POLICY PERSPECTIVE

Avoiding bio-perversity from carbon sequestration solutions

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Abstract

The development of a new carbon economy has the potential to offer win–win outcomes for environments and economies. Large-scale tree plantations are expected to play a major role in carbon economies but could have negative ecological and economic consequences when key environmental values such as biodiversity conservation are not considered. We discuss three potential "bio-perversities"—negative outcomes for biodiversity—that could result from inappropriate plantation tree programs aimed solely at reducing atmospheric carbon dioxide and mitigating rapid climate change effects. These are: (1) clearing native vegetation to establish tree plantations, (2) planting trees that become invasive taxa, and (3) tree plantations negatively affecting key ecosystem processes such as fire and hydrological regimes. These bio-perversities may result from common mistakes in environmental management: (1) too narrow a focus on a single environmental value, (2) failing to adequately quantify ecological uncertainty, and (3) failing to anticipate how different groups of people respond to an environmental problem. We highlight ways to prevent possible bio-perverse outcomes in large-scale plantation programs. These include requiring that risk assessments precede project establishment, full carbon accounting is undertaken, incentives used to stimulate tree plantation establishment are rigorously examined, and rigorous compliance and ecological monitoring is undertaken.

Bio-perversity—negative biodiversity and environmental outcomes arising from a narrow policy and management focus on single environmental problems without consideration of the broader ecological context.

Introduction

Emissions of carbon dioxide and other greenhouse gases are the major drivers of recent changes in the earth's climate (IPCC 2007). As part of efforts to tackle this problem, economic instruments such as carbon taxes and carbon trading markets are leading to the development of a carbon economy (Galatowitsch 2009; Hamilton *et al.* 2010; Garnaut 2011). Income from carbon offsetting has the potential to drive major land management changes as land owners shift land to higher carbon storage states through alteration of farming methods or transformation of vegetation cover (e.g., Grainger *et al.* 2009; Fargione *et al.* 2010; Paoli *et al.* 2010). Indeed, the development of a carbon economy has the potential to create win–win environmental outcomes (Danielsen *et al.* 2009; Venter *et al.* 2009) such as the ecological restoration of cleared land (Galatowitsch 2009) with subsequent improvements in other values like biodiversity conservation (Bekessy & Wintle 2008). Conversely, a narrow focus on carbon storage has the potential to create negative environmental outcomes if the protection and enhancement of other values such as biodiversity are not explicitly considered (Grainger *et al.* 2009; Putz & Redford 2009; Harvey *et al.* 2010; Paoli *et al.* 2010).

Several mitigation strategies have been proposed as part of efforts to tackle climate change. A prominent one is to sequester carbon into the terrestrial biosphere by establishing plantations of trees (e.g., Strengers *et al.* 2007; Hamilton *et al.* 2010). For the purposes of this paper, which is focused on plantation initiatives to sequester carbon, we define tree plantations as: "Stands of trees of native or exotic species that are specifically created by the regular placement of cuttings, seedlings, or seed through human management. Tree plantations are managed for an economic purpose such as the sequestration of carbon for future economic benefit but also may include the extraction of timber or timber-related products" Plantations are typically comprised of one or a few fast-growing exotic tree species in even-aged and evenly spaced stands (Bauhus *et al.* 2010; FAO 2010).

We suggest that incentives to sequester carbon through limiting deforestation and forest degradation (Harvey *et al.* 2010; Paoli *et al.* 2010) as well as through establishing plantations (Strengers *et al.* 2007; Bauhus *et al.* 2010) are likely to increase as the impacts of climate change become more pronounced and intense, and as ecological systems and processes are further modified by climate change (Steffen *et al.* 2009). In this article, we argue that harmful outcomes for biodiversity—what we term "bio-perversities"—can arise as unintended consequences from a range of efforts to reduce forest-based carbon emissions and enhance forest-based carbon sequestration. Perhaps the greatest of associated potential bio-perversities are those, which may arise from ill-conceived or inappropriate large-scale plantation tree establishment projects. We provide examples where bio-perversity may arise from plantation tree establishment, and identify approaches to avoid such outcomes in the context of an emerging carbon market.

Tree plantations in global carbon sequestration

Plantations encompass a wide range of models from small, species-diverse plantings that provide services additional to carbon sequestration, to large monocultures that focus solely on the production of wood and carbon sequestration. The characteristics of these plantations including the other resources produced (e.g., timber), plantation size, and species composition all help to determine how they will both integrate with, as well as affect, surrounding ecosystems. Of the ∼140 million hectares of plantation trees existing in 2005, at least 20% generated ecosystem services in addition to timber production (including carbon sequestration; Kanninen 2010). A survey of 226 carbon projects across 40 countries indicated the majority were in tropical-moist forests or temperate coniferous forests, followed by temperate broadleaf/mixed forests (Hamilton *et al.* 2010). The largest reported project areas were in Africa, Latin America, and Asia (795,015 ha, 669,952 ha, and 196,744 ha, respectively), with 76% using predominately native species (>85% of project area planted with indigenous species), 18% using mixes, and 6% using predominately nonnative species (>85% of project area planted with exotic species; Hamilton *et al.* 2010). Several carbon-offset markets consider ecosystem service benefits in addition to carbon sequestration as part of certification schemes (Ebeling & Fehse 2009; Hamilton *et al.* 2010).

Drivers of bio-perverse outcomes and their potential prominence in carbon plantation projects

Interventions in complex ecosystems often result in perverse outcomes—that is, paradoxical and unintended negative consequences (Tenner 1996; Hobbs *et al.* 2011). Examples include the impacts of biocontrol organisms on native species (e.g., the Southwestern Willow Flycatcher *Empidonax traillii extimus*; Hultine *et al.* 2010), trophic cascades triggered by the removal of species from ecosystems (Estes *et al.* 2011), and management practices leading to increased threat of high severity fires due to the accumulation of fuels (Arno & Fiedler 2005; Lindenmayer *et al.* 2011).

Bio-perverse outcomes from attempted solutions to ecological problems have a number of common characteristics, but if these are addressed at the outset of policy formation or project planning, managers may avoid associated problems. These characteristics include a narrow focus on a single ecosystem value or service, failure to accurately quantify ecological uncertainty, and failure to anticipate management responses to environmental regulations or incentives. In the case of plantation tree establishment, political, economic, and ecological factors increase the likelihood that one or more of these problems may occur.

Too narrow a focus on one ecosystem value or service

As a society, we benefit from a portfolio of environmental processes, goods, and services, with greenhouse gas reduction just one of many desired outcomes from environmental programs and policies. A narrow focus on carbon sequestration that ignores other societal values can lead to suboptimal management decisions and policy outcomes (Grainger *et al.* 2009; Harvey *et al*. 2010; Paoli *et al.* 2010). In particular, because resources for the development and implementation of programs and regulations are often scarce, from a cost-benefit perspective, a narrow focus on one ecosystem value can result in missed opportunities to achieve multiple desired outcomes (Paoli *et al.* 2010). A focus on portfolios of valued ecosystem attributes in plantations, including biodiversity and additional ecosystem goods and services, can leverage time and resources for program creation and result in solutions that optimize the production of multiple valued services (Phelps *et al.* 2011).

We argue that incentives to establish large-scale tree plantations for carbon sequestration should incorporate other values (Diaz *et al.* 2009) including the maintenance of key ecosystem processes (e.g., see Cao 2008) and the provision of habitat for biodiversity—such as in recent REDD+ projects (Convention on Biological Diversity 2011).

Failure to accurately quantify ecological uncertainty

A myriad of processes including abiotic factors and interactions among individual species at a range of spatial and temporal scales can make the management of ecosystems intrinsically complex. Managers of plantations for carbon sequestration need to understand how interactions between species affect carbon uptake and storage in multiple carbon pools, most notably plant biomass and soils. They must understand how disturbances such as catastrophic events (e.g., wildfires) and long-term processes (e.g., climate variability and climate change) might affect tree growth and longevity (e.g., see examples from China; Cao 2008). There also needs to be greater recognition of the ways in which plantations can influence biotic and abiotic conditions in neighboring areas.

This complexity necessitates responsible treatment of uncertainty in environmental decision-making via risk assessment and options-scoping in plantation tree projects (Regan *et al.* 2002; Halpern *et al.* 2006) for a systematic treatment and practical examples of environmental uncertainties.

Failure to anticipate management responses to environmental regulations or incentives

The creation of new environmental regulations may yield unforseen negative outcomes arising from stakeholders' decisions on how to meet new rule obligations or incentives (e.g., Garcia *et al.* 2009). Bio-perverse outcomes might arise if, for example, reward systems fail to distinguish between native and nonnative plantings, leading plantation growers to establish introduced species that may spread into surrounding land. In addition, poorly designed incentives might encourage replacement of existing native forests with plantations thereby leading to land conversion and biodiversity loss (Grainger *et al.* 2009)—as has occurred on the Tiwi Islands in northern Australia and also in parts of southern Australia (see Figures 1 and 2; Crowley *et al.* 2011). In a carbon sequestration context, it is critical to anticipate the different strategies that might be adopted by plantation growers to a particular policy and to create appropriate incentives that best achieve a range of ecologically desirable environmental outcomes (Grainger *et al.* 2009; Colyvan *et al.* 2011).

Figure 1 Native woodland removal in southeastern Australia on semi-cleared agricultural land (a–d), followed by the establishment of a Radiata Pine (*Pinus radiata*) plantation (e,f). This plantation was established for paper pulp and timber production, but also was claimed as a carbon offset (g). Patches of temperate woodland support large numbers of declining bird species and such vegetation types have been listed as threatened ecological communities since vegetation clearing for plantation establishment in this image. The sign shown in (g) reads: "This carbon sink plantation, established and managed by State Forests of NSW, is one of several measures to reduce total greenhouse gas emissions". (Photos by David Lindenmayer)

Figure 2 Clearing for plantation forestry on the Tiwi Islands. Plantation forestry requires the total clearance of native vegetation before the timber species are planted. (Photo by Charles Roche, Environment Centre NT)

Potential bio-perversities stemming from plantation tree programs designed to sequester carbon and ways to avoid them

Several authors have outlined some of the ways that bio-perverse outcomes may arise from the establishment of carbon economies. For example, Phelps *et al.* (2011) discuss how future carbon markets are likely to seek lowest-cost emissions reductions (such as from plantations) and are thus unlikely to seek REDD+ investments that integrate additional ecosystem services at increased costs. Grainger *et al.* (2009) have described how REDD+ investments in forests that deliver the greatest carbon benefits may direct funding away from traditional conservation priority sites. A further issue is what has been termed "leakage" (e.g., see Oliveira *et al.* 2007) in which increased conservation efforts in one area (e.g., through initiatives like REDD+) may lead to pressure to convert native vegetation to plantations in other areas, thereby resulting in significant losses of biodiversity (Grainger *et al.* 2009). Paoli *et al.* (2010) describe the risks of such bio-perverse outcomes in Indonesian peat swamp and mineral soil forests as one example.

In the following sections, we discuss three potential bio-perverse outcomes arising from carbon sequestration plantations: (1) land clearing to establish tree plantations, (2) the risks of plantation trees becoming invasive plants, and (3) the potential for plantations to negatively affect key ecological processes and disturbance regimes. These threats reflect some of the well-documented proximate causes of biodiversity loss globally; *viz*: habitat loss, invasive species, and threats from human-altered ecosystem processes (Millennium Ecosystem Assessment 2005).

We suggest that four mitigation strategies will be important to avoid the three key forms of bio-perversity outlined above. First, it will be essential to conduct risk assessments of ecological impacts. These would include: (1) An evaluation of the risks to existing ecosystems. For example, how likely is a plantation to change fire regimes resulting in decreases in biodiversity both within and adjacent to plantations? (2) An assessment of uncertainties in understanding of ecosystem processes. For instance, do we know how an introduced tree species will spread in a particular environment and location? And (3) An evaluation of tradeoffs between the ecosystem services gained and lost through plantation establishment. For example, are the benefits from carbon-offsets created on-site in a plantation balanced by the negative impacts on water regimes occurring on and off the plantation? Will the total amount of carbon sequestered in a newly established plantation equal the amount lost in the clearing of the forest it replaced? Many negative effects of plantations occur offsite and therefore evaluation of risks, uncertainties, and tradeoffs should not stop at the boundaries of a plantation, but should extend to surrounding areas.

A second important strategy to prevent bio-perverse outcomes will be to conduct full carbon accounting of ecosystems and proposed management activities. This would include quantifying the amount of carbon to be sequestered in plantations over a target time period relative to the ecosystems they replace, and would account for all emissions associated with plantation establishment (e.g., land clearing, burning, tree propagation, transportation) and plantation management (e.g., road construction and timber haulage).

A third mitigation strategy will be to thoroughly examine the incentives used to stimulate the establishment of tree plantations. This includes anticipating the different strategies that might be adopted by plantation growers to a particular policy, and should involve collaboration with local and regional policy-makers (those familiar with local governance systems) as well as ecologists (those familiar with local ecosystems). One aim would be to create incentives that broaden plantation goals beyond carbon sequestration to include a range of ecologically desirable environmental outcomes, including the maintenance of biodiversity (e.g., REDD+; Convention on Biodiversity 2011). However, we fully recognize the significant practical challenges to incorporating non-carbon ecosystem services (e.g., defining and quantifying biodiversity), as well as to funding the additional costs associated with monitoring and reporting on ecosystem services for which there are currently limited or no markets (Ebeling & Fehse 2009; Phelps *et al.* 2011). On this basis, Grainger *et al.* (2009) suggest an investment role in these areas for the considerable amount of "nonmarket funds" such as those from foreign aid, pollution permits, and private conservation funding.

A fourth strategy for avoiding bio-perverse outcomes will be to establish compliance and ecological monitoring programs (*sensu* Lindenmayer & Likens 2010) to detect bio-perverse outcomes. Such programs should include both local level "participatory" monitoring as well as subnational (regional) and national level "expert-based" monitoring (see Pistorius *et al.* 2010). Both kinds of monitoring at different scales would be critical for providing feedback to policy-makers and investors to alter incentive schemes and management practices to limit the risks of bio-perversity. However, significant challenges remain with respect to funding such monitoring programs (Ebeling & Fehse 2009) as well as the development of robust ways to integrate data and insights from the different kinds of monitoring conducted at different scales (see Lindenmayer & Likens 2010).

Avoiding bio-perverse land and natural forest clearing

Habitat modification is one of the greatest threats to biodiversity globally (Lindenmayer & Fischer 2006; Vié *et al.* 2009). Studies of the impacts of plantation tree establishment in environments such as temperate woodlands, native grasslands, and tropical forests demonstrate that vegetation conversion to densely stocked plantations of trees results in substantial losses of suitable habitat for a wide range of species (Tyndale-Biscoe & Smith 1969; Lindenmayer *et al.* 2008). For example, Harvey *et al.* (2010) have expressed concern about the potential for bio-perversity resulting from initiatives like REDD through promoting the establishment of Oil Palm (*Elaeis guineensis*) plantations which have limited value for biodiversity conservation. They highlighted the need to ensure that natural forest and nonforest systems are not converted to plantations (Harvey *et al.* 2010). The risks of conversion of natural vegetation to plantations might be particularly pronounced in relatively low carbon environments like native grasslands and shrublands (see Figure 1)—similar to what has occurred throughout large areas in China (Xu 2011) and in the South American biofuels industry (e.g., the conversion of formerly Cerrado-dominated vegetation; Mendonça 2011). As a result, although tree plantations can deliver some valuable ecosystem services (e.g., timber, fuel, food) and can sometimes have surprising value for some elements of the biota (e.g., Brockerhoff *et al.* 2008; Quine & Humphrey 2010), they do not have biodiversity values or ecological functions equivalent to natural vegetation (Lindenmayer & Hobbs 2004; Barlow *et al.* 2007; Felton *et al.* 2010; Gibson *et al.* 2011).

The adoption of the four strategies outlined above—ecological risk assessment, full carbon accounting, better assessment of the incentives used to stimulate the establishment of tree plantations, and the establishment of appropriately scaled and integrated compliance and ecological monitoring programs—will all be important for avoiding bio-perverse outcomes from land clearing.

Full carbon accounting assessment of areas being considered for conversion to plantations will be of particular importance and it may demonstrate the carbon sequestration value of maintaining native forest or grassland compared with plantation tree establishment. As an example, several studies have shown that monocultures of plantation trees may take longer to produce a net carbon gain and ultimately store less carbon in aboveground biomass and soil organic carbon than native primary forests, secondary (regenerating) native forests, and multistrata agro-forestry plantings (Danielsen *et al.* 2009; Kanowski & Catterall 2011). Forests with low tree diversity have also been shown to accumulate less carbon than forests with multiple tree species (Chen 2006). Exotic plantations have also been shown to deplete soil nutrients, and this may negatively affect the sustainability of carbon sequestration by reducing long-term productivity (Ewel *et al.* 1991). Accurate carbon accounting may indicate that plantation establishment will be best done on cleared agricultural lands of marginal economic value for farming or cropping (Lamb *et al.* 2001; Danielsen *et al.* 2009). Moreover, appropriately managed plantations in these areas might also mitigate problems like soil erosion and secondary salinity (Stirzaker *et al.* 2002) and promote conservation of some biota (Reino *et al.* 2010).

We suggest that appropriate definitions of forests and plantations are another absolutely critical part of avoiding bio-perverse land and natural forest clearing (Harvey *et al.* 2010). This is, in part, because nonforest environments can be classified as "forests" because they meet the structural definition of forests (Sasaki & Putz 2009). Indeed, the United Nations Framework Convention on Climate Change (UNFCCC) makes no distinction between natural forest ecosystems (including primary forests) and plantations. Such a lack of distinction means that it is potentially permissible to clear a natural forest and replace it with a plantation that can eventually attain height and crown density equivalent to that of a natural forest. We suggest that major carbon-based agreements should employ a definition of a plantation not unlike the one used in this article (as described earlier) to differentiate such areas from natural forests.

As we outlined above, a careful examination of the incentives used to stimulate the establishment of tree plantations is crucial for preventing bio-perversity. Notably, the UNFCCC recently established a set of basic safeguards for REDD+, including one stating that REDD+ should not incentivize the replacement of existing forests (to establish plantations; see UNFCCC 2011). However, the UNFCC safeguards fall short of the precautions we identify as necessary. There are also related safeguards, both for the voluntary carbon market and under development for future REDD+ carbon markets as well as through the Convention on Biological Diversity; Climate, Community and Biodiversity Association (CCBA), and the Forest Stewardship Council (Harvey *et al.* 2010).

Limiting bio-perverse species invasions from plantation trees

The spread of invasive species is a widely recognized threat to biodiversity worldwide (Simberloff *et al.* 2010). The most frequently used species in plantations are quick-growing trees from the genera *Pinus*, *Eucalyptus*, and *Acacia* (Doughty 2001) that are tolerant to a wide range of environmental conditions (Eldridge *et al.* 1994). When established outside their original range, some of these plantation tree species can become invasive. Bio-perverse outcomes from carbon sequestration plantation projects that result in invasive tree species may include biotic homogenization (Olden *et al.* 2004), genetic swamping (Barbour *et al.* 2010) and altered ecosystem processes (Simberloff *et al.* 2010). These sometimes irreversible invasions can often become costly to manage and lead to significant biodiversity loss (Richardson & Rejmanek 2004).

The risks of plantation trees becoming invasive plants may be reduced through all four of the strategies outlined at the beginning of this section. Reward schemes need to be coupled with a formal risk assessment process to account for the possibility of plantation trees becoming invasive plants. Risk assessment might indicate, for example, the value of using native rather than exotic tree species in plantation programs if native trees provide superior habitats for biodiversity (Hartley 2002; Gries *et al.* 2011), and managers could receive payments for providing such habitat. Broadening the focus of plantation programs to include native tree species, however, may require tree plantations to be managed somewhat differently than has traditionally been the case in the past (Putz & Redford 2009). Such management will require careful consideration of issues like the timing and frequency of thinning treatments to create habitat for wildlife (see Carey *et al.* 1999).

Ecological monitoring, both within and outside plantation estates, will also be an important strategy for limiting the risks of plantation trees becoming invasive. Early warnings of such problems significantly improve the chances that interventions to manage invasive species will be successful and cost-effective (McNeely *et al.* 2003).

Minimizing bio-perverse changes in key ecosystem processes and disturbance regimes

The modification of key ecosystem processes is well recognized as a major factor influencing biodiversity loss in many parts of the world. In particular, plantation establishment is suggested to have large impacts on hydrologic, geomorphologic and fire regimes both within plantations as well as in the surrounding landscapes. Plantation establishment has considerable potential to influence hydrologic cycles by altering water tables (Jackson *et al.* 2005). Such alterations can have profound effects on the landscape within and adjacent to plantations, resulting in compositional change of vegetation and losses of species richness (Farley *et al.* 2005; Cao 2008). Plantations of trees also may change fire regimes by introducing species that alter both flammability and fuel loads (e.g., Thompson *et al.* 2007). Altered fire frequency and severity may decrease native species richness both locally (Lindenmayer *et al.* 2008) and across landscape mosaics (Nelson *et al.* 2008).

Thorough, knowledge-based risk assessments of plantation projects and ecological monitoring will be essential for early detection and minimization of potential bio-perverse outcomes such as altered hydrologic and geomorphic cycles and altered fire regimes. Some locations will be deemed unsuitable for plantation establishment as a result of these considerations. It is imperative that incentives schemes and reward systems have clear regulations to prevent the establishment of plantations in regions that are unsuitable.

Concluding comments

The establishment of plantations of trees is a widely canvassed strategy for tackling climate change (e.g., Strengers *et al.* 2007; Hamilton *et al.* 2010), although to date only very few afforestation and reforestation projects commenced under initiatives like the Clean Development Mechanism within the United Nations Framework Convention on Climate Change (see Thomas *et al.* 2010).

We argue that narrowly focused large-scale plantations for carbon sequestration may produce a range of perverse environmental outcomes—bio-perversities. Three of these are clearing native vegetation to establish tree plantations, planted trees becoming invasive taxa, and tree plantations significantly altering key ecosystem processes. We argue that four strategies should be adopted to avoid these bio-perversities: ecological risk assessment, full carbon accounting, examination of incentives that stimulate tree plantation establishment, and establishment of compliance and ecological monitoring programs. Adoption of these strategies will allow us to actively seek the timely development and implementation of policies and standards aimed at minimizing bio-perverse outcomes.

Conversely, if the rush to plant trees and establish plantations for carbon sequestration results in a range of other environmental values being ignored, we may exacerbate existing environmental problems, contribute to further biodiversity loss, introduce additional obstacles to recovering or maintaining the ecological integrity of environments, and ultimately fail to mitigate the anthropogenic causes of climate change.

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