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New observations suggest vulnerability of the carbon sink in tropical rainforests

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Terrestrial ecosystems have slowed global climate change by sequestering carbon dioxide (CO2) from the atmosphere (Denman et al. 2007; Canadell et al. 2007) and tropical rainforests contribute to this significantly (Gurney et al. 2002, Sabine et al. 2004, Stephens et al. 2007). Whether rainforests will continue to be a net sink for carbon (C) in the future is an important and open question. The current expectation that rainforests will increasingly absorb anthropogenic C emissions in this century is largely based on coupled global modelling with some support from field studies. However, by considering long-term demographic processes such as tree mortality, we report that the capacity of rainforests to store C is more likely to decrease with global warming by approximately 20 Pg C per degree of warming, implying more rapid growth of global atmospheric CO2 and consequent climate change than is now anticipated. Specifically, we identify a broad, pantropical pattern of decreased above-ground biomass of rainforests growing in warmer climates that is most likely to be due to increased rates of tree mortality and that is explainable by constant mortality in thermal time. Considering 116 pantropical rainforest plots with various long-term mean annual temperatures (T, oC), basal area (BA), a measure that closely relates to total biomass and C stocks (BA, m2 of tree stems ha-1), declines on average by 2.08 m2 ha-1 oC-1. This decline has not been documented previously or factored into global climate models. This pantropical pattern of lower biomass in warmer climates implies a reduced capacity of rainforests to sequester C with global warming. To understand the causes of this broad pattern, we analysed data from North East Australia where 8210 trees in sixteen rainforest plots were measured over a period of 35 years, with T from 18.3 to 25.8 oC and mean annual rainfall from 1236 mm to 3470 mm. Temperature, rainfall and soil fertility are not correlated in these data. The response of these rainforests to warmer climates is consistent with the pantropical pattern (BA declines by 2.77 m2 ha-1 oC-1). These data, with repeated censuses over several decades, demonstrate that a forest's long-term BA (thus biomass and C stock) is primarily influenced by tree mortality rate which also affects other processes. Tree mortality rate () increases with T (= -2.135 + 0.152 T). Both mean tree growth and recruitment rates are highly and positively correlated to , presumably because tree deaths open gaps where light levels are enhanced. The direct effect of  on BA is highly significant and negative (BA= 64.266 -11.295). Thus, despite the stimulation of tree growth and recruitment by tree death, the net result of higher tree mortality in warmer climates is a decrease in total BA. Consistent with studies that have inferred a strong C sink for rainforests (Phillips et al. 2008), over short census intervals (2-6 years), 71 percent of sequential measurements of these forests show an increase in basal area. However, less frequent census periods of higher tree death result in decreased BA that counterbalance the more frequent periods of recovery and there is no long-term change in total basal area. So, BA is relatively stable over decades, it is predictable by long-term mean annual temperature and it does not show a long-term trend, suggesting a lack of CO2 fertilisation effect in these forests. Combining our estimate of decline in the C stock of rainforests with T, along with the estimated global area of rainforests (Sabine et al. 2004) gives a potential total C loss of approximately 20 Pg C per degree °C of warming. This analysis applies to the C stock of mature forests so rainforests recovering from previous anthropogenic disturbances could, in the short-term, counterbalance the loss of sink capacity in mature forests.

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