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Comment on "The global tree restoration potential"

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Bastin *et al.* (Reports, 5 July 2019, p 76) neglect considerable research into forest-based climate change mitigation during the 1980s and 1990s. This research supports some of their findings on the area of land technically suitable for expanding tree cover, and can be used to extend their analysis to include the area of actually available land and operational feasibility.

The paper by Bastin *et al.* (1) is to be welcomed for drawing fresh attention to the potential for expanding forest and tree cover to mitigate global climate change by sequestering CO_2 from the atmosphere. Unfortunately, it fails to acknowledge the huge amount of research in this field during the 1980s and 1990s. This is a common problem, since the UN Framework Convention on Climate Change did not begin negotiations on a Reducing Emissions from Deforestation and Degradation (REDD+) mechanism until 2007, and research to support REDD+ has grown rapidly since then. As Bastin *et al.* emphasize, time is short. So it is vital that new forest mitigation programmes build on pre-existing knowledge and do not try to 'reinvent the wheel'. Here we use key achievements of this early research to assess the contributions and limitations of Bastin *et al.*'s findings.

Bastin *et al.* (1) find "room for an extra 0.9 billion hectares (ha) of canopy cover which will store 205 Gt of carbon", and relate this to the net amount of carbon transferred into the atmosphere since pre-industrial times. Early estimates, however, focused on the size of a new forest sink needed to sequester a meaningful amount of carbon on a continuing basis. They included: (i) 500 million ha to absorb gross emissions in the 1980s of 5 gigatonnes of carbon per year (Gt C yr^{-1}) (2); and (ii) 465 million ha with a growth rate of 15 m^3 ha^{-1} yr^{-1} to sequester only the net annual rise of 2.9 GT C yr^{-1} in the atmosphere (3) after uptake by terrestrial and oceanic sinks.

Later studies showed that more than enough degraded tropical land existed to support forest expansion on this scale. Two papers presented to an Intergovernmental Panel on Climate Change (IPCC) Conference in January 1990 estimated that in the tropics: (i) 620 million ha of degraded lands were physically suitable for establishing this new "carbonforest", and another 137 million ha of degraded forests could be restored (4); and (ii) 500 million ha of land could be afforested by 2100 with a further 365 million ha of forest fallows having potential for restoration (5). Both studies were summarized in the First IPCC Assessment Report (6). The comparability of these findings with those of Bastin *et al.* (1) is remarkable, since Bastin *et al.* use very high (≤ 1m) resolution satellite data and cloud-based machine learning algorithms, while early estimates depended largely on United Nations statistics - though one 1990 estimate did use low (≥ 1 km) resolution satellite data (5).

Bastin *et al.* (1) also relate their principal finding to a recent IPCC estimate (7) that 950 million ha of new forests could help to "limit global warming to 1.5°C" by 2050. Since this estimate is based on the current net annual rise in CO_2 in the atmosphere, which is twice as high (≈ 5.7 GT C yr^{-1}) as in the 1980s, it is consistent with the 465 million ha considered appropriate 30 years ago (3).

Bastin *et al.* (1) do not evaluate the operational feasibility of expanding tree cover in time to tackle global warming promptly. Nor does the recent IPCC report, which discusses planting 950 million ha of new forests in just 30 years (7). Yet one early study (4) argued that to afforest 600 million ha over a 30 year period would require a planting rate 20 times higher than the contemporary rate of 1 million ha yr^{-1}. It anticipated REDD+ by showing that more modest planting rates could suffice if afforestation proceeded in parallel with programmes to reduce the rate of tropical deforestation, which is a major source of carbon emissions (4).

Bastin *et al.* (1) assess the potential to increase carbon density in existing forests, using carbon densities in protected areas as benchmarks, but do not mention a pioneering methodology for making restoration assessments which was devised in the early 1990s and applied to all tropical Asia. Starting with an FAO map of tropical forest area in Asia in 1980 derived from mediumresolution Landsat satellite data, the distribution of potential forest carbon density was determined by using Geographical Information System modelling to combine forest inventory data (8) with multiple environmental datasets. Using degradation factors developed as a function of human population density for each ecofloristic zone along a moisture gradient, actual carbon density was then mapped to identify the distribution of degraded forests which could be restored. This map agreed well with an alternative map of a global vegetation index quantified using low resolution satellite data (9, 10).

Commenting on Bastin *et al.*'s (1) paper, Chazdon and Brancalion (11) wisely stress the need to address "social and environmental issues" in tree restoration. The importance of integrating afforestation with forest conservation was recognized in 1991 (12). Early studies also estimated the costs of afforestation, e.g. just to plant a 300 million ha carbonforest over 30 years would cost US$4,000 million yr^{-1} (4). These costs would be offset by income from converting the wood produced in the new forests into energy and harvested wood products (HWP), so these forests would be sustainable carbon sinks. The potential role of HWP in climate change mitigation is still poorly understood.

Increasingly sophisticated tools for feasibility analysis were then developed. The 'technical suitability' of land for afforestation was distinguished from the 'actual availability' of land on which afforestation might be socially, economically and politically acceptable (10, 13), and the link between the level of national development (i.e. 'developmental time') and the area of actually available land was recognized in the new concept of 'national forest carbon transition functions' (14). Now that climate change is shifting the potential locations of biome boundaries (15), Bastin *et al.* (1) rightly allow for the influence of 'climatic time' on their assessment by including alternative climate change scenarios.

If Bastin *et al.*'s (1) paper gives new impetus to using forests to mitigate climate change then the results of this early research can finally be employed for the purpose for which they were originally intended.

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