Supporting bushland management decisions by simulating future outcomes: Native Vegetation Response Simulator, a tool for integrating scientific research and understanding

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Abstract Decision-making in natural resource management in the context of biodiversity conservation is a delicate balancing act. Stakeholders entrusted with the responsibility for sustainable management of our natural heritage need to integrate complex ecological processes such as weather, fires, insects and pathogens, fauna and flora, and social, cultural and political values as well as economic feasibility. When faced with such complex and highly integrated systems, employing suitable tools to support decision-making becomes inevitable. Although the knowledge base on key native vegetation dynamic drivers in Queensland is continually expanding, much of this knowledge remains isolated in various forms of access media, localised to sites and conditions and is rarely translated into a framework readily available for informing policy processes, planning initiatives and empowering land managers to adapt management actions to changing values and environmental conditions. Native Vegetation Response Simulator (NVRS) provides such a framework. This simulator is an enhanced adaptation of JABOWA-III forest model and captures the ecosystem changes of a site as driven by local monthly climatic data, basic soil characteristics, species composition and disturbances such as fire. The simulator projects regeneration, growth and mortality of individual species and can be used to assess the risk and impact of drivers and alternatives decisions before selecting a course of action. An overview of the simulator and sample results is provided here.

Keywords: gap model; fire response; vegetation dynamics; scenarios; dry sclerophyll forests; impacts assessment

Introduction

Effective conservation of biological diversity requires management of threats to biodiversity in private, leasehold and protected areas. However in cases such as the use of fire to promote environmental health and for risk minimisation in sub-urban areas, management actions are often subject to intense public scrutiny requiring the need to justify impacts and long-term consequences of the decisions. Hence stakeholders are faced with the need to integrate complex ecological processes such as variable weather, types of fires, insects and pathogens effects, fauna and flora diversity, and social, cultural and political values as well as economic feasibility in an attempt to justify sustainable management practices.

The knowledge base on key drivers of native vegetation dynamics in Queensland is continually expanding. However it is mainly localised to individual species, sites and events collected for different projects and stored in various forms of media. Hence this knowledge has rarely been translated into a framework readily available for informing policy processes, resource-planning initiatives and empowering land managers to adapt management actions to changing values and environmental conditions. Such a framework would ensure that existing knowledge is utilized and that new knowledge is adapted to complement existing knowledge. In response to this need and that of translating bushland science into practical tools, Environmental Protection Agency, Queensland is developing a native vegetation simulation framework for Queensland based on JABOWA-III (Botkin *et al.* 1999) forest dynamics model.

JABOWA-III model is an upgraded version of the original JABOWA model (Botkin *et al.* 1972). The model uses the knowledge of plant physiology and physiological ecology to mimic the growth of individual trees and a community of trees in a changing environment by simulating the establishment, growth and death of individual trees. Forest dynamic models based on JABOWA model (Botkin *et al.* 1972) have been used to simulate long-term forest succession for more than 30 years. For example, 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). Native Vegetation Response Simulator (NVRS) was adapted from JABOWA-III. The simulation model was calibrated to the species, climatic and site conditions in Queensland and then validated using information from St Mary State Forest and Detailed Yield Plots (DYP) data collected from the forest for a period of 50 years (Queensland Department of Primary Industries-Forestry). The model was capable of mimicking the stand dynamics of mixed species sclerophyll forests to sufficient accuracy of less than 10 % error in 50 years (Ngugi *et al.* 2005). Subsequent testing and application in risk assessment of impacts of selective logging on habitat trees availability in Pile Gully State forest in central Burnett district of Queensland has provided results that are consistent with principles of forest growth (paper in preparation).

One of the most useful features of NVRS is relative ease of adaptation to different geographic locations, which involves supplying the local monthly climatic data, basic soil physical characteristics and set of species occurring within the location. The objective of this paper is to demonstrate some practical applications of NVRS. A dataset from Pile Gully State forest is used in this overview.

The simulator

The NVRS is a non-spatial model for simulating vegetation dynamics. The model is a windows-based computer tool that provides a modelling framework for incorporating scientific understanding on ecology and growth patterns of individual species and communities. It requires only basic data on individual species growth variables under optimal growth conditions. These include maximum attainable diameter, height, annual diameter increment and lifespan, tolerance to water logging and drought, and species geographic distribution range. Optimal growth parameters for each species were obtained from detailed yield plots database (Queensland Department of Primary Industries-Forestry), electronic tree databases and tree reference books such as "Forest Trees of Australia" (Boland *et al*. 1984). Information on species fire response was obtained from Species Register database (Gill and Bradstock 1992) and New South Wales Flora Fire Response database (NSW 2002). Species parameter data are complemented by local data on soil texture, soil depth and mottling depth, and monthly temperature and rainfall data for as many years as can be obtained from the Australian Bureau of Meteorology.

The NVRS operates on an annual time-step, and outputs a detailed dataset at individual tree and species level at specified points in time. Hence the model is able to simulate changes in plant density, diameter size class distribution (stand structure) and species composition. Timing and intensity of disturbances such as logging and wind throw are also provided as interactive options to be specified by a user. The model can cater for selective tree harvesting and is being enhanced to include fire disturbance. There is scope for further development to cater for grazing and recreation impacts. The basic components of the fire module are described below.

Vegetation response to fire

Fire disturbance in the model helps to simulate the effects of fires on existing vegetation using user defined fire conditions. Weather forecasters and fire services in Queensland use McArthur Mark 5 Forest Danger Meter (McArthur 1967; McArthur 1973) operationally to determine fire hazard. Hence the fire module of the simulator is based on this Meter and equations derived from the Meter by Noble *at al* (1980). Two basic equations used in this model are:

$$ROS = 1.2 * F * FUEL * \exp(SLOPE * 0.069) \qquad (1)$$

$$FLHT = 0.013 * ROS + 0.24 * FUEL - 2.0 \qquad (2)$$

where *ROS* is the rate of spread of a fire in meters hr^{-1}, *FLHT* is flame height in meters, *FUEL* is the fuel load in tonnes ha^{-1}, *SLOPE* is slope of the land in degrees and *F* is the Fire Danger Index (FDI). In the user interface, *FUEL*, *SLOPE* and *F* variables are supplied by the user for the particular vegetation type, site and fire weather.

The height of leaf scorch is estimated to be six times the flame height (Luke and McArthur 1978). Species regeneration strategies after fire were limited to two functional types: resprouters and non-resprouters (seeders)(Noble and Slatyer 1981). It is assumed that all species are able to resist a 50 % canopy scorch (Luke and McArthur 1978; Noble and Slatyer 1981). Resprouting species will survive a fire that causes 100 % scorch through activation of buds protected by the bark to produce epicormic shoots. Non-resprouters do not survive fires that cause 100 % crown scorch, but depend on seeds released from the canopy during fire, fire-stimulated germination of seeds in the soil bank or dispersal from unburnt sites to recruit at a site (Noble and Slatyer 1981). In this Version of the model, a species whose above ground shoot is killed but survive through root sucker and basal sprout is only recruited back to the plot when it has attained a height of 1.3 m. Tree mortality from fire is assumed to increase asymptotically when crown scorch of non-resprouters is between 50 and 100 %, and that of resprouters is between 100 and 600 % (Shugart and Noble 1981).

Fuel accumulation and decomposition between fires were estimated from the equation used in BRIND model (Shugart and Noble 1981). This equation was obtained by fitting Oslon's 1963 model for fuel decomposition to fuel estimates obtained from wet sclerophyll forests by McArthur (1967).

$$FUEL = FUEL_{\max} * (1.0 - \exp(-FUELK * FIRTM)) \qquad (3)$$

where *FIRTM* is time since the last fire, $FUEL_{\max}$ is maximum fuel load reached (normally 23.5 tonnes/ha) and *FUELK* is fuel decomposition rate (normally 0.23 tonnes/ha yr^{-1}). Annual estimates of fuel accumulation for other vegetation types can be estimated using the equation and by supplying the maximum fuel load and decomposition rates through a user interface

Materials and Methods

The dataset used in this paper was obtained from Pile Gully State Forest (SF 220), lying between the latitudes 25^{o} 46' S and 25^{o} 53' S, and longitude 152^{o} 22' E and 152^{o} 33'E in central Burnett district of Queensland. The climate of the site is subtropical, with mean maximum temperature > 32.8 °C, mean minimum daily temperature of 6 °C and mean annual rainfall of 765 mm based on 100 years of weather data from Australian Bureau of Meteorology.

Pile Gully State Forest is approximately 195 meters above sea level and has been selectively logged since 1949 on 20–30 year cycles, and burnt on a 3-5 years 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).

Tree measurements and soil sampling

One intensely measured one-hectare circular plot was used in this example. The diameter over bark at breast height (dbh) and species of each tree with dbh greater than 10 cm was recorded. Forest regeneration was estimated by measuring all woody plants with dbh between 2 and 10 cm in a 0.25 ha quadrant. Four soil samples were obtained in the 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 and the minimum depth of the soil subject to water saturation (as shown by signs of mottling) were determined from the soil cores. Fifty years of local weather data of monthly rainfall and temperature were used.

Long-term simulation of forest scenarios

To demonstrate some of the applications of the model, five scenarios were simulated: (1) do nothing; (2) prescribed burn at 4-year interval similar to that applied in the forest; (3) annual prescribed burn; (4) wildfire at the potential drought conditions in Southeast Queensland and; (4) annual burn with mild climate change. Each of the four scenarios was simulated 50 times for a period of 50 years. The average simulated characteristics were determined from the 50 runs at the end of year 50.

Prescribed burns were applied during days with low FDI of 5, ensuring that maximum flame height did not exceed 1.5 to 2 m (Buckley and Corkish 1991). Estimates of fine fuel (dead fuel < 1cm diameter) and heavy fuel (dead fuel > 1 cm diameter) accumulation in dry sclerophyll forests were obtained from documented long term fire experiments at Bauple State Forest initiated in 1952 and 1973 respectively (Hannah *et al*. 1997). The mean estimates for fine fuel in the annual burnt site were 5 ton ha^{-1} and 7 ton ha^{-1} for the sites burnt every 2-5 years. For heavy fuel, the mean mass in the annual burnt site was 10.3 ton ha^{-1} and 49.7 ton ha^{-1} for the site burnt every 2-5 year. A wildfire was simulated in the 2-5 year burnt site using estimated total of fine and heavy fuel of 56.7 t/ha and FDI of 60. The quasi-equilibrium for fine fuel was estimated at 23.5 ton ha^{-1} (Buckley and Corkish 1991; Shugart and Noble 1981) and fuel decomposition rate of 0.23 ton yr^{-1}.

In this study, projected climate change for southeast Australia was obtained using OzClim (Jones *et al*. 2001), an Australian climate change scenario generator, based on CSIRO's CCAM (Mark2) global climate model (Hennessy *et al*. 2005) and Intergovernmental Panel for Climate Change (IPCC) scenario SRES A1B (SRES 2000). The predicted changes in monthly climate were applied to observed monthly data. This assumes no change in future weather variability, but that the mean increases or decreases (IPCC 2001).

Results example

The simulated outputs from NVRS provide a dataset that can be summarised to examine impacts of a range of management treatments. For example, Figure 1 shows the use of tree diameter in a comparison between do nothing scenario and that of the four treatments at the end of 50 years of simulated growth. In the absence of fire, the major driving force in the structure development of the stands is assumed to be the local variability in rainfall and temperature. The comparisons of tree size structure among the do nothing scenario, annual prescribed burn, annual prescribed burn combined with adjusted weather data for mild global warming and a 4-year prescribed burn showed only minor differences in the number of trees in each of the diameter classes (Figure 1). Since light burns are likely to cause changes in the small diameter classes, these results may indicate the domineering effects of the larger trees on the site. For diameter classes greater than 10 cm the impact of the annual and prescribed burns was minimal. However in the burn scenarios, the number of trees with diameter less than 10 cm may have been underestimated because at the time, the simulator did not cater for fire stimulated recruitment. This capability is currently being enhanced based on information from databases on species responses to fire (Gill and Bradstock 1992; NSW 2002). Prescribed burns used in this example were at low intensity, intended to cause minimal damage to trees with height greater than 2 m.

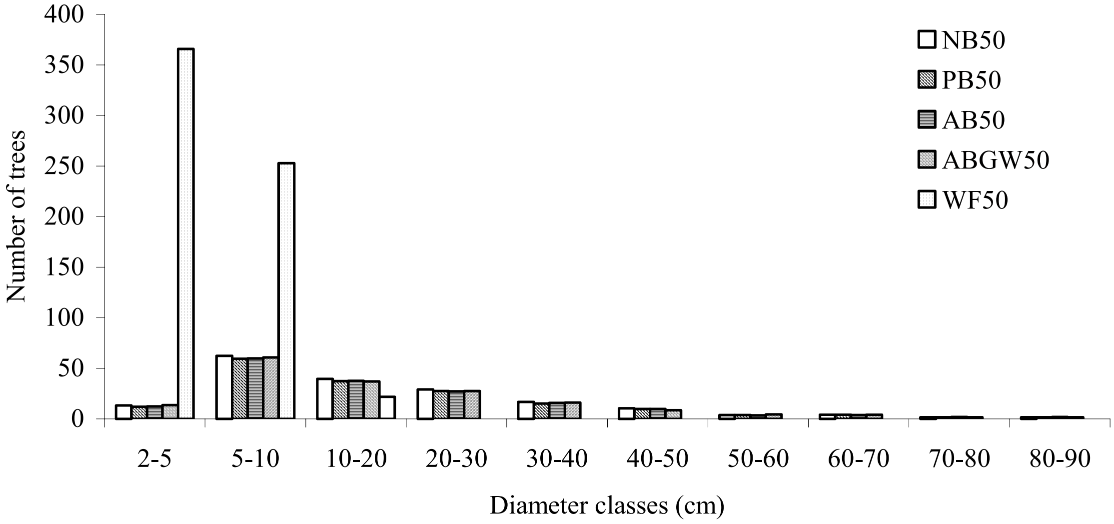


Figure 1. Diameter distribution of trees with dbh >2 cm in a one-hactare plot obtained at the end of a 50-year period of simulated growth. The five scenarios are: no burning (NB50), prescribed burn every 4 years (PB50), annual burn (AB50), annual burn with weather data adjusted for projected mild global warming (ABGW50) and wildfire occurring in year one assuming total fuel accumulation equivalent of a 4 years prescribed burn cycle.

Wildfire had the greatest impact on the stand structure in all plots as shown in Figure 1. The wildfire conditions produced a crown fire that killed all the existing trees and was followed by massive recruitment of trees. The largest trees resulting from the post wildfire recruitments were within the 10-20 cm diameter class after the 50 years period. The figure demonstrates that various management options can be compared at one point in time.

The outputs from the simulator can also be used to examine the impacts of proposed management actions on species composition in a site. For example, Figures 2a and b shows the relative number of trees of *Eucalyptus crebra*, *Eucalyptus exserta*, *Corymbia citriodora* subsp. v*ariegata* and *Corymbia intermedia* within the 0 to 30 cm diameter range at the start and end of an annual burn simulation. The figures indicate that the fire regime favours the recruitment of *Eucalyptus crebra*, *Corymbia citriodora* subsp. v*ariegata* and *Corymbia intermedia* but may have some adverse impacts on the recruitment of *Eucalyptus exserta* (Figure 2 b). It is then possible to zoom in and examine the impacts of the management treatments on the growth and development of individual tree species. Figures 2c and d, suggests that prescribed burn (PB50) may have adverse impacts on the recruitment of *Corymbia citriodora* subsp. v*ariegata* and *Eucalyptus crebra*. This may indicate the need to compare among replicated plots for detailed examination of the treatment regime.

Figure 3 taken from the user interface of the NVRS provides a visual representation of the forest being simulated. The interface also allows the user to simulate the succession starting from a bare plot within a forest.

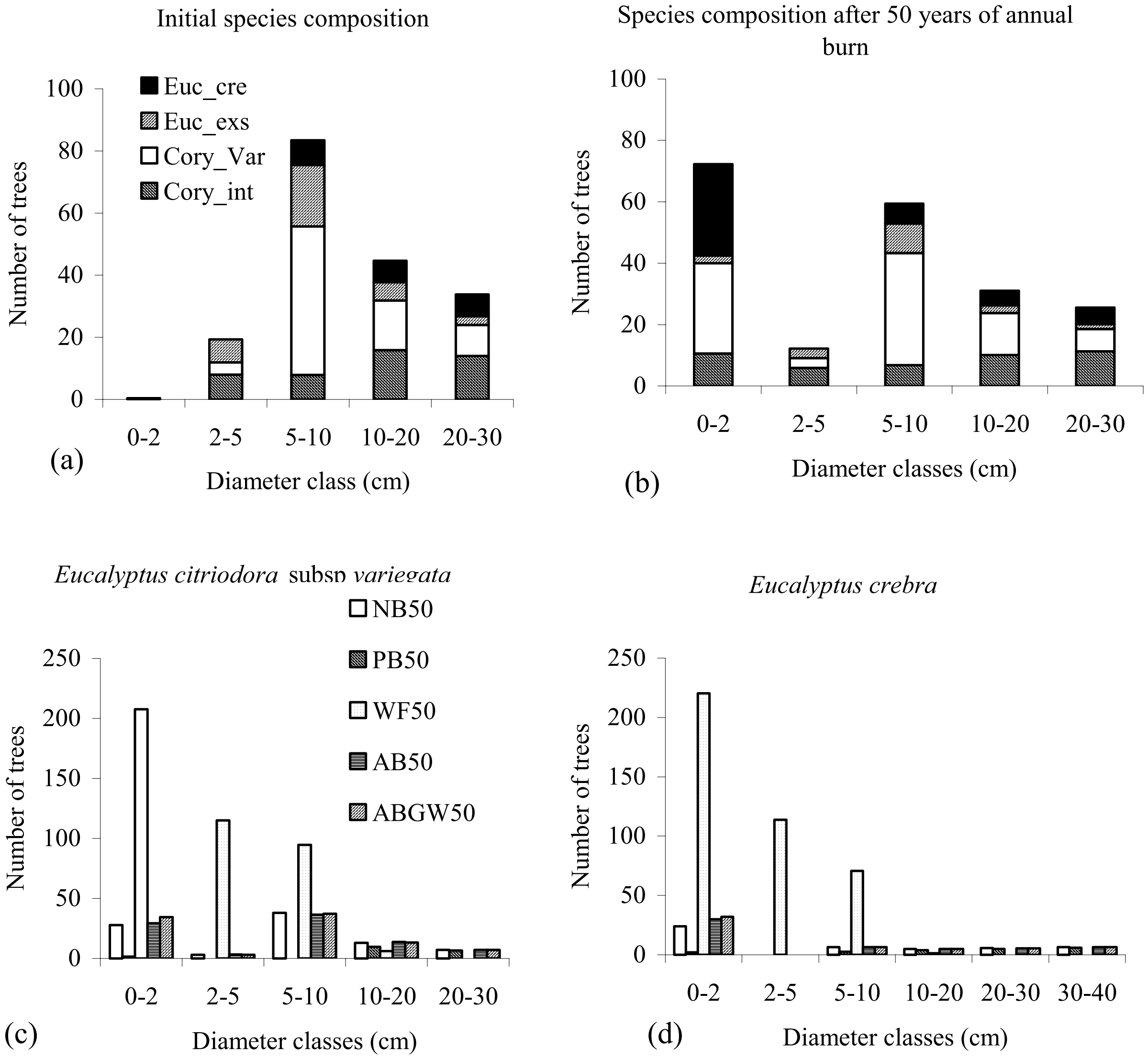
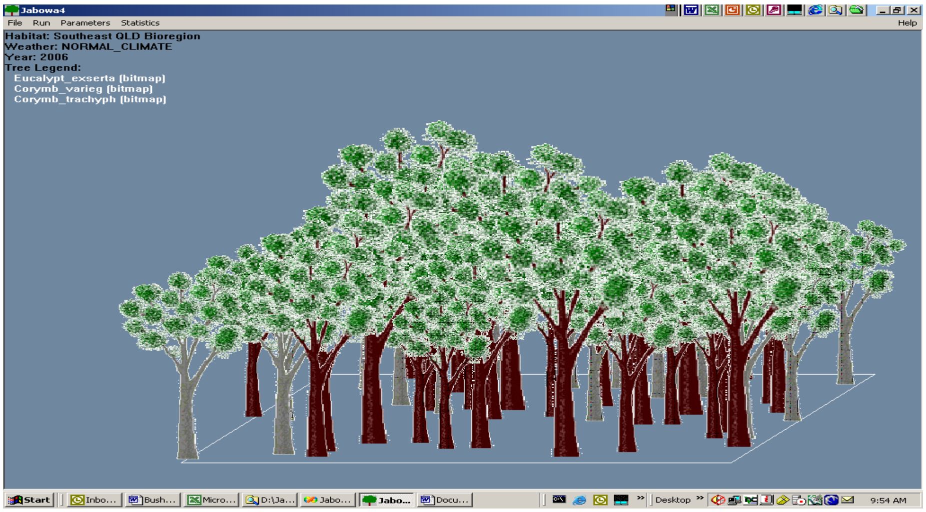


Figure 2. Species composition analyses of (a) *Eucalyptus crebra*, *Eucalyptus exserta*, *Corymbia citriodora* subsp. v*ariegata* and *Corymbia intermedia* at the start of simulation and (b) at the end of 50 years in the annual burn scenario. The number of trees of *Corymbia citriodora* subsp. v*ariegata* (c) and *Eucalyptus crebra* (d) at the end of 50 years under no burning (NB50), prescribed burn every 4 years (PB50), annual burn (AB50), annual burn with weather data adjusted for projected mild global warming (ABGW50) and wildfire occurring in year one assuming total fuel accumulation equivalent of a 4-year prescribed burn cycle.



Habitat: Southeast QLD Bioregion
Weather: NORMAL_CLIMATE
Year: 2006
Tree Legend:
Eucalypt_exserta (bitmap)
Corymb_varieg (bitmap)
Corymb_trachyph (bitmap)

Figure 3. Visual representation of tree dynamic processes by NVRS simulator

Conclusion

This simulator was used to explore vegetation management issues involving interactions between tree growth, fuel loads, weather conditions and a global warming scenario. Fire module presented here is being enhanced and requires rigorous testing using data from long-term fire experiments. The NVRS provides a framework for integrating knowledge and is a powerful tool that can be used to explore changes in flora diversity, fauna habitat characteristics, selective logging and revegetation issues. This is made possible by the core capability of simulating changes in age and size structure and species composition of woody plants driven by local monthly climatic data, basic soil characteristics, and species composition. The simulator can be used to examine impacts and compare the outcomes of alternatives decisions before selecting a course of action.

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References

Boland, D.J., Brooker, M.I.H., Chippendale, G.M., Hall, N., Hyland, B.P.M., Johnston, R.D., Kleing, D.A., and Turner, J.D. (1984) *Forest Trees of Australia*, 4th/ed. Melbourne : Nelson/CSIRO, 687 pp.

Botkin, D.B., Janak, J.F., and Wallis, J.R. (1972) Some ecological consequences of a computer model of forest growth. *Journal of Ecology* **60**, 849-873.

Botkin, D.B., Woodby, D.A., and Bergengren, J.C. (1999). JABOWA-3: A model of forest growth. The Center for the Study Of the Environment, New York.

Buckley, A.J., and Corkish, N.J. (1991) Fire hazard and prescribed burning of thinning slash in eucalypt regrowth forest, Rep. No. 29. Department of Conservation and Environment, Melbourne, Australia.

Bugmann, H. (2001) A comparative analysis of forest dynamics in the Swiss Alps and the Colorado Front Range. *Forest Ecology and Management* **145**, 43-55.

Develice, R.L. (1988) Test of a forest dynamics simulator in New Zealand. *New Zealand Journal of Botany* **26**, 387-392.

Gill, A.M., and Bradstock, R.A. (1992) A national register for fire response of plant species. *Cunninghamia* **2**, 653-660.

Hannah, D.S., Smith, G.C., and Agnew, G. (1997) Reptile and amphibian composition in prescribed burnt dry sclerophyll forest, southern Queensland. *Australian Forestry* **61**, 34-39.

Hennessy, K., Lucas, C., Nicholls, N., Bathols, J., Suppiah, R., and Ricketts, J. (2005) Climate change impacts on fire-weather in south-east Australia,. CSIRO Marine and Atmospheric Research, Aspendale, Victoria.

IPCC (2001) Summary for policymakers. In: Hougton, J.T., Ding, Y., Griggs, D.J., Noguer, M., Linden Van Der, P.J. and Xioaosu, D. (ed.) *Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, 944 pp.

Jones, R., Page, C., and Sims, G. (2001). OzClim. . Developed at CSIRO Atmospheric Research by the Climate Impact Group in collaboration with the International Global Change Institute (IGCI), New Zealand.

Kienast, F., and Kuhn, N. (1989) Simulating forest succession along ecological gradients in southern Central Europe. *Vegetatio* **79**, 7-20.

Kolström, M. (1998) Ecological simulation model for studying diversity of stand structure in boreal forests. *Ecological Modelling* **111**, 17-36.

Luke, R.H., and McArthur, A.G. (1978) *Bushfires in Australia*, Australian Government Publishing Service, Canberra, 359 pp.

McArthur, A.G. (1967) Fire behaviour in eucalypt forest, Rep. No. 107. Commonwealth of Australia Forest and Timber Bureau Leaflet.

McArthur, A.G. (1973). Forest Fire Danger Meter Mark5. CSIRO Forestry and Forest Products , Bushfire behaviour and management.

Mohren, G.M.J., van Hees, A.F.M., and Bartelink, H.H. (1991) Succession models as an aid for forest management in mixed stands in The Netherlands. *Forest Ecology and Management* **42**, 111-127.

Ngugi, M.N., Botkin, D.B., Jones, B., and Williams, A. (2005). Needs and opportunities for using a forest dynamic model as a practical tool in biodiversity conservation and management. In XXII IUFRO World Congress (Innes, J.L., Edwards, I.K. and Wilford, D.J., eds.), Vol. 7(5), pp. 34-35. Commonwealth Forestry Association, Brisbane, Australia.

Noble, I.R., Bary, G.A.V., and Gill, A.M. (1980) McArthur's fire-danger meters expressed as equations. *Australian Journal of Ecology* **5**, 201-203.

Noble, I.R., and Slatyer, R.O. (1981) Concepts and models of succession in vascular plant communities subject to recurrent fire. In: Gill, A.M., Groves, R.H. and Noble, I.R. (ed.) *Fire and the Australian biota*. Australia Academy of Science, Canberra, 311-338 pp.

NSW, N.P.a.W.S. (2002). NSW Flora fire response database. . Department of Environment and Conservation, Hurstville.

Pausas, J.G., Austin, M.P., and R., N.I. (1997) A forest simulation model for predicting eucalypt dynamics and habitat quality for arboreal marsupials. *Ecological Applications* **7**, 921-933.

Shugart, H.H. (1984) *A Theory of Forest Dynamics*, Springer-Verlag Inc., New York, 278 pp.

Shugart, H.H., and Noble, I.R. (1981) A computer model of succession and fire response of the high-altitude *Eucalyptus* forest of the Brindabella Range, Australian Capital Territory. *Australian Journal of Ecology* **6**, 149-164.

SRES (2000) Special Report on Emission Scenarios: Summary for policymakers. A special report of working group III of the intergovernmental Panel on Climate Change,. Cambridge University Press, UK, Cambridge.

Wein, R.W., El-Bayoumi, M.A., and Da Silva, J. (1989) Simulated predictions of forest dynamics in Fundy National Park, Canada. *Forest Ecology and Management* **28**, 47-60.