COST EFFECTIVE LICE CONTROL STRATEGIES IN NSW

AND THE VALUE OF EXTENSION

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Contributed paper presented at the 36th Annual Conference
of the Australian Agricultural Economics Society,
Australian National University, Canberra
10-12 February 1992

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ABSTRACT

Sheep lice represent a major cost to the Australian sheep industry. It was estimated that in the 1990-91 season, Australian sheep producers spent $134m controlling lice burdens and suffered production losses of $216m.

The study examined the benefits from greater extension in NSW, and a regional perspective was taken. A dynamic lice population model was developed to estimate the change in lice prevalence throughout the State over a twenty year period. In the model, aggregate costs of control and production losses incurred were expressed as a function of lice prevalence through time and the success rate of individual lice control strategies. Of the control options available, plunge dipping was found to be the most cost effective form of control available to producers. Diagnostic testing for lice prior to treatment was found to generate additional cost savings, especially in the high-rainfall areas of the State where lice prevalence is the lowest.

Gains in economic welfare as a result of greater extension were estimated with the use of a simple Edwards and Freebairn model. Allowances were made for the increasing responsiveness of producers through time following a reduction in the costs and effectiveness of their methods of lice control. Welfare gains to NSW producers associated with a 10% increase in adoption was estimated at $124m over a twenty year period. For other States, it was estimated that producer surplus would be reduced by some $25m over the same period. The total gain to Australia, which includes gains to domestic consumers, was estimated at $148m.

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BACKGROUND

The prevalence of sheep lice infestations in NSW has drawn much attention from both the private and public sectors. Throughout the last decade, the prevalence of lice in NSW has not declined. Preliminary estimates by NSW Agriculture suggest that currently up to 40 per cent of flocks in NSW are infested by lice (NSW Agriculture, 1991). The prevalence of lice in other states is also considerably high, especially in Western Australia where the flock prevalence has been estimated at 30 per cent (Hall, 1989). It is evident that sheep lice are not only a problem for NSW but also for Australia as a whole.

Despite an alarming prevalence of lice throughout Australian sheep flocks, the problem has generally been understated. It has been estimated that lice are *controlled at an average cost of nearly $500 per farm, which largely eliminates any potential production loss* (Beck et. al., 1985). In contrast, Wilkinson (1988) estimated that sheep lice cost the Australian sheep industry approximately $150 million annually, representing around $3,000 for an average size flock. The existence of such large discrepancies in estimates of the cost of lice, highlight the need for gaining a better understanding of the costs lice are imposing on the Australian sheep industry.

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[3] This project was undertaken at the instigation of Dr John Steel, Head, McMaster Laboratory, CSIRO, Sydney and with the encouragement and collaboration of Dr Helen Scott-Orr, Chief, Division of Animal Industries, Mr Ian Roth and other officers of NSW Agriculture. The project was co-ordinated under the direction of Dr Jim Johnston, Manager, Institute of Animal Production and Processing, CSIRO, Sydney. Their assistance and comments along with other staff of CSIRO and other State Departments of Agriculture are much appreciated. Naturally however, all remaining errors in this paper are the responsibility of the authors.

Of increasing concern is that while the average prevalence of lice in NSW is around 35 per cent, it is estimated that 85 per cent of producers are treating their sheep for lice (NSW Agriculture, 1991). The over-treatment and inefficient use of control techniques, have resulted in high levels of insecticide residue in wool clips and increased farm level costs unnecessarily. Large cost savings to Australian wool growers may be possible through more efficient lice treatment techniques and the use of diagnostic testing for lice.

In this study the control costs and production losses incurred throughout NSW as a result of sheep lice infestations are estimated. A representative farm level decision framework for lice control is then developed and used to estimate the expected farm level gain from different lice control strategies and diagnostic test methods. The model is used to assess the economic gain which can be generated by increasing the adoption of more cost effective lice control strategies throughout NSW.

THE CONTROL PROBLEM

Introduction

The *Damalinia ovis* is a sheep biting louse that causes itching by the host animal, which can lead to a reduction in clean fleece weight or a decline in the quality of the wool. Important biological factors that should be considered in the development of lice control strategies are the rate of multiplication of lice, the distribution of lice on the body of the sheep, and the rate of spread of lice from one animal to another.

Lice eggs are not visible without magnification. Insecticides will kill adults and nymphs but not eggs, although there is usually sufficient chemical residue to kill any nymphs as they hatch over a reasonable period of time. Heavy rain or plunge dipping can also lead to a heavy mortality of adult lice, nymphs and eggs.

A wide range of prevalences exist in different regions and can be explained through a variety of factors. Although lice populations are highly sensitive to environmental factors such as rainfall, temperature, humidity and solar radiation, livestock management has a major impact. The effects of these factors are discussed in more detail by Taleb (1991).

Methods of Lice Control

Historically, routine treatment and failure to detect lice infestations have been major reasons for the failure of lice control programmes. Routine treatment refers to the application of a treatment on a routine basis (eg. annually) without testing to determine whether lice are present.

The most widely used method for treating lice is the backline spray with synthetic pyrethroid chemicals. The product must be applied within 24 hours of shearing in a band along the sheep's back. The chemical will remain active in the fleece for up to 70 days there-by providing some preventative benefits. Most lice are killed within 7 days of treatment although some will survive up to 42 days after treatment.

Plunge or shower dipping with organophosphate chemicals is a more traditional treatment method. Compared to backline treatments it is considerably more complex and time consuming. Dipping may also give rise to various infections, notably - *caseous lymphadenitis, dermatophilosis, and arthritis.* The treatment is best applied between 10-30 days after shearing so as to give any cuts time to heal.

Long wool jetting uses the synthetic pyrethroid called cyhalothrin, and can be used from 3-9 months after shearing to control lice. Long wool jetting is not a widely used method due to the uncertainty of effective control, given the bulky fleece that the chemical must penetrate.

In Table 1 the costs of the three main lice treatment methods are reported for each of the three geographic zones.

<u>Table 1 Cost of Lice Treatment Methods by Geographic Zone, $'s/head.</u>

Method	Pastoral	Sheep-wheat	High-rain
Plunge Dip	0.87	0.61	0.60
Shower Dip	0.98	0.72	0.71
Backline	0.29	0.29	0.29

Source: Hall, 1989 (revised).

The Effects of Lice on Production

The production losses associated with lice infestations are of two types. The first is the loss associated with decreased fleece weight, and the second is the loss associated with a reduction in the price received for wool from cotting, increased noil and decreased fibre length of processed wool. Previous studies have found the effects on body weight gain to be insignificant (Kettle and Lukies, 1982, Wilkinson, 1986). Wilkinson (1982) also found that there was no marked variation in mean fibre diameter due to lice, although there may be a reduction in the length of wool from lice infested sheep.

The reduction in fleece weight associated with a lice infestation is dependent on the severity of the lice infestation. Niven and Pritchard (1985) estimated a range of fleece weight losses from 0.3kg to 0.9kg per sheep, and Wilkinson (1988) estimated a range of 0.2kg up to 1.0kg per sheep. Estimates by Wilkinson (1988) were used in this study and are provided in Table 2.

Table 2 Fleece Weight Loss by Level of Lice Infestation

Status	Clean Fleece Weight kg/sheep	Percentage Reduction
Lice Free	3.5	0.0%
Light Infestation	3.3	5.7%
Medium Infestation	3.0	14.3%
Heavy Infestation	2.7	22.9%

Source: Wilkinson, 1988.

The clean fleece weight reductions shown in Table 2 are based on an average clean fleece weight per sheep of 3.5kg. Due to varying wool yields from sheep throughout the different zones, the clean fleece weight reduction estimated by Wilkinson has been used to estimate a percentage weight reduction rather than an absolute weight reduction. It is assumed that these percentage weight reductions are constant over all sheep producing regions. The average wool cut per sheep was taken to be 5.07 kg, 4.55 kg and 4.60 kg for the pastoral, wheat-sheep and high rainfall zones respectively (ABS, 1990).

Table 3 Wool Sold by Micron Class, Sheep Numbers, Lice Prevalence and Wool Price by Geographical Zone.

Micron Class	Pastoral	Sheep-wheat	High-rainfall
< 21.5u	13%	32%	38%
21.5u-23.5u	35%	39%	44%
> 23.5u	52%	29%	18%
Sheep (m)*	8.6	45.3	16.1
Lice Prevalence (%)#	40	37.5	14.5
Wool Price C/Kg	564	623	644

Source: (Australian Wool Corporation, 1990) *(ABS, 1990) #(NSW Agriculture, 1991)

The estimation of the price reduction for wool from lice infested sheep is based on the average price of wool in each geographic zone and the percentage price reduction for wool damaged by lice. Wool was divided into three classes of micron - 21.5 microns or less, 21.6 to 23.5 microns and 23.6 microns or more and an average price for each zone calculated. The estimated price reduction for wool damaged by lice infestations was assumed to be 5%, 10% and 20% for light, medium and heavy infestations respectively (Wilkinson, 1988; Hall, 1989). These price reductions were adopted in this study, and were assumed to be constant across the three zones. Details are provided in Table 3.

Algebraically, the production loss per sheep (L) for a given level of infestation (x), is calculated for each zone from the following equation:

(1)

$$L_x = QP.[1-((1-W_x)+(1-D_x))]$$

L	=	production loss per lice infested sheep
Q	=	average wool cut per sheep in a given zone
P	=	average wool price in a given zone
W	=	proportionate wool weight loss from the level of infestation x
D	=	proportionate wool price discount from the level of infestation x
x	=	level of infestation (1=light, 2=medium, 3=heavy).

OPTIMAL LICE CONTROL MODEL

Expected Costs of Control

The optimal lice control strategy is that strategy which minimises expected costs as a result of lice. Expected costs include the actual cost of the control strategy and the production losses which are incurred through time. An evaluation period of 20 years was chosen for the analysis.

In equation 2 the mathematical expression for the expected cost of a lice control strategy for a given zone is given by:

(2)

$$EC_m^t = P_L^t.[P_e.C_m + ((1-P_e).(\sum_{X=1}^{3} P_x.(C_m+L_x)))] + [(1-P_L^t).C_m]$$

EC_m	=	the expected cost of adopting control method m in a given zone in year t
P_L	=	Expected prevalence of lice infested flocks in a given zone in year t
C_m	=	the cost of control method m in a given zone
L_x	=	the production loss in a given zone, associated with the level of infestation x
P_x	=	the probability of the level of infestation x resulting
P_e	=	the probability of eradicating lice from a single property with a particular control method

The expected cost of control is expressed in equation 2 as a function of the probability that lice are present (P_L), the actual cost of using control method (C_m), the probability that lice are eradicated from the property with that control method, (P_e), the probability that a given level of infestation occurs, (P_x), and the production losses associated with that level of infestation (L_x). Accordingly, the cost of control will vary depending on the control method used in a given zone. The expected cost of no control is zero if there are no lice present, and if lice are present a heavy infestation is assumed to result if no control is undertaken.The decision frameworks and associated costs are illustrated in Figures 1 and 2, for the 'no control' and 'control' options respectively.

Estimating The Prevalence of Lice Through Time

The expected prevalence of lice from year to year is based on the probability of certain events occurring in the future. Some future events will decrease the prevalence of lice and some will increase the prevalence of lice. The prevalence model is based on the condition given in equation 3.

(3)

$$P_L^t = P_L^{(t-1)} + [(1-P_L^{(t-1)}) . P_I^t] + [P_L^{(t-1)} . P_E^{(t-1)} . P_I^t] - [P_L^{(t-1)} . P_E^t]$$

P_L	=	Expected prevalence of lice infested flocks in a given zone in year t
P_I	=	the probability of flocks being re-infested by lice in a given zone in year t
P_E	=	the probability of eradicating lice from the entire zone

The expected prevalence of lice infested properties in year t for a particular zone is a function of the prevalence of lice infested properties carried over from the previous year, the probability that lice will be eradicated from the zone following control and the re-infestation factor that is applicable in the current year.

Figure 1 The Expected Cost of Not Controlling Lice

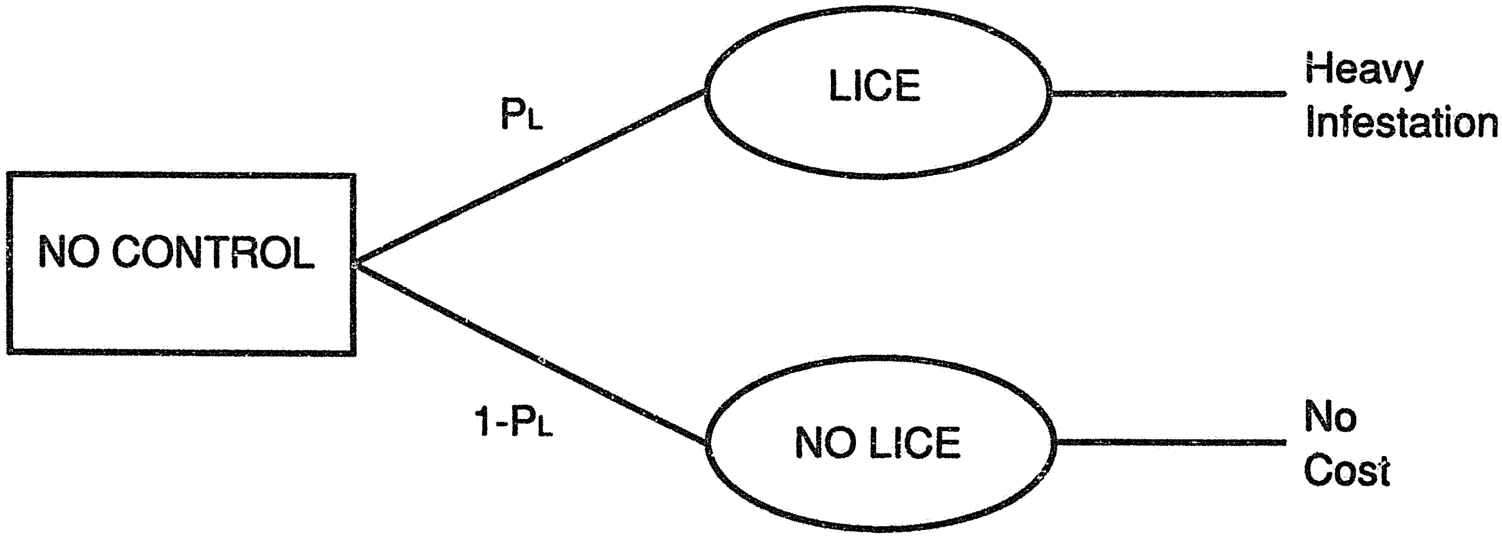
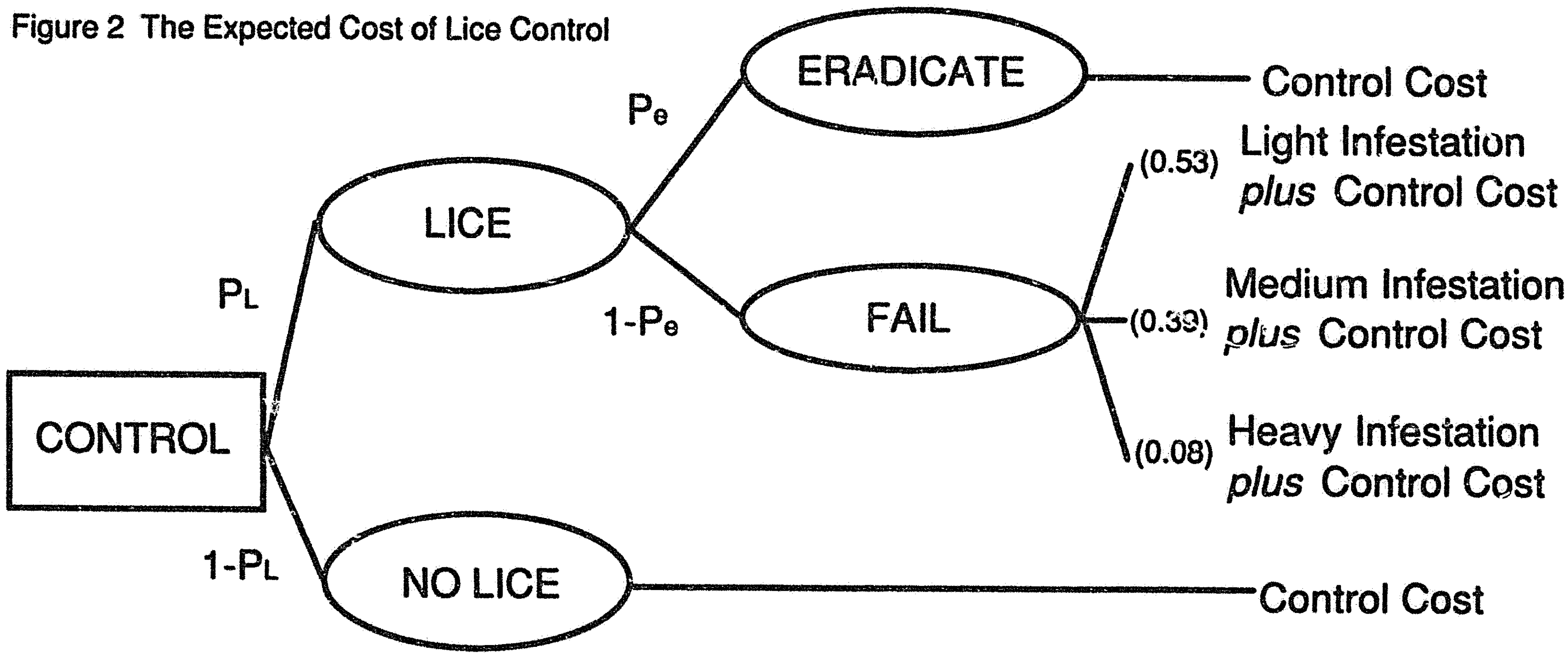


Figure 2 The Expected Cost of Lice Control



The two sources from which prevalence may increase are those properties that did not have lice initially (one minus the percentage of properties that are infested), and those properties from which lice have been eradicated. The amount by which prevalence will increase from one year to another will depend on the size of the re-infestation factor (see equation 5).

The total reduction in prevalence of lice infestations among the properties in a zone will also depend on the adoption rate of each control strategy. The aggregate level of lice eradication for a given zone is represented by equation 4.

(4)

$$P_E^t = \sum_{m=1}^{3} P_{e_m} . A_m$$

A = the percentage adoption among producers of control method m

Adoption rates and success rates were assumed to be constant over different zones, and therefore the reduction in prevalence in each zone is a function of the initial prevalence for the zone, and the weighted average control eradication rate. The proportion of producers adopting each control method were taken as 33.0%, 47.5% and 48.5% for shower dip, plunge dip and backlines respectively (Jordan et. al., 1988). It is assumed that these control measures are the only means of completely eradicating lice from a property.

The probability that each control option will successfully eradicate, has been estimated at 12 per cent, 71 per cent and 18 per cent, for shower dipping, plunge dipping and backline treatments respectively (NSW Agriculture, 1991). The success rate for plunge dips was unreasonably high, and can possibly be explained by the small sample of farmers that used plunge dips (Ian Roth, pers.comm., NSW Agriculture). However as this was the only information available it was used in the analysis.

The rate at which properties become re-infested is termed the re-infestation factor, and was estimated for each zone using a Reed-Frost type equation given by equation 5 below (Western Australia Department of Agriculture, 1990). Initially, the prevalence of lice in each zone in period t=1 was set equal to the prevalence of lice in t=t-1, by equating the number of properties eradicating lice with the number of properties that become re-infested.

(5)

$$P_I = 1-(1-k.P_n^t)^n.(1-k.P_s^t)^s$$

P_i	=	probability of re-infestation in a given zone
k	=	the rate of spread
P_n	=	probability that purchased sheep are infested in a given zone
n	=	number of trading contracts
P_s	=	probability that stray sheep will be infested in a given zone
s	=	number of sheep that stray onto property in year t

In the estimation of P_i it was assumed that the probability that purchased sheep will be infested and the probability that strays will be infested were both equal to the general level of prevalence in the zone. The number of trading contracts made per year refers to the number of lines of sheep purchased and an average value of 0.6 was used. Also, it was considered that 2 sheep was a reasonable estimate for the average number of sheep that stray onto a property in any one year (Western Australia Department of Agriculture, 1990).

The Severity of Infestation

To determine the probability of the resulting lice infestation (from failed control) developing into each of the three levels of infestation, a lice population simulation model was used. The starting prevalence for flocks where control has failed to eradicate, are assumed to be 75 per cent lightly infested and 25 per cent with a medium infestation. It was assumed that the application of a treatment would not leave a heavy infestation immediately after application.

The simulation model was developed by the Department of Agriculture in Western Australia (1990), to predict the development of a lice infestation over a period of one year, on a single sheep, in the absence of mid-year control. The model draws randomly from one of five years of weather data, obtained from the National Climate Centre, Melbourne. The lice population is determined on a daily basis, according to the death rates at various stages of the life-cycle, also combining the anticipated effects of weather changes. Only female lice are simulated, as the sex ratio of lice is 1:1, so that the total number of lice on the sheep at any one time is twice that of females. The input to the model is the number of females already existing on the sheep, which is used to determine the resulting level of infestation on the sheep at the end of the year. Once a total number of lice of 400,000 is reached, the model terminates.

The levels of infestation are described in terms of the number of lice on a sheep, as per the classifications specified by Wilkinson (1988). In terms of female lice, these numbers will be halved. The model was run with 25 different initial female lice populations that would be classed as light infestations, ranging from 100 to 2500 (half the total number of lice on the sheep). A further 11 initial female lice populations ranging from 5,000 to 125,000 (half the total number of lice on the sheep) were run, which represented sheep with an initial infestation that would be classed as medium. Each of the 26 starting populations were run 5 times, to incorporate the effects of changing weather conditions at each starting population.

The results were then grouped according to whether they represented light, medium or heavy infestations. The probability of control, that fails to eradicate, resulting in a given level of flock infestation was calculated from the following equation:

(6)

$$P_x=\sum_{b=1}^{2} P(\alpha_x/\beta_b)$$

P_x	=	the probability of the level of infestation x resulting
α_x	=	the year-end level of infestation in a flock, resulting when control fails to eradicate at the start of the year (output from the simulation model).
β_b	=	the initial level of infestation resulting from control that fails to eradicate (1=light, 2=medium)

In summary, of the simulations that had an initial starting population that would be classified as light, 67 per cent remained lightly infested, 33 per cent developed medium infestations, and no heavy infestations developed. Of those simulations that began with a population that would be classified as medium, 9 per cent dropped to light, 56 per cent remained at a medium infestation, and 35 per cent developed heavy infestations. Based on the probabilities that 75 per cent of control failures will leave only light infestations, and 25 per cent will leave medium infestations, it is estimated from equation 6 that of all control failures, 53 per cent will develop light infestations, 39 per cent will develop medium infestations, and 8 per cent will develop heavy infestations, by the end of the year (time of next treatment).

Expected Costs of Diagnostic Testing for Sheep Lice

The expected cost of three different lice diagnostic tests were also incorporated into the model. The first test considered was a visual inspection of the flock just prior to shearing. The main problem with this method of diagnostic testing is the difficulty in detecting light infestations (partially dependent on the skill of the inspector. The second test was a post-shearing Lice Detection Test (LDT), from which the results are received within six weeks. With this method an additional muster for treatment is only required if lice are found. Two potential problems with this method are that it is difficult to trace lice-infested wool from small lots, and also it is not possible to treat with backlines once the sheep nave grown six weeks of wool. The third test was a pre-shearing LDT. It involves taking a wool sample from a portion of the flock (assumed to be 25% in this analysis) at least six weeks prior to shearing, so that the test results are received in time to determine whether treatment is necessary, in which case the treatment is applied immediately after shearing.

The possible outcomes associated with diagnostic testing are shown in Figure 3. The expected costs of diagnostic testing can be expressed by equation 7.

(7)

$$ED_y^t = P_L^t . P_v . (EC^{*t} + D_y) + P_L^t . (1-P_v) . (L_3 + D_y) + (1-P_L^t) . (1-P_g) . (C^* + D_y) + (1-P_L^t) . P_g . D_y$$

ED_y	=	expected cost of diagnostic test y in year t
EC^*	=	minimum expected cost control method available in year t with test y
C^*	=	minimum cost control method available in year t with test y
D_y	=	cost of diagnostic test y
P_v	=	test sensitivity, ie. the probability that test y will correctly identify a true positive as a positive
P_g	=	test specificity, ie. the probability that test y will correctly identify a true negative as a negative
L_3	=	production loss for infestation level x (3=heavy)
y	=	diagnostic test method

The sensitivity of a pre-shearing visual inspection method of testing for lice was taken to be 60 per cent for a skilled inspector (Hall, 1989), and it is assumed to have 100 per cent specificity, that is, there is no chance of an inspector seeing lice when they do not actually exist. Thus the probability of failing to detect an infestation that actually exists will be 40 per cent, and the probability of detecting an infestation in a flock that is free of lice will be 0 per cent.

The sensitivity of the Lice Detection Test (LDT), which is used in both the second and third test options, was taken to be 80 per cent sensitive and 95 per cent specific ((Hall, 1989), (Dr Chris Hawkins, pers.comm., Regional Veterinary Epidemiologist, Western Australian Department of Agriculture, 1991). Thus with the LDT, the probability of having lice and not detecting will be 20 per cent, and the probability of detecting lice when lice are not present will be 5 per cent.

The available data on the costs of the test options were expressed as average costs per property, $25 for the LDT and $65 for the on-farm visual inspection (Wilkinson and Buckman, 1989). To convert these costs to a per sheep cost it was necessary to determine the average number of sheep on properties in NSW. The average number of sheep on properties in NSW were taken as 5378, 3042 and 3241 for the pastoral, sheep-wheat and high-rainfall zones respectively (Nosworthy, 1989). After applying weights for the number of sheep in each zone in NSW, the average property in NSW is estimated to stock 3375 sheep. As a result, the cost of the LDT was estimated at $0.01/sheep, and the cost of the on-farm visual inspection was estimated at $0.02/sheep.

The cost of the pre-shearing LDT was the actual cost of the LDT, as well as the costs of mustering 25 per cent of the flock (assumed to be 25 per cent of the mustering costs for the zone) and obtaining the sample to send for the LDT. The cost of obtaining the sample is based on one third of the contract rate for crutching a sheep ($0.61/sheep, (Beck et.al.,1985)), and is thus approximately $0.20/sheep. It is possible that there may also be some cost due to disrupting the fleece to obtain the sample, however this cost is considered too uncertain to be considered in this analysis. The total cost/sheep of the pre-shearing test will be $0.31, $0.24 and $0.24, in the pastoral, sheep-wheat and high-rainfall zones respectively.

Application of the Model: The Expected Cost of Lice

The expected costs of lice in year t, will depend both on the adoption rate of the control options in year t, and on the expected cost of the control options in year t, as shown by the following equation.

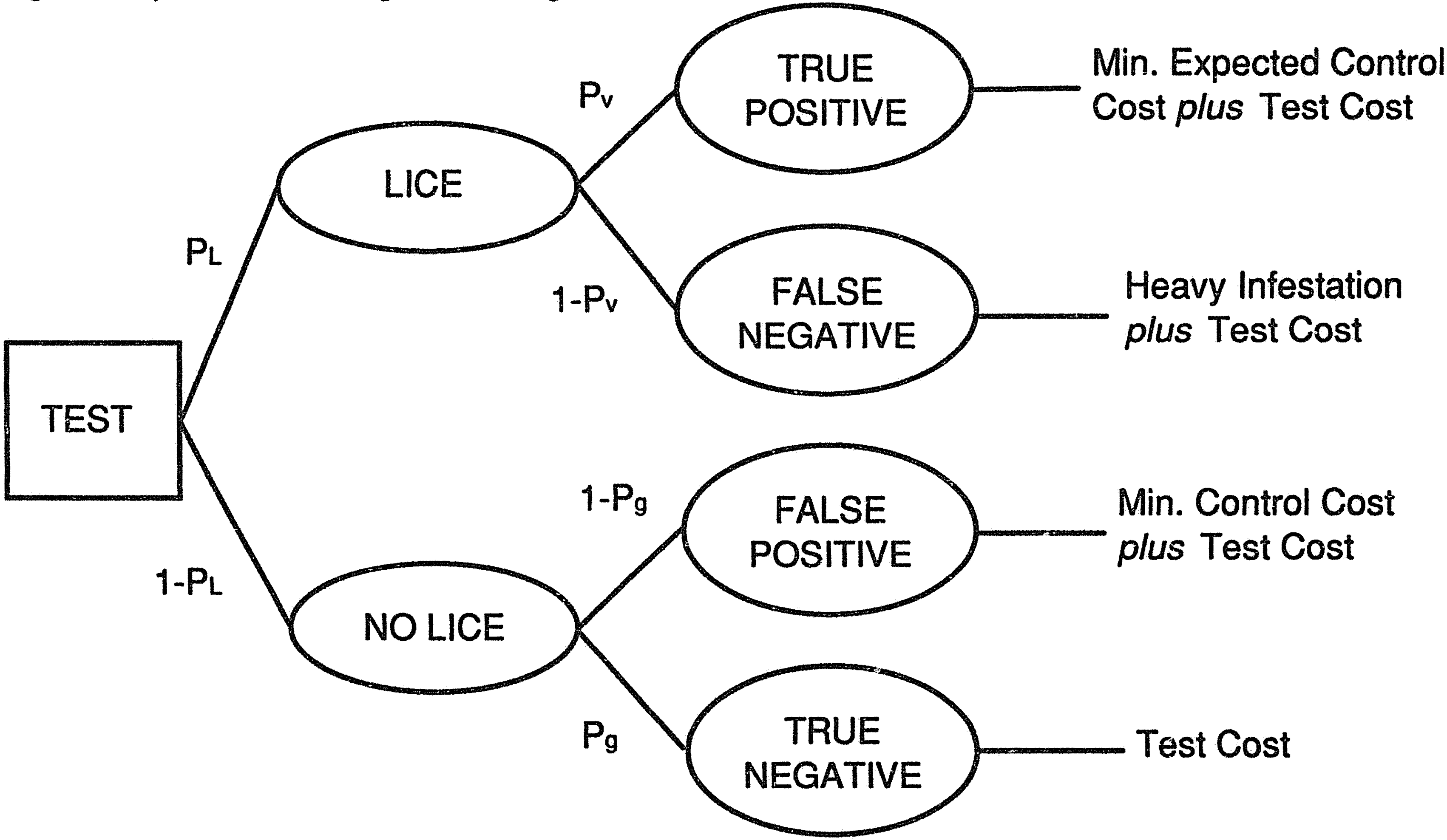
(8)

$$EL_t = \sum_{m=1}^{4} EC_{mt} \cdot A_{mt}$$

EL	=	the expected cost of lice in year t
EC	=	the expected cost of control method m in year t (1=shower dip, 2=plunge dip, 3=backline, 4=no control)
A	=	the adoption rate of method m, in year t

With extension the adoption rate A, will change for the first 10 years, as the extension adoption rate approaches its 10% ceiling level. The cost savings from extension are generated by promoting the use of the control option with the least expected cost. At the same time, the proportion of farmers using the relatively more costly control methods will decline. Further savings will also be achieved if the option being promoted (with the least expected cost) is also the option with the greatest probability of eradicating lice from a property. Due to the difficulty in accurately estimating the success rates (eradication) for different control options, sensitivity analysis was conducted to determine the effect of uncertain success rates on the expected costs of control.

Figure 3 Expected Cost of Diagnostic Testing for Lice



RESULTS

Estimated Annual Costs of Lice, 1990-91

The estimated production loss per sheep for each level of infestation is reported by geographic zone in Table 4 below. These estimates are obtained from equation 1, and are the values that are employed in the decision framework for calculating the expected costs of the various control and diagnostic test options.

Table 4 Production Losses by Level of Infestation, $'s/sheep

Level of Infestation	Pastoral	Sheep-wheat	High-rainfall
light	2.98	2.95	3.09
medium	6.55	6.48	6.77
heavy	10.98	10.85	11.35

The total production losses incurred by producers in NSW were $110m. Of the total production losses for NSW, $82m were borne by producers in the sheep-wheat zone, while the production losses for the pastoral and high rainfall zones were $17m and $12m respectively. The total production losses incurred in Australia were $216m. The total expenditure on lice control in NSW was estimated at $48m, while the total for Australia was estimated as $134m. For a more detailed discussion of the derivation of these results, see Taleb (1991).

Expected Costs of Control in Equilibrium

The expected costs in equilibrium are the expected costs of the control methods when the lice prevalence model described above is assumed to result in a constant prevalence each year. Table 5 shows the expected costs for shower dips, plunge dips, backline treatments, and for no control. Plunge dipping is the minimum expected cost control method in all zones, with a weighted average (weighted by the sheep numbers in each zone) expected cost of $1.11 per sheep. Although plunge dipping has an actual treatment cost that is considerably higher than for backlines, the eradication success rate is 71 percent for plunge dipping and only 18 per cent for backline treatments. Hence, plunge dipping has the lowest expected cost due to the low probability of incurring production losses during the year. Shower dipping has the highest expected cost out of the control methods, because it has the highest actual cost, and the lowest eradication rate, 12 per cent.

The expected costs of each control option are lowest in the high-rainfall zone, and highest in the pastoral zone. This is explained by the actual costs of control which are highest in the pastoral zone, the full amount of which is included in the expected costs of control. Although average production losses are higher in the high-rainfall zone, they are only partially reflected in the expected cost of control because they are based on the probability of the flock being lice infested (prevalence), which itself is considerably lower in the high-rainfall zone. The zonal distribution of the expected costs of "backline" and "no control" are directly correlated with prevalence. The actual cost of a backline treatment is constant across the three zones, so that the zonal distribution is based on the expected production loss (a function of prevalence). Similarly, the expected cost of "no control" (equal to the expected production loss) is also a function of prevalence.

Table 5 Expected Annual Costs of Control Under Equilibrium, $'s/hd.

Control Method	Pastoral	Sheep-wheat	High-rainfall	Weighted Average
Shower Dip	2.74	2.36	1.36	2.17
Plunge Dip	1.45	1.15	0.81	1.11
Backline	1.93	1.82	0.89	1.62
No Control	4.39	4.08	1.62	3.55

Plunge dipping was found to have the least expected cost based on the control success rate of 71 %. Due to the uncertainty of this parameter, sensitivity analysis was conducted to find the success rate for plunge dipping that would represent the break-even point between plunge dipping and the next least cost control option, backlines. These rates were 47%, 35% and 60% for the pastoral, sheep-wheat and high rainfall zones respectively. These results have important implications for the development of lice control strategies. When the success rate for plunge dipping is less than these break-even rates but greater than the backline success rate (18% in this analysis), then an extension policy aimed at promoting the least cost control option, will not simultaneously result in a decline in the prevalence of lice infested properties in that zone. Under such circumstances it is necessary to consider the effects of the changing prevalence on the expected costs of control (see Table 6 below), and hence adjustments may be required in terms of the control option that is promoted by extension.

The effect of different prevalence levels on the relative cost effectiveness of each control option can be seen from Table 6 below. Only the post-shearing Lice Detection Test (LDT) has been considered from the various test options. In each zone, the expected cost of the backline option is less than the expected cost of the plunge dip option for prevalence levels of 10% or less. As prevalence rises, plunge dipping becomes more cost effective due to its superior eradication success rate. In both the high rainfall and the sheep-wheat zones plunge dipping is more cost effective than the backline control option at a prevalence of 20%, where as in the pastoral zone backlines are still more cost effective at a prevalence of 20%, and it is not until a prevalence of 30% that plunge dipping is relatively more cost effective than backlines. From these results, it can be inferred that there is a trade-off between the actual cost of control and the expected production losses when selecting a control option. When prevalence levels are low or the wool value is low, then the backline control option with lower actual costs and a lower eradication rate will be preferred to plunge dipping. Conversely, when prevalence and wool value are high then the control option with the highest eradication rate will be more cost effective.

Table 6 The Expected Annual Costs of Lice as a Function of Prevalence, by Geographic Zone.

PASTORAL ZONE			
Prevalence (%)	10	20	30
Shower Dip ($/hd)	1.42	1.86	2.30
Plunge Dip ($/hd)	1.01	1.16	1.30
Backline ($/hd)	0.70	1.11	1.52
Post-shear LDT ($/hd)	0.35	0.68	1.02
SHEEP-WHEAT ZONE			
Prevalence (%)	10	20	30
Shower Dip ($/hd)	1.15	1.59	2.02
Plunge Dip ($/hd)	0.75	0.90	1.04
Backline ($/hd)	0.69	1.10	1.51
Post-shear LDT ($/hd)	0.32	0.62	0.94
HIGH RAIN ZONE			
Prevalence (%)	10	20	30
Shower Dip ($/hd)	1.42	1.86	2.30
Plunge Dip ($/hd)	1.01	1.16	1.30
Backline ($/hd)	0.70	1.11	1.52
Post-shear LDT ($/hd)	0.35	0.68	1.02

The Expected Costs of Diagnostic Testing in Equilibrium

The expected costs of diagnostic testing are shown in Table 7 below. The no test option is the control option with the lowest expected cost. The post-shearing Lice Detection Test (LDT) appears to be the most cost effective option with a weighted average expected cost of $1.06 per sheep, compared to $1.11 per sheep for "no test". The expected cost of the pre-shearing visual test has the highest weighted average, $167 per sheep, predominantly due to the higher probability of diagnosing a false negative (in which case no treatment will be applied and a heavy infestation is assumed to result), the cost of which increases rapidly with prevalence. The pre-shearing LDT ($1.30/sheep) is less cost effective than the post-shearing LDT ($1.06/sheep) due to the higher actual test costs. In equilibrium, the expected costs of control are constant over time because the prevalence is constant over time, and the minimum expected cost of control remains that of plunge dipping. However, with extension and a non-constant lice prevalence it is possible that backlines may in year t become more cost effective than plunge dipping. When control is required under the testing options, it is assumed that the minimum expected cost control option in year t is adopted. Thus, where backlines become more cost effective than plunge dipping, the expected cost of the post-shearing LDT will not be reduced because backlines are not available with that test.

The expected cost of the post-shearing LDT is lowest in the low prevalence high-rainfall zone, reflecting the greater benefits of testing when the probability of lice being present is low, and there is less chance of incurring production losses when the test diagnoses a false negative. As prevalence rises the expected cost of diagnosing a false negative increases. In the sheep-wheat zone the expected cost of not testing ($1.15) is lower than the expected cost of testing ($1.20), due to the higher prevalence and the lower actual costs of control (which are less likely to be incurred with testing). In the pastoral zone, higher expected costs of diagnosing a false negative due to the higher prevalence, is more than offset by the saving from the reduced likelihood of having to treat the sheep.

Table 7 Expected Annual Costs of Diagnostic Testing, $'s/hd.

Test Method	Pastoral	Sheep-wheat	High-rain	Weighted Average
No Test	1.45	1.15	0.81	1.11
Pre-shear Visual	2.12	1.91	0.74	1.67
Post-shear LDT	1.39	1.20	0.46	1.06
Pre-shear LDT	1.69	1.44	0.69	1.30

The expected cost savings from diagnostic testing compared the cost of not testing (assumed to be the minimum expected cost control method), are presented in Table 8 below. The benefits from testing are predominantly in the high-rainfall zone, where prevalence levels are low. In summary, the pre-shearing visual test would appear to be cost effective only in the high-rainfall zone, the post-shearing LDT appears to be cost effective in the pastoral and high-rainfall zones, but not in the sheep-wheat zone, and the pre-shearing LDT would appear to be cost effective only in the high-rainfall zone.

Table 8 Expected Annual Cost Saving From Testing, $'s/hd.

Test Method	Pastoral	Sheep-wheat	High-rain	Weighted Average
Pre-shear Visual	(0.67)	(0.76)	0.07	(0.56)
Post-shear LDT	0.06	(0.05)	0.35	0.05
Pre-shear LDT	(0.24)	(0.29)	0.12	(0.19)

An Application: The Effects of Extension

The results from modelling the effects of extension (see equation 8) are reported in Table 9 below. The cost savings are expressed in present value terms, and represent the expected cost saving per sheep in NSW over a 20 year period.

Table 9 Comparison of Costs of Lice With and Without Extension, Present Value over 20 Years, $'s/hd.

	Pastoral	Sheep-wheat	High-rainfall	Weighted Average
Current	34.98	30.90	16.59	28.10
Extension	32.15	28.10	14.78	25.58
Cost Saving	2.83	2.80	1.81	2.52

The distribution of the benefits from extension was estimated by utilising an Edwards Freebairn (1982) type model, the results of which are reported in Table 10 below. An extension policy generates productivity gains, which can be translated into a supply curve shift for the adopting region (NSW). As a result of a fall in industry prices, the gain to Australian producers as a whole will be less than the gain to NSW producers. It is also important to divide the gains in consumer surplus between Australian and overseas consumers, particularly for an export orientated commodity such as wool. Further details on the specifications used in modelling the supply shift and the resulting effects can be seen in Taleb (1991).

Table 10 Distribution of Benefits from Extension, Present Value over 20 Years, $M's.

Total Gain	180.40
NSW Producers	124.61
Australian Producers	99.10
Australian Consumers	48.86
Overseas Consumers	32.45
Australian Net Gain	147.96

Given an approximate cost of a lice extension campaign as $16m (based on the cost of the Western Australia Lice Eradication Campaign, present value for 10 years of extension), it was estimated that the approximate benefit cost ratio would be 9:1 for the extension campaign modelled.

CONCLUSION

The results of this study clearly demonstrate the significance of sheep lice throughout Australia. The annual costs of lice were estimated to be in the order of $216m in production losses and $134m in private expenditure on lice control. The total annual cost of lice in NSW was estimated at $158m, representing both control costs and production losses. At the same time lice prevalence levels in NSW are in the order of 32 per cent, and up to 40 per cent in the pastoral zone.

The formulation of lice control strategies is a dynamic problem, requiring periodic review and adjustment in response to changing lice prevalence through time. It may be inappropriate for an extension campaign to promote a single control method over the duration of the campaign, and control strategies may need to be revised with respect to changing circumstances.

Extension campaigns should also recognise that different lice control scenarios that exist for different geographic conditions. For example, the post-shearing LDT option is estimated to be the most cost effective strategy in the high-rainfall and pastoral zones, but plunge dipping is estimated to be the most cost-effective strategy in the sheep-wheat zone. Thus, to maximise the benefits from extension it may be necessary to devise different lice control strategies for different regions.

The results of this study were extremely sensitive to key data. An area that has received little attention, is the estimation of eradication success rates for particular control methods. Although such data is difficult to collect, it is essential to have reasonable estimates for the success rates of control methods to be able to pursue a lice control strategy with confidence that it is the most effective strategy available.

Alternative control technologies must also be considered, with the methods currently available providing a benchmark for comparison. This study only considered three methods of control and three methods of testing. There is potential for future research in both control and diagnostic testing methods. An example of a research area with a wide scope for productivity gains is the pre-shearing LDT. New sampling methods, such as vacuum sampling for the pre-shearing LDT are already being developed, and are likely to reduce the sampling cost and eliminate the fleece damage associated with shearing wool samples from sheep.

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