Building a Framework for Better Biodiversity Management

A Model to Inform Land Management Decisions at Grassland Offset Sites

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Abstract

The Natural Temperate Grasslands of the Victorian Volcanic Plains are a critically endangered ecosystem as such it is important that any development that occurs in them be effectively offset. Offsets are required to replace the amount and quality of vegetation that was lost in development and, given that the majority of Victoria's grasslands are degraded, it is important to determine how best to restore them. This project provides a working framework to improve a land manager's understand of the consequences of their management actions. Financial costs and social opinion are taken into account alongside the restorative qualities of a variety of different management actions. This was achieved through the creation of a Bayesian state-and-transition model, informed by the literature, costing information and survey elicited social data. The model shows that the preferred management strategies in the short term vary depending on whether costs and social opinion are taken into account alongside the improvement of biodiversity. In the long term burning every three to five years is the best option regardless of priorities, though depending on the location and species richness of a site it might be necessary to include some form of planting as well. Detailed knowledge of this model and its' outcomes has the potential to greatly improve grassland management decisions.

1. Introduction

It is increasingly common practice for companies that engage in business that impacts negatively upon the natural environment to expend resource to mitigate or alleviate this impact. Often, this is accomplished via offset sites, tracts of land purchased for the express purpose of repairing or preserving natural biodiversity to replace that which is lost through business practice. An issue arises when the management of such sites is planned for, however, as the current scientific understanding of the impacts different land management actions have on indices of flora and fauna biodiversity is lacking in some regards. In particular, a clear model which integrates current scientific understanding of land management with extra-scientific concerns, such as cost, for use by and with non-scientific stakeholders would be an invaluable step towards a clear pathway from scientific investigation to practical implementation.

The present project aims to generate a model for grassland biodiversity management consistent with the one described above. Three different components relating to several different land management actions will constitute the model: flora species richness and weed cover, cost of management action and community support for management action. Together, these components provide a framework for making the most effective, financially considered and socially endorsed decision about how to handle a grassland offset site.

1.1 Objectives

The present project was designed and executed with the following objectives in mind:

1. Provide an accessible, working framework for land managers to utilize in understanding the likely consequences of their restoration actions;
2. Integrate the relative financial costs of different land management actions into this framework to further inform the appropriateness of a given land management action;
3. Sample and summarise the degree of support or opposition a meaningful segment of the population has for different possible management actions and integrate this into the overall decision making framework;
4. Expand on previous methods for developing decision making models of environmental management to model possible future directions of research; and
5. Engage in and demonstrate the effectiveness of interdisciplinary collaboration in creating an accessible and useful model for environmental decision making.

1.2 Background information

Australia's grasslands have been degraded since European settlement through grazing, cropping, changed fire regimes and urban expansion. After a long history of these degrading processes only 1% of the original vegetation extent remains [1]. This study pertains to a pair of sites located in the Natural Temperate Grassland of the Victorian Volcanic Plain ecological community which is critically endangered [2].The sites were purchased by Hanson cement in order to offset the destruction of 145 hectares of Natural Temperate Grassland of the Victorian Volcanic Plain, when creating an offset it is important that the area is the same or better quality than that which is being lost. As such it is important to know how to best manage the sites. The grasslands in question have been grazed in recent history and the area includes areas of varying quality[3]. Some of the area in question is dominated by introduced grass species that were introduced as feed for cattle. In order to meet the requirements of an offset site the entire site must be restored to a high level of vegetation condition.

We approached this using methodology similar to that used in the literature [4]. Rumpff et al (2011) modelled the effect of management actions on the quality of woodland vegetation. Their state-and-transition model was created to enable land managers to predict the likelihood of proposed management actions achieving the goals set in the Goulburn Broken catchment management plan. The model describes the initial state of vegetation by the levels of a number of different vegetation components; it incorporates land use history and ongoing processes as well as management actions into predictions of the final state of the vegetation. This is potentially very useful to managers of woodland ecosystems but these relationships are largely quantified by expert opinion which, while it accurately represents expectations, doesn't necessarily reflect the actual outcome. Similar state-and-transition models have been used in rangeland management in North America [5,6]. This research aims to produce a model for grassland restoration which is founded in quantitative, scientific evidence and will be of use for land managers with any level of scientific knowledge. The model will include biodiversity as in the above models as well as cost and social opinion; allowing any manager to grasp the full implications of proposed management actions.

At present, community reaction to management decisions has primarily been considered following their enactment as a way of informing future decisions of the sort[7]. This is inefficient for two reasons: firstly, because it leads to potentially sub-optimal decisions in the initial instance and, secondly, because it presumes that community reaction to future management decisions will be consistent with previous reactions, despite future actions not necessarily being the same or even in a similar in context.

Despite its flaws, stakeholder input is considered to have both objective benefits for environmental outcomes [8] and can increase public trust in decisions made[9]. Decisions made with input from relevant stakeholders can allow for additional information to be considered that would otherwise not have been made available [8] as well as increase the effectiveness of the implementation of management actions through better understanding of those actions[9] and greater compliance with decisions made due to feeling of empowerment[9]s.

2. Methods

2.1 Literature review

A review of literature relating to the management of Victorian Volcanic Plains Grasslands was conducted. Existing reviews of grassland management were use to refine the searching criteria to those things widely believed to be effective. Articles with quantitative measures of the success of different management actions were sourced. These values were retained for use in a survey and Bayesian network.

2.2 Bayesian Network

Bayesian networks visually represent complex probabilistic relationships. In this case the Bayesian network represents the relationship between 12 different management actions (as defined in appendix A) and the richness of grassland plant species and its' weed cover. It is designed as a state and transition model whereby the initial state of the vegetation in terms of its weed cover and species richness is known and this information along with the combination of management actions performed combine to predict the resultant state of the vegetation.

Nodes are created to represent the variables influencing the outcomes of the question. In this case there are nodes for the initial species richness, the initial weed cover, the type of planting undertaken, the number of species planted, the type of weed control used, fire and grazing as well as the time horizon of interest. The nodes in a network are connected by links which represent the relationships between them. Values sourced from the literature were used to create rules which were entered into the Bayesian Network to quantify the links using the software Netica 6.1.4. The values quoted in the literature were taken as the maximum expected change from the initial value. Such that if a study found that there was an average of an 83% chance of tubestock plantings being successful, 83% of the total number of species planted was taken as the maximum that could be expected. This provides a conservative estimate of potential success. To further decrease the chances of over estimating success probability distributions, especially Beta distributions, were used to define the relationships that reflect the effects of environmental stochasticity. This is useful in the case when you know that the actual value will fall in a particular bracket but there is a higher likelihood of it occurring towards one of the ends than the other.

The model is able to calculate the species richness of a site and its weed cover given any staring condition and any possible combination of management actions but some assumptions are made about the order of actions. Weed control and fire are always assumed to have occurred before planting and grazing is assumed to be occurring both before and after seeding.

To add to the versatility of the network a node was added to calculate the cost of the different management actions. The costs for this were obtained from recent records of revegetation expenditures conducted by Hanson cement and variations in price between similar items were informed by Schirmer et al. (2000) paper. In addition to this nodes were added to combine the species richness and weed cover outputs into a vegetation quality node. This node assumes that low levels of weed cover are equally important to the quality of the site as its species richness and is achieved by scaling the upper value of the species richness node to 100, to match the scale of weed cover. Furthermore nodes were added to the model taking into account the results from the survey to provide information about how favoured a management strategy is likely to be. The information for this was entered as a table where values placed on each of the management actions chosen are added together to get a total value for community support.

2.3 Model Outcome Analysis

The average result of each individual management action was recorded for the effectiveness of its improvement of species richness and reduction in weed cover as well as their cost efficiency, the social efficiency, and when taking into account both cost efficiency and social effect. The cost efficiency of each of the actions was calculated using the cost data obtained from Hanson Cement records with the variations in price between similar items were informed by Schirmer's (2000) paper. Cost efficiency was calculated from the effectiveness of the intervention divided by its cost.

Logistic regression was then used to determine the probable effect of selecting each management action in combination with other management actions on the effectiveness, cost efficiency, social efficiency and when taking into account social and financial efficiency.

2.4 Survey

To extend on the model, which would inform the environmental benefits and social costs of different management actions, a survey was conducted to provide information on the apparent benefits of the different management actions. This additional dimension provides a landowner with a way of predicting how their management choice will be received and whether it is likely to be endorsed by their community. As the non-scientific community is informed on the efficacy of environmental management actions by the scientific community, it is believed that the position of researchers as stakeholders in environmental management will have a flow on effect to the wider community's reaction.

In order to gain an index of the scientific community's response to different available management actions, a survey was constructed consistent with an influence based, planner-centred approach to stakeholder participation (Goetz & Gaventa, 2001; Michener 1998). The survey contained the 8 different management actions considered in the model followed by a 7 point likert-type scale ranging from 1, "Totally Oppose", to 7, "Totally Support", and a space for a more detailed response to each management action (please find the complete survey in Appendix B).

The survey was conducted with research staff currently employed by the University of Melbourne in the Botany department. The sample was chosen due to their appreciable knowledge of land management actions and their status in the community. The final sample size totalled 23 complete responses. No missing data was recorded.

3. Results

3.1 Literature review results

A review of the literature revealed a number of management actions that were proposed to increase the species richness of a grassland and decrease its' weed cover. Biomass removal was seen to be very important for maintaining species richness over long timeframes and the two mechanisms most commonly proposed for this were burning every three to five years and grazing the site [10,11]. Planting by direct seeding or using tubestock was seen as a way to elevate species richness at a site [12,13]. Also common was the suggestion that weed control be undertaken prior to planting in order to create space for the new seedlings [13–16]. Weed control was also seen as a way to increase the quality of a site by decreasing the weed cover [17].

3.1.1 Species richness

There was substantial literature available about the effects of grazing on grasslands though little of it was quantified. Studies show that over a long time frame having grazing at a site is preferable to having no form of biomass removal [18,19]. A lack of grassland biomass removal has been shown to reduce the species richness of a site by 66% over long time periods. Low intensity continuous grazing has an average effect of reducing the initial species richness by one third over a long time period [10,20]. Rotational grazing was proposed in multiple sources to be better for maintaining high species richness at a site but was not directly quantified [11,18,19,21]. Fire was the alternative in terms of biomass removal and if a grassland was burnt at least once every five years it was shown to increase species richness by 42% [10,22,23].

Direct seeding is the most commonly proposed form of planting in grasslands and its success has been well quantified. The average success rate of direct seeding after one year was 66% [13,24], while over long time period the success was 44% [13,24]. On the other hand tubestock is planted as established plants which have a near perfect survival rate over one year but only a 43% chance of remaining at a site long term [24,25].

Weed control in grasslands is poorly quantified in the literature [14]. Studies on the success of weed control before experimental plantings formed the body of this research. As such long-term herbicide, where all plants in an area are sprayed equally and spraying in conjunction with scalping were quantified though they are thought to be potentially degrading influences[11] but spot spraying which is the most common form of weed control used in revegetation was not quantified in the literature[11,24,26] Long-term herbicide was found to decrease species richness by 83.3% while scalping with spraying was found to decrease species richness by 91.7% [14].

3.1.2 Weed Cover

Weed control, burning and grazing also all have impacts on percentage weed cover but the effects of these are poorly quantified in the literature. Vegetative cover was found to have reduced to less than 5% after long-term herbicide and to around 0% after scalping with spraying[14]. The effect of spot spraying is not quantified but it is endorsed in several papers, especially in cases where there are clumps of invasive species[19].

The effects of grazing on grassland weed cover are not quantified in the literature though the suggestion that weed cover increases with grazing intensity is prevalent in the literature[11,18,19]. Studies do quantitatively show that exotic species richness increases with increased grazing intensity which can be assumed to mean that the cover of exotic species increases as well [18,20]. Rotational grazing is thought to increase weed cover less than continuous grazing [18,19].

Fire is often used as a means of reducing the cover of exotic species at a site[17] and a study by Lunt and Morgan (1995) in the Victorian Basalt Plains Grasslands found that the percentage weed cover at burnt sites was 6.5% while it was 49% at unburnt sites.

3.2 Survey Results

All survey data were entered into Version 20 of SPSS for analysis. Tests for normality were conducted and, though the assumption of normality was violated for several of the questions, ANOVA has been demonstrated to be robust to violations of normality (Glass, 1972) and thus a repeated measures ANOVA was conducted to determine if there was significant difference between the preference stakeholders had for different land management methods. Analysis revealed a significant difference between the different land management options, $F(7,154) = 34.52$, $p < 0.001$. A table of the means and standard deviations of responses to each land management action are presented below, in Table 1.

Table 1.
Means and Standard Deviations of Responses to Each Surveyed Land Management Action

Method	Mean	Std. Deviation
Burning	5.61	1.699
Continuous Grazing	3.65	1.824
Rotational Grazing	3.70	1.769
Long-term Herbicide	1.70	1.020
Scalping with Herbicide	2.70	1.845
Spot Spraying	5.96	1.107
Tubestock Planting	6.04	.976
Direct Seeding	6.22	.998

As can be seen from the above table, four management options received a very high degree of support from the survey respondents: burning, spot spraying, tubestock planting and direct seeding. Unlike the three other highly supported options, burning received a higher variability in reactions to it as evidenced by its higher standard deviation. Some respondents reacted to the potential danger that burning poses if not handled correctly and on the importance of experienced individuals conducting the burns. Despite this, Bonferoni pair-wise comparisons revealed that all four of these land management actions did not receive a significantly different amount of support from one another (all p's>0.05) while all four were found to be significantly more supported than the other surveyed options (all p's<0.05). This indicates that these four options are, on average, equally supported by the surveyed research staff and all favoured compared with the other surveyed management actions.

Of the other management actions, two received average ratings of only just below the 'neither oppose nor support' response category, continuous grazing and rotational grazing, while, on average, two received responses more firmly in the opposed categories. Among these options, continuous grazing and rotational grazing were found to be significantly less opposed than long-term herbicide use (both p's<0.05) but not less opposed than scalping with herbicide (p>0.05) while scalping with herbicide was not significantly less opposed than long-term herbicide use (p<0.05). This indicates that, while long-term herbicide use was the most opposed action, the 4 opposed actions are not as clearly differentiable from one another as they are from the 4 more supported actions.

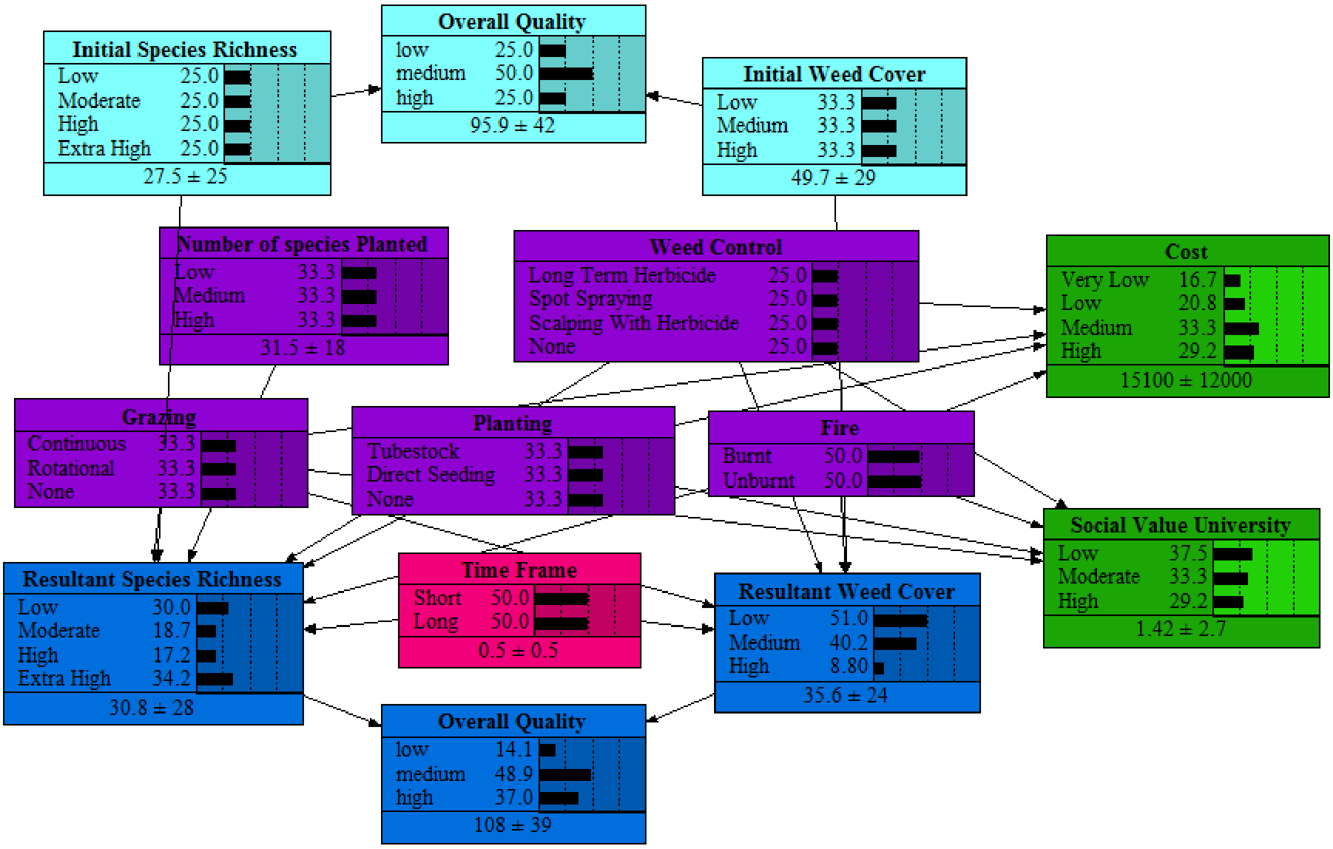

Figure 1.

State-and-transition framework for management decisions made in relation to grassland offset sites.

3.3 Bayesian Network Results

Once completed the Bayesian Network was comprised of 15 nodes and 28 links, as can be seen above in Figure 1. The nodes are divided into 5 different sets. Firstly there is the set that describes the initial state of the vegetation; which includes nodes for the initial quality of the vegetation, the initial species richness and initial weed cover. This set has been assigned a light blue colour. Next is the time horizon of interest which has is in its own set and is coloured pink. This represents the time that a result is desired for. A short time frame is classified as up to 2 years and anything over that timeframe is considered a long timeframe. Marked in purple is the set for management actions; these affect the resultant state of the vegetation. The set for the resultant state of the vegetation is coloured dark blue and includes the resultant weed cover and species richness as well as a node for vegetation quality. These nodes are informed by all of the aforementioned sets. The last set is the cost benefit set and is coloured green. This set contains nodes for the variables that aren't concerned with the environment, including nodes for the financial cost, and social values.

3.4 Costs

The prices used in the cost efficiency analysis are shown in Table 2 where they are arranged in descending price order. Planting tubestock and direct seeding were by far the most expensive options per hectare and grazing is assigned a cost of negative one to represent the possibility of leasing the land to farmers to satisfy the grazing requirement.

Table 2

Cost of management actions as derived from Hanson Cement records and Schirmer et al. (2000).

Management Actions	**Cost/ha (AUS$)**
Tubestock	27,000
Direct Seeding	21000
Scalping + Herbicide	2340
Burning	3600
Long-term herbicide	840
Spot Spraying	700
Rotational Grazing	-1
Continuous Grazing	-1

Table 3.
Table of mean outcomes of different management actions

		Spot Spraying	Long-Term Herbicide	Scalping with Herbicide	Burning	Continuous Grazing	Rotational Grazing	Direct Seeding	Tubestock
Average Effectiveness	Short Term Weed Cover	15.71	33.07	33.07	33.07	0.00	0.00	0.00	0.00
	Short Term Species Richness	0.00	-10.00	-10.00	19.31	0.00	0.00	38.33	43.94
	Long Term Weed Cover	0.00	2.68	2.72	33.00	-11.00	-11.00	0.00	0.00
	Long Term Species Richness	-10.00	-10.00	-10.00	30.81	0.00	0.00	-2.66	-3.09
Cost Efficiency	Short Term Weed Cover	0.02	0.04	0.01	0.01	0.00	0.00	0.00	0.00
	Short Term Species Richness	0.00	-0.01	0.00	0.01	0.00	0.00	0.00	0.00
	Long Term Weed Cover	0.00	0.00	0.00	0.01	-11.00	-11.00	0.00	0.00
	Long Term Species Richness	-0.01	-0.01	0.00	0.01	0.00	0.00	0.00	0.00
Social Benefit Efficiency	Short Term Weed Cover	31.32	45.82	50.54	64.29	0.00	0.00	0.00	0.00
	Short Term Species Richness	0.00	-19.57	-21.00	48.58	0.00	0.00	99.78	113.25
	Long Term Weed Cover	0.00	3.72	4.16	64.16	-18.31	-18.39	0.00	0.00
	Long Term Species Richness	-25.66	-18.60	-21.00	47.99	0.00	0.00	-6.91	-7.96
Financial Social Benefit Efficiency	Short Term Weed Cover	0.04	0.05	0.02	0.02	0.00	0.00	0.00	0.00
	Short Term Species Richness	0.00	-0.02	-0.01	0.01	0.00	0.00	0.00	0.00
	Long Term Weed Cover	0.00	0.00	0.00	0.02	-20.34	-20.43	0.00	0.00
	Long Term Species Richness	-0.04	-0.02	-0.01	0.01	0.00	0.00	0.00	0.00

3.5 Results of Individual Management Actions

The average result of choosing any of the management actions on their own on the effectiveness, financial cost efficiency, social cost efficiency and social and financial costs of improving species richness reducing weed cover are shown, above, in the in Table 3.

3.5.1 Species Richness

This shows that in the short term, the most effective actions were planting tubestock and direct seeding which are also the most efficient when also considering social costs. However burning is the most efficient action when financial costs are considered. Over a longer timeframe burning is always the best option. If no actions are undertaken over a long timeframe, the number of species present decreases by an average of 10

3.5.2 Weed Cover

Over a short timeframe long-term herbicide, scalping with herbicide and burning are similarly effective, when financial cost efficiency is considered long-term herbicide is the most preferable option. If both social and financial cost efficiency are taken into account burning is the most efficient option though spot spraying, long-term herbicide and scalping with herbicide are also very efficient. When only social cost efficiency is taken into account burning is the most efficient action. Over long timeframes, burning is always the most preferred option.

Continuous and rotational grazing had very low cost efficiencies because they were assigned a cost of -$1.

3.6 Results of Combinations of Management Actions

The relationship between the selection of each of the management actions and their effectiveness and efficiencies was analysed using logistic regression.

3.6.1 Species Richness

On a short time horizon, the selection of management actions; planting tubestock (df=637, z=7.99, p<0.001), direct seeding (df=637, z=3.672, p<0.001), spot spraying (df=637, z=8.156, p<0.001) and absence of weed control (df=637, z=9.333, p<0.001) were all correlated with increased management effectiveness. Selection of the variables of no planting (df=637, z=-10.708, p<0.001), long-term herbicide (df=637, z=-8.810, p<0.001) and scalping with herbicides (df=637, z=-8.262, p<0.001) was negatively correlated with management effectiveness. When the financial cost efficiency is taken into account planting tubestock (df=637, z=3.230, p<0.01), direct seeding (df=637, z=3.230, p<0.01), spot spraying (df=637, z=5.73, p<0.001) and an absence of weed control (df=637, z=6.239, p<0.001) are the best options. These same values are the most efficient in terms of social costs as well as when considering both social and financial costs, though the selection of burning also became effective (df=637, z=4.615, p<0.001).

Over long timeframes the selection of tubestock (df=637, z=-9.300, p<0.001), direct seeding (df=637, z=-9.452, p<0.001), spot spraying effectiveness (df=637, z=6.396, p<0.001) and no weed control (df=637, z=6.306, p<0.001) were still effective along with burning (df=637, z=8.233, p<0.001). When no planting is undertaken (df=637, z=-9.433, p<0.001)or long-term herbicide (df=637, z=-6.162, p<0.001) or scalping with herbicide (df=637, z=-6.770, p<0.001) is conducted the success of the management action is significantly reduced.

When it comes to financial cost efficiency, social cost efficiency and financial and social cost efficiency, all of the same management actions were found to be correlated with improved species richness though burning had the greatest effect when it came to social cost efficiency and when taking into account social and financial costs.

3.6.2 Weed Cover

On a short time horizon the selection of no weed controls was highly correlated with reduced effectiveness of management (df=70, z=2.837, p<0.01) while selection of the intensive forms of weed control; long-term herbicide and scalping with herbicide were correlated with increased management effectiveness (df=70, z=1.559, p<0.01). On a short time horizon it the cost efficiency of weed control was improved by selecting to spray uniformly (df=67, z=2.346, p<0.05) and decreased by selecting no form of weed control (df=67, z=-2.319, p<0.05) and by burning the site (df=67, z=-2.777, p<0.01). None of the management options were correlated with good outcomes in the analysis of social cost efficiency or when taking into account both financial and social costs.

On a long time horizon, the selection of burning (df=70, z=2.112, p<0.05) and of no grazing (df=70, z=2.714, p<0.01) was correlated with management effectiveness. In terms of social cost efficiency choosing to burn a site tended to provide good outcomes (df=67, z=2.168, p<0.17) as well as choosing to exclude grazing (df=67, z=2.906, p<0.01). In terms of financial cost efficiency and when taking into account both financial and social costs no management actions were correlated with increased management efficiency.

4. Discussion

A review of the literature allowed a state and transition model to be built that can be used as a tool to inform management decisions. It allows data to be input on the weed cover and native species richness of a site and predict how a number of well researched management interventions will influence these things. It also defines the quality of the vegetation as defined by the species richness and weed cover which may be useful in assessing sites to use as offsets. If you were to choose a high quality site it may be possible to preserve it with minimal work whereas a low quality site may take a lot of rehabilitation. The model also allows the financial costs of different management actions and the social repercussions of it to be ascertained. Using this model it is possible to determine how best to manage the site depending on the importance of improving the quality of the site, engaging and empowering the community and the available funds.

Further analysis of the outputs of the model revealed that species richness of grasslands could be effectively managed over short time periods by planting tubestock, direct seeding and spot spraying or avoiding weed control. Over long timeframes however it becomes necessary to remove biomass through burning to maintain the influence of these interventions. Weed control was found to be effectively decreased in the short term by uniform spraying or scalping with herbicides. In the long term however, weed cover was most effectively managed by burning in the absence of grazing.

In both short and long timeframes species richness is cost efficiently managed by planting tubestock, direct seeding, burning and a lack of weed control or spot spraying. Weed cover is cost efficiently managed by uniform spraying in the short term though there is no cost effective method for reducing weed cover in the long term. This may be misleading when compared to the results for species richness as the expensive planting actions were excluded from the cost efficiency analysis for weed cover on the basis that they aren't related.

From this it is evident that to best improve the quality of grassland vegetation, burning should be conducted no less frequently than every five years. Augmenting this by planting tubestock or direct seeding is an effective and cost efficient way to improve the quality of species poor sites.

Analysis of the survey revealed that there was strong agreement that planting tubestock and direct seeding were the most pleasing options for biodiversity. Spot spraying was generally seen in a positive light. On average burning was seen as a positive management action but there was substantial variance around this, indicating that it is potentially a more controversial form of management. The management actions fell broadly into two groups: the supported management actions which included burning, spot spaying and both forms of planting, and the opposed management actions which included both grazing options as well as the more intensive weed control options.

By incorporating the information from the survey into the model and its' analysis it becomes evident that in terms of increasing species richness, the outcomes that were most supported by stakeholders were those that were correlated with effectiveness however burning was only correlated with increased effectiveness in long time frames. This being the case it is unsurprising that in an analysis of the social cost efficiency of management actions, the same actions are chosen as when only looking at effectiveness. This remains unchanged when you take both social and financial costs into account.

This research indicates that over a short timeframe it may be preferable to spot spray to decrease weed cover and plant tubestock or direct seed the site heavily. Over a long timeframe, however, management that includes burning is the best option for increasing species richness and decreasing weed cover.

The environmental protection and biodiversity act (EPBC), which is responsible for the protection of the Natural Temperate Grasslands of the Victorian Volcanic Plains, includes reducing the intensity of grazing and developing strategic grazing plans to avoid soil compaction, develop strategic burning regimes, spot spraying, hand removing and burning to resolve the problem of weed invasion and replanting of native vegetation [27]. All of these actions were considered by our model, except for the hand removal of weeds, but our research suggests that some of these actions are less favourable than others. Our research agrees that high intensity grazing leads to an increased weed cover but suggests that changing the grazing regime may not reduce weed cover substantially. Furthermore our research finds that spot spraying is only effective in removing weeds in the short term which makes the inclusion of it into management strategies questionable. On the other hand our research is consistent with the suggestions of burning and replanting native vegetation.

The present study is limited by a lack of adequately quantified information about different management actions and the complex interactions between them. As a result some of the relationships were inferred from statements in the literature and logic. For example the effect of burning on native species richness is known [22,24,28] and the effect of continuous grazing on species richness is known [20,21] but there are few studies that look at how grasslands respond when the site is both grazed and burnt [28]. Further research is required to fully quantify these missing relationships and to quantify the impact of other, currently untested management actions such as slashing and hand weeding on a grassland ecosystem. A great strength of the current model is that ongoing monitoring of the site can be conducted and that information can then be used to update the model, making it more accurate.

A further limitation comes from the discrepancies found in the paper by Schirmer and Field, which was published in 2000, in which there was a substantial difference in costs quoted in different scenarios and by different companies for a given management action. For example, the quotes they obtained for the cost of direct seeding ranged from $8000 to $15000. As a result it is advisable to obtain quotes from a variety of different companies before employing them to manage a site. A further corollary of this is that it may be most beneficial to conduct a cost benefit analysis only after quotes are obtained for the different actions; another possibility provided by the present model.

Finally, the survey was administered to a convenience sample of ecological academics. As a result they mightn't form a representative sample of ecological academics as a group. Broader sampling would allow a greater certainty about attaining a representative sample of opinions. Furthermore, university academics have an amount of sway when it comes to informing policy and the public, but they are not the only stakeholder group when managing grassland offsets. A variety of other groups may have important opinions about the management of grassland sites such as the farmers union, the country fire authority and residents of surrounding areas. Future studies that include these groups in a similar survey would provide a more comprehensive reflection of how different actions will be perceived by society.

Due to the above mentioned limitations, further research will provide a more complete and accurate model for decision making. However, a strength of the current project is its demonstration of the utility of this form of modelling and of including stakeholder surveys into an overall decision making strategy. Updating information in the model and adding additional sources of stakeholder opinion will further improve the quality and reliability of decisions based on the model's recommendations.

5. Conclusion

The findings of this research allow for some recommendations to be made about how best to manage the vegetation at these offset sites, or any other grassland sites. Firstly we recommend that a long term view is taken when managing these areas; the idea of an offset is to preserve and restore areas of vegetation in perpetuity rather than for a proximal deadline. If however it is required that the quality of the vegetation is improved quickly, burning followed by either planting tubestock or direct seeding with spot spraying of weeds is recommended. For long term management of the site, the recommendations are different. Burning every three to five years is vital to the management of these grasslands and should form a part of all management strategies as it maintains high species richness over long periods and it decreases weed cover. In the case of sites with high native species richness, this should be sufficient to maintain the vegetation at a high quality. If the site has low species richness but is adjacent to a site with high richness, managing purely by burning may still be the best option, it avoids the costs of planting tubestock or direct seeding and will increase in species richness over time through passive regeneration [29]. In cases where the species richness at a site is low and the surrounding vegetation also has a low native species richness, it is necessary to plant tubestock or direct seed the site to improve its' quality. This research shows that direct seeding is marginally more socially supported and less expensive than tubestock plantings though both yield very similar results. On this basis direct seeding should be chosen over planting tubestock unless there is a compelling reason to use tubestock.

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Appendix A: Definitions

Tubestock:

Native grassland plants are planted as seedlings

Direct Seeding:

The seeds of native grassland plants are distributed across the site.

Burning:

Controlled burns would take place every 1 to 5 years. These would be low intensity burns which would remove the leaf litter/mast at the site as well as burning the existing vegetation.

Continuous Grazing:

A low density of stock would be present at the site at all times, no more than 6 sheep per hectare

Rotational Grazing:

The site would be grazed by densities of up to 12 sheep per hectare but stock would be removed for the spring season.

Spot Spraying:

Spraying is conducted by professionals who only spray introduced species. This aims to reduce weed cover without killing the native species.

Scalping with Herbicide:

The top layer of soil is removed; this removes all of the seeds that might sprout in future. A month or more after the topsoil is removed spaying is undertaken to kill any plants that have sprouted.

Long-Term Herbicide:

Widespread spaying would be undertaken; this would not discriminate between native and introduced species. A number of incidents of spraying would be spread over a longer timeframe, allowing for the plants that spring up after the initial spaying to be killed. This method aims to bring the vegetation back to a blank slate.

Appendix B: Survey

Benefits and Costs of Land Management Actions

EXPLANATORY STATEMENT

Please retain for your information

This is a project being conducted by Hannah Pearson and Max Fraser as part of their participation in the Quarry Life Award, an initiative to promote biodiversity by the Heidelberg Cement Group. The project is aimed, in part, at gaining an understanding of how different community groups view several land management actions that could be undertaken to improve biodiversity of grasslands.

Filling out the included survey will take approximately 10 minutes and your participation and response will be confidential. Upon request, your own results can be made available to you. Beyond that, only the researchers can access the information and the records will be destroyed at the completion of the project. A summary of the findings of the research can be made available to you, should you request it.

Participation in this research is entirely voluntary and, should you agree to participate, you may withdraw from the study at any time without consequence. Consent to participate will be assumed if the survey is returned to the researchers.

If you have any queries, please contact Max Fraser on 0408 770 509.

Hannah Pearson and Max Fraser

Below are descriptions of several land management actions that could be undertaken by landholders in an attempt to improve one or several aspects of grassland biodiversity. These indices include: fauna species richness, flora species richness, incidence or wellbeing of a particular endangered species or decreasing the incidence of a believed nuisance species. Following each land management action is a 7-point scale that is designed to capture to what degree you would support the action being employed. Please circle the option that best fits how supportive you would be about each strategy being undertaken.

In addition, we are interested to know what you think about each land management action in more detail and have included an open response section below the 7-point scale for you to offer more detailed information about your answer, should you wish. If you find you wish more space for detailed answers than is provided, please attach additional pages numbered consistently with the different land management actions.

Thank you for your participation!

Burning

Controlled burns would take place every 1 to 5 years. These are low intensity burns that would reduce the amount of leaf litter/mast present at the site.

Totally Oppose	Mostly Oppose	Slightly Oppose	Neither Oppose nor Support	Slightly Support	Mostly Support	Totally Support

Continuous grazing

The site would be grazed continuously at low stock densities (6 sheep per hectare or fewer).

Totally Oppose	Mostly Oppose	Slightly Oppose	Neither Oppose nor Support	Slightly Support	Mostly Support	Totally Support

Rotational grazing

The site would be grazed at densities of up to 12 sheep per hectare but stock would be removed for the spring season.

Totally Oppose	Mostly Oppose	Slightly Oppose	Neither Oppose nor Support	Slightly Support	Mostly Support	Totally Support

Long Term Herbicide

Widespread spraying would be undertaken. The spraying wont discriminate between native and introduced species and aims to bring the vegetation back to a blank slate

Totally Oppose	Mostly Oppose	Slightly Oppose	Neither Oppose nor Support	Slightly Support	Mostly Support	Totally Support

Scalping with herbicide

The top layer of soil is removed. This also removes all of the seeds that might sprout in future. A month or more after the topsoil is removed spaying is undertaken to kill any plants that have sprouted.

Totally Oppose	Mostly Oppose	Slightly Oppose	Neither Oppose nor Support	Slightly Support	Mostly Support	Totally Support

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Spot-Spraying

Spraying is conducted by professionals who only spray introduced species. This aims to reduce weed cover without killing the native species.

Totally Oppose	Mostly Oppose	Slightly Oppose	Neither Oppose nor Support	Slightly Support	Mostly Support	Totally Support

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Tubestock Planting

Native grassland plants are planted as seedlings.

Totally Oppose	Mostly Oppose	Slightly Oppose	Neither Oppose nor Support	Slightly Support	Mostly Support	Totally Support

Direct Seeding

The seeds of native grassland plants are distributed across the site.

Totally Oppose	Mostly Oppose	Slightly Oppose	Neither Oppose nor Support	Slightly Support	Mostly Support	Totally Support

Appendix C: Logistic Regression Equations

Note that ~ denotes a logit link

Short Timeframe Species Richness Effectiveness Equations

Probability of selecting tubestock ~ -1.251727+0.030649*effectiveness (df=637, z=7.99, p<0.001)

Probability of selecting direct seeding ~ -0.899311+0.013045*effectiveness (df=637, z=3.672, p<0.001)

Probability of selecting no planting ~ -0.143417-0.054999*effectiveness (df=637, z=-10.708, p<0.001)

Probability of selecting continuous grazing ~ -0.6686825-0.0002103*effectiveness (df=637, z=-0.060, p=0.952

Probability of selecting rotational grazing ~ -0.6600434-0.0007451*effectiveness (df=637, z=-0.212, p=0.832)

Probability of selecting no grazing ~ -0.7516401+ 0.0009752*effectiveness (df=637, z=0.275, p=0.783)

Probability of selecting no weed control ~ -2.149377+0.044234*effectiveness (df=637, z=9.333, p<0.001)

Probability of selecting spot spraying ~ -1.817350+0.035146* effectiveness (df=637, z=8.156, p<0.001)

Probability of selecting uniform spraying ~ -0.622106-0.044888*effectiveness (df=637, z=-8.810, p<0.001)

Probability of selecting scalping with herbicide ~ -0.647893-0.039981*effectiveness (df=637, z=-8.262, p<0.001)

Probability of selecting burning ~ 0.114732-0.005324*effectiveness (df=637, z=-13.76, p=0.110)

Long Timeframe Species Richness Effectiveness Equations

Probability of selecting tubestock ~ -0.886189+0.024054*effectiveness (df=637, z=-9.300 , p<0.001)

Probability of selecting direct seeding ~ -0.907856+0.026467*effectiveness (df=637, z=-9.452, p<0.001)

Probability of selecting no planting ~ -0.450859-0.074754*effectiveness (df=637, z=-9.433, p<0.001)

Probability of selecting continuous grazing ~ -0.650636-0.006415*effectiveness (df=637, z=-1.320, p=0.187)

Probability of selecting rotational grazing ~ -0.751575+0.007951*effectiveness (df=637, z=1.681, p=0.0928)

Probability of selecting no grazing ~ -0.681210-0.001737*effectiveness (df=637, z=-0.362, p=0.717)

Probability of selecting no weed control ~ -1.402849+0.032873*effectiveness (df=637, z=6.306, p<0.001)

Probability of selecting spot spraying ~ -1.408730+0.033394*effectiveness (df=637, z=6.396, p<0.001)

Probability of selecting uniform spraying ~ -0.907139-0.041054*effectiveness (df=637, z=-6.162, p<0.001)

Probability of selecting scalping with herbicide ~ -0.89935-0.04746*effectiveness (df=637, z=-6.770, p<0.001)

Probability of selecting burning ~ -0.289009+0.044962*effectiveness (df=637, z=8.233, p<0.001)

Short Timeframe Weed Cover Effectiveness Equations

Probability of selecting spot spraying ~ -1.135416+0.001543*effectiveness (df=70, z=0.150, p=0.88055)

Probability of selecting uniform spraying ~ -1.37500+0.01253*effectiveness (df=70, z=1.229, p=0.219230)

Probability of selecting scalping with herbicide ~ -1.47582+0.01599*effectiveness (df=70, z=1.559, p=0.119006)

Probability of selecting scalping with herbicide or uniform spraying ~ -0.609407+ 0.026513*effectiveness (df=70, z=2.666, p<0.01)

Probability of selecting no weed control ~ -0.29416-0.05393*effectiveness (df=70, z=-2.837, p<0.01)

Probability of selecting burning ~ -0.210934+0.008969*effectiveness (df=70, z=0.991, p=0.322)

Probability of selecting continuous grazing ~ -0.577377-0.005035*effectiveness (df=70, z=-0.522, p=0.6018)

Probability of selecting rotational grazing ~ -0.646679-0.001989*effectiveness (df=70, z=-0.209, p=0.8348)

Probability of selecting no grazing ~ -0.859869+0.006845*effectiveness (df=70, z=0.729, p=0.4658)

Long Timeframe Weed Cover Effectiveness Equations

Probability of selecting spot spraying ~ -1.086762-0.003594*effectiveness (df=70, z=-0.363, p=0.717)

Probability of selecting uniform spraying ~ -1.056170+0.003154*effectiveness (df=70, z=-0.363, p=0.743013)

Probability of selecting scalping with herbicide ~ -1.056230+0.003166*effectiveness (df=70, z=0.329, p=0.742118)

Probability of selecting either scalping with herbicide or uniform spraying ~ -0.021300+0.005359*effectiveness (df=70, z=0.627, p=0.530)

Probability of selecting no weed control ~ -1.086762-0.003594*effectiveness (df=70, z=-0.363, p=0.717)

Probability of selecting burning ~ -0.073781+0.019490*effectiveness (df=70, z=2.112, p<0.05)

Probability of selecting continuous grazing ~ -0.663186-0.013528*effectiveness (df=70, z=-1.417, p=0.15650)

Probability of selecting rotational grazing ~ -0.663186-0.013528*effectiveness (df=70, z=-1.417 p=0.15650)

Probability of selecting no grazing ~ -0.88723+0.02764*effectiveness (df=70, z=2.714, p<0.01)

Short Timeframe Species Richness Cost Efficiency Equations

Probability of tubestock selection ~ -0.71470+93.87952*cost efficiency (df=637, z=3.230, p<0.01)

Probability of direct seeding selection ~ -0.71332+91.83420*cost efficiency (df=637, z=3.230, p<0.01)

Probability of no planting selection ~ -0.71417-181.09930*cost efficiency (df=637, z=-5.398, p<0.001)

Probability of continuous grazing selection ~ -0.67210+0.05852*cost efficiency (df=637, z=0.003, p=0.998)

Probability of rotational grazing selection ~ -0.67201-0.46886*cost efficiency (df=637, z=-0.023, p=0.982)

Probability of no grazing selection ~ -0.73579+0.42013*cost efficiency (df=637, z=0.020, p=0.984)

Probability of no weed control selection ~-1.5869+459.0689*cost efficiency (df=637, z=6.239, p<0.001)

Probability of uniform spraying selection ~ -1.08005-280.03812*cost efficiency (df=637, z=-6.437, p<0.001)

Probability of scalping with herbicide selection ~ -1.08211-74.62258*cost efficiency (df=637, z=-3.413, p<0.001)

Probability of spot spraying selection ~ -1.3219+289.0315*cost efficiency (df=637, z=5.73, p<0.001)

Probability of burning selection ~ -0.01588+130.48024*cost efficiency (df=637, z=4.368, p<0.001)

Long Timeframe Species Richness Cost Efficiency Equations

Probability of tubestock selection ~ -0.79430+92.52804*cost efficiency (df=637, z=4.965, p<0.001)

Probability of direct seeding selection ~ -0.80812+100.63198*cost efficiency (df=637, z=5.292, p<0.001)

Probability of no planting selection ~ -0.62734-314.45879*cost efficiency (df=637, z=-7.683, p<0.001)

Probability of continuous grazing selection ~ -0.66256-12.10135*cost efficiency (df=637, z=-0.832, p=0.405)

Probability of rotational grazing selection ~-0.68373+12.68115*cost efficiency (df=637, z=0.844, p=0.399)

Probability of no grazing selection ~ -0.73556-0.16900*cost efficiency (df=637, z=-0.011, p=0.991)

Probability of no weed control selection ~ -1.4760+ 168.5805*cost efficiency (df=637, z=7.492, p<0.001)

Probability of spot spraying selection ~ -1.17147+67.45533*cost efficiency (df=637, z=3.573, p<0.001)

Probability of uniform spraying selection ~ -1.04991-113.89228*cost efficiency (df=637, z=-5.833, p<0.001)

Probability of scalping with herbicide selection ~ -1.05329-60.49935*cost efficiency (df=637, z=-3.79, p<0.001)

Probability of fire selection ~ -0.28497+354.36741*cost efficiency (df=637, z=8.671, p<0.001)

Short Timeframe Weed Cover Cost Efficiency Equations

Probability of uniform spraying selection ~ -1.5498+34.2325*cost efficiency (df=67, z=2.346, p<0.05)

Probability of scalping with herbicide selection ~ -0.8884-13.0396*cost efficiency (df=67, z=-0.778, p=0.43685)

Probability of spot spraying selection ~ -1.1434+7.5389*cost efficiency (df=67, z=0.554, p=0.57989)

Probability of no weed control selection ~ -0.4747-146.2394*cost efficiency (df=67, z=-2.319, p<0.05)
Probability of continuous grazing selection ~ -0.5665-4.9284*cost efficiency (df=67, z= -0.359, p=0.7198)
Probability of rotational grazing selection ~ -0.5841-3.5081*cost efficiency (df=67, z=-0.258, p=0.796)
Probability of no grazing selection ~ -0.9389+8.3525*cost efficiency (df=67, z=0.635, p=0.52516)
Probability of burning selection ~ 0.7722-62.4375*cost efficiency (df=67, z=-2.777, p<0.01)

Long Timeframe Weed Cover Cost Efficiency Equations

Probability of uniform spraying selection ~ -1.0015-0.1852*cost efficiency (df=67, z=-0.197, p= 0.84407)
Probability of scalping with herbicide selection~ -1.0015-0.1984*cost efficiency (df=67, z=-0.165, p=0.86933)
Probability of spot spraying selection ~ -1.0242-21.7519*cost efficiency (df=67 , z=-1.249, p=0.211766)
Probability of no weed control selection ~ -1.4331+10.0904*cost efficiency (df=67, z=0.502, p=0.616)
Probability of continuous grazing selection ~ -0.64861+0.01761*cost efficiency (df=67, z=0.449, p=0.6532)
Probability of rotational grazing selection ~ -0.64861+0.01761*cost efficiency (df=67m z=0.449, p=0.6532)

Probability of no grazing selection ~ -0.7843-0.1583*cost efficiency (df=67, z=-0.305, p=0.7604)
Probability of burning selection ~ 0.1494-0.1494*cost efficiency (df=67, z=-0.336, p=0.737)

Short Timeframe Species Richness Social Cost Efficiency Equations

Probability of tubestock selection ~ -1.227008+0.010714*social cost efficiency (df=637, z=7.644, p<0.001)
Probability of direct seeding selection ~ -0.916948+0.005050* social cost efficiency (df=637, z=3.821, p<0.001)
Probability of no planting selection ~ -0.112107-0.020733*social cost efficiency (df=637, z=-10.454, p<0.001)
Probability of continuous grazing selection ~ -0.662929-0.000203*social cost efficiency (df=637, z=-0.155, p=0.877)
Probability of rotational grazing selection ~ -0.6562637-0.0003514*social cost efficiency (df=637, z=-0.268, p=0.789)
Probability of no grazing selection ~ -0.7615198+0.0005651*social cost efficiency (df=637, z=0.427, p=0.789)
Probability of no weed control selection ~ -2.056305+0.014926*social cost efficiency (df=637, z=8.944, p<0.001)
Probability of spot spraying selection ~ -1.993529+0.015290*social cost efficiency (df=637, z=9.277, p<0.001)
Probability of uniform spraying selection ~ -0.56746-0.01878*social cost efficiency (df=637, z=-8.986, p<0.001)
Probability of scalping with herbicide selection ~ -0.596357-0.016565*social cost efficiency (df=637, z=-8.491, p<0.001)
Probability of burning selection ~ 0.0656388-0.0008272*social cost efficiency (df=637, z=-0.667, p=0.505)

Long Timeframe Species Richness Social Cost Efficiency Equations

Probability of tubestock selection ~ -0.858283+0.007841*social cost efficiency (df=637, z=4.469, p<0.001)
Probability of direct seeding selection ~ -0.885875+0.008911*social cost efficiency (df=637, z=5.043, p<0.001)
Probability of no planting selection ~ -0.445613-0.027757*social cost efficiency (df=637, z=-8.660, p<0.001)
Probability of continuous grazing selection ~ -0.613372-0.002900*social cost efficiency (df=637, z=-1.595, p=0.111)
Probability of rotational grazing selection ~-0.725405+0.002403*social cost efficiency (df=637, z=1.379, p=0.168)

Probability of no grazing selection ~ -0.7441097+0.0003908*social cost efficiency (df=637, z=0.220, p=0.826)
Probability of no weed control selection ~ -1.497959+0.012291*social cost efficiency (df=637, z=6.454, p<0.001)
Probability of spot spraying selection ~ -1.441656+0.013076*social cost efficiency (df=637, z=6.889, p<0.001)
Probability of uniform spraying selection ~ -0.870188-0.016804*social cost efficiency (df=637, z=-6.181, p<0.001)
Probability of scalping with herbicide selection ~ -0.858918-0.019751*social cost efficiency (df=637, z=-6.755, p<0.001)
Probability of burning selection ~ -0.302940+0.017497* social cost efficiency (df=637, z=8.219, p<0.001)

Short Timeframe Weed Cover Social Cost Efficiency Equations

Probability of uniform spraying selection ~ -1.139931+0.002277*social cost efficiency (df=67, z=0.387, p=0.69854)
Probability of scalping with herbicide selection ~ -1.357886+0.006953*social cost efficiency (df=67, z=1.191, p=0.233660)
Probability of spot spraying selection ~ -1.308162+0.005923*social cost efficiency (df=67, z= 1.015, p=0.309880)
Probability of no weed control selection ~ -0.55198-0.02589*social cost efficiency (df=67, z=-2.494, p<0.05)
Probability of burning selection ~ -0.220783+0.007419*social cost efficiency (df=67, z=1.367, p=0.172)
Probability of continuous grazing selection ~ -0.437828-0.004709*social cost efficiency (df=67, z=-0.829, p=0.407)
Probability of rotational grazing selection ~ -0.507997-0.002932*social cost efficiency (df=67, z=-0.524, p=0.6)
Probability of no grazing selection ~ -1.179476+0.007817*social cost efficiency (df=67, z=1.388, p=0.16522)

Long Timeframe Weed Cover Social Cost Efficiency Equations

Probability of uniform spraying selection ~ -1.0493496+0.0009532*social cost efficiency (df=67, z=0.176, p=0.860214)
Probability of scalping with herbicide selection ~ -1.053483+0.001406*social cost efficiency (df=67, z=0.260, p=0.794714)
Probability of spot spraying selection ~ -1.031831-0.001405*social cost efficiency (df=67, z=-0.256, p=0.798065)
Probability of no weed control selection ~ -1.273193-0.001122*social cost efficiency (df=67, z=-0.192, p= 0.848)
Probability of continuous grazing selection ~ -0.592544-0.008135* social cost efficiency (df=67, z=-1.501, p=0.1334)
Probability of rotational grazing selection ~ -0.592529-0.008149*social cost efficiency (df=67 z=-1.503, p=0.1329)
Probability of no grazing selection ~ -1.092087+0.017877*social cost efficiency (df=67, z=2.906, p<0.01)
Probability of burning selection ~ 0.011208+0.011600*social cost efficiency (df=67, z=2.168, p<0.05)

Short Timeframe Species Richness Social and Financial Cost Efficiency Equations

Probability of tubestock selection ~ -0.72414+34.44089*total cost efficiency (df=637, z=2.942, p<0.001)
Probability of direct seeding selection ~ -0.72712+35.99606* total cost efficiency (df=637, z=3.044, p<0.001)
Probability of no planting selection ~ -0.68379-71.57409*total cost efficiency (df=637, z=-5.283, p<0.001)

Probability of continuous grazing selection ~ -0.67188-0.19717*total cost efficiency (df=637, z=-0.020, p=0.984)
Probability of rotational grazing selection ~ -0.67160-0.46247*total cost efficiency (df=637, z=-0.048, p=0.962)
Probability of no grazing selection ~ -0.73644+0.67618*total cost efficiency (df=637, z=0.069, p=0.945)
Probability of no weed control selection ~ -1.563+159.501*total cost efficiency (df=637, z=6.311, p<0.001)
Probability of uniform spraying selection ~ -1.02285-143.25494*total cost efficiency (df=637, z=-7.041, p<0.001)
Probability of scalping with herbicide selection ~ -1.05761-48.00115*total cost efficiency (df=637, z=-4.30, p<0.001)
Probability of spot spraying selection~ -1.4139+137.1079*total cost efficiency (df=637, z=6.163, p<0.001)
Probability of burning selection ~ -0.04849+59.75866*total cost efficiency (df=637, z=4.615, p<0.001)

Long Timeframe Species Richness Social and Financial Cost Efficiency Equations

Probability of tubestock selection ~ -0.80418+31.99292*total cost efficiency (df=637, z=4.736, p<0.001)
Probability of direct seeding selection ~ -0.82154+35.53826*total cost efficiency (df=637, z=5.168, p<0.001)
Probability of no planting selection ~ -0.5903-121.1699*total cost efficiency (df=637, z=-7.550, p<0.001)
Probability of continuous grazing selection ~ -0.65461-5.80149*total cost efficiency (df=637, z=-0.975, p=0.33)
Probability of rotational grazing selection ~ -0.68901+5.03914*total cost efficiency (df=637, z=0.837, p=0.403)
Probability of no grazing selection ~ 0.403+0.84853*total cost efficiency (df=637, z=0.141, p=0.888)
Probability of no weed control selection ~ -1.4617+55.8647*total cost efficiency (df=637, z=7.187, p<0.001)
Probability of spot spraying selection ~ -1.2102+28.9749*total cost efficiency (df=637, z=4.105, p<0.001)
Probability of uniform spraying selection ~ -1.00927-48.25816*total cost efficiency (df=637, z=-5.766, p<0.001)
Probability of scalping with herbicide selection ~ -1.01985-31.91840*total cost efficiency (df=637 z=-4.453, p<0.001)
Probability of burning selection analysis ~ -0.3288+148.0542*total cost efficiency (df= 637, z=8.484, p<0.001)

Short Timeframe Weed Cover Social and Financial Cost Efficiency Equations

Probability of uniform spraying selection~ -1.4176+15.8530*total cost efficiency (df=67, z=1.776, p=0.0757)
Probability of scalping with herbicide selection~-0.8416-10.5721*total cost efficiency (df=67, z=-0.950, p=0.3422)
Probability of spot spraying selection ~ -1.3627+13.7027*total cost efficiency (df=67, z=1.546, p=0.122197)
Probability of no weed control selection ~ -0.4962-77.7363*total cost efficiency (df=67, z=-2.339, p<0.05)
Probability of burning selection ~ 0.7229-33.4015*total cost efficiency (df=67, z=-2.710, p<0.01)
Probability of continuous grazing selection ~ -0.5439-4.1342*total cost efficiency (df=67, z=-0.456, p=0.6484)
Probability of rotational grazing selection ~ -0.5668-2.9929*total cost efficiency (df=67, z=-0.334, p=0.7383)
Probability of no grazing selection ~ -0.9824+7.0437*total cost efficiency (df=67, z=0.813, p=0.41638)

Long Timeframe Weed Cover Social and Financial Cost Efficiency Equations

Probability of uniform spraying selection ~ -1.0015-0.1115*total cost efficiency (df=67, z=-0.195, p=0.845647)

Probability of scalping with herbicide selection ~ -1.0015-0.1173*total cost efficiency (df=67, z=-0.171, p=0.864583
Probability of spot spraying selection~ -1.0291-14.8103*total cost efficiency (df=67, z=-1.389, p=0.164773)
Probability of no weed control selection ~ -1.4381+8.2811*total cost efficiency (df=67 z=0.631, p=0.528)
Probability of continuous grazing selection~ -0.64845+0.01048*total cost efficiency (df=67, z=0.446, p=0.6556)
Probability of rotational grazing selection ~ -0.64874+0.01063*total cost efficiency (df=67, z=0.452, p=0.6512
Probability of no grazing selection ~ -0.78433-0.09307*total cost efficiency (df=67, z=0.316, p=0.7520)
Probability of burning selection ~ 0.1494-0.1101*total cost efficiency (df=67, z=-0.355, p=0.723)