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Trajectory of change in land cover and carbon stocks following European settlement in Tasmania, Australia

Louise M. Romanin*, Lynda D. Prior, Grant J. Williamson, David M.J.S. Bowman

School of Biological Science, University of Tasmania, Private Bag 55, Hobart, Tasmania 7001, Australia

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ABSTRACT

The conversion of temperate biomes in the Americas, Australia and New Zealand by European colonists, creating 'neo-European landscapes', is emblematic of the global environmental change inherent in the Anthropocene concept. The Midlands of Tasmania is a valuable model system for studying changes to land cover and above ground biomass in neo-European landscapes. Europeans colonized this area in early 19th century and disrupted a hunter-gatherer economy that has persisted for over 30,000 years. Aerial imagery, historical reconstructions, field surveys and future climate projections provided tools to chart changes in tree canopy cover and carbon stores in the Northern Midlands for the period 1788–2070. In the ~160 years between 1788 and 1940s, large areas of open woodland were cleared but carbon loss was modest (−14 %). In the ~60 years between 1940s and 2010, carbon loss accelerated (a further −21%) as clearing shifted from woodlands to forests. An estimated ~28% of the study area would need to be replanted with eucalypt plantations to capture the carbon lost between 1788 and 2010. Three general circulation models (GCMs) representing climate predictions for 2070 suggest that carbon storage in the landscape would change by +13% to −13.2% of 2010 levels, without any restoration intervention.

1. Introduction

Clearing native vegetation at a broad scale is a potent driver of global loss of biodiversity (Vitousek, 1997; Sanderson et al., 2002; Monastersky, 2014) and a major anthropogenic source of atmospheric CO_2 (Le Quéré et al., 2009). Creating arable land is a prime motivation for clearing vegetation. This process has occurred since the development of agriculture in the mid to late Holocene. In the 18th–19th centuries, European colonisation created agricultural landscapes in North America, Australia, New Zealand and southern South America (Crosby, 1986). These 'neo-European' agricultural areas were typically previously modified by indigenous people, especially through the use of fire to clear and alter vegetation structure and composition (Jones, 1969; Weiser and Lepofsky, 2009; Lightfoot et al., 2013).

Neo-European landscapes present interesting case studies of the interplay of culture and environmental change that is at the root of the Anthropocene concept. We use the term 'Anthropocene' as a metaphor to frame human impacts on the Earth system in both the prehistoric and historic period rather than specifying a precise time frame. Such temporal ambiguity is justified because of the long history of human impacts on the Earth System, beginning with the hunting of megafauna and burning of landscapes by humans and our antecedents in the Pleistocene (Glikson, 2013; Foley et al., 2013; Bowman, 2014). The development of agriculture in the Holocene increased human impacts on the Earth System (Ruddiman, 2003; Ruddiman, 2005; Ruddiman, 2007). Undoubtedly, the Industrial Revolution, often used to demarcate the start of the Anthropocene, has triggered ongoing planetary-wide impacts associated with burning fossil biomass, rapid growth in human populations and land cover change. Since the Second World War (WWII) a step change occurred in impacts on the Earth system, a period Steffen et al. (2007) termed 'the great acceleration' due to rising resource consumption, human population growth and powerful technologies resulting in more intensive and widespread negative impacts on natural landscapes (Crutzen and Steffen, 2003; Ellis et al., 2010).

The Midlands of Tasmania provides an excellent case study to document the rapid transition from hunter-gatherer to modern temperate agricultural landscapes that is at the core the Anthropocene concept. The Midlands is the second oldest agricultural landscape in Australia, settled in the first decade of the 19th century (Fensham, 1989). Before European colonisation in 1802, Tasmanian Aboriginal hunter and gatherers existed on the island for over 35,000 years (Colhoun and Shimeld, 2012). Palaeoecological evidence points to ecological disruptions caused

* Corresponding author.
E-mail address: louise.romanin@utas.edu.au (L.M. Romanin).

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by Aboriginal colonisation in the late Pleistocene, including changed fire regimes and loss of marsupial megafauna (Turney et al., 2008). Despite these disruptions, the available evidence suggests that, throughout the Holocene, Aborigines had achieved ecological sustainability, coexisting with a rich biota, including numerous endemic plant and animal species that have become extinct or threatened with extinction following European colonisation (Bowman, 1998; Fletcher and Thomas, 2007; Fletcher and Thomas, 2010). Like other Australian Aboriginal cultures, a key aspect of the Tasmanian's economy was the use of fire (Jones, 1969). Aboriginal landscape burning is thought to have maintained the grasslands and open grassy woodlands, which were rich in game (Gammage, 2008; Bowman et al., 2013). Such open vegetation proved ideal for European sheep grazing. By 1825 (Fensham, 1989; Morgan, 1992), most of the grassy lowlands of the Midlands had been allocated to free settlers, and the Aborigines were expatriated (Ryan, 2012).

Over the last 200 years, pastoralists cleared the Midlands to increase grass cover. This clearing targeted the most productive vegetation types, with a particularly intense period of tree removal following WWII, when artificial fertilisers, heavier machinery and the introduction of exotic grasses vastly improved the productivity of grazing lands (Kirkpatrick, 2007; Prior et al., 2013). In the past 20 years, large areas of Tasmania have been planted with fast growing eucalypts for woodchips. This region is too dry, however, for commercial forestry (Laffan, 2000). The contemporary landscape has less than 16% of the original native vegetation, which persists in highly fragmented, small and degraded patches (Fensham, 1989). Despite the small areas of remaining trees, land conversion has not ceased, with extensive irrigation programs under way. On the other hand, restoration schemes are designed to increase tree cover in this landscape (Bailey, 2013; Bryan, 2014; Greening Australia 2014a,b).

Using remotely sensed estimates of woody vegetation cover and above ground carbon stocks as response variables, we evaluate land cover changes since establishment of the agricultural landscape in the Midlands. We focus on four periods: (a) 1788, which provides a baseline under hunter-gatherer management, (b) 1800–1945 when agriculture was established, (c) 1945–2010, the period in which the current landscape was created, and (d) plausible future landscapes in 2070. We hypothesized that the first stage (1788–1945) of land cover conversion would have a minor effect on woody tree cover and carbon stocks compared to the second stage (1945–2010). This is because the hunter-gatherers had essentially opened up the landscape for pastoralism through targeted burning, whereas post World War II industrialised agriculture required far more extensive land conversion. By combining plans for intensive agriculture with three climate change scenarios we provide a reference point for current restoration schemes (Bailey, 2013). We estimate the amount of land that would need to be allocated for biosequestration to capture the carbon (a) lost between the 1940s and 2010 and (b) restore pre-agricultural (1788) levels.

2. Methods

2.1. Study region

We focus on land cover change in an area of 645 km^2 in the south of the Northern Midlands bioregion. This area is a broad floor of a north-south oriented graben (Fig. 1) (Fensham, 1989). The climate is classified as temperate with warm summer according to Köppen–Geiger classification (Peel et al., 2007). The region is located in a pronounced rain shadow, which is driest in Tasmania. The annual precipitation of ~500 mm is evenly distributed throughout the year. The area has warm summers and cool

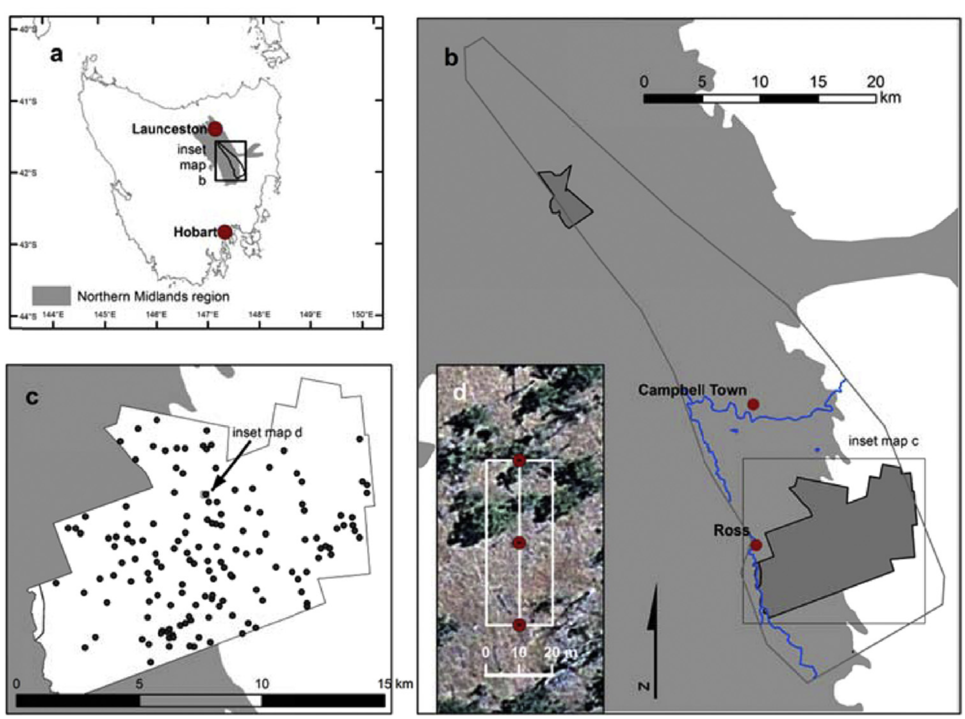

Fig. 1. (a) Map of Tasmania, showing the northern Midlands bioregion (shaded in grey), the cities of Launceston and Hobart and the study region. (b) Map of the study region (outlined), showing the two major towns major rivers in the region (blue) and the two field sites (dark grey), Tom Gibson Reserve in the north and a private property in the south. (c) Location within the private property of the field transects which were used in conjunction with aerial photography to estimate biomass across the study region. (d) Diagram of the field transect drawn to scale and superimposed on a satellite image. The white rectangle represents the belt transect inside which the diameters of all trees were measured. The three red circles indicate points at which tree cover was assessed using a densiometer.