Global Environmental Change 28 (2014) 166–181

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Supply of carbon sequestration and biodiversity services from Australia's agricultural land under global change

B.A. Bryan [a,*], M. Nolan [a], T.D. Harwood [b], J.D. Connor [a], J. Navarro-Garcia [c], D. King [a], D.M. Summers [a], D. Newth [d], Y. Cai [d], N. Grigg [e], I. Harman [d], N.D. Crossman [a], M.J. Grundy [f], J.J. Finnigan [d], S. Ferrier [b], K.J. Williams [b], K.A. Wilson [g], E.A. Law [g], S. Hatfield-Dodds [b]

[a] CSIRO Ecosystem Sciences, Waite Campus, Urrbrae, SA 5064, Australia
[b] CSIRO Ecosystem Sciences, Black Mountain, Canberra, ACT 2601, Australia
[c] CSIRO Ecosystem Sciences, Dutton Park, QLD 4102, Australia
[d] CSIRO Marine and Atmospheric Research, Black Mountain, Canberra, ACT 2601, Australia
[e] CSIRO Land and Water, Black Mountain, Canberra, ACT 2601, Australia
[f] CSIRO Land and Water, Dutton Park, QLD 4102, Australia
[g] School of Biological Sciences, The University of Queensland, St. Lucia, QLD 4072, Australia

ARTICLE INFO

Article history:
Received 18 September 2013
Received in revised form 12 May 2014
Accepted 18 June 2014
Available online

Keywords:
Scenarios
Biodiversity conservation
Ecosystem services
Climate change
Land use change
Carbon sequestration

ABSTRACT

Global agroecosystems can contribute to both climate change mitigation and biodiversity conservation, and market mechanisms provide a highly prospective means of achieving these outcomes. However, the ability of markets to motivate the supply of carbon sequestration and biodiversity services from agricultural land is uncertain, especially given the future changes in environmental, economic, and social drivers. We quantified the potential supply of these services from the intensive agricultural land of Australia from 2013 to 2050 under four global outlooks in response to a carbon price and biodiversity payment scheme. Each global outlook specified emissions pathways, climate, food demand, energy price, and carbon price modeled using the Global Integrated Assessment Model (GIAM). Using a simplified version of the Land Use Trade-Offs (LUTO) model, economic returns to agriculture, carbon plantings, and environmental plantings were calculated each year. The supply of carbon sequestration and biodiversity services was then quantified given potential land use change under each global outlook, and the sensitivity of the results to key parameters was assessed. We found that carbon supply curves were similar across global outlooks. Sharp increases in carbon sequestration supply occurred at carbon prices exceeding 50 \$ tCO_2^{-1} in 2015 and exceeding 65 \$ tCO_2^{-1} in 2050. Based on GIAM-modeled carbon prices, little carbon sequestration was expected at 2015 under any global outlook. However, at 2050 expected carbon supply under each outlook differed markedly, ranging from 0 to 189 $MtCO_2\ yr^{-1}$. Biodiversity services of 3.32% of the maximum may be achieved in 2050 for a 1 \$B investment under median scenario settings. We conclude that a carbon market can motivate supply of substantial carbon sequestration but only modest amounts of biodiversity services from agricultural land. A complementary biodiversity payment can synergistically increase the supply of biodiversity services but will not provide much additional carbon sequestration. The results were sensitive to global drivers, especially the carbon price, and the domestic drivers of adoption hurdle rate and agricultural productivity. The results can inform the design of an effective national policy and institutional portfolio addressing the dual objectives of climate change and biodiversity conservation that is robust to future uncertainty in both national and global drivers.

1. Introduction

Beyond food provision, agroecosystems can provide services that can contribute to addressing the dual challenges of biodiversity decline and global climate change (Bateman et al., 2013; Power, 2010). Reforestation of agricultural land can remove

* Corresponding author. Tel.: +61 402 881 598.
E-mail address: brett.bryan@csiro.au (B.A. Bryan).

http://dx.doi.org/10.1016/j.gloenvcha.2014.06.013
0959-3780/

significant amounts of carbon dioxide from the atmosphere, store it in plants and soils (Harper et al., 2012; Rhemtulla et al., 2009), and thereby help mitigate climate change (Mackey et al., 2013; Smith et al., 2008). Reforestation of diverse, local, native ecosystems (*environmental plantings*) may also accrue co-benefits for biodiversity (Benayas et al., 2009; Lin et al., 2013; Mackey et al., 2013; Pichancourt et al., 2014) by increasing habitat area, improving landscape connectivity, and enhancing species persistence under climate change (Renton et al., 2012; Summers et al., 2012). Market mechanisms, such as a price on carbon, are seen as an essential component of the policy armory for addressing global climate change (Benítez et al., 2007; IPCC, 2014; Rogelj et al., 2013). Market-based incentives encouraging reforestation for supplying carbon sequestration, biodiversity, and other services from agroecosystems have become increasingly common (Farley and Costanza, 2010). However, the individual and combined influence of market-based incentives is complex and uncertain (Bryan, 2013; Dumortier, 2013). While opportunities for carbon and biodiversity co-benefits from market-based policies have been identified (Crossman et al., 2011; Venter et al., 2009), trade-offs and perverse outcomes are a risk (Bradshaw et al., 2013; Dickie et al., 2011; Lindenmayer et al., 2012). Understanding the likely influence of incentives on the supply of carbon and biodiversity from agricultural land is necessary to support effective policy interventions (Fensham and Guymer, 2009; Freedman et al., 2009; Lindenmayer et al., 2012).

Markets present landholders with opportunities for new income streams from the sale of credits for supplying additional, permanently sequestered carbon and the conservation and enhancement of native biodiversity (Yang et al., 2010). Economic opportunities, mediated by institutional factors, drive land use change (Lambin et al., 2001; Mann et al., 2010) and hence, the supply of both carbon sequestration and biodiversity services (Bryan, 2013; Patrick et al., 2009). Policy impacts on land use change and the supply of ecosystem services have been widely assessed based on the effects on economic returns from land use (Antle and Stoorvogel, 2006; Bryan et al., 2008, 2011b; Crossman et al., 2011; Flugge and Abadi, 2006; Paul et al., 2013a; Polglase et al., 2013). In practice though, rates of land use change diverge from that predicted by profit-maximizing economic theory (Lubowski et al., 2008). Barriers to adoption include: a lack of key structural and relational mechanisms such as capital, knowledge, expertise, technology, land, and labor (Corbera and Brown, 2010; Upton et al., 2014); competing objectives; negative perceptions of environmental objectives; and policy and institutional risk and uncertainty (Dilling and Failey, 2013; Dumortier, 2013; Raymond and Robinson, 2013). Conversely, landholders also derive other non-market benefits from reforestation such as recreation, aesthetic, bequest, intrinsic, and other values (Raymond et al., 2009; Shaikh et al., 2007). These barriers and benefits generate significant uncertainty around the influence of market policy on reforestation and the supply of carbon sequestration and biodiversity from agroecosystems.

The supply of carbon from agricultural land depends on the relative prices for crops and carbon, as well as assumptions around discount rates, growth rates, and costs (Birch et al., 2010; Paterson and Bryan, 2012; Wise et al., 2007). Two earlier reviews reported that under the cost range of 10–150 \$ tC^{-1} it may be possible to sequester 250–500 MtC yr^{-1} in the US, and upwards of 2000 MtC yr^{-1} globally for several decades (Richards and Stokes, 2004); and that the costs of sequestering carbon through tree planting and agroforestry were more than double the costs of forest conservation (12.71–70.99 US\$ tCO_2^{-1}) (van Kooten et al., 2004). Recent studies at global, regional, and local scales have produced a range of results consistent with these earlier syntheses and concluded that the receipt of realistic carbon-related payments by landowners can have substantial impacts on future land use patterns and terrestrial carbon sequestration (Ahn, 2008; Alig et al., 2010; Antle and Valdivia, 2006; Benitez et al., 2007; Funk et al., 2014; Golub et al., 2009; Jackson and Baker, 2010; Lubowski et al., 2006; Povellato et al., 2007; Torres et al., 2010; Townsend et al., 2012). Reforestation in Australia's agricultural regions has been found to be more profitable than existing rain-fed agriculture – particularly cereal cropping and grazing systems – even at relatively low carbon prices (Flugge and Abadi, 2006; Flugge and Schilizzi, 2005; Harper et al., 2007; Maraseni and Cockfield, 2011; Paterson and Bryan, 2012; Paul et al., 2013a,b; Polglase et al., 2013; Renwick et al., 2014). For example, Flugge and Abadi (2006) found that reforestation was more profitable than cropping-grazing systems in south-west Western Australia at a carbon price from 45 to 66 \$ tCO_2^{-1}. In the Lower Murray region of southern Australia, Paterson and Bryan (2012) found that carbon supply began at 20 \$ tCO_2^{-1} with reforestation more profitable than rain-fed agriculture in most areas at carbon prices above 60 \$ tCO_2^{-1}. Under their most plausible cost assumptions, Polglase et al. (2013) found that environmental plantings started to become profitable (including opportunity cost) at carbon prices above 40 \$ tCO_2^{-1}.

A carbon market alone will not automatically generate biodiversity co-benefits from reforestation (Hall et al., 2012; Nelson et al., 2008; Thomas et al., 2013). While environmental plantings provide biodiversity benefits and are compatible with carbon markets (Bradshaw et al., 2013), there is a risk that these markets will favor fast-growing monocultures (*carbon plantings*) or other agroforestry options as they are more profitable – being cheaper to establish, and sequestering more carbon much faster (Hunt, 2008; Kanowski and Catterall, 2010). Monocultures however, typically provide little biodiversity benefit (Hall et al., 2012; Smith, 2009). Financial incentives, administered through programs such as agri-environment schemes and payments for ecosystem services, can supplement carbon incomes and achieve biodiversity co-benefits by fine-tuning the location and type of reforestation occurring in agricultural land and closing the gap in economic returns from environmental plantings (Bryan and Crossman, 2013; Crossman et al., 2011; George et al., 2012; Thomas et al., 2013). Enabling landholders to bundle ecosystem services payments with carbon credits for reforestation can reconnect biodiversity and climate change policy objectives (Bekessy and Wintle, 2008; Hunt, 2008; van Oosterzee et al., 2010). Carbon markets can boost inadequate conservation budgets and help finance the substantial restoration task required to maintain biodiversity in agroecosystems (Hein et al., 2013). In return, biodiverse environmental plantings can contribute to the permanence of stored carbon by enhancing the value placed on new forests by society (Diaz et al., 2009).

A few studies have undertaken an integrated assessment of market policy on the supply of carbon and biodiversity from agroecosystems. Several studies have found significant opportunity to generate both carbon sequestration and biodiversity services under relatively modest carbon prices in Australia through environmental plantings (Carwardine et al., unpublished manuscript; Paul et al., 2013a; Polglase et al., 2013; Renwick et al., 2014). In assessing five conservation payment targeting strategies for the Willamette Basin, Oregon, Nelson et al. (2008) found persistent trade-offs between carbon sequestration and species conservation. In assessing economic returns from agriculture, and from carbon and environmental plantings under six carbon price scenarios, Crossman et al. (2011) found that annual payments of 6–120 US\$ ha^{-1} yr^{-1} may cover the opportunity cost of environmental plantings in high priority biodiversity areas, depending on the carbon price. Bryan and Crossman (2013) found that agricultural commodity prices and carbon price drove the supply of carbon sequestration through reforestation and, along with biodiversity payments, also influenced biodiversity benefits. They