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HOW OFTEN SHOULD WOODY WEED INFESTATIONS BE MANAGED?

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INTRODUCTION

Invaded landscapes must be managed to ensure they remain productive, ecological frameworks have been developed to determine which populations should be managed (Moody and Mack 1988). However, many of the models used inside these frameworks assume the weed can be eradicated and this is often impractical and uneconomic. Woody weed management tends to be infrequent as woody weeds are often slow growing, thus, a single management action has benefits for a number of years. Furthermore, infestations are often in remote locations and a single weed management intervention is high relative to annual grazing returns. As such, weed management can be thought of as an ongoing reinvestment project with cost and benefits over the longer-term. For example in Figure 1, a steady state weed population has been found that is one hundred years old and unmanaged. If it was decided to be managed every 15 years, this would result in periodic weed management costs, as well as ongoing benefits. Primary benefits from weed management are the proportions of area returned to pasture production.

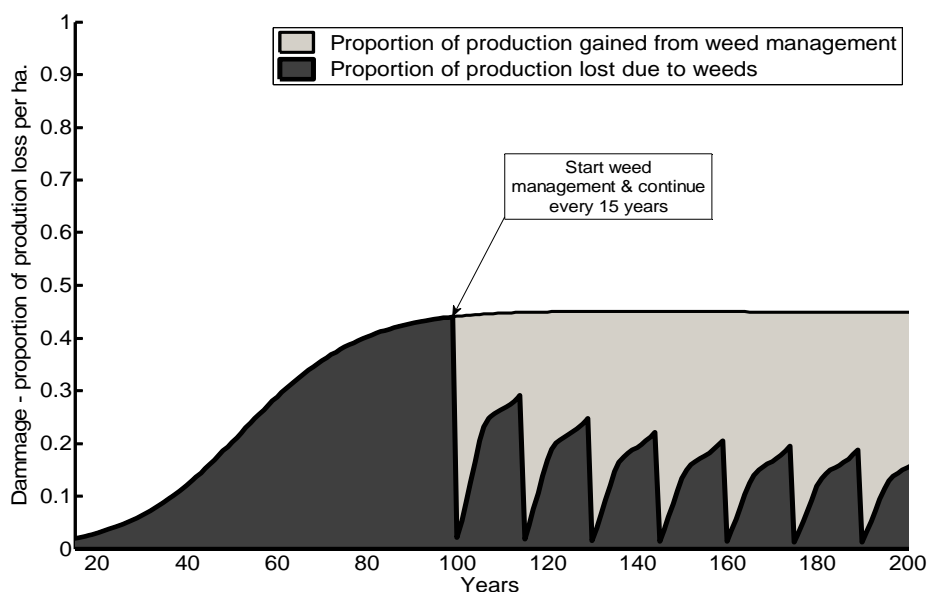


Figure 1: An illustration of damage to pasture production over time and the benefits of increased pasture production over time due to management.

There are four main considerations when weighing up the cost and benefits of woody weed management of grazing land; (1) the effectiveness of the weed management method used (i.e. what proportion will be removed); (2) the duration and degree of these benefits; (3) the cost of weed management; and (4) the financial returns from the pasture production. Often the first two and last two are investigated separately. Weed ecologists often focus on the efficacy of different weed management methods and population response. Whilst, weed economists tend to look at the cost and benefits of different weed management strategies as a once off investment and pay little attention to the longer term implication of weed population dynamics and temporal benefits to grazing production. Providing the efficacy of weed management remains unchanged and that population dynamics of a weed population can be accurately predicted, it is possible to develop a weed management strategy based on the cost of weed management and the weed free gross margin from grazing.

The most efficient management frequency can be derived from net present value (*NPV*) analysis of benefits and costs over time. We construct an analytical framework that synthesises the complex relationships between the weed's population dynamics, imposed weed costs, and benefits and costs of management strategies to determine the optimal frequency of managing *Ziziphus mauritiana* (chinee apple) in northern Queensland rangeland upland zones. This analysis is based on mechanical removal of adult plants where most adult plants are removed and destroyed. Adult plants should be targeted as these produce the most seed and reduce pasture production more than smaller individuals.

STUDY SPECIES

Chinee apple was introduced to Australia over a hundred years ago; it can survive for several decades and can reproduce five years after germination. Mature tree are between 2 – 8 metres tall, have a canopy of up to 8 metres in diameter, and are drought tolerant (Grice 1998; Grice 2002).

METHODS

To determine the optimal frequency of weed management we use the *NPV* for the different management frequency regimes. The *NPV* is defined as the discounted sum of the difference between the benefits B_t and costs C_t , that are attributed to weed management, that occur in each period t over the timeline T , and r is the time discount rate. The *NPV* is given by:

$$NPV = \sum_{t=0}^T \frac{(B_t - C_t)}{(1+r)^t} \quad (1)$$

The current annual net benefit of each management frequency can be estimated with the equivalent annual value (*EAV*) method as:

$$EAV = \frac{r NPV}{1 - \frac{1}{(1+r)^T}} \quad (2)$$

This can be thought of as the *average annual net benefit* (or loss) over the planning horizon at today's prices. The cost of weed management is density dependent. It has been assumed that in the period that an infestation is managed half the cost of weed management is fixed and the other half is density dependent. If there are very few weeds to be managed then the cost of weed management is half that of a fully infested area. Fixed costs cover the transportation of machinery, search and monitoring effort of the managed area. The cost of management C_t is defined as:

$$C_t = \beta_t \times \left(\frac{p}{2} + \frac{p \times W_t}{2} \right) \quad (3)$$

where the decision to manage in year t is represented by the dummy variable β_t , where zero indicates no management and one is management for the period. The maximum actual cost of each management is p . The weed density is $0 \leq W_t \leq 1$. The benefits of management are given by:

$$B_t = (d - D_t) * y_{wf} \quad (4)$$

which is the reduction of the yield loss from d to D_t (the damage after management at time t), as a result of a reduction in weed density. The financial benefit of management is derived for the weed free gross margin per ha (y_{wf}). The relationships between weed density and yield loss (damage) can be explained with a rectangular hyperbolic function (Cousens 1985):

$$D_t = \frac{\psi x_t}{1 + \frac{\psi x_t}{\tau}} \quad (5)$$

x_t is the weed density, ψ is a damage vector index for yield lost per weed in each life stage. The maximum possible yield loss is τ . To model weed density x_t over time we used a stage projection matrix. For further explanation of this technique see Caswell (2001). The population state transition is:

$$x_{t+1} = Hx_t - \beta v \circ x_t \quad (6)$$

Where v is the efficacy of weed management, and H is the annual stage projection matrix.

RESULTS

The optimal frequency of weed management can be derived for either the cost of weed management given a weed free gross margin, or the weed free gross margins given the cost of management. Alternatively, a decision table can be derived for the optimal frequency of weed management given both the costs of weed management and weed free gross margins. Anything with a management frequency greater than 30 years is taken to be a once off management strategy and thus the net annual cost is provided for that decision (Figure 2).

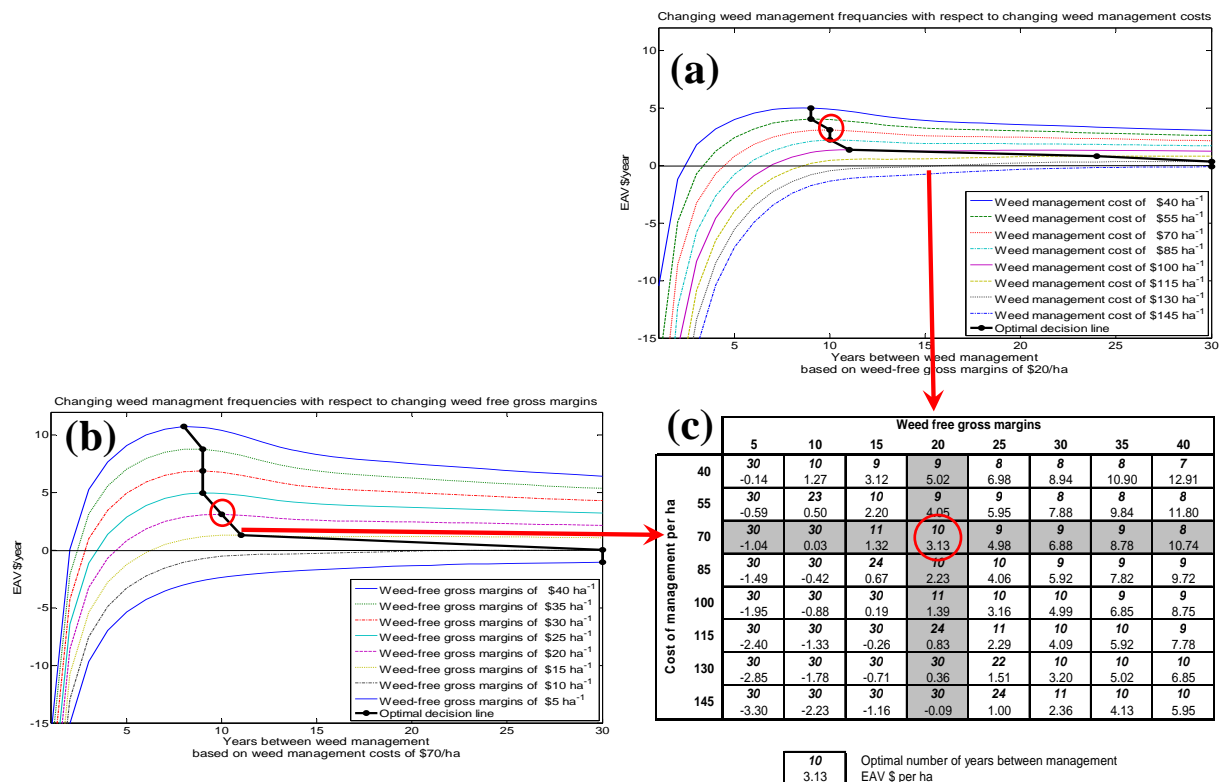


Figure 2: (a) indicates the optimal frequency of management when weed-free gross margins are fixed and weed management costs change. The Optima decision line is used to derive the rows in the (c) Optimal Decision Table. (b) indicates the optimal frequency of management when weed management costs are fixed and weed-free cross margins change. The Optima decision line is used to derive the columns in the (c) Optimal Decision Table. The circles in both figures and table indicate the optimal frequency and EAVs for the same combinations of weed management costs and weed-free gross margins.

To derive an Optimal Decision Table requires a few steps. Firstly the EAVs for different combinations of weed management costs, weed free gross margins, and different frequencies of management are derived, these are shown as the smooth curves in both Figure 2a & b. Then the optimal decision line is taken as the optimal frequencies, highest EAV, for each combination of weed free gross margins and weed management cost per hectare, see Figure 2a & b. This information is then surmised into the

Optimal Decision Table Figure 2c, which gives the optimal frequency and expected *EAV* for each combination of weed free gross margins and cost of management. Results in the Optimal Frequency Table can be used without Figure 2a & b, however these are given to show how the same weed management decision, (see circles in Figure 2) will be derived regardless if weed management costs or weed free gross margins are changed with respect to the other.

DISCUSSION

It has been shown that when both ecological and economic processes are taken into account, and provided the right combination of weed management costs and weed free gross margins are present, the woody weeds can be managed cost effectively. Even when weed management is found to be uneconomic, this analysis can still help decision makers. For example, if the annual net loss of managing an infestation is \$3.50 per hectare per annum, then this is the amount an external stake holder is required to pay the grazier to compensate for the management of an infestation. Alternatively, a land manager may undertake weed management even when it is uneconomical, with the knowledge of what such an undertaking may cost. For example, if a grazier has several thousand hectares and there is a one hundred hectare infestation, and once again if the cost per hectare is \$3.50 per annum, the manager may believe that \$350 p.a., is warranted for good governance of the land.

This modelling framework is elegant in its design relative other optimisation modelling techniques such as Optimal Control and Dynamic Programming. It also allows for more ecological detail as it does not have the 'curse of dimensionality' often encountered with Dynamic Programming. Although this illustration has not accounted for spatial spread, these results can be thought of as the minimum benefits or maximum loss, as weed containment will only increase the benefit of management. The model may be developed further to account for the value of preventing future invasions that would reduce pasture production in areas that are currently weed free. This will result in an upward shifting of optimal frequency curves, which will in turn result in higher frequencies of management and increase *EAVs*.

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