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Assessing regulating and provisioning ecosystem services in a contrasting tropical forest landscape

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A B S T R A C T

Ecosystem services are the bridge between nature and society, and are essential elements of community well-being. The Wet Tropics Australia, is environmentally and biologically diverse, and supplies numerous ecosystem services. It contributes to the community well-being of this region, Australian national economy and global climate change mitigation efforts. However, the ecosystem services in the region have rarely been assessed undermining strategic landscape planning to sustain their future flow. In this study, we attempted to: (i) assess the quantity of five regulating ecosystem services – global climate regulation, air quality regulation, erosion regulation, nutrient regulation, and cyclone protection, and three provisioning ecosystem services – habitat provision, energy provision and timber provision across rainforests, sclerophyll forests and rehabilitated plantation forests; (ii) evaluate the variation of supply of those regulating and provisioning ecosystem services across environmental gradients, such as rainfall, temperature, and elevation; (iii) show the relationships among those ecosystem services; and (iv) identify the hotspots of single and multiple ecosystem services supply across the landscape. The results showed that rainforests possess a very high capacity to supply single and multiple ecosystem services, and the hotspots for most of the regulating and provisioning ecosystem services are found in upland rainforest followed by lowland rainforest, and upland sclerophyll forest. Elevation, rainfall and temperature gradients along with forest structure are the main determinant factors for the quantity of ecosystem services supplied across the three forest types. The correlation among ecosystem services may be positive or negative depending on the ecosystem service category and vegetation type. The rehabilitated plantation forests may provide some ecosystem services comparable to the rainforest. The results demonstrated disturbance regimes (such as tropical cyclones) may have influenced the usual spatial trend of ecosystem service values. This study will assist decision makers in incorporating ecosystem services into their natural resource management planning, and for practitioners to identify the areas with higher values of specific and multiple ecosystem services.

1. Introduction

The goods and services human populations receive from an ecosystem are ecosystem services (Costanza et al., 1997; Daily, 1997; MA, 2005). Forests supply diverse ecosystem services like climate regulation, air quality regulation, and clean water, which are necessary for human well-being (Raymond et al., 2009). Besides enormous ecological values (Harrison et al., 2014; Nelson et al., 2009), the economic values of forest ecosystem services are incredible (Baral et al., 2014a; Costanza et al., 1997; Ninan and Inoue, 2013), although formally unrecognized. Most of the supply of global ecosystem services are declining (MA, 2005; Shaw et al., 2011), potentially undermining community well-being (Barbier, 2015; Mutoko et al., 2015; van Jaarsveld et al., 2005). Therefore, global efforts both in the science and policy arena have intensified to include ecosystem services in landscape management, planning and decision making. This is apparent by the forming of a number of organizations linking ecosystem services science and practice such

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as the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES http://www.ipbes.net), Ecosystem Services Partnership (ESP, http://www.fsd.nl) and A Community on Ecosystem Services (ACES).

One of the core challenges with the inclusion of ecosystem services in landscape management, planning, and decision making is the multi-scale and multi-dimensional complexity of assessing ecosystem services (de Groot et al., 2010) including the spatial and temporal interactions among ecosystem services, land use and land cover, and management interruptions (de Groot et al., 2010; Palomo et al., 2013; van Oudenhoven et al., 2012). Furthermore, ecosystem services assessment is even more difficult in tropical forested landscapes, due to the more complex and dynamics nature. As ecosystem services science is a relatively new approach (Fisher et al., 2009), rapid assessment using proxies (like area) and secondary data are widely used (Seppelt et al., 2011), but these methods are unable to explain the variability of ecosystem services supply across the forest types and strong environmental gradients. Additionally, without optimal assessment and mapping of ecosystem services the sustainable benefits of ecosystem services conservation are not achievable (Naidoo et al., 2008).

The nature and quantity of ecosystem services supply from a landscape varies with forest and other land cover types (Baral et al., 2014b; Burkhard et al., 2012; van Oudenhoven et al., 2012). The supplies of ecosystem services are also governed by vegetation and other environmental attributes (de Groot et al., 2002, 2010; García-Nieto et al., 2013; Müller and Burkhard, 2012; Seppelt et al., 2012). Therefore, assessing ecosystem services for a forested landscape using vegetation attributes of different forest types is likely to be more consistent than using some proxies such as area. Yet, little research is available which uses vegetation attributes for ecosystem services assessment for forested ecosystems (Alamgir et al., 2014a; Seppelt et al., 2012). One of the main reasons for this may be attributed to the diversified data requirements necessary to assess ecosystem services using vegetation attributes.

It has been shown that the diversity and quantity of ecosystem services supply from tropical forests are higher than many other forest biomes such as temperate and boreal forests (Daily, 1997; Galicia and Zarco-Arista, 2014; Liu et al., 2015), and that the supply of ecosystem services is declining at a higher rate from tropical forests (Liu et al., 2015; Mutoko et al., 2015). Yet, it is unclear how ecosystem services supply varies in different forest types within a tropical forested landscape. After a comprehensive review of ecosystem services mapping, Martínez-Harms and Balvanera (2012) concluded that identification of the key areas of ecosystem services supply is necessary for development of appropriate future strategies to ensure a sustainable supply of ecosystem services.

The Wet Tropics of northeast Australia is a unique landscape dominated by wet tropical rainforests, sclerophyll forests, rehabilitated plantation forests, together with other forest types (Stork and Turton, 2008). The exceptional biodiversity values of the Wet Tropics forests are formally recognized both from Australian (Hilbert et al., 2001; Williams et al., 2003) and global studies (Bertzky et al., 2013; Le Saout et al., 2013), while ecosystem service values for these forest complexes are yet to be explored. Only a few efforts have been initiated by Australian Federal and State governments, collaborating with local natural resource management bodies, to include ecosystem services in the natural resource management planning of this region (Alamgir et al., 2014b; Pert et al., 2014). In this study, we attempted to conduct a comprehensive evaluation of five regulating and three provisioning ecosystem services supplied from dominant forest types in the Wet Tropics landscape – rainforests, sclerophyll forests, and rehabilitated plantation forests.

Our specific objectives were to: (i) assess the quantity of five regulating ecosystem services – global climate regulation, air quality regulation, erosion regulation, nutrient regulation, and cyclone protection; and three provisioning ecosystem services-habitat provision, energy provision and timber provision; (ii) evaluate the variation of supply of those regulating and provisioning ecosystem services across environmental gradients, such as rainfall, temperature, and elevation; (iii) show the relationships among those ecosystem services; and (iv) identify the hotspots of single and multiple ecosystem services supply.

2. Materials and methods

2.1. The study area

Our study was conducted in the Wet Tropics bioregion (hereafter the region) of northeast, Australia (Fig. 1). The region is one of 89 bioregions in Australia, with each bioregion having unique climate, geology, landform patterns, ecological features and biological communities (Department of Environment, 2015). The region is more than two million hectares in area (Stork et al., 2011); with a contrasting landscape of various forest types where rainforests and sclerophyll forests are dominant (Fig. 1). The region enjoys a seasonally wet tropical climate (Hilbert et al., 2001; Williams et al., 2003) with a diverse range of environmental gradients-elevation from few metres above mean sea level (msl) to more than 1000 m; total annual rainfall from less than 1000 mm to more than 3000 mm (up to 8000 mm at the mountain peaks) (Ostendorf et al., 2001); and mean annual temperature ranges from 24 °C to 26 °C (16–20 °C in the mountains) (Ostendorf et al., 2001).

Due to the high ecological and world heritage values, ~45% of the region (mainly tropical rainforest) has been declared as a World Heritage Area since 1988 (Stork et al., 2011), and is now considered the sixth most irreplaceable natural habitat on the planet (Le Saout et al., 2013).

2.2. Typology and framework of ecosystem service assessment

The Millennium Ecosystem Assessment (MA) has provided a detailed and comprehensive typology and framework for the assessment of ecosystem services, and has subsequently been widely used (Baral et al., 2013; Burkhard et al., 2012; Harrison et al., 2014; Schneiders et al., 2012). Therefore, we utilized the typology of MA (MA, 2005) for selected ecosystem services, which are illustrated in Table 1.

2.3. Sampling and data collection

In the Wet Tropics region we sampled a total of 66 sites (each plot an area of 0.05 ha (50 m × 10 m)). In the rainforests type we sampled a total of 24 sites (i.e. 13 sites found in mesophyll forests, nine in notophyll forests, and two in disturbed rainforests). In the sclerophyll forest type we sampled a total of 34 sites (32 from sclerophyll forests and woodlands, and two from the disturbed sclerophyll forests). In the rehabilitation plantation forest type (i.e. forests aged between 10 and 19 years) we sampled six sites. In the heath and shrubland forest type we sampled two sites (detailed forest description in supplementary material). The sampled sites were located on a map prior to entering the field to avoid creeks and other water bodies. To avoid edge effect, we maintained at least a 50 m distance to our plots from roads, water bodies, and agricultural lands. As the region has a diverse environmental gradient, our plots were distributed from 12 metres (m) to more than 1000 m above msl; from less than 1000 mm to more than 3500 mm annual rainfall; and less than 20 °C to more than 25 °C mean annual temperature ranges.

We used a modified transect method for collection of tree data within the 0.05 ha (50 m × 10 m) plots (Fig. 2) (Burrows et al., 2002;