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Ecosystem services capacity across heterogeneous forest types: understanding the interactions and suggesting pathways for sustaining multiple ecosystem services

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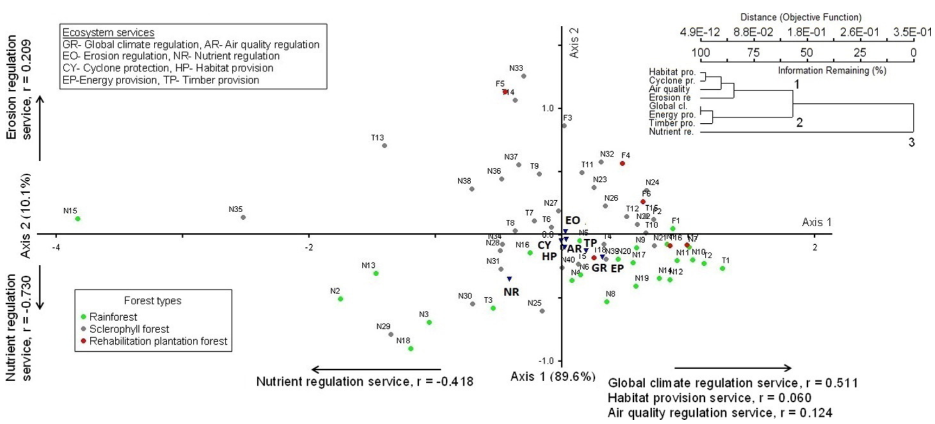
HIGHLIGHTS

- Multiple ecosystem services supply across three forest types was evaluated.
- The supplies were highest in rainforests followed by rehabilitated and sclerophyll forests.
- Global climate regulation had synergies but nutrient regulation had trade-offs impact.
- Two synergy groups and one trade-off group were identified.
- Three integrated pathways were recommended to sustain the supply of multiple ecosystem services.

GRAPHICAL ABSTRACT



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ABSTRACT

As ecosystem services supply from tropical forests is declining due to deforestation and forest degradation, much effort is essential to sustain ecosystem services supply from tropical forested landscapes, because tropical forests provide the largest flow of multiple ecosystem services among the terrestrial ecosystems. In order to sustain multiple ecosystem services, understanding ecosystem services capacity across heterogeneous forest types and identifying certain ecosystem services that could be managed to leverage positive effects across the wider bundle of ecosystem services are required. We sampled three forest types, tropical rainforests, sclerophyll forests, and rehabilitated plantation forests, over an area of 32,000 m^2 from Wet Tropics bioregion, Australia, aiming to compare supply and evaluate interactions and patterns of eight ecosystem services (global climate regulation, air quality regulation, erosion regulation, nutrient regulation, cyclone protection, habitat provision, energy provision, and timber provision). On average, multiple ecosystem services were highest in the rainforests, lowest in sclerophyll forests, and intermediate in rehabilitated plantation forests. However, a wide variation was apparent among the plots across the three forest types. Global climate regulation service had a synergistic impact on the supply of multiple ecosystem services, while nutrient regulation service was found to have a trade-off impact. Considering multiple ecosystem services, most of the rehabilitated plantation forest plots shared the same ordination space with

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rainforest plots in the ordination analysis, indicating that rehabilitated plantation forests may supply certain ecosystem services nearly equivalent to rainforests. Two synergy groups and one trade-off group were identified. Apart from conserving rainforests and sclerophyll forests, our findings suggest two additional integrated pathways to sustain the supply of multiple ecosystem services from a heterogeneous tropical forest landscape: (i) rehabilitation of degraded forests aiming to provide global climate regulation and habitat provision ecosystem services and (ii) management intervention to sustain global climate regulation and habitat provision ecosystem services.

1. Introduction

The global flow of ecosystem services from tropical forests is the highest among terrestrial ecosystems (Costanza et al., 1997). Tropical forests are also rich in multiple ecosystem services (Alamgir et al., 2016; Lewis, 2006; Saatchi et al., 2011). Tropical forest areas are shrinking worldwide due to deforestation, land use change, and many other reasons (Achard et al., 2002; Hansen et al., 2013). Moreover, a substantial part of the remaining tropical forests are experiencing various forms of degradation (Ghazoul et al., 2015). Globally, >500 million hectares of tropical forests are estimated to be in various stages of degradation (Ghazoul et al., 2015), undermining the capacity of tropical forest landscapes to supply valuable multiple ecosystem services (Liu et al., 2015). Therefore, sustaining multiple ecosystem services supply from tropical forests is necessary, but it remains as a challenge both for the scientific and policy arenas (Portman, 2013). Furthermore, identification of certain ecosystem services that could be managed to leverage positive effects across a wider bundle of ecosystem services may be useful in effective decision-making processes (Egoh et al., 2009; Harrison et al., 2014; Villamagna et al., 2013).

One problem of sustaining the supply of multiple ecosystem services from a tropical forested landscape is the optimal quantification and understanding of the pattern and interaction of multiple ecosystem services across different forest types within a landscape, as multiple ecosystem services are often determined by the vegetation attributes of a forest type within the forested landscape (Galicia and Zarco-Arista, 2014; Palomo et al., 2013). Multiple ecosystem services at the landscape level are also affected by the land cover types (Burkhard et al., 2012), environmental variables (Rasche, 2014), and management regimes (Castro et al., 2015; Sohel et al., 2014). However, as a whole, the multiple ecosystem services across different forest types (with different vegetation attributes) within a landscape are still unclear (de Groot et al., 2010). As such, understanding the patterns, interactions, and quantification of multiple ecosystem services using vegetation attributes needs to be further examined if management factors (such as optimal forest rehabilitation) are to be fully considered in sound decision-making processes used to sustain the multiple ecosystem services supply from tropical forested landscapes (Alamgir et al., 2014; Zuidema et al., 2013).

Another problem of sustaining multiple ecosystem services from a heterogeneous tropical forested landscape is the identification of the groups of ecosystem services, which act synergistically with each other and which may undermine the supply of one another (the so-called trade-off services). On a broader scale (beyond the forest types), the synergies and trade-off groups often vary with land cover (de Groot et al., 2010; Foley et al., 2005). However, there is still an unresolved question, that is, how do synergies and trade-off groups of ecosystem services vary across different forest types within a heterogeneous forested landscape (Galicia and Zarco-Arista, 2014)? If a management option is taken into consideration targeting sustaining an ecosystem service supply, it may have a positive or negative impact on the supply of other ecosystem services, which is principally determined by the synergies or trade-offs between the particular ecosystem service and other ecosystem services (Baral et al., 2013b; Bennett et al., 2009; Galicia and Zarco-Arista, 2014; Raudsepp-Hearne et al., 2010). Therefore, it is crucial to identify the synergies and trade-off groups of multiple ecosystem services across the forest types (Galicia and Zarco-Arista, 2014; Villamagna et al., 2013), if multiple ecosystem services from a landscape are to be enhanced.

Our study compares the following eight ecosystem services: global climate regulation, air quality regulation, erosion regulation, nutrient regulation, cyclone protection, habitat provision, energy provision, and timber provision from rainforests, sclerophyll forests, and rehabilitated plantation forests of the Wet Tropics bioregion of northeast Queensland, Australia. We considered these eight ecosystem services noting their significance at the local–regional scale (air quality regulation, cyclone protection, energy provision, and timber provision) (Turton, 2008; WTMA, 2009) and global scale (erosion regulation, nutrient regulation, global climate regulation, and habitat provision) (Alamgir et al., 2016; Hilbert et al., 2001; Preece et al., 2012; Williams et al., 2003). Many of these ecosystem services are thought to closely interact with each other (Bennett et al., 2009; Egoh et al., 2009; Harrison et al., 2014; Villamagna et al., 2013) and potentially maintain the forest condition of the Wet Tropics bioregion into the future (Stork and Turton, 2008). In order to achieve the study aims, we collected forest vegetation attribute data at the scale of the forest stand from the Wet Tropics bioregion and conducted mean comparison, multivariate analysis, and two-way cluster analysis. We then assessed the pattern of these eight ecosystem services across three forest types in the landscape. In addition, we evaluated the interaction among these ecosystem services, and the synergies and trade-off groups among the eight ecosystem services identified. Finally, we discuss the opportunities and potential mechanisms required to sustain the supply of multiple ecosystem services across a heterogeneous tropical forest landscape.

2. Materials and methods

2.1. The study area

Our study was conducted in the Wet Tropics bioregion, northeast Queensland, Australia (Fig. 1), which has an area of approximately 2 million ha (Goosem, 2002) and comprises a heterogeneous, complex landscape dominated by intergrading rainforests and sclerophyll forests (Ash, 1988). This is one of the 89 bioregions in Australia that are unique in climate, geology, landform pattern, ecological features, and biological communities (Department of Environment, 2015). The Wet Tropics bioregion experiences a seasonally wet tropical climate with a mean annual rainfall of 1200–4000 mm, mean annual temperature range of 17–31 °C (Goosem, 2002; Trott, 1996), and elevation ranges from a few meters above mean sea level (msl) to approximately 1000 m, although the highest peak within the region is 1622 m.

2.2. Overview of the forest types

The rainforests of the Wet Tropics bioregion are characterized by dense canopies, high biological diversity, and broad-leaved trees from a variety of plant families, including the Moraceae, Myrtaceae, Rutaceae, and Sapindaceae (Adam, 1994; Bowman, 2000). The rainforests of this bioregion are distributed from the lowland floodplains to the uplands (>1000 m above msl). The structure and composition of the rainforests of the Wet Tropics are largely controlled by the rainfall, temperature, soil type, and elevation (Webb and Tracey, 1981). The rainforests have