Carbon sink for a century

Intact rainforests have a long-term storage capacity.

With fossil-fuel combustion and land-use activities threatening to double atmospheric carbon dioxide this century[1], maintaining large forests as carbon reservoirs becomes an additional conservation incentive. We have developed a stochastic-empirical model that simulates forest-carbon cycling and now use this model to explore the response of the central Amazonian forest to an increase in biomass productivity. Our results show that these trees will accumulate carbon in their wood for more than a century after a productivity increase, underscoring the value of intact tropical forests.

Evidence from eddy covariance studies[2], analysis of forest inventory plots[3], and atmospheric inversion models[4] indicate that undisturbed neotropical forests remove a significant portion of human-derived CO_2 emissions from the atmosphere. Although these results do not provide insight into causal factors, open-top chamber experiments indicate that CO_2 doubling enhances the production of woody tissue per unit leaf area by about 25% (ref. 5), and plant physiological ecology provides a mechanistic basis for this response[6].

The response of forest carbon storage to higher productivity is a function of the fraction of production allocated to, and the residence time of, the component reservoir[6]. Large wood (trunks and branches of or over 10 cm diameter and roots over 5 cm diameter) in central Amazon forest represents about 45% of total carbon storage and 30% of above-ground production, with a mean residence time of 80 years. Thus, compared with other ecosystem components, large wood has a high storage capacity, with a relatively long lag time after disturbance. Passive soil organic matter also has a large storage capacity, but carbon movement into this pool is very slow[7].

Our model[8] was parameterized using extensive field data of individual trees larger than 10 cm base diameter (D_b), including recruitment, growth and mortality ($n = 18$ hectares), tree allometry (327 trees)[9], maximum size of trees ($n = 220$ species), wood density ($n = 268$ species), and wood decomposition[10] rates (155 dead trees). The model starts by filling 20×20 m cells (stands) with a variable number of trees whose characteristics are assigned using random deviates from the empirical distributions. Each year, variation in recruitment, growth, mortality and decomposition determines the carbon balance of the entire plot (and aggregate of stands).
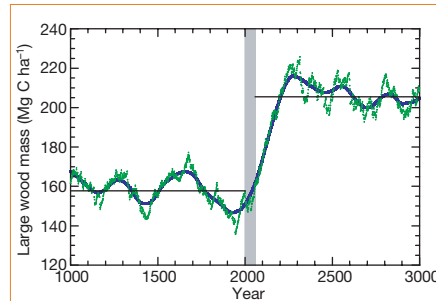
We demonstrated model reliability by

Figure 1 Example of large-wood carbon storage response predicted by the model[8] to a 25% increase in biomass productivity over 50 years (0.25% per year). Cubic-spline fit shows averaged response; mean carbon storage (thin horizontal lines) stabilizes 127 ± 28 (95% C.I.) years (mean of eight 100-ha runs) after a 50-yr production increase (grey bar) with an accumulation rate of 0.5 Mg C ha^{-1} yr^{-1}. Stability is defined as when any year's mass falls within a 95% C.I. of the mean (final 500 years) large-wood mass.

comparing predictions with the same field data (respectively), including large wood (predicted, 164 Mg C ha^{-1}; field value, 156 Mg C ha^{-1}) and coarse litter (16 vs 15 Mg C ha^{-1}) carbon stocks, large wood growth (1.6 vs 1.7 Mg C ha^{-1} yr^{-1}) and mortality (1.8 vs 2.1 Mg C ha^{-1} yr^{-1}) rates, mean D_b (20.4 vs 21.1 cm), mean age for trees with greater than 100 cm D_b (383 vs 425 yr), and maximum tree age[11] (1,192 vs 1,372 yr).

We used this model to investigate the response of large-wood carbon storage to a 25% increase in production distributed over 50 years for a 100-ha plot. As expected, carbon accumulated during years of increasing productivity. But once the productivity increase stopped (as a result of other limiting factors), large wood continued to accumulate carbon for over a century (Fig. 1).

Central Amazon upland (non-flooded environments) trees grow very slowly (mean, 1.1 mm D_b yr^{-1}), and carbon storage only reached a new dynamic equilibrium once most trees had grown for their entire lives (mean age, 175 years) under conditions of enhanced productivity and the mass of a tree of mean D_b had stabilized at a higher value.

Forests respond in complex ways to increased atmospheric CO_2 and other global changes[12], and our model does not include potential limitations to a productivity increase or changes in vegetation characteristics. But for a given increase in productivity, it reveals that large-wood carbon storage will exhibit a lengthy lag time.

Avoiding deforestation will help industrialized countries to meet their Kytoto protocol emission-reduction obligations. Deforestation not only transfers carbon stocks directly to the atmosphere by combus-

Figure 2 The central Amazonian rainforest. The conservation value of tropical forests includes providing habitat for about half of the world's biological diversity, maintaining existing hydrological cycles and providing chemical precursors for the biomedical industry, not to mention the aesthetic and intrinsic value of a vast natural wilderness. The trees can also act as an important sink for carbon, continuing to accumulate it in their wood for over a century after an increase in biomass productivity.

tion, but it also destroys a valuable mechanism for controlling atmospheric CO_2.

Given a large increase in productivity, we calculate the rate of carbon sequestration to be of the order of 0.2–0.3 petagrams of carbon per year (which amounts to US$2–3 billion per year at $10 per Mg C) for large wood of the intact forest in Amazonia (Fig. 2), compared to fossil-fuel emissions of roughly 6 Pg of C per year. In all scenarios that reduce emissions to levels commensurate with the Kyoto protocol, numerous net biospheric exchanges of carbon are important. But terrestrial sequestration can only offer a partial solution, so controlling atmospheric CO_2 will require substantial reductions in fossil-fuel emissions in the coming decades.

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