

Temperate Deciduous Forests

Peter B Reich and Lee Frelich

Volume 2, **The Earth system: biological and ecological dimensions of global environmental change**, pp 565–569

Edited by

Professor Harold A Mooney and Dr Josep G Canadell

in

Encyclopedia of Global Environmental Change
(ISBN 0-471-97796-9)

Editor-in-Chief

Ted Munn

© John Wiley & Sons, Ltd, Chichester, 2002

Temperate Deciduous Forests

Peter B Reich and Lee Frelich
University of Minnesota, St. Paul, MN, USA

Temperate deciduous forests are among the major biomes on earth. They are also among the biomes that have been most heavily impacted by global change factors. Although there is the perception that the greatest concern should be held for tropical rain forests, temperate deciduous forests have a smaller fraction of original vegetation remaining than boreal or tropical forests, and also have been more severely impacted by land use change and air pollution. Temperate deciduous forests are most common in Europe, eastern North America, Japan and China, and in all these regions humans have used them heavily as a resource. Logging, grazing, conversion to agriculture, fire suppression and manipulation of wildlife populations, have caused massive alterations of forest composition, structure and diversity. Temperate biomes in Europe and North America bore the brunt of the industrial revolution, providing wood for fuel, building materials, and raw material in industrial processing. Boreal biomes have been spared widespread permanent conversion in vegetation type due to their inappropriateness for intensive agriculture. Conversion from native vegetation to agricultural landcovers has become widespread in the tropics only late in the 20th century. Thus, temperate forests have experienced more severe impacts over broader areas than any other large forest biome (Williams, 1989).

Additionally, because they are present in some of the most heavily populated and industrialized regions on earth, temperate deciduous forests have also been subject to biological invasions and to elevated levels of air pollution, including ozone, sulfur dioxide (i.e., acid deposition) and nitrogen deposition. Nonetheless, the land covered by temperate deciduous forests (as opposed to land once converted to agriculture) generally increased late in the 20th century. In this essay, we will describe the extent and characteristics of temperate deciduous forests, and the major global change agents that impact them.

NATURE AND EXTENT OF TEMPERATE DECIDUOUS FORESTS

Temperate deciduous forests occupy a central position among the world's biomes, occurring in regions of intermediate temperature, precipitation and latitude. They are bracketed geographically by biomes that are more extreme in climate, productivity and diversity: boreal forest and tundra to the colder high latitudes; temperate coniferous forests

and grasslands toward the drier climate zones; and tropical forests in warmer regions (Reich and Bolstad, 2001). Forest vegetation is classified by broad climate zones (tropical, temperate, boreal) and by leaf form and habit (broad versus needle-leafed forest, evergreen versus deciduous). Temperate forests are considered one of the five dominant forest types, along with boreal forest, temperate mixed or coniferous forests, subtropical/tropical wet forests, and subtropical/tropical dry forests. Generally, a forest is considered temperate if it is found in a climate with a warm summer and a markedly cool or cold winter. Typically, temperate forests are found between 3 and 18 °C mean annual temperature, with midwinter mean monthly temperatures generally below 8 °C and midsummer mean monthly temperatures generally above 18 °C.

Temperate forests occupy much of North America, Europe, Asia, Australia, New Zealand, and a small part of South America, but those in the southern hemisphere are almost exclusively evergreen, so temperate deciduous forests are generally restricted to mid-latitude belts in the Northern Hemisphere. Although needle-leafed deciduous forests occur, the most common of these are Larix-dominated and typically a component of boreal forests and these will be largely ignored in this essay. Thus, we will focus on broad-leaved forests.

Broad-leaved deciduous forests typically occupy colder and/or moister parts of the temperate zone than broad-leaved evergreen forests, which span the ecotones between warm temperate, subtropical, and Mediterranean biomes. For instance, in Japan, moving from north to south within a continuously moist climate, native forests are dominated by mixed conifer–hardwood forests in the cold temperate north, by broad-leaved hardwoods in the central region, and in the warm temperate south, by mixed deciduous–evergreen or evergreen broad-leaved forests.

MAJOR GLOBAL CHANGE ELEMENTS, MECHANISMS OF IMPACT, AND MAGNITUDE OF EFFECTS

There are a number of different global change factors that collectively influence temperate deciduous forests of the world. These include land use history, current land management, climate change, fire suppression, changes in atmospheric chemistry, and invasions of exotic species. These human impacts on temperate forests have been both direct and indirect. Direct impacts include site conversion to other land covers and land uses, including inadvertent effects on the native species composition. Indirect impacts include the introduction or elimination of herbivorous or competing species, fire suppression and attendant changes in disturbance regimes, atmospheric pollution, particularly carbon dioxide (CO₂), ozone, sulfur, and nitrogen compounds, changes in the age structure of forest through cutting

patterns and practices, and changes in stand age demographics on longer time scales related to historical changes in local, national, and global economies. Although their effects tend to interact, for simplicity we will discuss each in turn.

Land Use History

Almost all temperate deciduous forests have been severely impacted by human use. In Europe and North America, less than 1% of all temperate deciduous forests remain in undisturbed state, free of logging, grazing, deforestation or other intensive use. The largest direct impacts on temperate deciduous forests stem from conversion to other land uses. Pre-industrial forest extent is unknown, but conversion to other landcovers has been profound. Native forests have been all but eliminated in some countries, such as Ireland and Britain. In general, roughly half the original temperate deciduous forestland has been converted to other uses, primarily agriculture. Thus, forest conversion to agriculture has been of critical importance. In Europe, massive deforestation occurred centuries ago. In eastern North America, deforestation migrated westward with agricultural settlement from the 1600s to the mid 1800s. For instance, lands originally almost entirely forested, such as Vermont, were more than 80% deforested and converted to agriculture in the 19th century. However, many temperate zone economies have shifted from rural, agricultural to urban manufacturing and technologically driven economies. This has led to large-scale agricultural abandonment and the reversion of agricultural lands back to forests. Recent studies indicate an increase in forest area and volumes in both North America and Europe (Kauppi *et al.*, 1992; Houghton, 1995).

Land Management and Fire Suppression

Although fire was not historically as severe a disturbance in temperate deciduous forests as in boreal or temperate coniferous forests, it nonetheless played an important historical role (Pyne, 1982). In eastern North America, Native American burning and lightning resulted in relatively frequent fire in the temperate deciduous forests. This was important to drier regions such as near the prairie–forest border. Forest fire had a tremendous impact on the composition and age structure of the forest, since certain species have adaptations such as thick bark, ability to sprout, and rapid post-fire colonization that enable them to thrive under such conditions (Reich *et al.*, 1990; Abrams, 1992; Kruger and Reich, 1997; Peterson and Reich, 2001).

Fire frequency regulated the balance between late successional species such as sugar maple, beech, and linden and shade-intolerant early successional species of oak and aspen. Oak and aspen were most abundant along the prairie forest border and areas with sandy soil where fires were most frequent (Grimm, 1984; Abrams, 1992).

With increasing development following European settlement and expansion, fires in temperate deciduous forests became much less frequent. This was due to cessation of intentional burning, direct suppression of fires, and land use changes that disrupted the contiguity of burnable vegetation across the landscape. Hence, temperate deciduous forests have gradually become increasingly dominated by shade-tolerant species such as maple, beech, ash, and linden, with decreased abundance of oaks (Crow, 1988; Abrams, 1998). In the absence of fire, oaks do not establish well in either shaded understories or sunlit openings, because they are neither shade tolerant nor fast growing (Reich *et al.*, 1990; Abrams, 1992; Kruger and Reich, 1997). Hence, a major change in temperate deciduous forests of North America has resulted from the ascendancy of fire-intolerant species to a dominant position in these regions. However, oaks are expanding their range westward into the prairie–woodland region, as a consequence of fire suppression. Fire suppression has likely had similar effects in Europe and Asia, but the greater time since active fire regimes makes it more difficult to be specific about the changes that have occurred.

Along with fire management, silvicultural management has also altered the temperate deciduous forest regions of Europe and North America (Parry, 2000). In Europe, almost all native temperate deciduous forest has been extirpated and of the remaining area still forested, or again forested, the majority has been planted to monocultures or mixtures not necessarily representative of the native vegetation. Much native temperate deciduous forestland has been planted with Scots pine or Norway spruce monocultures, or deciduous mixtures dominated by *Fagus*. In North America, many temperate deciduous forests have been replaced by pine plantations or mixed forests, especially in the southeast. Conversely, forests dominated by pines in the northern range of temperate deciduous forests have often shifted to aspen dominance following logging.

Species Effects: Local and Invasions

Local species extirpations (e.g., *Castor canadensis*, the North American beaver) and introductions (e.g., *Lymantra dispar*, the European gypsy moth to North America) can have large aggregate impacts on species composition and nutrient and mass cycling rates. The exotic Chestnut blight and Dutch elm disease have caused the virtual disappearance of native Chestnut (*Castanea*) and American elm (*Ulmus*) from the temperate deciduous forests of North America. Uncharacteristically low and high region-wide populations of beaver and white-tailed deer, respectively, have caused shifts in the relative abundance of tree species whose populations or habitat are affected by browsing of these animal species. Although temperate deciduous forests in northeastern North America have not been invaded by a successful tree canopy dominant from overseas, the Asian

species *Paulownia* is a successful invader in the southeastern US and two small trees, *Lonicera* spp and *Rhamnus cathartica*, have displaced native shrubs and prevented tree regeneration in many suburban regions of the eastern US. Moreover, the nitrogen-fixing tree, *Robinia pseudoacacia* has greatly expanded its range in eastern North America in the past several centuries. In Europe, several North American species, including white pine, black locust, and red oak, were planted and have become naturalized in the temperate deciduous forest region.

Impacts on Temperate Deciduous Forests Due to Changes in Atmospheric Chemistry

The potential indirect effects of elevated CO₂ on climate warming, and resultant consequences, are addressed elsewhere (see various papers in volume 1, and **Intergovernmental Panel on Climate Change (IPCC): an Historical Review**, Volume 4). Additionally, due to its role as substrate for photosynthesis, elevated atmospheric CO₂ levels may directly increase forest productivity and cause shifts in species composition (Parry, 2000). Numerous hypotheses have been proposed regarding which kinds of species will be favored under enriched CO₂ conditions, with faster-growing, less shade-tolerant species often considered potentially more responsive. However, the evidence is extremely inconclusive, leaving us with high uncertainty regarding how elevated CO₂ levels will change future forests (see **Nitrogen Cycle**, Volume 2; **Nitrogen Deposition on Forests**, Volume 2).

Elevated levels of nitrogen deposition and tropospheric ozone are also common in temperate deciduous forests regions and known to have significant effects on forests. Atmospheric nitrogen inputs have increased significantly over the last 30 years (Aber *et al.*, 1989), with large increases in per hectare nitrogen inputs reported, particularly in Europe (Kauppi *et al.*, 1992). Nitrogen deposition may be having substantial effects on tree production and patterns of carbon and nitrogen cycling (Townsend *et al.*, 1996; Magill *et al.*, 1997). Changes in nitrogen availability could have large impacts on species composition (toward more nitrogen-demanding taxa), litter quality and quantity, decomposer populations, and nutrient and mass cycling rates (see also **CO₂ Enrichment: Effects on Ecosystems**, Volume 2; **Plant Growth at Elevated CO₂**, Volume 2). Ozone is present at elevated levels during the growing season in the European, North American, and probably Asian regions of temperate deciduous forests. These pollution levels are sufficient to cause reduced productivity at leaf, tree, and stand-scales (Reich, 1987; Ollinger *et al.*, 1997). Whether ozone pollution causes shifts in forest composition is still unclear. Increases in atmospheric greenhouse gases may also have large impacts through climatic alterations (see below).

Climate

The climate in temperate deciduous forest zones has been fairly stable for the last 1000–2000 years. The impact of warming during the 20th century has not yet manifested itself in forest change, although it is likely that direct human disturbance in temperate deciduous forests would mask any change due to climate that may have occurred.

Temperate deciduous forests are heavily impacted by wind disturbance, including tornadoes and thunderstorm downbursts in central North America and hurricanes (or typhoons) and severe extra-tropical low-pressure systems for forests near the oceans. The frequency of such stand-leveling winds is expected to increase under a warmer climate, so that fewer stands would reach old-growth stages of development. Warmer climates would also cause mixed effects due to greater drought stress and fire frequency in some regions, but fewer in other regions.

POTENTIAL TEMPERATE FOREST RESPONSES TO GLOBAL CHANGE

How will changing environmental factors (climate, CO₂, nitrogen deposition, land use) collectively affect temperate forest net primary production (NPP) and associated processes? Although it is nearly impossible to address these questions empirically at the present time (due to the lack of data), these issues may be addressed from a conceptual and quantitative modeling framework (Parry, 2000; Reich and Bolstad, 2001).

Acknowledging the shortcomings of current models, what do they suggest about temperate forest responses to global change issues such as land use change, elevated CO₂, nitrogen deposition, ozone pollution, climate and other issues? Running and Nemani (1991) modeled forest ecosystem response to various climate change factors, including a doubling of atmospheric CO₂, a 4°C temperature rise, and 10% increased precipitation, and found predicted changes which depended on the forest type and current climatic conditions. Model simulations by Aber *et al.* (1995) suggested that neither an unrealistically large (6°C) temperature warming, a 15% decrease in mean annual precipitation, nor a doubling of atmospheric CO₂ had substantial consistent effects on NPP of temperate forests in the northeastern US. However, the occurrence of all three changes simultaneously resulted in model predictions of increased productivity because increased water use efficiency associated with elevated atmospheric CO₂ would enable sustained higher canopy photosynthesis during the summer and an extended growing season without development of severe soil water deficits. For the same region of the northeastern US, model predictions of NPP responses to ambient ozone pollution levels that occurred from 1987 to 1992 (Ollinger

et al., 1997) suggested that forest productivity is currently reduced by 5–10% annually across the region.

Hudson *et al.* (1994) developed a linked terrestrial/atmospheric global carbon cycling model to investigate global carbon pools, and to aid in illuminating discrepancies in the measured global carbon balance. They report concurrence with the notion of temperate forests being largely nitrogen limited, and identify increased atmospheric nitrogen deposition, originating from fossil fuel combustion and other anthropogenic sources, as contributing to large increases in carbon immobilization in terrestrial vegetation.

Using the BIOME3 model, simulations suggest that temperate deciduous forests in Europe may substantially increase in productivity under combined global change scenarios during the next 80 years (Parry, 2000). Moreover, the optimal type shifts from the more northern mixed forest to temperate deciduous forest in roughly one-third of the European temperate zone under this simulation.

SUMMARY

Temperate deciduous forests are important to regional economies as a source of wood, they provide many regional ecological services, and they play a major role in the global carbon cycle. As illustrated above, we can characterize temperate deciduous forest changes, and are beginning to understand the collective impacts of a variety of global change factors on the processes that combine to control composition and ecosystem function in these forests. As scientists, we still face enormous challenges in understanding those complex interactions and in measuring forest patterns and processes at relevant regional to global scales. In this century, temperate forests will continue to play an expanding role as demands for fiber, ecological services (such as water supply and stream water quality, carbon storage, and others), other ecological benefits (wildlife, other biodiversity) and other human values (recreation, tourism, aesthetics, spirituality) increase with burgeoning global populations. Given that temperate deciduous forests are located in regions that are highly developed and already highly disturbed by human use, their future extent, composition, health, and productivity may well signal whether human civilization at high population density is compatible with the sustainability of ecological and economic health and productivity in any ecosystem type or biome.

REFERENCES

- Aber, J D, Nadelhoffer, K J, Steudler, P, and Melillo, J M (1989) Nitrogen Saturation in Northern Forest Ecosystems, *BioScience*, **39**, 378–386.
- Aber, J D, Ollinger, S V, Federer, C A, Reich, P B, Goulden, M, Kicklighter, D W, Melillo, J M, Lathrop, R G, and Ellis, J M (1995) Predicting the Effects of Climate Change on Water Yield and Forest Production in the Northeastern United States, *Clim. Res.*, **5**, 207–222.
- Abrams, M D (1998) The Red Maple Paradox, *BioScience*, **48**, 355–364.
- Abrams, M D (1992) Fire and the Development of Oak Forests, *BioScience*, **42**, 346–353.
- Crow, T R (1988) Reproductive Mode and Mechanisms for Self-replacement of Northern Red Oak (*Quercus rubra*) – a Review, *For. Sci.*, **34**, 19–40.
- Goulden, M L, Munger, J W, Fan, S M, Daube, B C, and Wofsy, S C (1996) Exchange of Carbon Dioxide by a Deciduous Forest: Response to Interannual Climate Variability, *Science*, **271**, 1576–1578.
- Grimm, E C (1984) Fire and Other Factors Controlling the Big Woods Vegetation of Minnesota in the Mid-nineteenth Century, *Ecol. Monogr.*, **54**, 291–311.
- Houghton, R A (1995) Changes in the Storage of Terrestrial Carbon Since 1850, in *Soils and Global Change*, eds R Lal, J Kimble, E Levine, and B A Stewart, CRC Press, Inc., Lewis Publishers.
- Hudson, R J M, Gherini, S A, and Goldstein, R A (1994) Modeling the Global Carbon Cycle: Nitrogen Fertilization of the Terrestrial Biosphere and the Missing CO₂ Sink, *Global Biogeochem. Cycles*, **8**, 307–333.
- Kauppi, P, Mielikäinen, K, and Kuusela, K (1992) Biomass and Carbon Budget of European Forests, 1971 to 1990, *Science*, **256**, 70–74.
- Kruger, E L and Reich, P B (1997) Responses of Hardwood Regeneration to Fire in Mesic Forest Openings. I. Post-fire Community Dynamics, *Can. J. For. Res.*, **27**, 1822–1831.
- Magill, A H, Aber, J D, Hendricks, J J, Bowden, R D, Melillo, J M, and Steudler, P A (1997) Biogeochemical Response of Forest Ecosystems to Simulated Chronic Nitrogen Deposition, *Ecol. Appl.*, **7**, 402–415.
- Melillo, J M, Kicklighter, D W, McGuire, A D, Moore, B, Vorosmarthy, C J, and Grace, A L (1993) Global Climate Change and Terrestrial Net Primary Production, *Nature*, **363**, 234–240.
- Ollinger, S V, Aber, J D, and Reich, P B (1997) Simulating Ozone Effects on Forest Productivity: Interactions Among Leaf-, Canopy-, and Stand-level Processes, *Ecol. Appl.*, **7**, 1237–1251.
- Parry, M L, ed (2000) *Assessment of Potential Effects and Adaptations for Climate Change in Europe: the Europe ACACIA Project*, Jackson Environment Institute, University of East Anglia, Norwich, 1–320.
- Pastor, J, Dewey, B, Naiman, R J, McInnes, P F, and Cohen, Y (1993) Moose Browsing and Soil Fertility in the Boreal Forests of the Isle Royale National Park, *Ecology*, **74**, 467–480.
- Peterson, D and Reich, P B (2001) Fire Frequency and Stand Dynamics in an Oak Savanna–Woodland Ecosystem, *Ecol. Appl.*, (in press).
- Pyne, S J (1982) *Fire in America: a Cultural History of Wildland and Rural Fire*, Princeton University Press, Princeton, NJ.
- Reich, P B (1987) Quantifying Plant Response to Ozone: a Unifying Theory, *Tree Physiol.*, **3**, 63–91.
- Reich, P B, Abrams, M D, Ellsworth, D S, Kruger, E L, and Tabone, T J (1990) Fire Affects Ecophysiology and Community

- Dynamics of Central Wisconsin Oak Forest Regeneration, *Ecology*, **71**, 2179–2190.
- Reich, P B and Bolstad, P (2001) Temperate Forests: Evergreen and Deciduous, in *Global Terrestrial Productivity*, eds H Mooney, J Roy, and B Saugier, Academic Press (in press).
- Running, S W and Nemani, R R (1991) Regional Hydrologic and Carbon Balance Responses of Forests Resulting from Potential Climate Change, *Clim. Change*, **19**, 349–368.
- Schimel, D S (1995) Terrestrial Ecosystems and the Carbon Cycle, *Global Change Biol.*, **1**, 77–91.
- Townsend, A R, Braswell, B H, Holland, E A, and Penner, J E (1996) Spatial and Temporal Patterns in Terrestrial Carbon Storage due to Deposition of Fossil Fuel Nitrogen, *Ecol. Appl.*, **6**, 806–814.
- Williams, M (1989) *Americans and Their Forests*, Cambridge University Press, Cambridge.