased winter precipitation and increased groundwater storage are combined in a linear model, they explain more than 50% of the annual variability in ice thickness on Green Lake 4 ($R = 0.714$; $p < 0.01$). For 2001 (a year not included in the model fit), they predict an ice thickness of 104.5 cm which corresponds closely to the actual measurement of 106 cm made on March 26, 2001.

P A L

Palmer L T E R

The Antarctic Peninsula, a relatively long narrow extension of the Antarctic continent, defines a strong climatic gradient between the cold dry continental regime to its south and the warm moist maritime regime to its north. The potential for these contrasting climate regimes to shift in dominance from season-to-season and year-to-year creates a highly variable environment that is sensitive to climate perturbation. Long-term studies in the western Antarctic Peninsula (WAP) region provide the opportunity to observe how climate-driven variability in the physical environment is related to changes in the marine ecosystem. This is a sea ice-dominated ecosystem where the annual advance and retreat of the sea ice is a major physical determinant of spatial and temporal change in its structure and function, from total annual primary production to the breeding success and survival of seabirds (Smith et al. 1999).

The WAP region has experienced a statistically significant warming trend during the past half century. In addition, a statistically significant anti-correlation between air temperatures and sea ice extent has been observed for this region. Consistent with this strong coupling, sea ice extent in the WAP area has trended down during this period of satellite observations and the sea ice season has shortened (Smith & Stammerjohn 2001). Ecological responses to this climate variability are evident at all trophic levels, but are most clearly seen in a shift in the population size and distribution of penguin species with different affinities to sea ice (Fraser et al. 1992; Smith et al. 1999). The basis for understanding the possible causal factors associated with WAP penguin population trends originated with the hypothesis that a decrease in the number of cold years with heavy winter sea ice due to climate warming produced habitat conditions more suitable for ice-intolerant (Chinstrap & Gentoo), as opposed to ice-dependent (Adelie), penguins. Fig. 1 shows the changes in Adelie and chinstrap populations near Palmer Station during the past two decades, and for gentoo penguins since founder colonies became established in the area during the early 1990s. These trends clearly support this "ice reduction" hypothesis and would not have been evident without long-term records.

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Table 1. Penguin Data

Year		Chinstraps	Adélies	Gentoos	No.
75	15,202				
76	10	77	46		
78					
79		13,701			
80					
81					
82					
83	99	13,461			
84	109				
85	150				
86		13,117			
87		10,147			
88					
89	203	13,082			
90	221	11,626			
91	162	12,380			
92	179	12,088			
93	214	12,004			
94	204	11,056		14	
95	252	11,063		33	
96	233	9,258		45	
97	251	8,877		56	
98	187	8,423		26	
99	220	7,796		149	
00	325	7,161		296-	

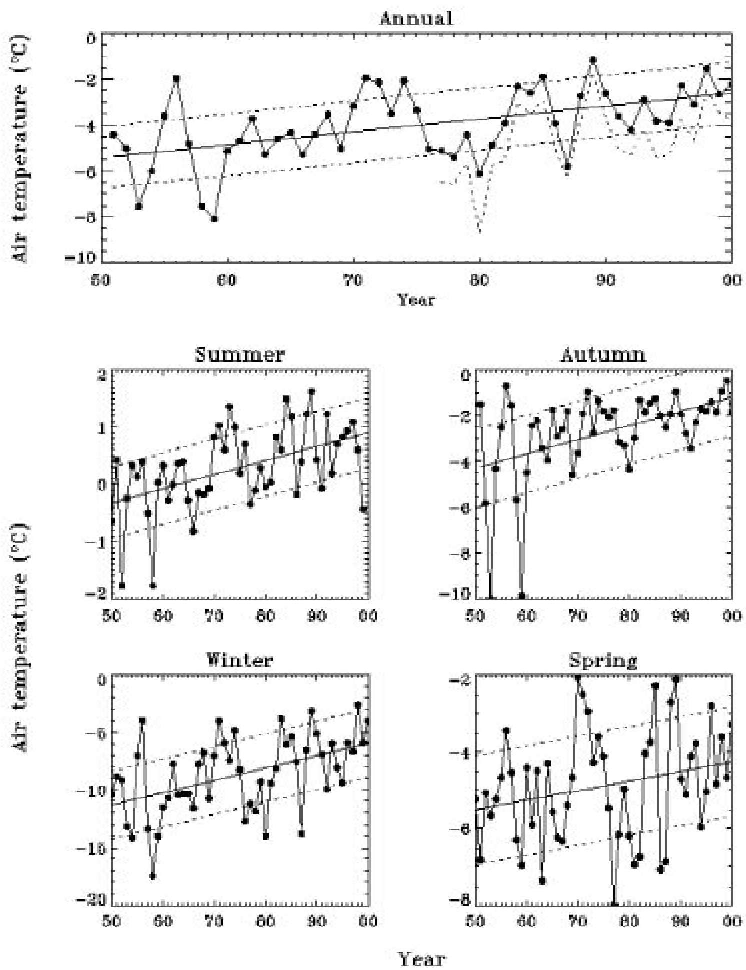
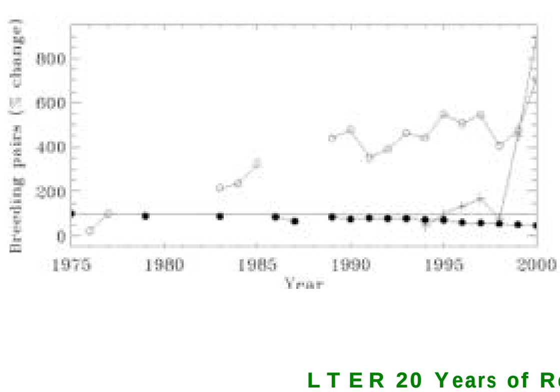


Fig. 1 Twenty five year trends in Adelie & chinstrap penguin populations at Arthur Harbor (Palmer Station) and for gentoo penguins since founder colonies became established in the early 1990's. Solid dots, Adelie penguins normalized to 100% in 1975 when the record began. Chinstrap (open circles) and gentoo (plus signs) penguins are normalized to 100% in 1977 and 1995, respectively, one year after founding colonies began.

2. Faraday/Vernadsky (65(15(S, 64(15(W) annual average air temperatures from 1945 to 2000 (N=56). The solid line is the least-squares regression line with a gradient of 0.052(C/year and the dotted lines indicate (one standard deviation from this line. A linear regression model shows the warming trend over this period to be significant at greater than the 99% confidence level. The shorter Rothera (67(34(S 68(08(W) annual temperature is shown dotted. Temperature data for Faraday/Vernadsky and Rothera kindly supplied by the British Antarctic Survey.



PIE
Plum Island Ecosystem LTER

The Effect of Historical Changes in Land Use and climate on the water budget of the Ipswich River Basin

Human activities have altered enormously the timing, magnitude and nature of inputs of materials such as water, sediments, nutrients and organic matter to estuaries (Hopkinson and Vallino 1995). Climate variability and long-term patterns of climate change also have immense effects on the timing, magnitude and nature of material inputs. These inputs largely dictate estuarine water residence time, the distribution of salinity and habitats, sedimentation and marsh accretion as well as trophic status. One of the goals of the PIE LTER is to document climate and land use change historically and to examine the effect of these changes on material inputs. Our focus to date has been on the hydrologic cycle of the Ipswich River watershed, the largest watershed draining into Plum Island Sound.

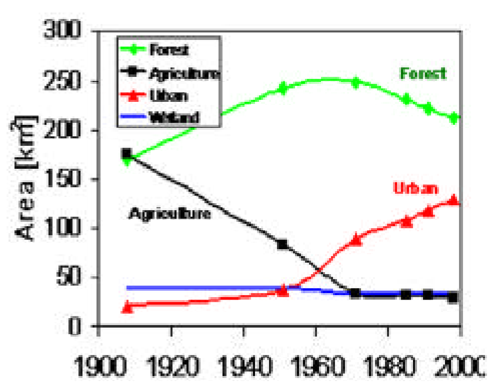


Figure 1.

The Ipswich River basin has undergone major changes in land use during the past 300 years, but especially in 20th century. We have analyzed both statewide spatial databases extending back to 1971 and town-level tabular data from the Department of Agriculture to 1907. During colonial times and through the middle of the 19th century, forestland was cleared for agricultural use. A shift in economics however led to abandonment of agricultural lands beginning around 1850. Agricultural abandonment and forest re-growth continued through the first half of the 20th century. Beginning in the 1950's, urbanization increased dramatically at the expense of forest and agricultural land (Fig 1).

Considerable water is exported from the Ipswich river Basin. Export for public water consumption outside the basin has not changed much overtime, but the gradual increase in the export of sewered wastewater has become an important component of overall diversions. Overall net diversions constitute about 10% of total precipitation or about 20% of streamflow.

The historical water budget indicates that precipitation has increased at an average rate of 2.9 mm per year (Fig 2). Runoff (streamflow + diversions) does not display a significant long-term trend. Evapotranspiration, calculated by difference from precipitation and runoff, displays a significant trend (1.6 mm per year), which is supported by independent climatological evapotranspiration estimates from ET models.

The conversion of forest to residential land use should normally lead to a decrease in evapotranspiration, primarily because of a reduction in interception evaporation. The conversion typically results in greater runoff because of impervious surfaces that lead directly to streams. However, our historical water budget indicates that ET in the watershed has increased. We investigated whether a change in climate is masking the effect of land use conversion on ET. An analysis of meteorological records revealed that the near-surface atmosphere has become more humid over time. Consistent with the complementary relationship in regional ET, the increased humidity is indicative of higher ET rates.

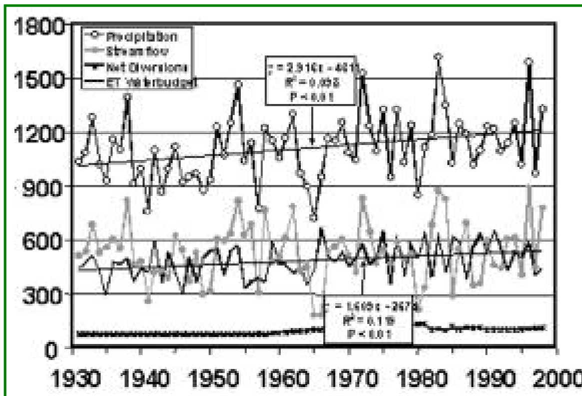


Figure 2.

We assessed the effect of changing land use on basin-scale ET using a simple, physically-based water balance model. Results indicate that conversion of forest to residential land use will lead to a decrease in ET, primarily because of a decreased importance of interception. Incorporating actual land use changes into the model, we calculate that the conversion of forest to residential land use has decreased ET a maximum of 25 mm per year.

Combining the results from our historical water budget with the simulations produced by the water balance model, we conclude that the combined effect of climate and land use change has been large in the Ipswich Basin. Comparing average annual values during the 50-yr period 1949-1998, precipitation has increased by 143 mm (13%), and ET has increased by 79 mm (17%). Adding to this the effect of land use change, the total increase in ET without deforestation would have been 104 mm, which corresponds to a 23% increase.

We are interested in how the hydrologic budget will change in future years, given the expected increase change in global climate. We are also interested in how continued urbanization will affect the timing and magnitude of not only water but also nutrients and sediments. A combination of long-term observations and modeling under support from the LTER program will enable these types of analyses to be conducted.

SBC
Santa Barbara Coastal LTER

Reef communities along the California coast have changed substantially in recent decades and other major biological changes appear on the near horizon. Some of the changes appear to have climatic links; others are tied to biological shifts. On the climate change side, there has been a gradual increase in sea surface temperature in this region over the past century, which has been accompanied by lower production (McGowan et al. 1998). In addition to these long term trends, there are more abrupt changes among years and decades.

Long-term studies have enabled investigators at the Santa Barbara Coastal LTER site to document ecosystem changes associated with this warming at the decadal scale. We have seen shifts to dominance by southern species in kelp forest fish at two sites in southern California, including one in the Santa Barbara Channel (Fig 5; Holbrook et al. 1997). Since the early 1970s, the proportion of species in fish assemblages that are cold-water, northern species has dropped by about half, while the proportion of southern, warm-water species has increased nearly 50 percent. Overall, there has been a substantial decline in total fish abundance, which correlates closely with declines in productivity (Holbrook et al. 1997). These patterns suggest an ongoing redistribution of marine species along the coast of California that is consistent with predicted northward shifts in species' ranges in response to ocean warming.

Because these shifts in reef fish assemblages have occurred gradually over the last 25 years they would have gone largely undetected had our research been constrained to a typical three- to five-year grant. Thus detecting ecosystem responses to gradual climatic changes is but one of many reasons for conducting long-term ecological research.

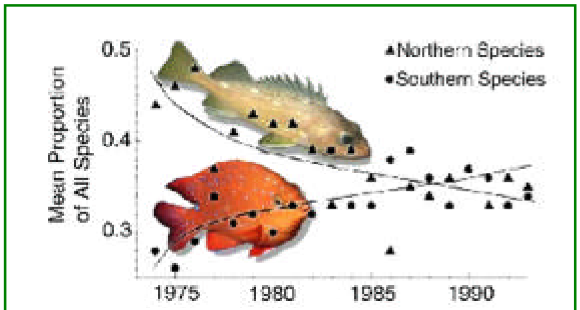


Figure 5. Changes in fish species composition in So. California Kelp Forests

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S E V

Sevilleta L T E R

Ecology of Infectious Zoonotic Diseases

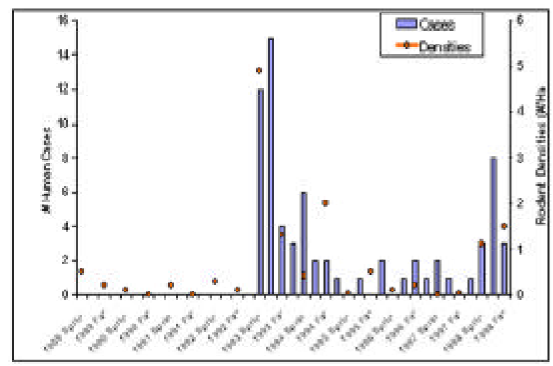
The long-term studies of rodent populations on the Sevilleta have proved valuable in unraveling elements of the outbreak of Hantavirus initially identified in the southwestern US. In spring 1993, scientists at the Federal Centers for Disease Control and Prevention (CDC) enlisted the aid of Sevilleta scientists in identifying ecological aspects of the epidemic of Hantavirus Pulmonary Syndrome, which resulted in dozens of deaths in the US. CDC scientists suspected that, as with other hantaviruses, the likely vector for the disease would be a rodent. Serological tests of rodents in the epidemic region revealed the virus in several rodent species. Residents of the afflicted areas observed exceptionally abundant rodent populations in the winter of 1992-1993, which may have resulted in high numbers of rodent-human contacts, contributing to disease transmission and the sudden epidemic.

Biologists at the Sevilleta were conducting the only long-term observations of rodent communities in the region. The Sevilleta data showed large population increases in the critical rodent species (Peromyscus spp.) during 1992 and early 1993. Comparison of the rodent data to regional climate data indicated that the rodent population dynamics were positively associated with the above-average precipitation during the 1992 El Nino and the mild winter of 1992-1993, which led to increased ecosystem productivity and subsequent rodent population explosions (the “trophic cascade hypothesis;” Parmenter et al. 1993). These data provided a causal mechanism for the epidemic’s timing and spatial distribution in the Southwest. Furthermore, blood samples from routinely collected museum specimens of rodents were analyzed to determine that the virus was indeed present, though undetected, before the epidemic in the region’s rodent populations. Research by Dr. Terry Yates and UNM Medical School researchers identified a new species of Hantavirus in a different Sevilleta rodent species, the harvest mouse, Reithrodontomys megalotis. Results of the Sevilleta analyses were used to develop rodent/virus sampling strategies, models to predict potential disease outbreaks, and disease prevention plans for human populations. More recently, additional studies have advanced techniques for measuring long-term changes in rodent populations. In addition, Dr. Yates has developed a collaborative research program with the CDC to expand rodent population studies in New Mexico, and three of the CDC monitoring sites lie adjacent to the Sevilleta Research Field Station. Finally, with NIH funding, the Sevilleta NWR has become the site of two major hantavirus programs utilizing large rodent enclosures to examine the ecology of hantavirus transmission in wild rodent populations.

In addition to research on Hantavirus, the ecology of bubonic plague has been the focus of Sevilleta studies. New Mexico typically has more than half of all the human plague cases in the United States. Recent studies by Parmenter et al. (1999) and Enscore et al. (2001) of long-term climate patterns have shown that winter-spring precipitation, followed by cooler-than-average summers, create enhanced conditions for plague outbreaks. These patterns are consistent with the “trophic cascade hypothesis” in creating large populations of plague host species (small mammals), while concomitantly creating optimal conditions (cool and moist) for fleas (the plague vector) to reproduce and survive. Predictive models have been constructed to provide early warnings of environmental conditions in which plague outbreaks may occur.

Historical Climate Development and Drought Predictions

Sevilleta scientists have collaborated with Drs. Julio Betancourt (USGS, Tucson, AZ) and Thomas Swetnam (U. Arizona Tree Ring Laboratory), on the development of historical climate, fire, and floristic records for the Sevilleta region based on tree ring analyses and pack-rat middens. Recent results of these studies have led to an understanding of the impact of severe drought, leading us to simulate how climatic fluctuations may affect ecosystem structure and functioning (Swetnam and Betancourt 1998). Additional insights on these precipitation records gleaned from tree ring data on the Sevilleta over the last 700 years have revealed a cycle of ~60 yr between severe, decade-long drought periods; given that the most recent recorded decade-long drought occurred in the 1950’s, the next predicted drought in the Southwest should begin within the next 10 years. These results are now being provided to land managers and political leaders for incorporation into long-term water use plans in the Rio Grande Basin.



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SGS
Shortgrass Steppe LTER

Modeling plant response to precipitation

The shortgrass steppe is a semi-arid ecosystem, receiving approximately 320 mm of precipitation a year. Precipitation is the primary influence on forage production in the shortgrass steppe, so it is important for researchers to understand the nature of this relationship in order to make predictions about how the ecosystem may respond to climate change. Lauenroth and Sala (1992) analyzed a 52 year data set of annual forage production and precipitation collected at the Shortgrass Steppe LTER site. They compared their model of vegetation response to precipitation over a long time period in one ecosystem to another model that had been constructed using precipitation and forage production data from many ecosystems across a precipitation gradient in the Great Plains at one point in time. The model based on data collected from one point in time offered significantly different predictions about the response of vegetation to precipitation in the shortgrass steppe as compared to the long-term model developed by Lauenroth and Sala. The one point in time model overestimated forage production during wet years and underestimated forage production during dry years (Fig. 1). This is a significant source of error should the one time model be used to predict responses of a single ecosystem to climate change that would not have been discovered without the use of long-term data.

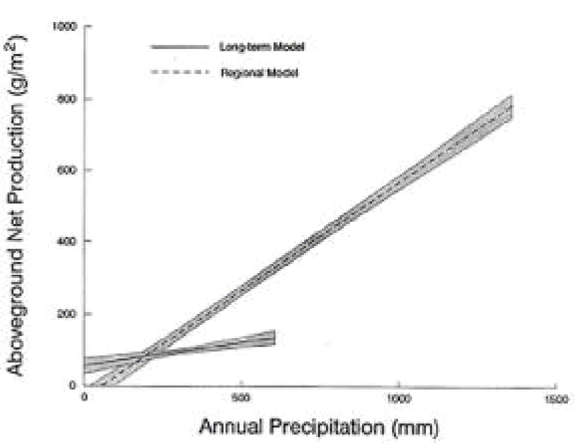

Figure 1. Relationships between aboveground net primary production and annual precipitation for a regional model (one-time model) for the Central Grassland Region of the U.S. (Sala et al. 1988) and for the long-term model developed in Lauenroth and Sala 1992. Shaded areas represent 95% confidence intervals.

Relative effect of grazing and precipitation on forage production

The shortgrass steppe is extensively grazed by domestic cattle. Researchers at the shortgrass steppe LTER investigated the relative effects of variation in annual precipitation and different levels of livestock grazing on annual forage production by analyzing a 24 year dataset. They determined that annual forage production was more sensitive to variations in precipitation than to long-term differences in grazing regimes (Milchunas et al. 1994), an important consideration when making management decisions about grazing in shortgrass steppe.

Exotic plant invasion in the shortgrass steppe

In the early 1970s, LTER researchers added water, nitrogen, and the combination of the two to experimental plots on the shortgrass steppe, in amounts far exceeding what this ecosystem normally experiences. These treatments were continued for five years, and data on plant community composition were collected for each year of treatment. At the end of this experiment, the plots which had received excess water and water plus nitrogen had significantly higher biomass than the nitrogen or control plots, but at that time no large differences in plant community composition between the treatments were apparent (Lauenroth et al. 1978). The researchers predicted a gradual reversion back to normal vegetation with the cessation of enrichment. Seven years after the cessation of the treatments, researchers returned to these plots and sampled the vegetation for an additional 10 years. They observed large changes in community composition as a result of the past enrichments, most notably the water and nitrogen enriched plots had been invaded by exotic weeds which were dominating the community (Milchunas and Lauenroth 1995), a condition that persists into today (Lowe 2000). Conclusions and predictions about how the shortgrass steppe responds to resource enrichment based on the initial short-term experiment were vastly different from conclusions based on long-term monitoring of these plots, stressing the important of long-term research in our understanding of community response to disturbance.

Effects of increased minimum temperatures on shortgrass steppe vegetation

The shortgrass steppe, and the diets of cattle grazed on this system, are dominated by one species, Bouteloua gracilis (blue grama). Alterations in the abundance of this species could significantly impact livestock production and community composition on the shortgrass steppe. Researchers at the shortgrass steppe LTER analyzed a 23 year data set investigating the effect of temperature on the aboveground production of several important shortgrass steppe species, including blue grama. The researchers found that average annual minimum temperatures were increasing and had a negative impact on the production of blue grama, and a positive effect on the production of exotic, annual forbs (Alward et al. 1999). The examination of this long-term dataset provided scientists with a basis for predictions about how global warming may affect the shortgrass steppe. These results would not have been possible if the study was limited to the traditional time frame for ecological studies which is 3-5 years in duration.

Effects of Nitrogen Fertilization on the uptake of the greenhouse gas methane

Aerobic soils are a significant sink for the greenhouse gas methane. Short-term experiments on the shortgrass steppe exploring the relationship between nitrogen fertilization and the soil uptake of the greenhouse gas methane found no reduction in the soil uptake of methane with nitrogen fertilization (Burke, unpublished data). However, data from a long-term fertilization experiment on the same soil type in the shortgrass steppe, with a similar rate of nitrogen application, found that annual application of nitrogen from 1976 to 1989 reduced the uptake of methane by 41% (Mosier et al. 1991). Long-term research is essential to our understanding of how ecosystems will respond to the diverse factors involved in global change.

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VCR
Virginia Coast Reserve
LTER

Keeping Up with Sea Level Rise

Coastal salt marshes must grow upward to keep pace with rising sea level or else they are submerged and eroded away. At the Virginia Coast Reserve LTER the rate relative sea level rise has been 3.5 mm/yr. over the 20th century, 1.0 mm/yr. of which is due to the eustatic sea-level rise and 2.5 mm/yr to land level changes. The critical question is: how do the marshes keep up with sea level?

For marshes connected to barrier islands there is ample sand in circulation to supply the needed materials for upward growth. However, marshes located in the lagoon are a different story. Detailed sediment transport studies have revealed that sediments are imported to the marsh surface during the tidal flooding. At the same time, sediment transport off the marshes during the ebbing of the tide cannot be detected. Deposition on the marshes was not the problem. Removal of excess sediments was. Deposition on the marsh surface during tidal flooding was more than adequate to keep up with relative sea level rise. The problem was how were sediments being exported from the marsh surfaces. Observations under a wide range of conditions revealed that export of sediments from the marsh surface occurred during heavy rains at low tide. Rain during storms erodes sediments from the marsh surface and also was observed to wash sediments of the Spartina alterniflora stems. Thus, the climate controls on upward growth of marshes are due both to sea level rise and the local rainfall regime.

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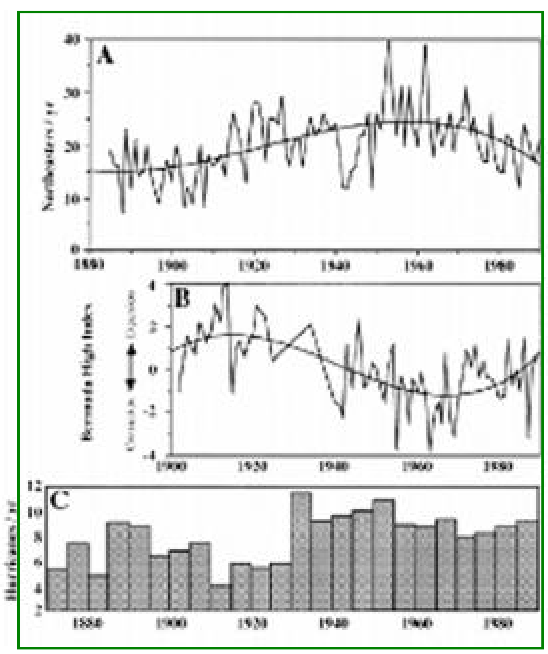
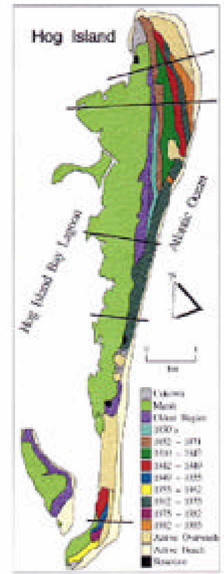
Changes in Storm Regimes

The dominant agents of ecological disturbance at the Virginia Coast Reserve are winter storms. They generate storm tides, high waves and longshore currents and result in the redistribution of sediments that both erodes and builds the islands. For example 90% of the upland land surface of Hog Island is new since 1871. Thus storms, usually thought of as destructive agents, are often the most important land building agents. The illustration of Hog Island to the lef shows the time increments within which each unit of land was laid down. The black lines indicate the locations of vegetation transects established in 1987.



On coasts it is the power of waves that move sands and build and destroy landscapes. Three types of weather systems produce the winds to generate these waves: extratropical, frontal storms, strong high-pressure cells, and tropical storms [A, B and C in the illustration to the right]. The frequency of each weather system in the region of the VCR has changed over the past century.



The average annual number of storms that impact the Virginia Coast is about 20 storms per year. However, since the turn of the century there has been a systematic increase storminess at this LTER site (Hayden 2000). Around 1900 there were fewer than 10 storms per year on average. Today there are in excess of 25 storms per year. This pattern of storm climate change is evident along the Atlantic Coast but the magnitude of the change increases with latitude. This trend in extratropical storm frequency [illustration panel A above] storminess is not like the monotonic increase in storminess projected by some General circulation Models of global warming due to a doubling of carbon dioxide (Hayden 2000).

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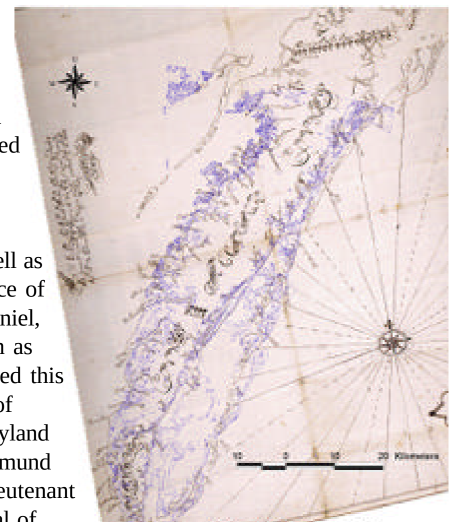
Landscape Change since 1693



Virginia Coast Reserve, 1693 & 1989

St. Thomas Jenifer, surveyor of Accomack and Northampton Counties, died in 1693. Jenifer was at various times clerk of the Provincial Court, militia officer, and alderman as well as surveyor, sheriff, and justice of the peace. Jenifer's son Daniel, seeking his fathers position as surveyor drew and conveyed this map of the Eastern Shore of Virginia and southern Maryland "For his Excellency Sir Edmund Andros their Majesties Lieutenant and (sic) Governor General of Virginia." The original map, dated 1693, is in the Virginia Historical Society, in Richmond, VA.

Modern satellite based maps of the Virginia Coast Reserve LTER [blue in the illustration to the right] is laid over Jenifer's map printed in brown. The two maps were geo-registered over the 90 kilometers of the study area. The shape and overall configuration of the peninsula on the 1693 map compared to a space photo is remarkable. In addition, island shapes and tidal creeks are remarkable in their detail and similarity to modern renderings. Other maps of this quality did not exist until the 1850s. The Jenifer map is the object of study by VCR scientists as it will tells us much of the landscape changes of the last 400 years. Our conceptual models and geomorphologic studies suggest about an 80 year cycle in island erosion and accretion. The Jenifer map is of such quality that we will be able to better define this cycle.

Daniel Jenifer did not get the job of surveyor of Accomack and Northampton Counties despite the strong Royalist support St. Thomas Jenifer had lent the Governor.

N E T

Network-level Research and Synthesis

The Future of Ecoinformatics in LTER

The primary driver for Eco-informatics research and application in LTER is the new type of scientific inquiry made possible by transforming advances in information technology into tools for the management and use of information that solves problems for ecologists. Collaborative, multi-disciplinary research programs to facilitate these new lines of inquiry have produced a need for scientific information systems that communicate across spatial, disciplinary, and cultural boundaries. As LTER moves into its third decade, informatics will play a critical role in defining, facilitating and implementing this expanding, new ecology. The scale and complexity of the task presents a number of challenges for organizing and coordinating the diverse skills and resources withina network of research sites.

LTER Network Information System: Interoperability Framework

Addressing the challenges of synthesis in ecology in the next decade calls for the application of information technology beyond simple data storage and electronic publication to develop an active, globally integrated information network with the capacity to discover, access, interpret and process data facilely across comparability and scaling barriers. Creation of this infrastructure requires investment of effort and resources into three broad areas that span the transformation of observations from data to information and to knowledge (Figure 1):

* Develop a system of networked data storage to provide long-term management and accessibility of ecological data
* Define procedures and develop tools to facilitate the communication of science and the integration and synthesis of primary data
* Promote and support research activities using archived data sources for broad, synthetic research

DATA: Establishing Data Storage Network

Ensure availability and usability of data through: (1) the creation of data repositories that actively accumulate valuable data sets and ensure their long-term viability and accessibility, (2) development and adoption of standards for documenting databases and the research that produced them to ensure the usability of these data, and (3) development and adoption of solutions that will reverse the traditional information attrition trends for data sets.

INFORMATION: Integration and synthesis of data

Research activities that creates the interface between the data storage systems and the kinds of synthetic research to be facilitated including the representation of ecological 'meaning' in semantic metadata, performing intelligent searches and processing of heterogeneous data sets, and automatically producing synthetic data sets.

KNOWLEDGE: Promote and support synthetic research collaborations

Integrating information at broad spatial or temporal scales requires adopting new perspectives on the relationship between data management and research that focuses on communications and knowledge discovery, management, and dissemination.

Organizational Structure - EcoInformatics Consortium (Ecoinformatics.org)

Realizing this vision clearly lies beyond the scope of a single project or institution, wee are creating an Eco-Informatics Consortium (Ecoinformatics.org) as a vehicle for continued informatics activities capitalizing on recognizing the strengths and contributions of everyone. The consortium will serve to formalize the ad-hoc partnerships that have developed between groups currently working to address similar goals and will provide a mechanism to capitalize on synergism, increase communication and coordination, and accomplish "collective" goals.