Landscape Ecology **13**: 103–109, 1998.

Potential impact of harvesting for the long-term conservation of arboreal marsupials

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(Received: 5 March 1997; accepted 26 April 1997)

Key words: harvesting, logging, forest management, landscape, arboreal marsupials, simulation

Abstract

We used a simulation approach to study the trade-off between forest harvesting and the conservation of arboreal marsupials in managed eucalypt forests of south-eastern New South Wales (Australia). The EDEN gap model is used to predict tree biomass harvested and the resulting shifts in habitat quality (HQ) for arboreal marsupials under different harvesting scenarios. These harvesting scenarios generate a gradient of biomass harvested by varying rotation length and tree retention in different topographic positions. The results suggest that the shape of the curve of reduction of HQ along the harvesting gradient is very sensitive to topographic position and hence to the proportion of topographic units in the landscape. Consequently arboreal marsupial management in logged forests will be region-dependent as each region will have its own pattern of landscape complexity.

Introduction

The analysis of the likely long-term consequences of different management scenarios is a key component of sustainable ecosystem management. Computer simulation models are powerful tools for performing such analyses in forest ecosystems (e.g., Franklin and Forman, 1987; Hansen et al. 1993, 1995). Individual-based gap replacement models (gap models) have been shown to simulate realistically the forest dynamics in a wide range of ecosystems (Shugart, 1984; Urban and Shugart, 1992), and they may represent the best type of model to simulate the response of biota in forest ecosystems to management and disturbance.

Long-term consequences of current management techniques on Australia's arboreal marsupials are unknown. For the conservation of this unique fauna, two main approaches are needed: 1) creation of an appropriate reserve network (e.g., Pressey et al. 1993; Margules and Redhead, 1995); and 2) integration of conservation into the management of production forests (off-reserve conservation). We suggest that both approaches are needed to ensure the conservation of the arboreal marsupials. The present work focuses on the second approach. The purpose is to study the trade-off between forest harvesting and the conservation of arboreal marsupials in managed eucalypt forest at different landscape positions in south-eastern New South Wales (Australia) using a simulation approach.

Arboreal marsupials are a well defined taxonomic as well as ecological group. We use therefore a guild approach rather than an individual species approach because there is insufficient information for any of the individual species. The most abundant arboreal marsupial in the study area is the greater glider (*Petauroides volans*). The other marsupial species found were feathertail glider (*Acrobates pygmeus*), sugar glider (*Petaurus breviceps*), yellow-bellid glider (*Petaurus australis*), squirrel glider (*Petaurus norfolcenisis*), common brushtail possum (*Trichosurus vulpecula*), and common rintail possum (*Pseudocheirus peregrinus*) (Pausas et al. 1995). In south-eastern Australia, arboreal marsupials have been shown to be strongly dependent on forest structure and composition and are therefore vulnerable to disturbance by forest management practices (Tyndale-Biscoe and Calaby, 1975; Linden-

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mayer et al. 1991; Pausas et al. 1995). Braithwaite et al. (1984) showed that the occurrence of the arboreal marsupials treated as a guild is strongly dependent on forest composition, leaf nutrient content and soil fertility. All require plant products preferably with high nutrient contents and low tannins. Such food is available only from certain eucalypt and *Acacia* species when growing on fertile soils. Using generalized linear modelling we extended the analysis of Braithwaite to include topography, tree size classes, and other structural characteristics to predict guild occurrence (Pausas et al. 1995).

The questions that arise when managing eucalypt forest for conservation are: is there a level of logging that ensures the conservation of the arboreal marsupials in wood production forests? If so, what is this level? How can we investigate the level of logging compatible with long-term conservation? What is the shape of the trade-off curve between logging and the quality of habitat for the arboreal marsupials? Do landscape descriptors determine this shape? Is the shape of this curve similar for different environmental conditions? We suggest that these questions may be studied using gap simulation models. Some hypothesised shapes of the trade-off curve are shown in Figure 1. We define the quality of habitat (HQ) for the forest animals as the availability of food and nest sites (Pausas et al. 1995). The increase in logging (by increasing intensity or frequency) would increase the wood harvested until a maximum is archived (Figure 1). After reaching this maximum, the increase of logging would, in the long-term, reduce the harvest (over-harvesting). However, the HQ may follow different pathways. An 'optimistic' hypothesis could be that with increasing harvesting, the HQ would reduce only slightly until near the maximum production point and only later would HQ decrease (e.g., Figure 1a). On the other hand, a 'pessimistic' hypothesis would be that any harvesting would strongly reduce the HQ (e.g., Figure 1b). Different possibilities between these two extreme scenarios are possible, but what factors determine these possibilities at landscape level? There would not be any conflict between wood production and conservation under the 'optimistic' scenario, however under the 'pessimistic' scenario there would not be any possibility of arboreal marsupials remaining in wood production forests. In the study area tree species composition is strongly dependent on topographic position (Austin 1978, Austin et al 1990, Austin et al 1996). Habitat quality and timber potential may therefore vary with topographic position. This paper investigates the basic landscape issue: does the interaction between HQ and logging vary with topography? If this is the case then conservation management strategies at a regional and landscape level will need to take account of changing patterns and proportions of landscape units.

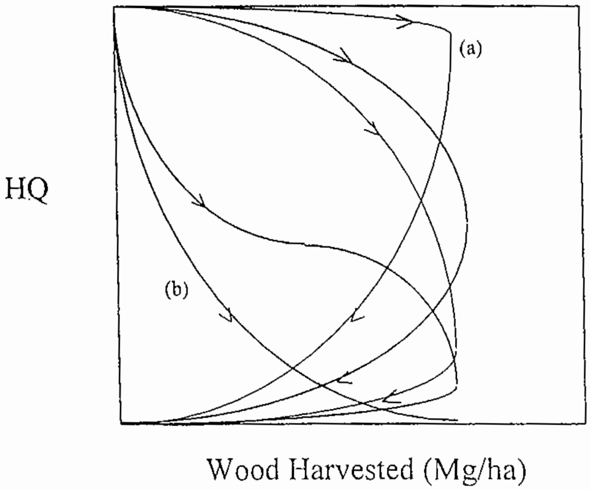

Figure 1. Some of the possible shapes of the trade-off curve between habitat quality for forest animals and the wood harvested. Arrows indicate the direction of increasing harvesting from a non harvesting scenario (top left corner). For all pathways indicated, the wood harvested increases to a maximum and later decreases, but the curves differ in the way that the habitat quality (HQ) is reduced. The actual values would depend on the ecosystems. Curve (a) is an example of an 'optimistic' hypothesis , while curve (b) shows a 'pessimistic' scenario (see main text).

For sustainable forest management, we need a tool to test the effect of different long-term management strategies on habitat quality for forest animals. The present paper is an example using an eucalypt forest-gap dynamic model (EDEN), to demonstrate the use of forest gap models for evaluating the conservation value of a forest (in terms of habitat quality, not population viability) under alternative logging strategies in the coastal forests of New South Wales. There are other types of simulation models that have been used to test the long-term consequences of forest management for arboreal marsupials. Recently, Lindenmayer and Possingham (1994) provided a good example based on the population viability analysis (PVA) of Leadbeater's Possum (*Gymnobelideus leadbeateri*). However, their model could not be applied to our study because it does not take into account the different tree species composition, the topographic position or the different soil nutrients. All of these parameters have been shown to be important for predicting the occurrence of arboreal marsupials in the coastal forests of New South Wales (Braithwaite et al. 1984; Pausas et al. 1995, 1997). PVA models are a different approach and have been used for predicting the viability of marsupial populations under different management strategies in less complex landscapes (e.g., Lindenmayer and Possingham 1994).

Methods

Model description

All simulations were made using the EDEN model (Pausas et al. 1997). EDEN is an individual-based gap model (JABOWA-type model, Botkin et al. 1972; Shugart 1984) of eucalypt forest dynamics, which was developed on the basis of BRIND (Shugart and Noble 1981). The main features distinguishing EDEN from its predecessor include (a) the response of trees to fire based on Strasser et al. (1996); (b) a model that predicts the habitat quality (HQ) for arboreal marsupials based on Pausas et al. (1995); and (c) the possibility to simulate the dynamics of forest patches in complex landscapes. In EDEN, different landscape positions are defined by altitude, topographic position and soil nutrient level although without an explicit spatial location (the current version of EDEN do not keep track of the position of forest patches). Qualitative soil nutrient levels (very low, low, medium, high and very high) were used based on geochemical analysis in the study area (see Austin et al. 1995, for details). The model also includes a harvesting module that allows the simulation of logging of a given proportion of trees, of a given minimum diameter, and at a given logging interval (see Pausas et al. 1997, for more details of the model). HQ is determined by availability of food (leaves, gum, pollen and arthropods) and nest sites (holes in trees) for the arboreal marsupials. These marsupial species used 20 different tree species as den trees, *Eucalyptus cypellocarpa*, *E. fastigata* and *E. viminalis* being the species most used (Pausas et al. 1995). HQ is estimated as the probability of occurrence of arboreal marsupials based on forest and site attributes following the statistical model developed by Pausas et al. (1995) for the forest of south-eastern New South Wales (Australia):

$$\mathrm{HQ} = \mathrm{f(FNI,\ BarkI,\ HoleI,\ PTN,\ Topo,\ SNutr)}$$

where *HQ* is the probability of occurrence of arboreal marsupials, *FNI* is the foliage nutrients index, *BarkI* is the amount of decorting bark (as a measure of availability of arthropods), *HoleI* is an index of the susceptibility of trees to defects, *PTN* is the number of potential nesting trees (greater than 60 cm in diameter), *Topo* is the topographic position, and *SNutr* is the soil nutrient level. *FNI, BarkI* and *HoleI* are computed following Pausas et al. (1995) and their values depend on the tree species composition. HQ was positively related to *FNI*, *BarkI*, *HoleI* and *PNT*. HQ was also higher at high soil-nutrient levels than at low soil nutrient levels, and higher in gullies and on flat sites than on slopes and ridges (see Pausas et al. 1995, for more details).

The EDEN model computes HQ from the attributes generated during the simulation of the forest dynamics. It simulates the dynamics of 1/12 ha forest patches on the Eden district, south-eastern New South Wales (Australia), and predicts the structure and composition of the forest and quality of habitat for arboreal marsupials. An array of forest patches may be used to simulate a landscape unit such as a logging coup (the smallest sized unit of forest management). The complexity of the landscape of the study area may be simulated by different topographic positions and soil nutrient levels. Forty-three tree and large shrub species of the Eden area (i.e., the main species found in the study area) were parameterized based on the CSIRO forest database. These species include 27 eucalypt species (species with narrow, pendulous, evergreen leaves), 10 rainforest species (species with broader, non-pendulous evergreen leaves), and 6 other species (i.e., *Acacia*, *Allocasuarina* and *Banksia* species). A description of the study area and its vegetation is given elsewhere (Austin 1978; Austin et al. 1990, 1996).

Simulations

The environmental scenarios simulated correspond to forests located in the Eden district (south-eastern New South Wales, Australia) at 600 m elevation and at different topographic positions: gullies, ridges, north-facing slopes and south facing slopes. For gullies and ridges, the model was run for high and low soil nutrient levels, while for slopes, only results at high soil nutrient levels are reported here because there was little change in HQ due to increased logging between the different nutrient levels. Eleven harvesting scenarios (Sc0 to Sc10, listed in Table 1) were imposed on each of the environmental scenarios. Some of the harvesting scenarios simulate sawlog harvesting with different rotation times (Sc1 to Sc4) while others (Sc5 to Sc10) simulate woodchipping. Scenario Sc0 represents the

Table 1. Scenarios simulated using the EDEN model. *MinDBH*: minimum diameter (cm) of the trees harvested; *Rotation*: rotation length (years); and, *Trees*: percentage of trees harvested. For example, Sc1 simulates harvesting 80% of the trees with a diameter greater than 50 cm every 200 years.

Scenario	MinDBH (cm)	Rotation (yr)	Trees (%)
Sc0		no harvesting	
Sc1	50	200	80
Sc2	50	100	80
Sc3	50	75	80
Sc4	50	50	80
Sc5	20	200	80
Sc6	20	100	80
Sc7	20	75	80
Sc8	20	50	80
Sc9	20	30	80
Sc10	20	30	100

absence of harvesting. We do not intend here to test the specific effect of each scenario, rather we want to create a gradient of biomass harvested to be able to test the trade-off with HQ.

The results were also studied at the landscape level by aggregating different patches from different topographic positions, although without an explicit spatial context. As an example, a mountain landscape composed of 25% by area with ridges, 25% with gullies and 50% with slopes (half facing north and half facing south) is given.

The model was first run for 1000 years for each environmental condition (i.e., each topographic position and nutrient level) in order to stabilize the model. Then, each harvesting scenario was run over 1000 years in 20 patches (i.e., 1.67 ha). The average of habitat quality and the annual biomass harvested in the 20 patches over this second set of 1000 years was considered as a measure of the long-term habitat quality and forest production. Only the change of these two parameters versus the non-harvesting scenario is reported here. Results predicting different vegetation composition under different environmental scenarios are reported by Pausas et al. (1997).

Results and discussion

An example of a simulation result for 400 years is shown in Figure 2. It suggests that low-intensity harvesting does not significantly affect the HQ on south-facing slopes (compare Sc0 and Sc2). However, more intensive harvesting does reduce the values of HQ (e.g., Sc8 and Sc10).

The changes in HQ due to harvesting were predicted to be different in different landscape positions (Figure 3). In gullies, the HQ did not change significantly with increased harvesting, until a certain level when the HQ began to drop. On ridges and slopes, HQ decreased almost linearly with increased harvesting. North-facing slopes showed the same trend as ridges (not plotted for clarity), while south-facing slopes showed a slightly different pattern (Figure 3).

The percentage of change in HQ due to harvesting was not significantly different between soils of different nutrient status. While actual HQ is determined more by soil nutrient level than by topography (Pausas et al. 1995), the relative change in HQ is more influenced by the topographic position (Figure 3).

These results suggest that there may be a level of forest management that allows for the conservation of arboreal marsupials in logged forests, however, this level depends on the landscape position. Gullies may support a higher level of logging than ridges. The results should be viewed in conjunction with the empirical results reported earlier (Pausas et al. 1995) that ridges have lower habitat quality than gullies, and therefore, logging reduces the HQ of ridges more quickly than in gullies. The results also suggest that at the landscape level, the trade-off curve of HQ-harvesting depends on the area of the landscape occupied by each topographic position. Figure 4 shows an example of a landscape with 25% ridges, 25% gullies and 50% slopes (half facing north and half facing south). Other combinations would give other results, that is, the habitat quality of a landscape dominated by ridges and slopes would be lower and more sensitive to harvesting than a landscape dominated by gullies and flat areas.

The simulated annual biomass harvested (y-axis of Figure 3 and 4) is greater than the 'real' or 'useful' biomass harvested, because (a) the biomass simulated includes the whole tree, while foresters only use a proportion of the biomass of the tree; and (b) the model does not assume any loss of wood during the harvesting procedure. Furthermore, this difference between the simulated yield and the useful timber yield is not

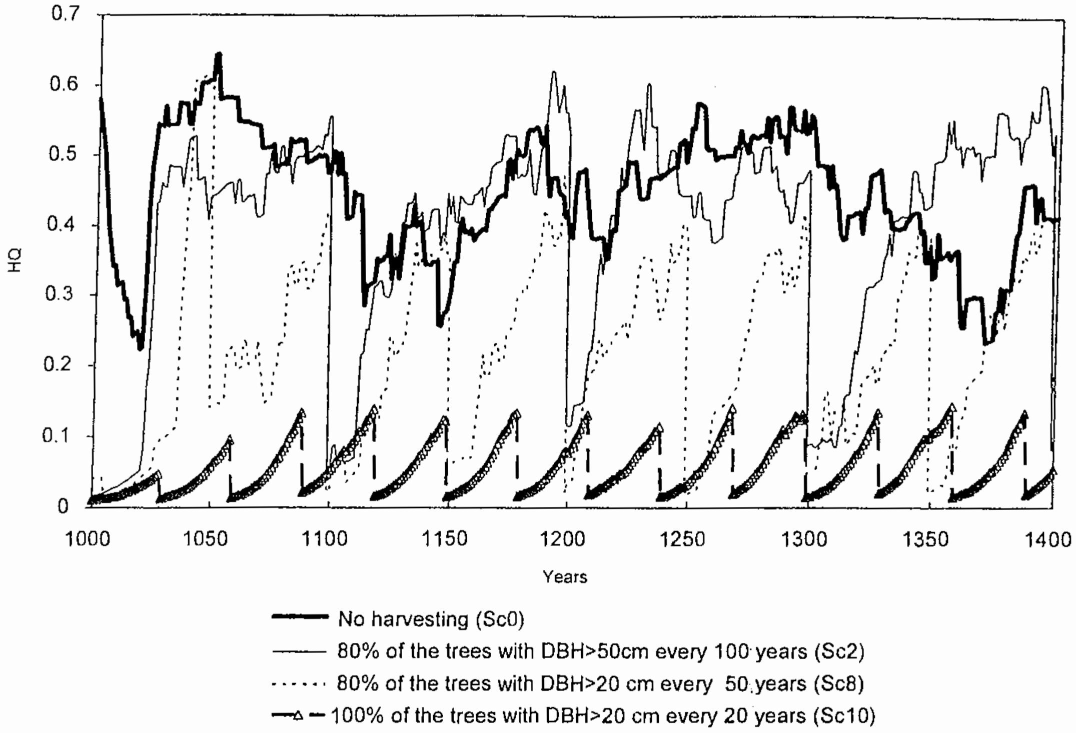

Figure 2. Changes in habitat quality for arboreal marsupials during 400 years of simulation under four different harvesting scenarios (Table 1) on a south-facing slope at 600 m of altitude in the Eden area, New South Wales (Australia).

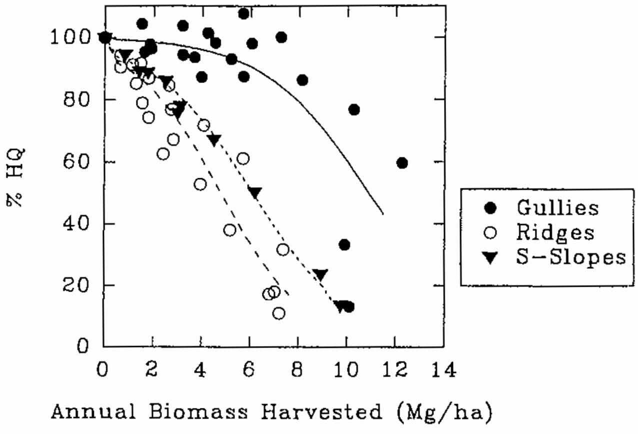

Figure 3. Changes in habitat quality for arboreal marsupials (%HQ) with increasing harvested biomass (from non-harvesting, 100%HQ) in forest patches at different topographic positions (gullies, ridges and south-facing slopes). The symbols represent mean HQ values of 20 patches for 1000 years simulated by the EDEN model.

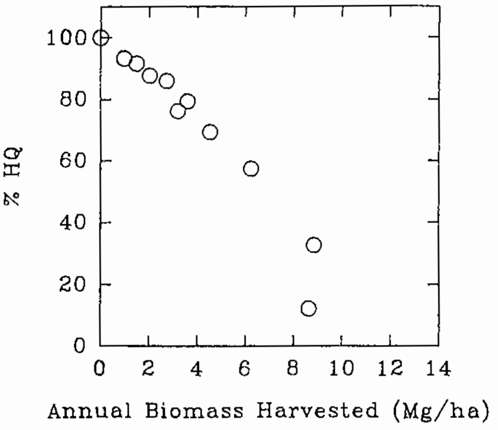

Figure 4. Changes in habitat quality for the arboreal marsupials (%HQ) with increasing harvested biomass (from non-harvesting, 100%HQ) in a landscape composed by 25% of ridges, 25% of gullies, 25% of south-facing slopes and 25% of north-facing slopes.

constant; rather, it varies with changes in intensity or frequency. In translating the biomass harvested to an economic value several points must be taken into account. Different harvesting scenarios have different costs, not only because frequency or intensity varies, but also because of the cost of providing access and the relationship of that cost with the biomass harvested. In general, low intensity harvesting scenarios are more expensive in relation to the wood obtained than high intensity ones.

In the present study we used the guild approach for arboreal marsupials because of the lack of information for individual species and especially for endangered species with low abundance. However, this approach is still useful for management purposes (Chapin et al. 1992; Hansen et al. 1993). The model can be improved when habitat and landscape requirements of individual species are known. Lindenmayer (1994) also comments on the lack of information on arboreal marsupials when reviewing the possible role of corridors in mitigating the impact of logging on the arboreal fauna in similar forests to those studied here. Home range, dispersal behaviour and life-history parameters all effect the use of corridors by different species. Habitat quality at the landscape level is a function of the HQ of local patches in different topographic positions and the patterns of those units in the landscape. Lindenmayer (1994) and Lindenmayer et al. (1993) comment that in the eucalypt forests of Victoria the wet gullies may support cool temperate rainforest which is unsuitable habitat for the greater glider. Such a different pattern of forest type distribution would give a very different landscape HQ value even where the eucalypt forests on the rest of the topographic sequence were similar to those modelled here. Landscape HQ is very sensitive to such local differences and logging practices with conservation objectives need to take account of this.

The EDEN model predicts the HQ for arboreal marsupials based on forest and site attributes (Pausas et al. 1995, 1997). This value is independent of the values of surrounding areas and the mobility of the animals. In the model, after harvesting, the HQ recovery depends only on forest attributes, without taking into account the HQ of the surrounding area and possible migration from this area. For example, in an isolated forest patch, the HQ (the potential occurrence) may recover after logging, but arboreal marsupials may not be able to recolonize the patch (actual occurrence) if the next patch of suitable habitat is a long distance away. This needs to be considered when managing highly fragmented forests.

Conclusion

Gap models are useful tools for testing long-term forest management strategies in eucalypt forests. EDEN can be useful for investigating the long-term consequences of alternative forest management practices in the study area. Results obtained with the EDEN model suggest that the trade-off between conservation and production in eucalypt forests is largely constrained by the complexity of the landscape. The proportion of the landscape occupied by different topographic positions determines the sensitivity to management strategies. The habitat quality for arboreal marsupials of landscapes dominated by ridges and slopes would be more sensitive to harvesting than landscapes dominated by gullies and flat areas. The simulation demonstrates that the behaviour of individual patches on different topographic positions are sufficiently different to require inclusion in any model designed to evaluate the metapopulation dynamics of arboreal marsupials and their population viability in logged forests. A spatially explicit version of the model would be needed to take into account other landscape processes such as the mobility of the animals and the fragmentation of habitat. The development of this new spatially explicit version linked with an economical submodel should be the next step in improving the EDEN model for the purpose of forest management (Turner et al. 1995).

Acknowledgements

The present work has been financed by the Spanish government with a postdoctoral fellowship to the first author. We thank I. Davies for writing the code for the EDEN model and B. McCormack for comments on logging strategies. Useful comments on the manuscript were provided by C.R. Margules and S.J. Cork.

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