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Safeguarding reforestation efforts against changes in climate and disturbance regimes

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ABSTRACT

Reforestation schemes, which encompass environmental plantings and natural regeneration of vegetation on cleared land, are increasingly being established for the purposes of mitigating anthropogenic carbon emissions. However, these schemes are themselves at risk from climate change and associated changes in disturbance regimes. Simultaneously, there is increasing pressure on reforested areas to achieve multiple co-benefits, e.g. maximizing carbon storage, ameliorating environmental degradation and promoting biodiversity objectives, all while not adversely affecting community values, such as agricultural production. Here, we review the myriad of biophysical risks posed by climate change to reforested areas while documenting management actions and policies that can enhance both the resistance and resilience of reforested areas to such risks. While it is difficult to buffer vegetation against the direct effects of climate change, such as elevated temperature and changed precipitation patterns, it is possible to manage some of the indirect effects, such as wildfire, drought and insect defoliation. Methods for reducing the vulnerability of reforested areas range from site-specific management actions, particularly around design and location, through to regional and national scale initiatives, such as vulnerability assessments and decision support tools. The complexity of objectives and risks posed to reforested areas means that it is vitally important to evaluate outcomes from across the current estate of reforested areas. However, there is currently no national protocol in place in Australia to track, monitor or evaluate the outcomes of reforestation. Thus, we recommend the establishment of a national framework for analyzing and supporting the growing range of reforestation activities.

1. Introduction

The widespread establishment of environmental plantings and other forms of reforestation are being targeted by many governments to mitigate increasing levels of atmospheric carbon dioxide (Hulvey et al., 2013; Australian Government, 2014; United Nations, 2016). Compared to other abatement opportunities, carbon offsetting through reforestation may provide valuable mitigation opportunities at relatively low cost (Tavoni et al., 2007). Historically, non-commercial forest plantations have been established to provide a range of landscape services other than carbon abatement, including shelter for livestock, improved landscape amenity, and the amelioration of environmental problems such as dryland salinity and water quality issues caused by erosion and nutrient runoff (Cunningham et al., 2015). More recently, the purpose of reforestation has been broadened to include a suite of environmental services including reduction or reversal of landscape biodiversity losses (Cunningham et al., 2015). A number of recent studies have highlighted the potential opportunities for reforestation globally, including in Australia (Paul et al., 2013; Griscom et al., 2017), Brazil (Shimamoto et al., 2014) and the USA (Sharrow and Ismail, 2004).

Longevity is a key requirement to achieve many of the current objectives for reforested areas (United Nations, 2016). This is embodied in regulatory requirements such as permanence (e.g. 100 years; Australian Government, 2014). These requirements mean that reforested areas must be robust to risks and viable over long time periods. Drought, fire, pests and grazing pose biophysical risks, while changing land regulation and opportunity cost may affect the economic viability of reafforestation (Kragt et al., 2017; Nolan et al., 2018a, 2018b). A disruptive issue

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facing reforested areas is climate change, which is likely to affect the frequency and severity of disturbances, and rates of vegetation growth (Nolan et al., 2018a). Thus, climate change is likely to have important consequences for carbon sequestration rates and may adversely affect provision of environmental services. Once environmental plantings are established, there are few options for adaptation to climate change (Millar et al., 2007). Assessment of the risks posed by changing climate and disturbance regimes over the lifetime of reforested areas during the planning and design stages is critical.

Climate change will generate local effects on tree growth and survival, but will also have effects at regional and national scales over which disturbances and risks occur. Reducing risk to reforested areas is likely to be best achieved if there is co-ordination of risk mitigation strategies at scales larger than individual project boundaries (Nolan et al., 2018a) and would be assisted by a co-ordinated regional or national scale framework for managing reforestation that geographically disperses risk.

In this paper, our objectives are to (i) identify the vulnerabilities of reforested areas to climate change and associated changes in disturbance regimes; (ii) identify mechanisms to reduce the vulnerability of reforested areas to climate change; and (iii) evaluate the role of decision support systems and modelling in managing the reforestation estate at a national scale. As part of our review, we present a case study on the use of vegetation established for carbon abatement in Australia.

2. Defining reforestation

Here, the term ‘reforestation’ is an umbrella term used to refer to all types of woody vegetation established for environmental purposes. This includes vegetation established from planted seedlings or from directly sown seed. We also include human-induced regeneration, which is where natural regeneration of vegetation on cleared land is facilitated by a change in land management, for example by fencing to remove grazing by livestock and wild herbivores. Reforestation encompasses a spectrum of environmental, social and economic objectives. Reforested areas may incorporate multiple-species of trees and shrubs established from either plantings, natural regeneration, or regrowth from rootstock. They are often established for long periods and for one or more objectives, e.g. carbon sequestration, flood mitigation, erosion control, biodiversity conservation and other landscape benefits (e.g. aesthetics). Although they may be established in different ways, in reality all reforested areas, whatever their primary goal, have the capacity to yield a range of co-benefits as well as dis-benefits.

3. Vulnerability of reforested areas to changing climate

Vulnerability is ‘the degree to which a system is susceptible to, or unable to cope with, adverse effects of change’ (IPCC, 2013). It is a function of exposure to unfavourable conditions and the sensitivity of the system to those conditions, which collectively define impact (Fig. 1). Vulnerability varies across systems, depending on their adaptive capacity to adjust to change or cope with the consequences of change.

3.1. Exposure

Climate plays a major role in shaping the distribution and composition of forests (Engelbrecht et al., 2007). It follows that the direct and indirect biophysical effects of climate change will pose challenges to reforested areas in the future (Table 1). Increases in maximum and minimum temperatures are projected for most regions of the world, with projected global average warming at the end of the 21st century ranging between 1.1 and 6.4 °C (IPCC, 2013). All climate models predict changes in global mean precipitation as a consequence of the intensification of the global hydrological cycle, with increases likely in the tropical and higher latitude regions and decreases likely in subtropical and mid-latitude regions (IPCC, 2013). Associated with these broad-scale trends is an expected increase in the frequency, duration and intensity of droughts and heatwaves, as well as reductions in relative humidity (IPCC, 2013).

Extreme climate events and their associated disturbances play a key role in fine scale patterning of species distributions (Reyer et al., 2013), and can thus have an important influence on the long-term survival of reforested areas. In particular, forest mortality events can be triggered by droughts and heatwaves (Mitchell et al., 2014), extreme storm events, e.g. cyclones (Kanowski et al., 2008) and from increases in the frequency and intensity of wildfires (Flannigan et al., 2009; Bradstock, 2010). There are also strong links between climate and the abundance and distribution of forest pathogens and insects that reduce productivity or contribute to mortality (Kurz et al., 2008).

Changing global climate is likely to have both positive and negative effects for reforested areas. In temperature-limited environments, warmer mean annual temperatures may increase growth due to lengthening of the growing season (Vitasse et al., 2011). This may increase the potential distribution of species currently restricted by mean minimum temperatures, provided dispersal is not limited. However, changes in litter layers associated with climate-induced changes in the ratio of production to decomposition may change the fire hazard. Warmer temperatures may also result in higher rates of transpiration, leading to water stress (Duan et al., 2014); reduced frost hardening, leading to more severe frost damage when these events do occur (Woldendorp et al., 2008); and increased pressure from pathogens, many of which favour warmer conditions (Sturrock et al., 2011). In contrast, reduced precipitation in subtropical and mid-latitude regions may reduce growth rates and growing season length, affecting seed production and recruitment success (Suarez and Kitzberger, 2008). Increased atmospheric CO_2 may lead to a “fertilization effect” that increases productivity, particularly in drylands (Donohue et al., 2013). However, any increases in productivity may be offset by increases in extreme climate events, while changes in atmospheric CO_2 may also alter the balance of grassy, shrubby and tree life forms through differential changes in water use efficiency (Polley et al., 1994).

3.2. Sensitivity

The sensitivity of reforested areas to changes in climate and associated disturbance regimes is a function of both their resistance and resilience to disturbance. Resistance is defined as the capacity of a system to absorb a disturbance without major loss, whereas resilience is the capacity to recover from severe disturbance (Lake, 2013). The resistance and resilience of environmental plantings will vary as a function of species composition, diversity, and within-species genetics. Following disturbance, some species are more susceptible to mortality than others. For example, high intensity fire kills some species whereas others are capable of resprouting (Clarke et al., 2013). Some fire-killed species have adaptations that enable them to persist locally through fire-stimulated recruitment (Clarke et al., 2013). Indeed, some reproduction strategies require fire to promote regeneration. Resprouting can also occur following other disturbances such as drought, windthrow or herbivory, a strategy utilized by a diverse range of species globally (Vesk and Westoby, 2004).

Further adaptations to drought, or periodic water stress, include a suite of plant traits which confer drought tolerance. These include anisohydric stomatal behaviour, where stomatal conductance during soil drying remains unregulated (compared with isohydric behaviour where there is tight regulation of stomatal conductance; Tardieu and Simonneau, 1998). By keeping stomata open, anisohydric species are able to continue fixing carbon and avoid the potential carbon starvation that would otherwise occur during drought (McDowell et al., 2008). These species typically possess a range of adaptations to low soil moisture, including a high degree of resistance to xylem embolism, small leaves and low specific leaf area (Brodribb et al., 2014, Nolan