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Developed-developing world partnerships for sustainable development (3): Reducing carbon sequestration uncertainties in south Indian tropical dry evergreen forest

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ABSTRACT

Climate regulation services provided by tropical dry evergreen forest (TDEF), a threatened habitat of India's Coromandel Coast, appear significant due to high carbon assimilation rates. International markets for climate regulation represent an 'anchor service' potentially promoting TDEF restoration, co-beneficially generating multiple linked ecosystem services. Understanding the forest type and carbon sequestration rate is essential to underpin these markets. Literature suggests that TDEF is a broad categorisation of forest types shaped by environmental conditions and human pressures, a plastic biome rather than a definitive vegetation type, though regionally representative if now highly fragmented. Previous estimates of carbon sequestration potential in restored TDEF were found to be flawed, calculated from incorrectly stated units in a source paper. Structured literature review confirms the sparsity of relevant literature, though the distinctive nature of TDEF makes data transfer from other forest types unreliable. From the limited literature, carbon sequestration potential from restoration of TDEF is of the order of 292 tC ha^{-1} (1071 tCO_2e ha^{-1}), subject to multiple stated assumptions and significant uncertainty that is unquantifiable based on limited data. Further research is required to quantify TDEF carbon sequestration and additional ecosystem services, expanding potential market-based restoration and informing optimal land use policies and practices.

1. Introduction

Consensual international studies (e.g. IPCC, 2001, 2007) provide compelling evidence linking climate change to human-induced increases in atmospheric concentrations of greenhouse gases, particularly carbon dioxide. The Kyoto Protocol explicitly accounts for sequestration of carbon through reforestation and afforestation (IPCC, 2007). Carbon assimilation, defined as the overall rate of fixation of carbon through the process of photosynthesis, has become central to climate change research (Kaul et al., 2009, 2010). Tropical dry forests are of particular significance, accounting for approximately 42% of the landmass of the tropics (Miles et al., 2006). Field et al. (1998) estimated that annual net carbon sequestration by tropical forests and savanna cumulatively account for 60% of global terrestrial photosynthesis, and tropical forests are of particular importance as stored carbon is portioned more or less equally between vegetation and soil (Ramachandran et al., 2007; Ravindranath et al., 1997; Malhi et al., 1999) though a study by Kaul et al. (2010) found that soil carbon can be almost double that in the biomass. Climate regulation services by tropical dry evergreen forest (TDEF) may be particularly significant, as Kaul et al. (2010) found that evergreen forests in India assimilate carbon at a higher rate than other forest and grassland types. This may exceed the world's highest total biomass carbon density (living plus dead) reported by Keith et al. (2009) as 1867 tC ha^{-1} from Australian Central Highlands temperate moist *Eucalyptus regnans* forests found amongst published global site biomass data (the source reference is Van Pelt et al. (2004) for living plus dead total biomass in > 100 year-old *E. regnans* forest), a value that excludes soil carbon.

Forest loss or degradation has an adverse effect on controlling atmospheric carbon concentrations. During the 1990s, tropical deforestation released approximately 1–2 billion tonnes of carbon per year, equating to 15–25% of annual global greenhouse gas emissions which

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exceeded transportation sector emissions over the same period (Gibbs et al., 2007; Madeira, 2008). Conversely, IPCC (2000) estimated a total global potential carbon sequestration through afforestation and reforestation activities for the period 1995–2050 of between 1.1 and 1.6 Pg C yr^{-1} (1.1 and 1.6 × 10^9 Mg or tonnes C yr^{-1}), of which 70% could occur in the tropics. Consequently, carbon sequestration and biodiversity protection received increases in priority in scientific, governmental and civil-society agendas as a means to mitigate climate change (Diáz et al., 2009). Under the international REDD+ programme, investment for carbon offsetting from developed nations funds protection and regeneration of developing world forests, providing developing nations with a source of revenue for the service of climate regulation (United Nations, 2008, 2014). This type of market-based instrument has promoted forest protection and plantation programmes in developing countries, yielding a range of benefits including carbon credits and the generation of significant income (Niles et al., 2002). Forest regeneration can also produce a range of linked ecosystem service co-benefits in addition to the marketed service (Everard et al., 2017).

Quantifying the potential rate by which climate regulation can be influenced by forest conservation and restoration is necessary to underpin global markets for this ecosystem service. However, despite a broad literature on carbon stocks, publications specifically addressing sequestration rates for different tropical forest types are sparse. In India, Mani and Parthasarathy (2007) used different methods to estimate that above-ground biomass in TDEF varied from 39.69 to 173.10 Mg C ha^{-1} (tC ha^{-1}). For India's dry tropical forest resource as a whole, Singh and Singh (1991) estimated an average standing crop of 66.98 t ha^{-1}. Chhabra et al. (2003) estimated that the total soil organic carbon (SOC) pool in Indian forests ranges from 4.13 Pg C (4.13 × 10^9 Mg or tonnes C) for the top 50 cm soil depth to 6.18 Pg C (6.18 × 10^9 Mg or tonnes C) for the top 1 m soil depth. Based on different forest types in India, the national average of soil organic carbon per ha in forest soil was estimated as 183 Mg C ha^{-1} (Jha et al., 2003).

Across India, approximately 36 million ha of degraded and non-forest lands were afforested between 1951 and 2002 (FSI, 2003; Forestry and Wildlife Statistics of India, 2004). Ravindranath et al. (1997) and Kaul et al. (2009) respectively calculated marginal net sequestration rates of 5 Tg C (5 × 10^6 Mg or tonnes C) for the reference year 1986 and of 1.09 Tg C (1.09 × 10^6 Mg or tonnes C) for 2002 for India as a whole. Lal and Singh (2000) estimated that, at then currently reported rates of biomass productivity of natural forest cover (1.1 Mg ha^{-1} yr^{-1}) and plantations (3.2 Mg ha^{-1} yr^{-1}), forest carbon sequestration potential was in the range of 1.1 and 2.7 Pg C (1.1 and 207 × 10^9 Mg or tonnes C), respectively, by the years 2020 and 2045. However, substantial variation was observed between forest types found in India, with total long-term average carbon stocks in biomass and wood products calculated at 156 Mg C ha^{-1} for slow growing long rotation forests and in the range of 101–134 Mg C ha^{-1} for fast growing short rotation forests. These optimistic estimates of potential sequestration are however undermined by reports of rapid loss and degradation of forests across India. Based on satellite data, Jayakumar et al. (2009) found alarming decreases in the extent of all of India's major forest types (evergreen, deciduous, southern thorn and southern thorn scrub), all the more concerning as these rapid declines had occurred after India's Conservation Act was passed in 1980 and the launch of a National Forest Policy in 1988, amongst other conservation initiatives intended to limit deforestation and conserve biodiversity.

Everard et al. (2017) describe how developing-developed world partnerships potentially present win-win opportunities for addressing climate-active gas emissions at lower cost, recognising the geographical independence of where carbon is emitted, stored and sequestered. This is broadly consistent with measures under the REDD+ programme. Principles of how REDD+ would operate in India are discussed by Sharma and Chaudhry (2013). The particular case explored by Everard et al. (2017) – a partnership between south-west England and Tamil Nadu state, India, under The Converging World (TCW) model – was described in terms of an expanded PES (payment for ecosystem services) framework, initially founded on globally beneficial services generated by the function of carbon sequestration in the biomass and soil of restored tropical dry evergreen forest (TDEF). However, a far wider, societally beneficial set of services (water regulation, storm buffering, harvested food and medicinal products, soil formation, etc.) provided by regenerating TDEF was also recognised. If subsequently characterised and quantified, these additional services could provide additional bases for PES markets. The process of carbon sequestration in TDEF is the basis for the 'anchor service' (sensu Everard, 2014) of climate regulation, constituting the driving interest around which systemic consideration and design can optimise co-delivery of a range of linked ecosystem service benefits referred to variously as 'environmental services' (*sensu* Schomers and Matzdorf, 2013) or 'bundles' (Balvanera et al., 2016: p.48) of greater potential cumulative societal benefit. Everard et al. (2017) recognised that initial quantification of this anchor service was limited by sparse published data on sequestration rates in restored TDEF. Considerable disparity was noted between published generic rates in temperate systems and the very few data available for a representative tropical evergreen forest type, citing Ramachandran et al. (2007) as the only directly comparable case study. Everard et al. (2017) acknowledged substantial uncertainties in values extrapolated from such a sparse evidence base, though methods used to translate a value published by Ramachandran et al. (2007) into market values were conservative, precautionary and framed as being highly uncertain.

Quantification and monitoring of ecosystem service production and, if necessary, sanctioning mechanisms are necessary to underpin the development and operation of effective PES schemes (Meijerink, 2008; Sommerville et al., 2011; Potschin and Haines-Young, 2016). For robust climate regulations and linked markets to be established for TDEF restoration, it is necessary to be clear about both the characteristics of this forest type and its associated carbon sequestration rate.

A review by Everard (2018) addresses the characteristics, representativeness, function and conservation importance of TDEF on India's Coromandel Coast, comprising the south-eastern coastal region of peninsular India seaward of the Eastern Ghats and bordering the Bay of Bengal, between False Divi Point in the north and Kanyakumari at India's southern tip (Fig. 1). This review found that TDEF is a product of natural forces (tectonic movement and biogeography, climate, soil type) as well as anthropogenic factors relating to forest use, conversion and protection throughout the long history of human activity on the Coromandel Coast (Begley, 1993; Begley et al., 1996; Chandra, 2011). The population of Tamil Nadu state has boomed post-Independence from just over 30 million in 1951 to in excess of 79 million in 2017 (Indiaonlinepages.com, undated), intensifying these pressures, which have resulted in regionally characteristic though now fragmented forest with a 9–12 m canopy comprising climax vegetation that is commonly evergreen. The simple leaves often with waxy upper surfaces characteristic of this forest type limits evapotranspiration, seeds are often contained in small fruits appearing between April and September, and trees exhibit slow growth with dense, hard wood and a general lack of thorns though with some exceptions, all apparently adaptations to infrequent, intermittent and unpredictable rains. However, the broad literature reviewed by Everard (2018) reveals a high degree of heterogeneity of even closely adjacent extant forest stands, leading to the conclusion that, though there are some characteristic tree species, the categorisation of TDEF is representative of a larger, plastic biome (as for example 'tropical rainforest' or 'coral reef') distinctive to the Coromandel Coast and some other global regions with a similar biogeography rather than a specific vegetation type. However, whether biome or distinctive forest type, the functions that TDEF performs and the breadth of ecosystem services that it provides are considered significant (Everard et al., 2017) and in particular through carbon sequestration functions that appear to be particularly significant given observed high soil organic carbon in TDEF.