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Restricting new forests to conservation lands severely constrains carbon and biodiversity gains in New Zealand

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ABSTRACT

Increased afforestation of non-productive land could deliver win–win solutions for greenhouse gas mitigation through carbon sequestration and biodiversity gains, referred to here as increased 'ecological integrity'. We examined the potential trade-offs when selecting non-forested lands in New Zealand for natural forest regeneration to maximise gains in either, or both, carbon and biodiversity. We also examine the effect on potential gains and trade-offs of excluding non-conservation lands from spatial planning for conservation. The most significant per-hectare gains, for both carbon and biodiversity, were those occurring on non-conservation lands because conservation lands are mainly restricted to low-productivity environments where indigenous vegetation is already well represented. By contrast, productive environments, such as alluvial plains, where almost no indigenous vegetation remains, are primarily on non-conservation lands. These lands will need to be included in any reforestation strategy or else the most degraded ecosystems will not be restored. We found that biodiversity suffers a greater trade-off when carbon gain is prioritised than carbon does when biodiversity is prioritised. Trade-offs between carbon and biodiversity were higher on non-conservation lands but decreased with increasing area regenerated. Our study shows that natural regeneration will provide substantial increases in carbon and biodiversity on non-conservation lands compared with conservation lands. This emphasised the need for improved incentives to private land owners if carbon and biodiversity gain from afforestation is to be maximised.

1. Introduction

Protected natural areas (conservation lands) have been recognised for some time as potential carbon sinks, where carbon sequestration through afforestation could aid reductions of global carbon dioxide concentrations without displacing economic activity (Miles and Kapos, 2008). However, the primary role of conservation lands is biodiversity conservation and enhancement. The limited funds available for conservation necessitate careful consideration of the projects that can maximise biodiversity gain (Schindler and Lee, 2010). Prioritisation of carbon during reserve design for existing ecosystems can lead to lower biodiversity than if biodiversity alone is prioritised (Chan et al., 2006; Anderson et al., 2009; Naidoo et al., 2008; Moilanen et al., 2011; Thomas et al., 2013). However, it remains unclear whether these negative trade-offs also occur during spatial allocation of natural regeneration to provide new forests. This study compares hypothetical scenarios where natural regeneration of forest is spatially allocated to maximise either or both carbon and biodiversity gain across conservation lands of New Zealand. These gains are compared with those possible when non-conservation lands are also included.

The potential for carbon markets to compromise biodiversity has been known for over 10 years (e.g. Schulze et al., 2002). An international attempt to counter the potential trade-off between carbon and biodiversity has been made through the establishment of the United Nations' REDD+ (Reducing Emissions from Deforestation and forest Degradation in developing countries) programme that specifically targets the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries. One potential outcome of REDD+ is the protection of biodiversity in natural forests instead of converting natural forests to faster-growing non-native plantations. More economically developed countries, such as New Zealand, could also contribute to the twin goals of increased biodiversity and carbon

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sequestration, using slightly different mechanisms to those posed by REDD+, namely the creation of new conservation lands through natural regeneration of indigenous forests. Existing conservation lands in more economically developed countries are generally dominated by ecosystems of little economic value for farming (e.g. Pressey, 1994; Aycrigg et al., 2013). In New Zealand, these lands tend to be in steep, cool, wet mountain environments with low soil fertility (Leathwick, 2003; Walker et al., 2006). In contrast, both in New Zealand and abroad, the areas that have been most heavily impacted by human activities (e.g. alluvial floodplains, riparian habitats and coastal ecosystems) are severely under-represented in conservation lands (Pressey, 1994; Walker et al., 2008). Current conservation lands may therefore have limited opportunities for carbon gain, since these lands are dominated by low-productivity environments with low carbon sequestration rates and low potential carbon storage. Consequently, we compare per-hectare scenarios where natural regeneration is spatially allocated across the whole of New Zealand or is restricted to existing conservation lands.

There is significant potential for carbon sequestration through indigenous forest regeneration across New Zealand lands that are currently used for pastoral agriculture (Trotter et al., 2005). New Zealand was heavily deforested only recently (starting in c. CE 1200) – first by Polynesian settlers (McWethy et al., 2009) and then by Europeans, with a corresponding reduction in indigenous forest cover from approximately 85% of the total land area to less than 30% (Wilmshurst et al., 2007). Consequently, there are large areas of land that do not currently support forest but could do so, potentially. The establishment of a national plot network to measure change in carbon stocks has provided a means for objective estimation of current carbon stocks in forests and shrublands. Current stocks across this plot network also provide a means for estimating potential carbon gains on other non-forested lands assuming similar forest types can be achieved (e.g. Mason et al., 2012a). When examining potential gains we confine our investigation to the use of natural regeneration for establishing indigenous forests, as this method has been demonstrated as economically viable (Funk et al., 2014), partly because it does not require substantial capital outlay.

We have assessed biodiversity gain through change in 'ecological integrity' during natural regeneration of indigenous forests. Ecological integrity was defined by Lee et al. (2005) as 'the full potential of indigenous biotic and abiotic factors, and natural processes, functioning in sustainable communities, habitats, and landscapes' and has subsequently been adopted by the New Zealand Department of Conservation (DOC) as its primary biodiversity goal (DOC, 2014a). Lee et al. (2005) suggested ecological integrity is demonstrated through long-term indigenous dominance (high influence of indigenous species on ecosystem processes compared with non-native species), occupancy by all appropriate biota, and full representation of ecosystems (environmental representation). We previously quantified gains in ecological integrity through catchment-scale natural regeneration of indigenous forests on agricultural lands (Mason et al., 2012b). Here, we extend the approach to national-scale natural regeneration with a specific focus on conservation implications.

We examine scenarios where natural regeneration of indigenous forests is spatially allocated to maximise either, or both, biodiversity or carbon sequestration for the whole of New Zealand and for conservation lands only. We address two main questions:

1. Are potential carbon and biodiversity gains on conservation lands considerably lower than on non-conservation lands?
2. How big is the trade-off between carbon sequestration and biodiversity when spatially allocating natural regeneration for the mean of both values? Does the magnitude of the trade-off differ when natural regeneration is constrained to conservation lands?

2. Material and methods

2.1. LUCAS vegetation carbon monitoring system and carbon gain estimates

The Land Use and Carbon Analysis System (LUCAS) is a national plot network designed to monitor changes in forest and shrubland carbon stocks in order for New Zealand to meet its reporting obligations under the UNFCCC (United Nations Framework Convention on Climate Change). Within LUCAS, over 1250 survey plots (of 20×20 m) were established on an 8-km grid to estimate national carbon stocks in indigenous woody vegetation (Coomes et al., 2002). We estimated carbon in live- and dead-wood pools for these plots. We then modelled the sum of live and dead carbon for each plot (total current carbon, TCC) as a function of key environmental (e.g. mean annual temperature, soil nitrogen) and land-cover (e.g. forest type) variables using generalised additive modelling (GAMS). We then used the Generalised Regression and Spatial Prediction package (GRASP; Lehmann et al., 2002) to provide national maps of current carbon in woody vegetation. Current carbon stocks in non-woody vegetation types, which were not covered by the LUCAS sampling universe, were obtained from Tate et al. (1997). Details of the model used to predict current woody carbon are supplied in Mason et al. (2012a).

Evidence for different types of anthropogenic disturbance (e.g. logging or clearing) was recorded in surveys of LUCAS plots. We used type of disturbance with the percentage of forest cover in the neighbourhood of the plots to construct GAM models for current carbon stocks as a function of type of disturbance. We then estimated disturbance–adjusted carbon values by comparing the predicted value (from the disturbance model) with the mean TCC values of plots with the same percentage forest cover but exhibiting no evidence of disturbance. We added the difference to the observed TCC value for the plot to give the disturbance–adjusted carbon value:

$$\mathrm{DAC}_i = \mathrm{TCC}_i + \left[\mathrm{ND} - \hat{C}_i\right], \tag{1}$$

where DAC_i is the disturbance–adjusted carbon value for plot i, TCC_i is the total current carbon value, ND is the mean TCC value for undisturbed plots and $\hat{C}_i$ is the predicted carbon value from the disturbance model. This essentially removes the human disturbance signal from carbon stock estimates in the LUCAS plots, and as such provides a measure of potential carbon storage in the absence of human disturbance.

The disturbance–adjusted carbon values (DAC_i) were then modelled in GRASP using environmental variables to produce national maps of potential carbon storage across all lands, whether currently forested or non-forested. Potential carbon gain was estimated as the difference between potential and current carbon stocks. Details of the disturbance–adjusted carbon model and the GRASP model for Spatial Prediction of potential carbon stocks are given in Mason et al. (2012a).

2.2. Biodiversity gain through natural regeneration of indigenous forests

The quantitative Vital Sites and Actions (VSA) framework was developed for assessing biodiversity benefit through management intervention (Overton et al., in press). It assesses marginal improvement in ecological integrity (sensu Lee et al., 2005) through gains in either 'species occupancy and dominance' or 'environmental representation'. To assess potential gain in environmental representation through natural regeneration of indigenous forests we used a metric called 'restored significance',