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Long-Term Trends in Ecological Systems:

A Basis for Understanding Responses to Global Change

Contents

Chapter 5

Patterns of Net Primary Production Across Sites

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Net primary production (NPP) is a fundamentally important and commonly measured ecosystem process that provides an integrative estimate of energy capture and flow into systems and consequently of the energy available for use by other trophic levels. A wide range of productivity levels occurs globally (figure 5-1) with high temporal dynamics among sites (chapter 14). In this brief overview, we discuss approaches to estimating NPP, highlight site-specific trends in productivity, and provide examples of past synthetic analyses across space and time. We focus on aboveground components of NPP for reasons explained below.

Methods of Measuring and Estimating NPP

In terrestrial ecosystems, NPP includes both aboveground (ANPP) and belowground (BNPP) components. Data and analyses are much more common for ANPP because measuring belowground components is technically difficult (Fahey and Knapp 2007). In general, ANPP in terrestrial systems can be directly measured via destructive harvest or estimated with nondestructive (for example, allometric) techniques. Data in this book include both approaches and, because the units of NPP are usually grams of dry mass (or carbon) per unit area per unit time (usually per year), comparisons across ecosystems are facilitated. In addition to the challenges associated with measuring BNPP, estimating ANPP in forests and NPP in aquatic systems often require techniques that use much different spatial and temporal scales than what is employed in ecosystems dominated by herbaceous plants. For a recent review of the most commonly used and accepted methods of estimating both ANPP and BNPP, see Fahey and Knapp (2007).

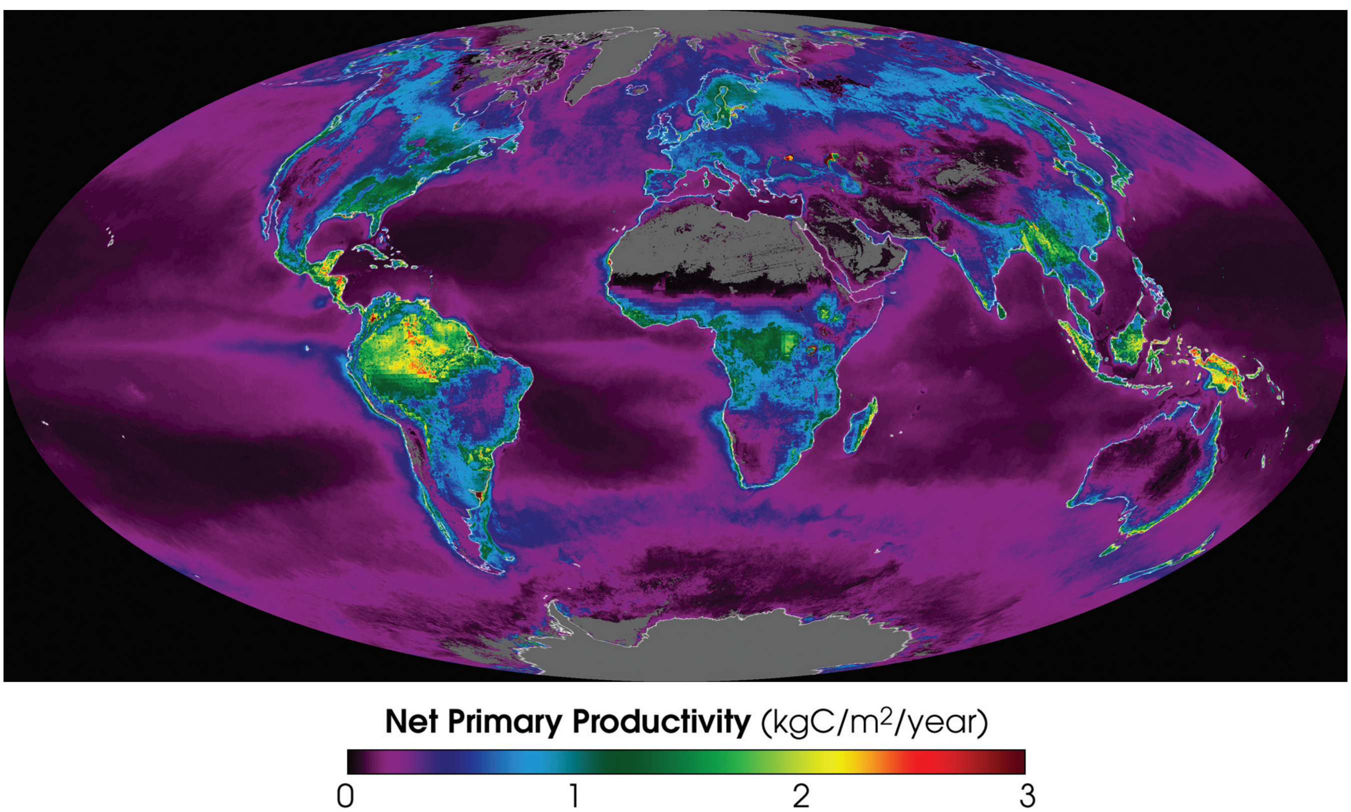

Figure 5-1. Global patterns in annual average net primary production on land and in the ocean in 2002. The yellow and red areas show the highest rates, 2 to 3 kilograms of carbon per square meter per year. The green, blue, and purple shades show progressively lower productivity. (Map from NASA Goddard Space Flight Center, http://science.hq.nasa.gov/oceans/system/climate.html.)

Temporal and Spatial Trends in ANPP

For many sites, both increasing and decreasing trends in ANPP are evident over time (figures 14-1 to 14-4) and are often a consequence of disturbance regimes or changes in plant community composition. In many sites, spatial variation among locations within a site can overwhelm temporal variation (figure 5-2). However, strong interannual variation in ANPP over time is not always the rule; instead, trends in ANPP (either positive or negative) can be quite consistent from year to year (figure 5-3). Additional trends in ANPP, surrogates for NPP, and aquatic productivity are included in chapter 14.

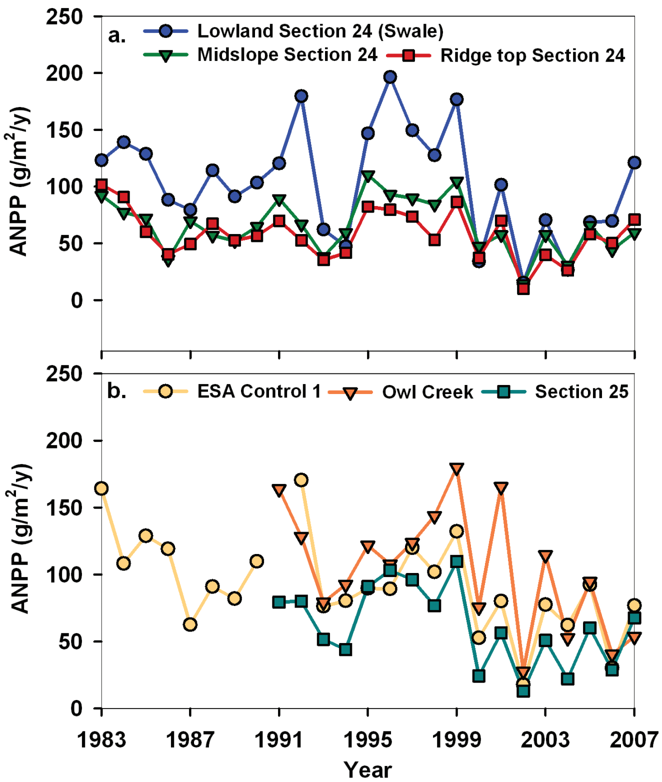

Figure 5-2. Patterns of aboveground net primary production (ANPP) for the Shortgrass Steppe (SGS) from 1983 to 2007 for 6 locations based on topographic position and soil texture from high sand (Owl Creek) to low sand (Pasture 25). (Original data from http://sgs.cnr.colostate.edu/; synthesized data from http://www.ecotrends.info.)

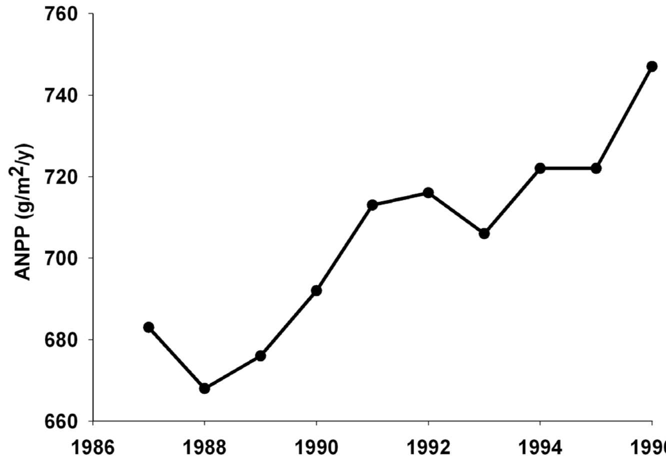

Figure 5-3. Pattern of aboveground net primary production (ANPP) for a mixed deciduous forest site at the Hubbard Brook Ecosystem Study (HBR) site from 1987 to 1996. (Original data from http://intranet.lternet.edu/cgi-bin/anpp.pl; synthesized data from http://www.ecotrends.info.)

Cross-Site Synthetic Analyses

One of the advantages of the EcoTrends database is that it facilitates more comprehensive synthetic analyses of NPP data across space and time. The determinants of differences among sites in NPP quantity and dynamics have long been of interest to ecologists (Rosenweig 1968, Webb et al. 1978). More recent analyses have begun to take advantage of long-term data across sites (Knapp and Smith 2001, Huxman et al. 2004). These analyses have provided key insights into the relative roles of biotic versus abiotic drivers of dynamics as well as elucidating where and when biogeochemical versus climatic factors underlie patterns of NPP across biomes. For example, the strong role that precipitation plays in determining ANPP across grassland sites is clearly evident in a multisite analysis (figure 5-4) (Muldavin et al. 2008). Across a broader range of terrestrial ecosystems, differential sensitivity to mean annual precipitation appears with other limitations (temperature or biogeochemistry) becoming more important in more mesic and productive ecosystems (figure 5-5) (Huxman et al. 2004).

Biotic constraints on ANPP, such as vegetation composition or meristem limitation, can also explain patterns across sites. Lauenroth and Sala (1992) pointed out a space versus time discrepancy when comparing the temporal relationship between ANPP and precipitation at an individual site compared with the same relationship based on ANPP and precipitation across sites (spatial vs. temporal trends, figure 5-6). The shallower slope of the relationship at any one site reflects site-specific vegetation constraints on the capability of the ecosystem to respond to changes in precipitation. A similar pattern can be seen for a broader range of sites (figure 5-5). Shifts in plant species composition within a site, due to woody plant encroachment or invasion of shrubs into grasslands, can dramatically change ANPP at that site (with no change in environmental conditions) as well as alter patterns of ANPP across sites (Knapp et al. 2008).

Another manifestation of how vegetation structure can influence ANPP responses to changes in precipitation was demonstrated by Knapp and Smith (2001) in a multisite synthetic analysis of long-term ANPP data. The interaction between meristem density (low in xeric ecosystems and high in mesic ecosystems) and interannual variability in precipitation (high in xeric ecosystems and low in mesic ecosystems) resulted in a pattern where the greatest interannual variability in ANPP (CV in figure 5-7) was in grasslands.

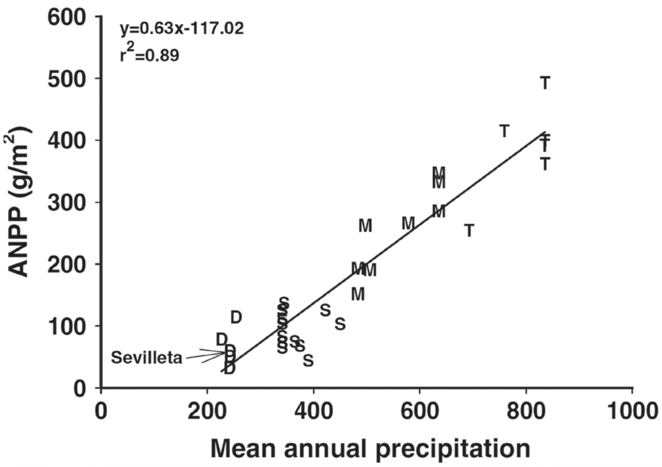

Figure 5-4. Regional comparison of aboveground net primary production (ANPP) and long-term mean annual precipitation for four grassland types: D = desert grassland, S = shortgrass steppe, M = mixedgrass prairie, T = tallgrass prairie (Muldavin et al. 2008). The Sevilleta site is identified. Reprinted with permission from Springer Science+Business Media.

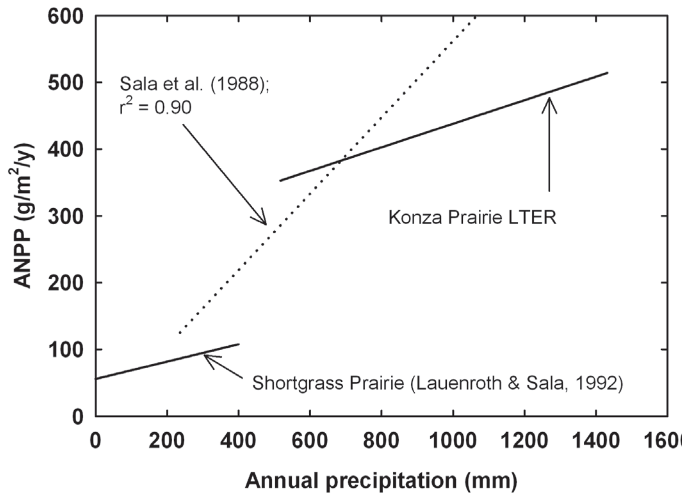

Figure 5-6. Aboveground net primary production (ANPP) has a different relationship with mean annual precipitation for sites located across a rainfall gradient (dashed line) compared with the relationship between ANPP and precipitation in each year for two sites (solid lines): the Shortgrass Steppe (SGS) site (Sala et al. 1988, Lauenroth and Sala 1992) and the Konza Prairie Biological Station (KNZ) site (Knapp et al. 1998). Reprinted with permission from Oxford University Press, Inc.

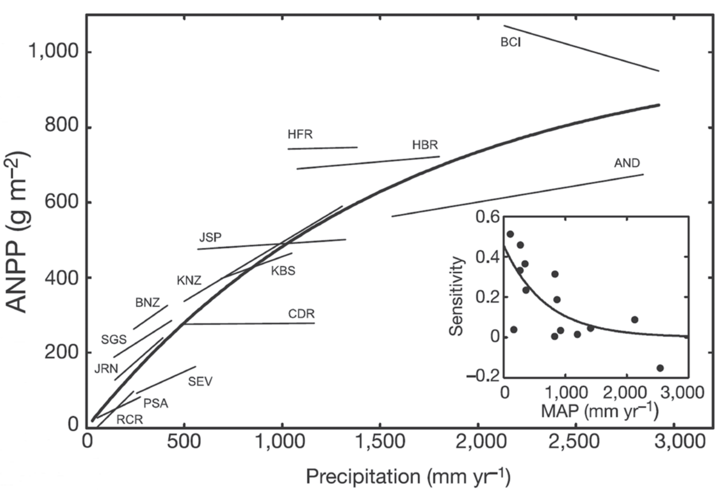

Figure 5-5. Between-year variation in aboveground net primary production (ANPP) across a precipitation gradient for 14 sites. Site-specific relationships developed using linear regression (Huxman et al. 2004). The overall relationship (bold line) shown for all sites: ANPP = 1011.7 x (1 – exp[-0.0006 x PPT]); $r^2 = 0.77$; $P < 0.001$. Inset shows site-level slopes of ANPP versus annual precipitation as a function of mean annual precipitation (MAP). Reprinted with permission from Macmillan Publishers Ltd.

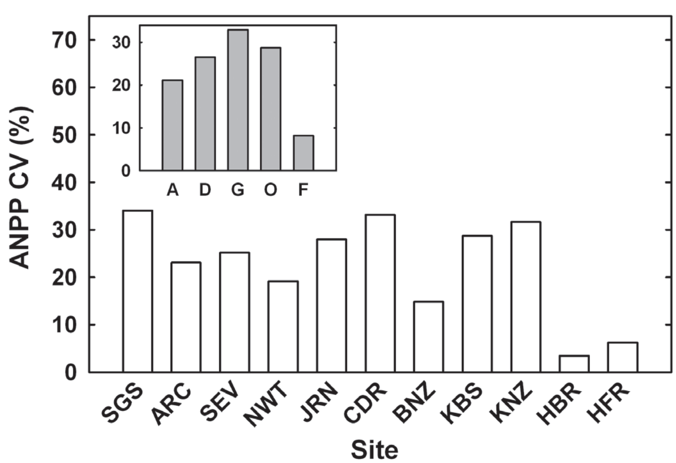

Figure 5-7. Comparison of the temporal coefficient of variation (CV) in aboveground net primary production (ANPP) for 11 sites. Inset shows CV data combined by biome type: A = arctic and alpine sites, D = desert sites, G = grassland sites, O = old fields, F = forest sites (Knapp and Smith 2001). Reprinted with permission from AAAS.

Future Analyses

In a changing world where both global and local changes in climate and nutrient deposition are affecting resources that influence NPP (chapters 11, 12), a re-assessment of past studies and assumptions is warranted, and many questions remain to be addressed (Smith et al. 2009):

- How do the dynamics and amplitude of change in NPP vary across a broad range of ecosystems?
- What are the key drivers of NPP change and dynamics? Is there convergence among ecosystems to a few key drivers?
- How can we more directly compare patterns and controls of NPP in terrestrial and aquatic systems?
- How do ecosystems vary in their sensitivity to their drivers, and is there predictive value in this sensitivity?

Conclusions

Understanding patterns and controls of NPP have been a long-standing challenge for ecological research. This challenge remains a core research area for many sites. As the number of comparable long-term datasets across ecosystems grows, answers to these and other key questions about NPP will be possible in the future.

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