Application of a Forest Dynamics Simulation Model to Native Vegetation Management in Queensland

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EXTENDED ABSTRACT

Although forest dynamics simulation methods based on gap dynamics have been in existence for more than 35 years since the JABOWA model (Botkin et al. 1972) was first published, few of these models have moved beyond research tools to a decision and policy formulation support role.

These models simulate growth and succession of tree species under changing environmental conditions that include light, soil moisture, temperature and availability of nutrients. The models have been used to investigate forest succession, response of forested ecosystems to management related disturbances and possible effects of climate change (Botkin 1993, Kimmins 2003). However, there has not been widespread use of these valuable tools for decision making as would be hoped. It appears that much of the model use has been targeted to researchers more than decision makers. This has led to increasing complexity in most of these models to the extent that decision makers find them impractical in terms of operating skill, lack of flexibility, data requirement, and time commitment (Robinson and Freebairn, 2001).

While forest dynamic models have contributed to the knowledge and understanding of forest succession, there is much to be gained through greater direct application of these models by decision makers to manage forests. Current work at Environmental Protection Agency, Queensland (EPA), suggests that forest dynamics models have capacity to contribute to: achievement of balanced approaches towards forest conservation and sustainable forest management; translation of available forest knowledge into a language suitable to stakeholders; understanding of adaptation of forests to climate change at a local scale; on-the-ground forest management practices by focusing on priority policy issues and enhancement of forest management through innovative technologies.

Several growing forces combined are providing a major impetus for the application of forest dynamics models in natural resource management. These include managing impacts of disturbances such as fire, grazing, tree harvesting in natural forests, tree clearing and climate change. This is coupled by strong legal requirements for managing forests in a sustainable manner including compliance to pre-determined outcomes in terms vegetation structure and species composition.

Evolving technological advances in computing and accessibility of computers to decision makers provide an opportunity for delivering tools to support decision making on sustainable management of forests for multiple uses. The EPA has adapted a generic forest dynamics simulation model and enhanced it in order to support vegetation management decisions. We have trialled this new model (Ecosystem Dynamics Simulator (EDS)) on wet/dry sclerophyll forests and brigalow vegetation types in Queensland.

In this paper, EDS was used to investigate the likely long-term impacts of a proposed once-only tree harvest at Pile Gully State forests, on woody species composition and diameter size class distribution and in relation to conservation of forest fauna. Two scenarios were examined: (1) no harvesting; and (2) harvest of all trees having suitable commercial characteristics and having diameter greater than 30 cm. The impacts of the harvest were examined against EPA Code of Practice for Native Forest Timber Production in Queensland. These results showed that species composition and size class distribution were not adversely affected. EDS can play a useful role is estimating the long-term impacts of a forest disturbance such as selective harvesting of trees in complex sclerophyll forests.

1. INTRODUCTION

As public concern and legislative requirements for environmental protection in Australia increase (EPBC Act 1999, NC Act 1992, VM Act 1999), land managers must consider ecologically sound and justifiable techniques for managing and restoring Australia's vegetation communities and wildlife, some of which are now categorised as endangered or of concern (Sattler and William, 1999). This task, however, requires the availability of a suite of tools that can integrate current state of knowledge and management experience of these resources, in order to support timely decision making and policy development.

Although the knowledge base of key factors driving native vegetation dynamics in Queensland is continually expanding, much of this knowledge remains isolated in various forms of access media, is localised to sites and project conditions and has not been translated into a simulation framework readily available for informing policy processes, planning initiatives and empowering land managers to simulate and adapt management actions to changing values and environmental conditions (Ngugi et al. 2006).

In response to provision of suitable management tools, the EPA is developing a forest dynamics simulator that is capable of capturing current state of forest knowledge into a form that will allow land managers to test alternative management actions and select those most appropriate for their specific issues and objectives.

The EDS was adapted from a generic forest dynamics model called JABOWA II (Botkin, 1993). This model was chosen because of its ability to function simultaneously in different geographical locations with exactly the same model structure, while changing only the climatic data, soil properties and the set of species observed at a local site. The approach is particularly appealing to a resource manager because sourcing data required to run the model is easy.

The adaptation process of EDS involved calibrating it to the species, climate, and site conditions of Queensland, and then validating it using data from plots that were repeatedly measured in mixed species forests for more than 50 years. The model projected tree growth and survival with less than 10 percent variation from observed results over 50 years (Ngugi et al. 2005, Ngugi et al. 2007).

Since fire plays such an important role in Australian ecosystems, we have added a fire simulation module enabling users to vary both the intensity and frequency of prescribed fire events and to examine the likely effects on vegetation (Ngugi et al. 2006).

This paper reports a case study that was undertaken to support decision making on the likely impacts of a proposed tree harvest at Pile Gully State Forest on habitat characteristics for forest fauna. The harvest was to remove good quality timber trees having diameter greater than 30 cm.

A major consideration during commercial tree harvesting in native forests in Queensland is the retention of habitat and recruitment trees to meet wildlife conservation requirements. These requirements are contained in Schedule 6 of the EPA Code of Practice for Native Forest Timber Production in Queensland (EPA Code, EPA QLD 2002). Under Schedule 6, a minimum of six live habitat trees preferably with diameter at breast height (1.3 m above ground level) greater than 50 cm and two recruitment trees per hectare should be retained in perpetuity in Pile Gully forests.

To elucidate the potential long-term impacts of the harvest on woody species composition and size class distribution we examined two scenarios: (1) no harvesting; and (2) harvest of all trees having specified characteristics for sawn timber industry and having diameter greater than 30 cm. The impacts of the harvest were examined against EPA Code.

2. METHODS

2.1 Study area

This study was conducted in Pile Gully State Forest (SF 220), located between the latitudes 25^o 46' S and 25^o 53' S, and longitude 152^o 22' E and 152^o 33'E in southwest Queensland. The climate of the site is subtropical, characterised by hot humid summers and cool, dry winters. December and January are the hottest months with mean maximum daily temperature > 32.8 °C, while July is the coldest month with mean minimum daily temperature of 6 °C based on 100 years of climate data from Australian Bureau of Meteorology. The mean annual rainfall is approximately 765 mm.

Pile Gully State Forest is approximately 195 meters above sea level and covers an area of 8920 ha. The forest has been selectively logged since 1949 on 20–30 year cycles, and burnt on a

3-5 year cycle to keep understorey sparse and allow grass to grow for grazing by cattle (D. Prendergast, personal communication). The dominant tree species are *Corymbia citriodora* subsp. v*ariegata* (spotted gum), *Eucalyptus crebra* (narrow-leaved ironbark) and *Eucalyptus decorticans* (gum-topped ironbark). These species are mixed with less dominant species including *Corymbia trachyphloia* subsp. *trachyphloia* (brown bloodwood), *Corymbia intermedia* (red bloodwood), *Eucalyptus exserta* (queensland peppermint), *Eucalyptus acmenoides* (white mahogany), *Eucalyptus tereticornis* (forest red gum), *Eucalyptus moluccana* (grey box), *Corymbia tessellaris* (carbeen bloodwood), *Angophora leiocarpa* (smooth-barked apple) and *Angophora floribunda* (rough barked apple). The understorey varies with fire but is mainly composed of grasses, *Acacia aulacocarpa* (black wattle), *Alphitonia excelsa* (red almond), *Alstonia constricta* (bitterbark), *Acacia leiocalyx* (curracabah) and *Allocasuarina torulosa* (baker's oak).

2.2 Overview of JABOWA-II model

The JABOWA-II forest dynamics model is a hybrid model that uses the knowledge of plant physiology and physiological ecology, and empirical growth data to simulate the growth of individual trees and a community of trees in a changing environment. A detailed description of the model is given in Botkin (1993) and general descriptions of processes contained in JABOWA family of models are presented by Shugart (1984) and Kimmins (1997). The development of a forest stand is obtained by simulating establishment, growth and death of individual trees. The number of saplings added in any year is a stochastic function of the maximum number of saplings per species that can be recruited annually, multiplied by the light available at the forest floor and site quality (the product of soil moisture and nitrogen conditions and thermal conditions of the environment). Some key environmental conditions that affect tree growth include light, soil moisture, temperature and availability of nutrients. Growth of each tree is calculated by decreasing the maximum potential diameter growth rate by growth multipliers for each of the environmental factors that is below optimum.

Death of individual trees may occur from lightning strike, storm, fire and other random causes. This inherent risk of death is assumed to be an exponentially distributed event whose probability is a measure of the expected life span of the tree species, and that only one percent of healthy trees reaches the maximum age. Trees are also subject to a higher mortality if they are growing slower than a predetermined minimum annual diameter increment.

Forest dynamic models based on JABOWA model (Botkin et al. 1972) have been applied to simulate long-term forest succession for more than 35 years (Kimmins 1997). Some applications include: Australian montane *Eucalyptus* forests of Brindabella Range, New South Wales (Pausas et al. 1997; Shugart and Noble 1981); North American forests (Shugart 1984); Fiordland, New Zealand (Develice 1988); Swiss forests (Bugmann 2001; Kienast and Kuhn 1989); forests in The Netherlands (Mohren et al. 1991); Canadian forests (Wein et al. 1989); and boreal forests in Finland (Kolström 1998).

2.3 Parameterisation of the EDS model

Parameter estimates for each of the tree species observed in Pile Gully forests were determined using the detailed procedure contained in Botkin (1993). Estimates of growth characteristics of individual species were obtained from the Native Forest Permanent Plots (NFPP) database for Queensland. The database contains data for more than 640 plots, with earliest plots established in 1937 (Beetson, 1992) and re-measured regularly until year 2006.

2.4 Field data collection

Eleven one-hectare circular plots distributed across the major forest types in Pile Gully State Forest were intensively measured. The diameter over bark at breast height (dbh) and species of each tree with dbh greater than 10 cm was recorded. All trees with dbh greater than 30 cm were assessed for commercial log wood recovery based on the visual assessments of bole straightness and the minimum length of log (2.4 m). Large trees (dbh >50 cm) that had visible hollow or were not suitable for commercial harvest and met the EPA Code standards as habitat trees were marked for retention whilst trees that met the commercial characteristics were marked for cutting. Trees that had poor form but had diameter greater than 30 cm, were dominant or co-dominant and of a species known to develop hollows were retained as habitat recruitment trees, while trees that had some stem damage but could be cross cut for a reasonable log were marked for cut.

Forest regeneration within each plot was estimated by dividing the plot into four 0.25 ha quadrants and by measuring all woody plants with dbh greater than 2 cm in the northwest quadrant. Four soil samples were obtained in each sample plot, with each soil core dug at the centre of each quarter of the plot. Soil texture of the top 30 cm of the soil profile, soil depth down to one metre and the minimum depth of the soil subject to water saturation (as shown by signs of mottling) were determined from the soil cores.

2.5 Simulation of forest scenarios

The long-term change in forest structure was examined by considering two scenarios: (1) starting with the current stand structure, the stand was simulated assuming that no harvesting will take place; and (2) starting with a harvested plot, by assuming that all trees that were selected for harvest were removed from the initial plot. For each of the 11 plots, each of the two scenarios was simulated 50 times for 90 years, and the average simulated characteristics of each plot were determined at year 30 and year 90. The simulations assumed that routine fuel reduction burning and grazing management procedures for Pile Gully State Forest would be maintained. The effect of proposed harvest on woody species composition was determined using Simpson's Index of Diversity (1-D). This index represents the probability that two individuals randomly selected from a sample will belong to different species and takes into account the number of species present, as well as the abundance of each species. The value of this index ranges between 0 and 1, and the greater the value, the greater the sample diversity.

3. RESULTS

3.1 Initial forest stand characteristics

The forest was composed of actively growing stands of mixed species with approximately 90 % of the trees having dbh between 10 and 30 cm. Stems with dbh smaller than 10 cm were dominated by *Acacia* species (wattle) and the largest number of recruits was observed in Plot four where more than 4700 trees were within the diameter range of 2 to 9.9 cm. Total basal area of individual plots ranged from 8.3 to 16.8 m^2 ha^{-1} (Table 1), with a combined average of 11.4 ± 1.5 m^2 ha^{-1}. Plot 8 had the highest basal area marked for removal (47 %). In all other 10 plots, the proposed basal area for removal ranged from 8 and 34 % (Table 1), and the average basal area marked for removal from all the plots was 26 ± 6.4 %.

The average stand structure of the eleven plots before and after the proposed harvest is presented in Figure 1. On average, 13 trees would be removed from the 31-40 cm diameter class, 6 trees in the 41-50 cm class and 3 trees in the 51-70 class. No trees would be removed in diameter classes greater than 70 cm. The approximate number of trees with a diameter greater 30 cm that would be retained after the proposed harvest as habitat trees was 19 ± 4.4 stems ha^{-1} and approximately 4 stems with diameter greater than 90 cm for an area of 10 ha of forest. Statistical significance test (t-test) was used to compare the difference between the means of size class distributions before and after the harvest. The test showed that the numbers of trees retained in the 31- 40 cm class and 41-50 cm class were significantly ($p < 0.05$) smaller than the tree count before the harvesting.

Table 1: Plot basal area (BA), count of stems with diameter at breast height (dbh) below and above 30 cm and the proportion of plot basal area (percentage) that was marked for removal during harvesting.

Plot number	Plot BA (m^2)	No. of stems with dbh < 30 cm	No. of stems with dbh >30 cm Before cut	After cut	% BA removed
1	13.7	325	51	16	25
2	10.9	480	44	20	28
3	12.3	927	49	30	20
4	12.6	4708	40	17	22
5	9.3	412	29	11	30
6	9.2	697	35	23	14
7	16.8	942	40	32	8
8	10.1	173	39	10	47
9	8.3	196	35	14	34
10	10.7	356	37	17	27
11	11.3	164	52	21	34
Averages	11.4	853	41	19	26

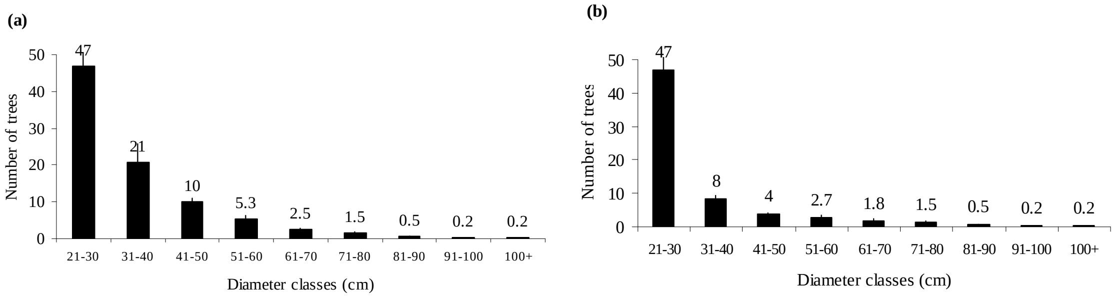

Figure 1. Average size class distribution of 11 plots before (**a**) and after (**b**) the proposed harvest of selected trees with diameter at breast height greater than 30 cm. The data labels on each bar shows the number of trees in the class.

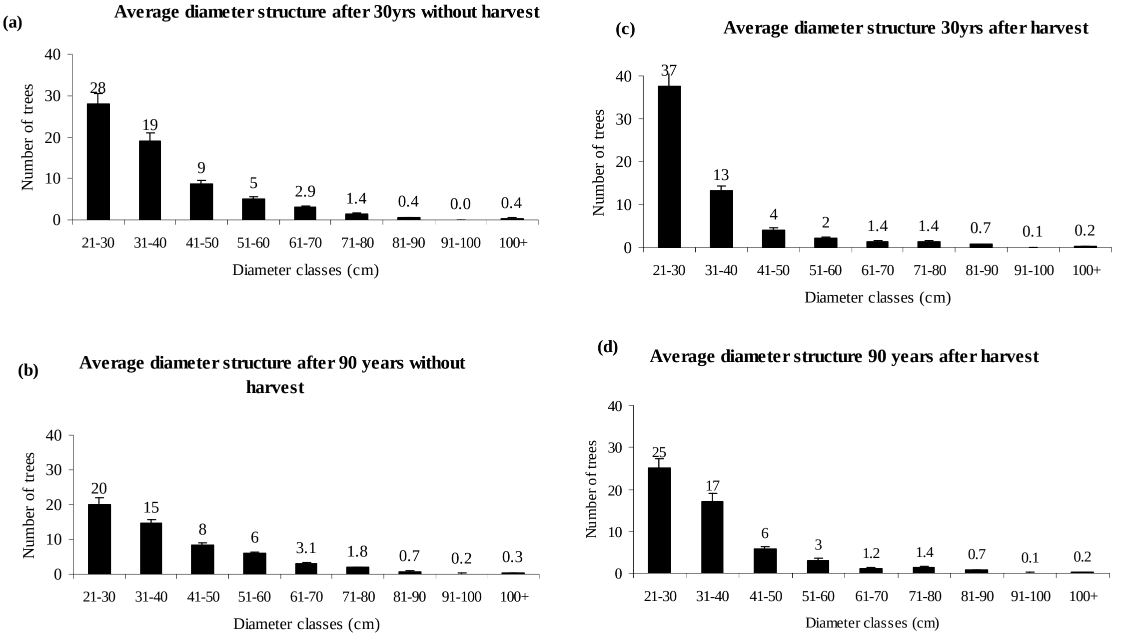

Figure 2. Average size class distribution of 11 plots after 30 and 90 years of simulation, assuming that no harvesting will take place ((a) and (b)) and assuming that all commercial trees will be cut ((c) and (d)). The data labels on each bar show the number of trees in the class.

3.2 Simulated forest scenarios (without harvesting and after harvesting)

The structure of the forest after 30 and 90 years of simulation and in the presence and absence of harvesting shown in Figure 2, indicated a progression of individual trees to higher diameter classes and a decrease in the number of trees in the 21-30 cm diameter class. Comparison between the simulated number of trees in each diameter class for both the harvest and no harvest scenarios at 30 years, showed no significant differences between stem counts at 21-30 cm class and 31-40 cm class, but there were significantly less stems in the 41-50 cm and 51-60 cm classes after the harvest. After 90 years, the number of stems in the 51-60 cm class and 61-70 cm class were still significantly ($P < 0.05$) fewer in the harvested scenario than in the unharvested scenario. Species diversity value of 0.63 obtained using Simpson's Index of Diversity 1-D before harvesting and 90 years after harvest showed that there was no decline in species diversity during the simulation period.

4. DISCUSSION

The use of EDS to assess the long-term impacts of forest disturbances in complex mixed-species and mixed-age forests provided insights that are difficult to obtain by other methods. A major contribution is the capacity to make detailed projections of growth and survival of individual trees and present the structural characteristics of the forest (species composition and age and diameter size class distribution). This capacity is essential for predicting outcomes of alternative forest management policies and in the development of balanced approaches towards forest conservation and sustainable forest utilisation.

This paper has examined the ecological impacts of a once-only intensive harvest of commercial trees with a dbh greater than 30 cm, in terms of continuous provision of quality habitat characteristics for wildlife. Detailed assessment of habitat and commercial characteristics of individual trees in the 11 hectares of forest showed that the average basal area that could be removed through a commercial logging was 26 ± 6.4 %. This value was below the maximum allowable basal area removal of 50 % that is stipulated by the EPA Code. The average number of trees with dbh > 30 cm retained per hectare after the proposed harvest of 19 ± 4.4 trees was also within the requirements of the EPA Code.

The diameter size-class distribution of the 11 plots immediately after harvest showed a presence of at least six non-commercial trees with diameter > 50 cm (Figure 1) that were suitable for habitat trees and habitat recruitment trees. Although the forest has been harvested on a 20-30 years rotation in the past, the presence of a substantial number of trees that are suitable for retention as habitat trees is an indication that silvicultural treatments that involved destruction of non-commercial trees in the past to enhance growth of commercial trees in the coastal hardwood forests of southeast Queensland (Holzworth, 1996) had not been directly applied to the Pile Gully forests. However the number of large trees > 80 cm which are considered most suitable for hollow formation was very small with approximately one tree in a hectare.

The general diameter size structure of forests in Pile Gully with only a small number of trees with diameter > 60 cm is that of an actively growing forest trying to recapture site occupancy after previous selective harvests (Figure 1). In the absence of logging, more trees are expected to increase in size and progress to higher size classes as shown in Figure 2. This progression and increase in number of larger trees is accompanied by greater shading leading to suppression of understorey trees. Over time succession processes have the net effect of reducing stem density through self-thinning and death of short lived species, leading to old-growth conditions of ecosystem functions (Putz et al. 2001).

The simulation of harvested plots for a 30-year period indicated that more trees would progress to the 31-40 cm diameter class compared to non harvested plots. At the end of the 30 year period there was no significance difference in stem count for this dbh class between harvested and non-harvested plots. There was also greater mortality in this size class in the non-harvested plots, most probably because of competition. Similarly, although there were 50 % more trees with diameter >30 cm in the non-harvested forest than in the harvested forest immediately after a harvest operation (Figure 1), this gap was gradually reduced to about 41 % in 30 years (Figure 2a and 2c) and about 16 % in 90 years (Figure 2b and 2d). While this response demonstrates that the forest has the capacity to rejuvenate, the result is consistent with the finding that logging effects on tree populations continue for many years after logging is completed (Eyre 2005 , Smith and Lindenmayer 1992).

5. CONCLUSION

This study has shown that a selective harvesting operation removing trees to a minimum diameter of 30 cm in Pile Gully State forests may not adversely impinge on the minimum number of habitat trees required by the EPA Code. The simulation results incorporating effect of weather and soil conditions suggest that the harvested forest has a good potential to rejuvenate in structure as shown after 30 years. However trees with diameter greater than 80 cm will continue to be scarce far beyond 100 years. The EDS model provided a useful tool for investigating potential ecological risk of the proposed harvest to the conservation of forest fauna by interrogating alternative scenarios and comparing the outcomes. Damage of retained trees through smash, road access and the possible increased effect of fire from harvest residual on retained vegetation were not investigated in this study.

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