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Restoration of ecosystems for biodiversity and carbon sequestration: Simulating growth dynamics of brigalow vegetation communities in Australia

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ABSTRACT

Restoration of abandoned and degraded ecosystems through enhanced management of mature remnant patches and naturally regenerating (regrowth) forests is currently being used in the recovery of ecosystems for biodiversity protection and carbon sequestration. Knowledge of long-term dynamics of these ecosystems is often very limited. Vegetation models that examine long-term forest growth and succession of uneven aged, mixed-species forest ecosystems are integral to the planning and assessment of the recovery process of biodiversity values and biomass accumulation. This paper examined the use of the Ecosystem Dynamics Simulator (EDS) in projecting growth dynamics of mature remnant brigalow forest communities and recovery process of regrowth brigalow thickets. We used data from 188 long-term monitored plots of remnant and regrowth forests measured between 1963 and 2010. In this study the model was parameterised for 34 tree and shrub species and tested with independent long-term measurements. The model closely approximated actual development trajectories of mature forests and regrowth thickets but some inaccuracies in estimating regeneration through asexual reproduction and mortality were noted as reflected in stem density projections of remnant plots that had a mean of absolute relative bias of 46.2 (±12.4)%. Changes in species composition in remnant forests were projected with a 10% error. Basal area values observed in all remnant plots ranged from 6 to 29 $m^2\,ha^{-1}$ and EDS projections between 1966 and 2005 (39 years) were 68.2 (±10.9)% of the observed basal area. Projected live aboveground biomass of remnant plots had a mean of 93.5 (±5.9) $t\,ha^{-1}$ compared to a mean of 91.3 (±8.0) $t\,ha^{-1}$ observed in the plots. In regrowth thicket, the model produced satisfactory projections of tree density (91%), basal area (89%), height (87%) and aboveground biomass (84%) compared to the observed attributes. Basal area and biomass accumulation in 45-year-old regrowth plots was approximately similar to that in remnant forests but recovery of woody understorey was very slow. The model projected that it would take 95 years for the regrowth to thin down to similar densities observed in original or remnant brigalow forests. These results indicated that EDS can produce relatively accurate projections of growth dynamics of brigalow regrowth forests necessary for informing restoration planning and projecting biomass accumulation.

1. Introduction

Clearing and modification of natural forested ecosystems for agriculture and livestock production have a long history and consequences in terms of environmental damage and loss of biodiversity are well documented. Recent global forest resource assessment data estimate that around 13 million hectares of forests are converted to other uses through deforestation or lost through natural causes such as severe drought and forest fires each year (FAO, 2006). Livestock production occupies 70% of all land used for agriculture, or 30% of the land surface of the planet (Steinfeld et al., 2006). Although cleared land is initially intended for agricultural use or livestock production, follow up costs of controlling woody weeds and impacts of economic forces have resulted in millions of hectares of abandoned lands (Ramankutty and Foley, 1999; Lugo and Helmer, 2004; Williams et al., 2008). The consequence is a fragmented landscape characterised by remnant patches of the mature forests and regrowth forests at different stages of development.

Emerging opportunities rendered by carbon markets are anticipated to provide incentives for managing regrowth forests on deforested landscapes for both biodiversity conservation and carbon sequestration outcomes (O'Connor, 2008; Williams et al., 2008; Fensham and Guymer, 2009). These opportunities emanate from the Clean Development Mechanism (CDM) and the proposed Reduced Emissions from Deforestation and Forest Degradation (REDD) of the Kyoto Protocol that state explicitly that carbon

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sequestration initiatives should be compatible with preservation of biodiversity (Diaz et al., 2009). Suitable long-term planning tools are needed to guide the process of restoration of biodiversity as well as project carbon accumulation. Forest growth forecasting tools have long been used to support decisions on sustainable ecosystem management for multiple benefits.

Deforested and abandoned lands have in the last two decades been the focus of reforestation programs in many countries aimed at restoring ecological integrity of these ecosystems to their original state or substituting them with forest plantations to address demands for forest products (Sayer et al., 2004). In terms of conserving endemic flora and fauna diversity, mitigation against habitat destruction and loss through ecological restoration effort is best served by utilizing locally occurring species that are adapted to local conditions and have an established role in the landscape. Naturally regenerating (regrowth) forests in a landscape that is characterised by patchy remnant forest stands are well suited to provide interim habitat and habitat connectivity to the benefit of both flora and fauna (Bowen et al., 2009). Planning and assessment of assisted recovery of landscapes through ecological restoration is often limited by lack of information on long-term dynamics of slow growing woody species that are subject to natural and anthropogenic disturbances. Hence little is often known about the likelihood of and time required for the species composition and structural characteristics of these regrowth forests to resemble those of mature forest communities (Johnson and McDonald, 2005; Dwyer, 2009). This need can be partly addressed by utilizing the currently available data and knowledge to calibrate existing vegetation dynamics simulation tools that can be applied over appropriate scale of space and time.

The Brigalow (Brigalow) Belt in Australia is an example of a broad natural ecosystem that has in the past been subject to extensive vegetation clearing for pastoral production and arable farming. The Belt spans semi-arid and eastern Queensland and northern New South Wales (see Fig. 1) covering more than 36 million hectares in the 500–750 mm rainfall zone (National Forest Inventory, 2003). Current data suggest that only about 14% of the brigalow dominated vegetation that existed before clearing remains (Johnson and McDonald, 2005). Consequently, brigalow remnant and regrowth forests have a significant habitat role as fauna refuges in fragmented and cleared landscapes (Johnson and McDonald, 2005; Bowen et al., 2009; Butler, 2009; Dwyer et al., 2009). Brigalow regrowth forests regenerate from root suckers on cleared land and disturbed areas and are characterised by high density tree stands (>11,000 stems ha^{-1}) often dominated by *Acacia harpophylla* F. Muell. species.

Despite the wide use of growth forecasting yield models in coastal forests of Australia, no such models exist for uneven aged, mixed-species low inland forests of low commercial value such as brigalow forest communities. Forest succession models based on Gap phase dynamics have wide acceptance and applicability especially when dealing with mixed species ecosystems that are poor in available data (Bugmann, 2001; Porte and Bartelink, 2002; Shugart, 2002; Larocque et al., 2006; Fyllas et al., 2007). The Ecosystem Dynamics Simulator (EDS) gap model used for this study has been adapted from JABOWA-II (Botkin, 1993) to support long-term projections of growth dynamics of native vegetation in Australia (Ngugi et al., 2007).

The aim of this study is to model growth dynamics of brigalow forest communities to enable long-term planning and assessment of assisted recovery. The capacity to project elements of these forests is necessary for estimating changes in carbon accumulation and biodiversity attributes. The EDS model was calibrated and validated in projecting changes over time in structural characteristics (stem density, height, *dbh* and basal area), species composition and accumulation of live aboveground biomass. This study utilised data from the only long-term ecological monitoring experiment for remnant brigalow forest communities and regrowth brigalow forests. The dataset consisted of 182 plots in mature forest, with 18 plots that have been remeasured at least three times between 1966 and 2010, 158 plots that have been inventoried at least twice and six plots of regrowth vegetation measured 16 times over the same period.

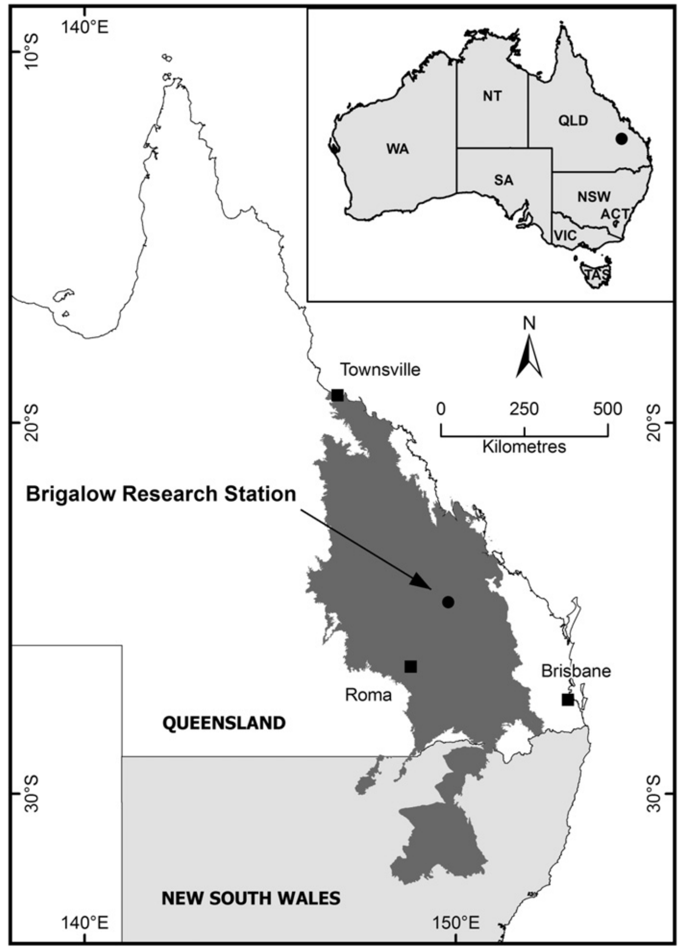

Fig. 1. Location of Brigalow Research Station study site and the spatial coverage of the Brigalow Belt within Queensland and New South Wales. The States are: QLD, Queensland; NSW, New South Wales; ACT, Australian Capital Territory; SA, South Australia; NT, Northern Territory; WA, Western Australia; TAS, Tasmania.

2. Materials and methods

2.1. Significance of brigalow forest communities

Many vegetation communities within the Brigalow Belt are characterised by brigalow (*Acacia harpophylla*), a leguminous tree that is usually 10–15 m in height and is commonly found in open forests and woodlands. The cracking clay soils (vertosols) supporting brigalow communities are relatively fertile, an attribute that has led to these communities being extensively cleared for agricultural and pastoral production (Johnson, 1976; Scanlan, 1991; Johnson, 1997). Consequently mature brigalow ecosystems are among the most threatened in Queensland (Johnson, 1997; Johnson and McDonald, 2005) and remnant brigalow forests are now protected as endangered ecological communities under Australia's Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act, 1999), and as endangered regional ecosystems under the Queensland Vegetation Management Act 1999 (QLD VM Act,