A Tree Hollow Simulation Model for Forest Managers: The Dynamics of the Absence of Wood in Trees.

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Abstract Of the many species that inhabit Australian wood production forests those that use hollows in trees are considered to be amongst the most vulnerable to the impacts of timber harvesting. This is because hollows suitable for occupation by wildlife may take several hundred years to develop and the type of logging operations used, as well as the interval between harvesting events, may severely impair the recruitment of such trees. A highly flexible deterministic computer model (HOLSIM) was developed for simulating forest dynamics. This model predicts the long term dynamics of hollow bearing trees which occur in a single species forest stand under an variety of different timber harvesting regimes over a time scale of centuries. It was applied to a timber harvesting scenario in the Mountain Ash (*Eucalyptus regnans* F.Muell.) forests of Victoria, south-eastern Australia. HOLSIM is a planning tool for forest managers and wildlife planners. It will assist them in forecasting long-term forest stand conditions that result from particular forest management regimes. It is extremely important to be able to make predictions over several harvesting cycles in order to examine the effects of harvesting strategies on the structure of forest ecosystems, anticipating the impacts of forestry operations on hollow-dependent fauna, determining if given management strategies will meet particular targets, and helping to better integrate biodiversity conservation within wood production forests.

1 INTRODUCTION

Trees with hollows are an important structural feature of many types of Australian wood production forests. This is because many animals which require hollows are amongst those considered to be the most vulnerable to the impacts of timber harvesting [McIlroy, 1978; Recher *et al.*, 1980; Lindenmayer *et al.*, 1990a, 1991a, 1991b; Scotts, 1991; Gibbons and Lindenmayer, 1996]. In Australian Eucalypt forests tree hollows suitable for occupation may take several hundred years to develop [Ambrose, 1982; Saunder *et al.*, 1982; Lindenmayer *et al.*, 1991c; 1993; Gibbons, 1994]. Typical logging regimes may prevent or impair the recruitment of such hollow-bearing trees [Lindenmayer *et al.*, 1990b; Recher, 1996; Gibbons and Lindenmayer, 1996]. For this reason it will take a long time to rectify any hollow shortages in wood production forests caused by inappropriate logging regimes. Tree hollows are a key habitat component for a wide variety of taxa, both vertebrate and invertebrate providing both nesting and denning sites as well as a place for animals to perch and roost.

Logging strategies which include the retention of trees with hollows can help to avoid hollow shortages and decrease the impact of logging on fauna which depend upon hollows. The long-term effectiveness of tree retention strategies remains unknown [Gibbons and Lindenmayer 1996]. This is due to the long-term nature of hollow dynamics which means that it is extremely difficult to determine the effectiveness of tree-retention schemes in the field. The dynamics of hollows in a forest are of a considerably longer term than the professional careers of foresters and wildlife managers, which means that individuals are unlikely to observe the long-term consequences of given management actions, nor easily understand the full effects of their activities.

Given this difficulty, we've developed HOLSIM, a simulation model to explore and forecast the long-term dynamics in stand structure which result from different logging regimes and tree retention strategies.

HOLSIM was parameterised for Mountain Ash (*E. regnans*). This is an important wood production forest type which occurs as a single species stand. It is heavily utilised both by wood producers and by hollow using fauna [Gibbons and Lindenmayer, 1996]. It normally occurs as a predominantly single species forest which simplifies the modelling process. A multiple species stand would necessitate the inclusion of inter-species interactions which are not currently paramaterisable to an adequate degree. Mountain Ash stands are often of an even age as bush fires and logging events usually precede the recruitment of new trees. HOLSIM is designed to work with complex stand structures and is not specifically designed for an even aged stand.

This paper will describe the HOLSIM model with respect to the reasons why modelling choices were made as they were. An application of the model will give results leading to important conclusions about the way in which tree retention strategies operate and could be beneficially modified.

2. MODEL

HOLSIM was designed with a number of explicit considerations. The model should be applicable to forests where there is limited data on hollow ontogeny. It had to allow a wide array of management stratagems. It had to simulate the stand over a long time scale. It was to be designed to run on a personal computer to allow it to be used as an exploratory tool for forest managers.

HOLSIM is a completely deterministic model. The number of any particular type of tree is the average, or expected, number of trees for that type and the structure of the stand is the average structure. This has the advantage that for a single set of parameters the program need only be used once to achieve its result rather than the multiple runs required for a stochastic model. The drawback to this is that the model only produces the average forest structure and does not produce an indication of the variance to be expected. In particular, this means that random catastrophes such as the wildfires common in Australian Eucalypt forests can not be modelled with HOLSIM.

2.1 Structure of Model

Trees are categorised into a state determined by their size and condition or form. The stand is described by the expected number of trees in all possible states. There is no spatial component explicitly built into this model such as the location of individual trees. The state of the tree has two defining attributes, its size class and its tree form.

There are fifty size classes structured so that the average tree will increase one size class in each five year time step, although some will increase more than one. The size class is therefore not a simple function of height or girth which makes the growth process simple to model but adds complexity elsewhere.

If the size-classes were any broader there would be difficulties in modelling even aged stands. The general assumption of this categorisation model is that each tree in a category represents an average tree for that category. With small size-classes this works well but for larger ones even aged effects would be smoothed out as trees were averaged across each size-class.

The other dimension on which the categories were separated into was the form of the tree. This was a measure of the state of senescence of the tree. There were eight tree forms ranging from healthy trees without hollows through living trees with hollows through dead trees in various states of decay. Dead trees which have collapse are considered to be out of the system. Transition frequencies between these tree forms were available for Mountain Ash [Lindenmayer *et al*, 1997].

2.2 Transition Processes

During each time step, the distribution of trees in the forest changes through a series of transition processes. These processes include: senescence, mortality through overcrowding, density independent mortality, growth, recruitment and logging. The processes are summarised in Figure 1. These processes were modelled in a phenomenological fashion rather than by focussing on key driving processes like water, light and nutrients because data on the influences of these

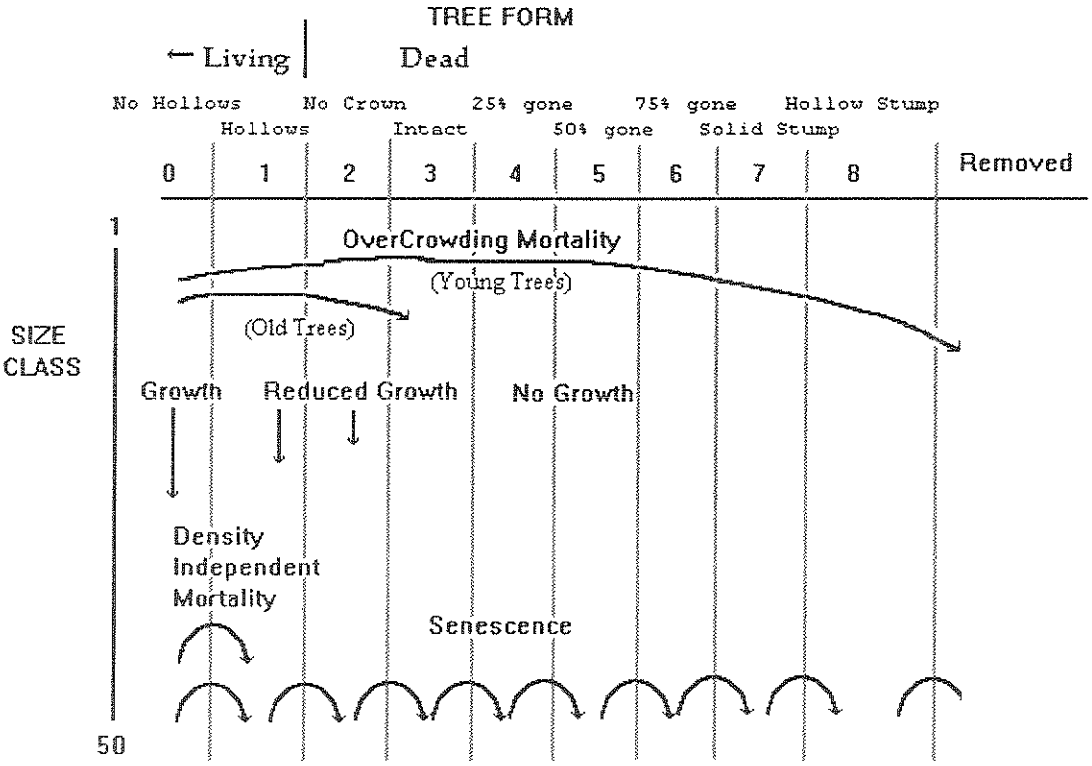

Figure 1. Schematic diagram of transition processes. Trees are divided into size classes from 1 to 50 and tree forms from 0 to 8. The main processes are; overcrowding mortality which transfers trees into tree form 3 or removes them from the system. Mortality and senescence moves trees to the right and growth moves trees downwards - the only two valid directions.

processes on the long term growth of trees and formation of hollows is rare or non-existent for most tree species.

Growth was parameterised using information on Mountain Ash gathered by Ashton [1976]. Living trees could increase by up to two size classes in a time step, although most of them would only increase one. Trees which were living but damaged grow at a much slower rate.

Self-Thinning occurs when the stand is over crowded. Each size class and tree form has a specific space requirement. The total space requirement was calculated at each time stepfor the entire stand and if it was greater than the available space then trees would be removed or moved from a living to a dead tree form until the space requirement was satisfied. Trees were removed starting from the smallest and then by increasing size class. This method is based upon the assumption that the resource requirement for each tree is a linear function of space. The order in the removal of trees might not be appropriate for different tree species.

Trees senesced by applying a tree form transition matrix taken from field measurements [Lindenmayer *et al*, 1996]. They also died from a density independent mortality component. A proportion of larger trees which die from this component do not immediately collapse but remain standing.

Recruitment primarily occurs in Mountain Ash only after a disturbance [Attiwill, 1994]. Because wildfires have been excluded, the only source of disturbance in this model is logging. After each logging event trees were added to the smallest size class until the maximum stocking rate was reached.

Complex logging regimes can be modelled in HOLSIM. A logging regime consists of a repeated cycle of separate and possibly different logging events. Each logging event consists of a number of commands to retain a set number of types of trees or remove a proportion of a set number of types of trees. The events could take place at any point in the cycle and a delay could be included before the beginning of the initial cycle.

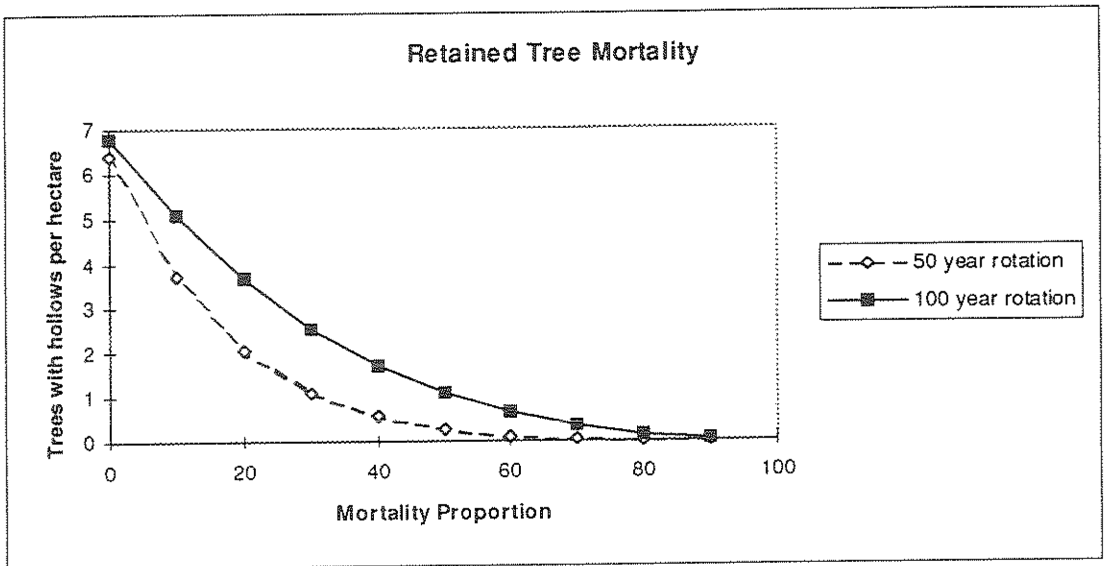

Figure 2. The minimum number of trees with hollows per hectare which occurs in a rotation cycle after a steady cycle has been reached. Mortality proportion is the proportion of trees which are to be retained but collapse due to the logging event.

We looked at the number of trees with hollows as our primary measure of the forest although the program can output the number of trees of every size class and tree form for each time step. It was possible to look at the number of hollows because the frequency with which they occur in trees of different size classes and tree forms was known [Lindenmayer *et al*, 1993]. However, for territorial animals the number of trees is a better measure to use than the number of hollows.

Trees which are set aside during a logging event for future retention can suffer from an increased rate of mortality. This is caused both by the increase in exposure of the trees to the elements as well as the effects of high intensity post-logging fires which are often used to promote regeneration on a logged stand. The post-logging mortality for retained trees can be varied within the program.

3. APPLICATION

We used HOLSIM to explore the interplay between post-logging mortality and the length of the rotation cycle on a simple retention scheme. At each harvest ten trees were retained and the rest were removed. The trees were set aside starting with trees in the largest size class and then decreasing size classes until ten trees in total had been set aside. Trees with hollows were selected for retention in each size class before trees without hollows for that size class.

There was no lower limit on the size class of trees which could be retained so that there ten trees would always be retained even if they were in the smallest size class. This is important because if only the larger trees or hollow bearing trees were retained then the long term number of trees with hollows would decrease exponentially unless the rotation length was extremely long. For example if only hollow-bearing trees were retained then the rotation time would have to be considerably longer than 100 years to maintain even a minimal number of trees with hollows because it takes 90 years before trees can even begin to form hollows.

Rotation lengths were set at 50 and 100 years and post-logging mortality was varied between 0 and 90%. Output was taken as the minimum number of trees which have hollows during a logging cycle after the system has had sufficient time to settle down to an equilibrium cycle. The stand size was 25 hectares for all runs

4. RESULTS

The results of this test are shown in Figure 2. It is immediately obvious from this diagram that there is a non-linear relationship between the long term number of trees with hollows and the two variables examined. It is also clear that not all of the trees which are being retained are hollow bearing.

When logging-related mortality is zero the number of trees with hollows lies around 65 to 70% of the number of trees retained. This percentage decreases as the mortality increases. When there is no post-logging mortality approximately 3 of the 10 trees being retained do not have hollows but will act as replacements as the trees with hollows decay and collapse. This was not specified in the retention scheme but it arose naturally when the system was allowed to reach an equilibrium cycle.

When post-logging mortality increases, the number of hollow bearing trees decrease in a non-linear fashion. For example when the post-logging mortality rate is 50% then there are less than half the number of hollow bearing trees than when the post-logging mortality rate is 0. This means that a greater proportion of the trees being retained are not yet hollow bearing. The post-logging mortality has a significant impact on the number of trees with hollows because the hollow bearing trees can be very old and a proportion of them are lost at each logging operation which would be much greater than that lost through normal senescence. For example, when the post-logging mortality is 50% then half of the very best hollow bearing trees are lost and a significantly larger proportion of the trees retained must be recruitment trees.

There is little difference in the number of trees which have hollows when the post-logging mortality is zero between different rotation lengths. When the post-logging mortality increases, a difference quickly emerges between the short and longer rotation cycles. Each logging event now adds an additional mortality for the hollow bearing trees. When the retained trees are perfectly retained (Ie zero post-logging mortality) then it doesn't matter how often the other trees on the stand are logged, but when there is a loss associated with each harvest then the rotation length can have a critical effect.

These non-linear effects mean that the benefit of retaining extra trees diminishes with an increasing proportion of trees lost through logging related mortality. It could well be desirable to try to diminish the effects of logging related mortality rather than retaining a greater number of trees. There are a number of practical ways in which to achieve this. The retained trees could have a spatial configuration designed to mitigate the effects of increased exposure on the older hollow-bearing trees - perhaps by clumping them. The effect of high intensity regeneration burns could be reduced by clearing brush from around the base of the retained trees before the burn.

5. CONCLUSIONS

HOLSIM is a planning tool designed for forest managers and wildlife planners. It is designed to help forecast the stand conditions which arise from forest management regimes over a large time scale. The parameters that the model requires for a tree species are of those which are practicably obtainable.

The application of this model showed the importance of retaining trees with hollows and trees which do not have hollows as well. It also showed the dramatic impact that post-logging mortality can have on retained tress. This mortality can greatly exaggerate the damage done on the hollow bearing trees of a stand when the rotation length is short.

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