APPENDIX D

Ecosystem Carbon Fluxes

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The recent history of disturbance largely determines whether a forest system will be a net source or sink of carbon. For example, net ecosystem productivity (NEP, see Table D.1 for a list of definitions and acronyms used in this appendix) is being measured across a range of forest types in Canada using the eddy covariance technique. In mature forests, values range from -19.6 tons of carbon per hectare (t C per ha) per year in a white pine plantation in southern Ontario (Arain and Restrepo-Coupe, 2005) to -3.2 t C per ha per year in a jack pine forest (Amiro *et al.*, 2005; Griffis *et al.*, 2003). In recently disturbed forests, NEP ranges from +58.0 t C per ha per year in a harvested Douglas-fir forest (Humphreys *et al.*, 2005) to +5.7 t C per ha per year in a seven year old harvested jack pine forest (Amiro *et al.*, 2005). In general, forest stands recovering from disturbance are sources of carbon until uptake from growth becomes greater than losses due to respiration, usually within 10 years (Amiro *et al.*, 2005).

Table D.1 Ecosystem Productivity Terms and Definitions. (Terms and definitions apply to Appendices D and E of this report.)

Term	Acronym	Definition
Net Primary Production	NPP	Net uptake of carbon by plants in excess of respiratory loss
Heterotrophic Respiration	R_h	Respiratory loss by above- and below-ground heterotrophs (herbivores, decomposers, *etc.*)
Net Ecosystem Production	NEP	Net carbon accumulation within the ecosystem after all gains and losses are accounted for, typically measured using ground-based techniques. By convention, positive values of NEP represent accumulaitons of carbon by the ecosystem, and negative values represent carbon loss.
Net Ecosystem Exchange	NEE	The net flux of carbon between the land and the atmosphere, typically measured using eddy covariance techniques. Note: NEE and NEP are equivalent terms but are not always identical because of measurement and scaling issues, and the sign conventions are reversed. Positive values of NEE (net ecosystem exchange with the atmoshpere) usually refer to carbon released to the atmosphere (*i.e.*, a source), and negative values refer to carbon uptake (*i.e.*, a sink).

Sources: Randerson *et al.* (2002); Chapin *et al.* (2006).

Table D.2 Comparison of net ecosystem exchange (NEE) for different types and ages of temperate forests. Negative NEE means the forest is a sink for atmospheric CO_2. Eighty-one site years of data are from multiple published papers from each of the AmeriFlux network sites, and a network synthesis paper (Law *et al.*, 2002). NEE was averaged by site, then the mean was determined by forest type and age class. SD is standard deviation among sites in the forest type and age class.

NEE (t Carbon per ha per year)			
	Regenerating Clearcut (1 to 3 years after disturbance) (1 site, 5 site-years)	Young forest (8 to 20 years old) (4 sites, 16 site-years)	Mature forest (>20 years old) (13 sites, 60 site-years)
Evergreen Coniferous Forests	–1.7 to +12.7 mean = 7.1, (SD 4.7) (1 site, 5 site-years)	–0.6 to –5.9 mean = –3.1, (SD 2.6) (4 sites, 16 site-years)	–0.6 to –4.5 mean = –2.5, (SD 1.4) (6 sites, 20 site-years)
Mixed Evergreen and Deciduous Forests	NA	NA	–0.3 to –2.1 mean = –1.0, (SD 0.6) (1 site, 6 site-years)
Deciduous Broadleaf Forests	NA	NA	–0.6 to –5.8 mean = –2.7, (SD 1.8) (6 sites, 34 site-years)

In the United States, extensive land-based measurements of forest/atmosphere carbon exchange reveal patterns and causes of sink or source strength (Table D.2). Results show that net ecosystem exchange (NEE) of carbon in temperate forests ranges from a source of +12.7 t C per ha per year to a sink of -5.9 t C per ha per year. Forests identified as sources are primarily forests in the earliest stages of regeneration (up to about eight years) following stand-replacing disturbances such as wildfire and logging (Law *et al.*, 2002). Mature temperate deciduous broadleaf forests and mature evergreen coniferous forests were an average sink of -2.7 and -2.5 t C per ha per year, respectively (12 sites, 54 site-years of data). Values ranged from a source of +0.3 for a mixed deciduous and evergreen forest to a sink of -5.8 for an aggrading deciduous forest, averaged over multiple years. Young temperate evergreen coniferous forests (8 to 20 years) ranged from a sink of -0.6 to -5.9 t C per ha per year (mean -3.1). These forests are still rapidly growing and have not reached the capacity for carbon uptake.

Mature forests can have substantial stocks of sequestered carbon. Disturbances that damage or replace forests can result in the land being a net source of carbon dioxide (CO_2) for a few years in mild climates to 10-20 years in harsh climates while the forests are recovering (Law *et al.*, 2002; Clark *et al.*, 2004). Thus, the range of observed annual NEE of CO_2 ranges from a source of about +13 t C per ha per year in a clearcut forest to a net sink of -6 t C per ha in mature temperate forests.

For Mexican forests, estimates of net ecosystem carbon exchange are unavailable, but estimates from other tropical forests may indicate rates for similar systems in Mexico. In Puerto Rico, aboveground NPP in tropical forests range from -9.2 to -11.0 t C per ha per year (Lugo *et al.*, 1999). Below-ground NPP measurements exist for only one site with -19.5 t C per ha per year (Lugo *et al.*, 1999). In Hawaii, above-ground and below-ground NPP of native forests dominated by *Metreosideros polymorpha* vary depending on substrate age and precipitation regime. Above-ground NPP ranges between -4.0 to -14.0 t C per ha per year, while below-ground NPP ranges between -5.2 and -9.0 t C per ha per year (Giardina *et al.*, 2004). Soil carbon emissions along the substrate age gradient range from +2.2 to +3.3 t C per ha per year, and along the precipitation gradient from +4.0 to +9.7 t C per ha per year (Osher *et al.*, 2003). NEP estimates are not available for these tropical forests, so their net impact on atmospheric carbon stocks cannot be calculated.