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The costs of reforestation: A spatial model of the costs of establishing environmental and carbon plantings

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ABSTRACT

Reforestation presents a potentially important tool for carbon abatement and reducing the impact of climate change and may also provide valuable biodiversity benefits. However, the economic returns are critical in determining whether it will be a viable land use and this is highly sensitive to assumptions around upfront establishment cost. Few studies have examined the spatial variability in establishment costs or developed spatially explicit layers that estimate these costs. Here we developed a model to predict the spatially explicit costs of establishment of monoculture tree plantations for carbon sequestration (or carbon plantings) and mixed species plantations for carbon sequestration and biodiversity benefits (or environmental plantings). Within this model we parameterised three separate methods of establishing revegetation; manual planting of tubestock, mechanical planting of tubestock and direct seeding. A decision tree was used to select between the different establishment methods based on soil and terrain parameters. We applied this model to a case study across the intensive agricultural districts of Australia. We populated the model with spatially explicit cost elements from literature and interviews with industry practitioners across Australia. For the case study, 3206 km^2 of carbon plantings were allocated to manual tubestock establishment and 903,127 km^2 were allocated to mechanical tubestock establishment with cost estimates ranging from \$1763 ha^{-1} to \$6396 ha^{-1}. For environmental plantings, 326,512 km^2 were allocated to direct seeding, 3206 km^2 were allocated to manual tubestock and 576,615 km^2 were allocated to mechanical tubestock establishment with costs ranging from \$1703 ha^{-1} to \$9097 ha^{-1}. These layers present an increasingly important tool for planning and policy development particularly for decision making around complex issues of land use and climate change.

Introduction

Bio-sequestration of greenhouse gases has significant potential to offset emissions from industry and transport (Conant, 2011). In particular, tree plantations are capable of removing large amounts of carbon dioxide from the atmosphere and, while this carbon dioxide remains stored within the biomass (on site or as wood products), can contribute substantially to climate change mitigation (e.g. Canadell and Raupach, 2008; Richards and Stokes, 2004). The recent introduction of carbon markets in many countries opens up opportunities for landholders to derive income from growing trees and also contribute to the abatement of carbon dioxide emissions (Perdan and Azapagic, 2011; Sedjo and Sohngen, 2012). Large areas of cleared land could provide substantial opportunities for the re-establishment of trees (hereafter reforestation) and the bio-sequestration of carbon (e.g. Grace and Basso, 2012; Richards and Stokes, 2004). However, there is significant uncertainty around the economic viability of this land use and the likely uptake by land holders. One of the greatest sources of this uncertainty is the cost of establishment of plantations (Bryan et al., 2010b, 2008; Paterson and Bryan, 2012). The economic viability of plantations is very sensitive to the costs of planting or stand establishment because they occur early on and are less influenced by discounting in traditional economic analysis of cash flow. This is particularly important where the main income is generated through the carbon sequestration rather than wood production. There is a requirement for more accurate estimates of these establishment costs to inform economic decisions on adoption of reforestation for carbon sequestration.

The economic viability of carbon bio-sequestration has been explored in numerous studies (e.g. Bryan et al., 2010b, 2008; Crossman et al., 2011; Plantinga et al., 1999; Plantinga, 1997;

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Polglase et al., 2013; Sohngen and Mendelsohn, 2003; van Kooten and Sohngen, 2007). The methodologies used in these studies fall into three categories; bottom-up engineering, sectoral optimisation, and econometrics (Alig, 2010; Richards and Stokes, 2004; Stavins and Richards, 2005). Each methodology has strengths and weaknesses. Sectoral optimisation and econometrics are substantially more complicated than bottom up studies requiring more data and a more detailed understanding of all market forces. Nonetheless, because they are better able to account for changes in market conditions they are often more reliable although somewhat less transparent (Richards and Stokes, 2004; Sedjo and Sohngen, 2012). Bottom-up studies, considered the most transparent and straightforward of these options, rely heavily on suitable and accurate parameterisation (e.g. Crossman et al., 2011; Guitart and Rodriguez, 2010; Guthrie and Kumareswaran, 2009; Paul et al., 2013a,b). Despite detailed assessments of biophysical productivity and economic viability, some of the largest sources of uncertainty in the conclusions of these bottom-up studies are the assumptions around the cost of establishing trees in the landscape (Paterson and Bryan, 2012). Thus there is a need to develop better estimates of the costs of establishing revegetation which can in turn inform research into the long term economic viability of carbon bio-sequestration. Findings from this research can be used in policy development and help land managers better understand the long term challenges posed by different management options.

Reforestation costs vary from country to country due to differences in labour and material costs between different jurisdictions and economies. Estimates of establishment costs also vary substantially within individual countries. However, examples of the costs used in recent studies from Australia include: Bryan et al. (2008, 2010b) used a flat rate of \$740 ha^{-1} for the establishment of oil mallee for biomass plantations. Similarly, Crossman et al. (2011) used single values of \$1250 ha^{-1} for monoculture plantations and \$2000 ha^{-1} for mixed species biodiversity plantations in southern Australian agricultural districts. Guitart and Rodriguez (2010) itemised a range of costs involved in establishing eucalyptus plantations in Brazil, including; deep ripping, fertiliser application, mechanical weed control, planting seedlings and some thinning but still only provided a single estimate of total costs per hectare (US\$ 343). Townsend et al. (2012) used establishment costs ranging from \$7440 ha^{-1} to \$9100 ha^{-1} for commercial native plantations, depending on the species, and a flat rate of \$250 for non-commercial revegetation. Alternatively, Hunt (2008) examined establishment costs ranging from \$5112 ha^{-1} to scenarios in excess of \$50,000 ha^{-1}. These were largely driven by the unit cost per tree (\$5.40 planted) providing an exponential rise in cost per hectare with increased stems per hectare (SPH). Polglase et al. (2011) used figures ranging from \$1000 ha^{-1} to \$3000 ha^{-1} which included some variation costs with SPH and the purpose of the plantations (e.g. environmental plantations versus monoculture plantations for carbon).

Some of the variation in the establishment costs used in the studies discussed above is no doubt due to the inclusion of different parameters and differences in production systems. For example, very large plantations may require road construction to facilitate access thus increasing establishment costs significantly. Alternatively, large plantations would benefit from the economies of scale that would reduce costs. Nonetheless, the substantial variation between the different establishment costs used in these studies raises many questions about their suitability and accuracy. Estimates that range from \$250 ha^{-1} to more than \$50,000 ha^{-1} will strongly influence the economic viability of these different reforestation systems. The large variability in the estimates of these establishment costs has been the source of criticism in a recent submission to the Carbon Farming Initiative (Preece, 2011), a programme set up to assist land holders identify and utilise opportunities from the introduction of a price on carbon in Australia (DCCEE, 2010). Similar observations have been made in other jurisdictions. A review of the costs of carbon sequestration from the United States and around the world (Richards and Stokes, 2004) found significant differences in cost estimates and attributed this to inconsistencies in methodologies, terminologies, basic assumptions and geographic scope. With some exceptions (e.g. Guitart and Rodriguez, 2010) there is generally little detail of how total establishment costs were determined, or any breakdown of the different individual components that make up the total costs. Due to the sensitivity of establishment cost in the overall economic viability of revegetation, more accurate estimates are required to provide reliable economic cost benefit assessments and reduce the uncertainty for land holders and policy makers. Another limitation of many cost estimates is the absence of any real spatial variation. Site specific properties such as rainfall, soil type, and terrain have high degrees of spatial variability and are known to impact upon establishment methodologies and costs (e.g. Barrett-Lennard et al., 1991; Greening Australia Victoria, 2003). However, these factors are typically not included in developing estimates of establishment costs. There are some exceptions to this (e.g. Polglase et al., 2008, 2011), however, the spatial variability included in these estimates (five regions across Australia) only encompass broad scale bioclimatic variability.

In this study we reviewed the methods and costs of reforestation by combining a literature search with a series of interviews with industry practitioners. We used this information to develop a regional scale model for quantifying the establishment costs of reforestation. We parameterised the model by collating, synthesising, and updating spatially explicit data from a previous study (Schirmer and Field, 2000) and validated our calculations with a second series of interviews. We applied this model in a case study over the intensive agricultural areas of Australia to calculate the spatially explicit establishment costs of reforestation. We applied the model to the establishment of two revegetation types; monoculture tree plantations specifically for carbon sequestration (carbon plantings), and mixed species plantations that provide carbon sequestration potential as well as a biodiversity benefit through the use of mixed species that are ideally endemic to the area (environmental plantings). We also created a simulated dataset using the same data variability as the case study in order to quantify the influence of each cost parameter with the Spearman's rank correlation test. We discuss the advantages and limitations of the model and the ability to apply it more generally in order to provide more certainty to agricultural landholders who want to contribute to the climate change solution, and policy makers who want to refine policy levers.

Review of methods and costs of reforestation

Reforestation generally falls into three main categories; assisted natural regeneration, direct seeding, and planting seedlings or tubestock (Greening Australia Victoria, 2003). Assisted natural reforestation typically involves encouraging latent seed stores within the soil and surrounding vegetation by developing suitable seedbeds and excluding grazing. While not uncommon, this method has a mixed success rate and is relatively passive compared to direct seeding and tubestock (Dorrough et al., 2006; Rodrigues et al., 2011). Assisted natural reforestation will not be covered further in this paper. Direct seeding involves applying seed propagules directly to the soil where reforestation is required without first germinating seeds off-site and then replanting seedlings. Alternatively, tubestock establishment requires seedlings to be grown to a suitable level of maturity in nurseries; these are then replanted at the reforestation site (Schirmer and Field, 2000). For the purposes of this review we consider establishment to be planting trees in the