Combined management options to reduce sheep lice prevalence and its associated costs

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Honours Thesis

University of Tasmania, Hobart

October 2014

Declaration

Submitted in partial fulfilment of the requirements for the degree of Bachelor of Agricultural Science with honours, University of Tasmania, Hobart.

October 2014

I hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma and, to the best of my knowledge, contains no copy or paraphrase or material published or written by any other person, except where due reference is made in the text of this thesis.

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23rd October 2014

Acknowledgements

I would like to thank my supervisor Brian Horton for his knowledge, technical support and commitment to this project. I would also like to thank my co-supervisors Anna Carew and David Parsons for their support throughout this project, the Australian Wool Education Trust for providing funding and the University of Tasmania.

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Abstract

Combinations of management options were investigated as potential lice control strategies to determine if combinations of specific lice management practices could be used to provide reductions in lice prevalence and its associated costs.

Using a predictive model, a series of management practices were used to determine if combinations could provide reductions in lice prevalence and costs when simulated over a 20 year period. The predictive model used in this study was adapted from a model developed previously based on the findings from a 2004 national lice survey. From the 2004 survey the model includes nine different sheep production regions across Australia all of which have different lice prevalences, number of sheep and proportion of properties. The lice prevalence model uses a series of equations to determine the effects of specific management options on the lice prevalence and net present value results over a 20 year period.

Management options included in the model are eradication rate, lice detection, intervention level, biosecurity of stray sheep and biosecurity of purchased sheep. Specific costs and benefits of management options were calculated based on published data or were comparable with standard industry costs.

Lice detection methods and intervention levels were found to provide minimal reductions in costs or lice prevalence when used in combination with one other management factor. However when used in combination with two or more management factors these options were found to provide additional useful reductions in lice prevalence and lice costs.

Combinations of eradication rate and biosecurity of purchases were found to provide the greatest reductions in lice prevalence and costs. With current management practices, lice prevalence is at 16.3% of properties infested and lice costs are approximately 893 cents per sheep over 20 years. With appropriate management over 20 years lice prevalence reduced to 0.48% of properties infested and cost can be reduced to 421 cents per sheep per years. Combinations of several management options were then investigated to determine if the use of three or more management options could improve reductions. The results from this study confirm combinations of management options can provide valuable reductions in lice prevalence and lice costs. Combinations of eradication rate, biosecurity of purchased sheep, intervention level and lice detection methods were found to provide the greatest reductions in lice prevalence and costs over a 20 year period.

Biosecurity of purchased sheep was found to be a more cost-effective option than biosecurity of strays through improved fencing as this option has a greater effect on reducing regional lice prevalence. Combinations of biosecurity of purchases and biosecurity of strays were found to not be cost-effective.

The findings from this study can be used can be used to further investigate the use of predictive models in lice control if the reliance on chemical treatments is to be reduced. The lice prevalence model could potentially be developed for industry use to help identify possible lice control strategies and provide information to support lice management decision making.

1. Literature Review

Introduction

Australia is the world's largest wool producing country, producing approximately 25% of the world's wool (ABS, 2005) and wool is a highly important industry for the Australian economy as it generated $2.7 billion in 2011/12 (ABS, 2013). Wool plays a large role in Tasmania's agricultural industry producing over $80 million dollars per year and employing over 1000 people (DPIPWE, 2007). Qualities such as low vegetable matter, high strength and fine micron counts contribute to the superior quality of Tasmanian produced wool products (DPIPWE, 2007, Lance, 2001). Approximately 90% of the wool produced in Tasmania is exported to regions such as Europe and China (DPIPWE, 2007).

Sheep body lice (*Bovicola ovis*) are a serious issue for farmers and wool producers in Australia. Lice infestations can cause significant damage to wool resulting in decreased quality and economic losses (Niven and Pritchard, 1985, Wilkinson et al., 1982). Lice infestations cost the Australian Wool Industry $123 million per year (Sackett et al., 2006) and have become the third most economically significant health management issue for sheep in Australia (James et al., 2002a). Sheep infested with lice produce less wool and wool of a poorer quality than that of uninfested sheep (Wilkinson et al., 1982) and, if left untreated, lice infestations can cause losses of up to 30% of wool value (Niven and Pritchard, 1985).

Approximately 60% of the total costs associated with lice infestation in Australia were from treatments used to control infestations (Sackett et al., 2006). For example, use of a long wool treatment to reduce wool losses can cost approximately $1 per annum per sheep treated (Lucas and Horton, 2014). Treatment costs are high as a large proportion of sheep are treated for lice every year even when lice are not detected (Reeve and Thompson, 2005). Costs could be reduced if unnecessary treatments could be eliminated. However, this would require improvement of lice detection so that treatments would only be applied when lice were actually present.

An Australia-wide lice prevalence survey undertaken in 2004 estimated lice prevalence at 20% of flocks infested (Walkden-Brown et al., 2006). Popp et al., (2012) speculated, however, that lice prevalence has since increased. This perceived increase in lice prevalence throughout Australia may have been caused through increasing resistance to insect growth regulator treatments, (James et al., 2008, Levot and Sales, 2008b), inadequate treatment applications, (Levot and Sales, 2008b) or poor biosecurity (Joshua et al., 2010, Horton and Carew, 2014). Appropriate control of lice infestations depends on adequate detection, treatment and prevention, if lice prevalence is to be reduced (Morcombe et al., 1996, James et al., 2002b).

This literature review investigates the biology of lice and how they are spread, the current management practices used such as lice detection, lice biosecurity and lice eradication and the associated issues with resistance and assesses the use of statistical models in identifying areas of improvement within lice control. This study highlights the need for further development of decision support tools such as the Lice Prevalence Model which can be used to provide information to producers and extension officers on lice control strategies.

Lice Biology and Spread

Sheep body lice (*Bovicola ovis*) are obligate parasites of sheep that live on the host through all life stages (Crawford et al., 2001). Lice are between 1.5mm to 2mm in size making them extremely difficult to see when on sheep (LiceBoss, 2013). They reside on wool follicles where they feed on skin cells, wax and bacteria associated with the sheep skin surface. Lice infestations cause the skin to become irritated which results in sheep rubbing up against objects such as fences to relieve itching. This rubbing causes wool breakage leading to decreases in quality and quantity of wool (Wilkinson et al., 1982).

Lice are extremely vulnerable to environmental conditions and require a narrow range of temperature and humidity in order to survive (Crawford et al., 2001). At temperatures of 37°C with humidity between 70% and 90% is optimal, with lice having the ability to move up and down wool fibres in order to obtain these preferred conditions. Females require temperatures between 30°C and 40°C in order to reproduce successfully. Temperatures that are too high or too low will cause decreases in the number of eggs laid and impair nymph survival, while at humidities above 90% eggs will fail to hatch (Crawford et al., 2001). Heavy rain can also have an effect on lice populations; if the fleece becomes saturated for more than 6 hours, nymphs and adult lice can drown and eggs fail to hatch (Murray, 1968).

Due to the slow reproductive rate of lice when compared to other insect pests on farms, infestations may remain undetected for months after flock exposure. Female lice can lay up to two eggs every three days, depending on environmental conditions (Crawford et al., 2001). The eggs are attached to wool fibres close to the skin and hatch after about 10 days. Nymphs will go through three instar stages where their skin is shed before becoming an adult which takes approximately 21 days (Joshua et al., 2010). All life stages can be found in the tip wool, but most are adults or third instar nymphs (Murray, 1968).

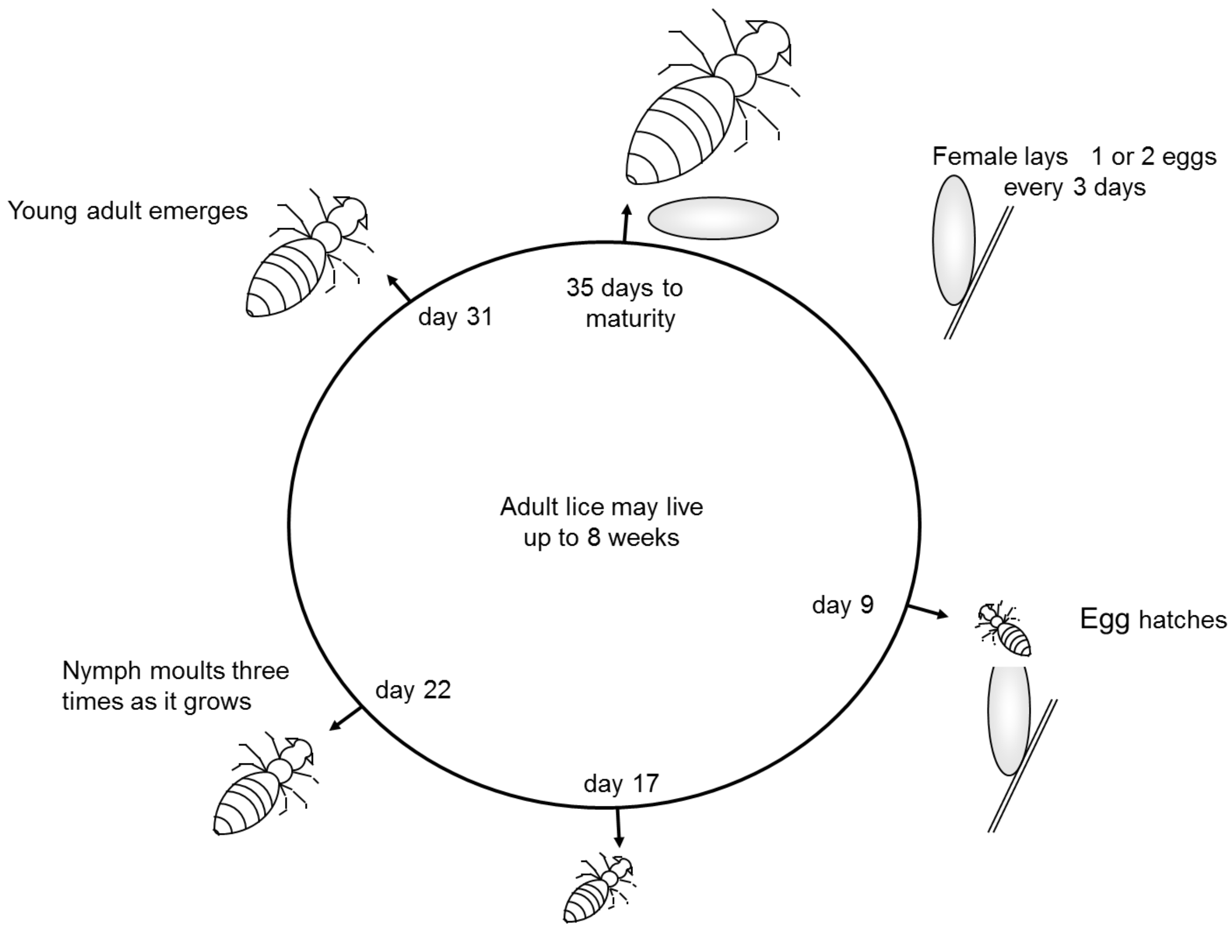

Figure 1.1 *Life cycle of sheep body louse (Bovicola ovis) from* (Horton et al., 1998).

Lice do not have the ability to fly or jump; they rely on direct contact to spread by individuals walking from the wool of one sheep to another (Levot, 1995, Lymbery and Dadour, 1999, James et al., 2002b). Lice will stay close to sheep skin during daylight and move along to the end of the wool follicle during darkness. This allows for lice to directly transfer to another individual when sheep are in close contact, however lice will also transfer during daylight as close contact of wool provides sufficient darkness. It has been suggested that these insects can spread through contact with wool on fences, and wool or wool grease found in shearing sheds, on shears and even on shearer's moccasins. However James et al., (2002b) have suggested this type of transfer would be extremely rare and that direct sheep to sheep contact is the main mechanism for lice transfer. These findings suggested that contact with contaminated tools and facilities is a feasible cause of new infestations, however the chances of this type of transfer occurring would be less likely than sheep to sheep transfer.

Ewe to lamb transmission of lice is an important issue in sheep production. Close contact between ewe and lamb means infested ewes could transfer lice to their lambs very quickly (Joshua et al., 2010). Hence, careful consideration of ewe treatment strategies needs to be made in the lead up to lambing as lice control treatments can take between 2 and 18 weeks for all lice to be killed. An inadequate lag time between treatment and lambing means ewes may still have live lice that can transfer to their untreated lambs, and maintain the infestation (Joshua et al., 2010).

Current Management Practices

- ***Lice Detection***
- ***Biosecurity***
- ***Lice Eradication***

Lice Detection

This section examines the common methods used and compares them on their efficacy, cost and level of expertise required. The methods included are visual inspection, fleece partings, locks wool tests and laboratory testing.

Detection is a key component of lice control because the implementation of appropriate prevention and treatment methods relies heavily on the detection of lice (James et al., 2002b, Morcombe et al., 1996). If undetected at shearing and hence not treated, low level lice infestations may continue until the next shearing (12 months), during which time populations will increase and may significantly damage (or reduce) wool production (Wilkinson et al., 1982). This highlights the need for an effective lice detection test that will provide accurate and fast results and allow farmers to make informed decisions about treating for lice infestations (Morcombe et al., 1996). There are a wide range of methods of lice detection. Simple methods involve looking at sheep and fences for physical signs of rubbing and wool damage. More intensive and more precise methods require fleece partings or using shearers to detect lice. Highly sensitive laboratory tests of wool or wool grease have been available (Popp et al., 2012). These detection methods can be time intensive and vary greatly in cost and accuracy.

Looking for signs of rubbing is less accurate than examining individual sheep through wool partings. However, this visual examination for rubbing is considered less labour intensive than wool partings. A survey of wool producers in three different regions of South Australia found 91% of the producers surveyed checked their sheep for lice. Out of these, 63% checked for signs of rubbing and 39% closely inspected sheep found to be rubbing (James and Riley, 2004).

A two stage sampling method is frequently used to detect lice. The two stage method consists of selecting individuals that show obvious signs of rubbing or wool damage, and inspecting those sheep for visible lice through wool partings (James et al., 2002b). Ten fleece partings focusing on the back and sides of the animal are made on each individual sheep to determine if lice are present (James and Moon, 1999). Increasing the number of sheep inspected (as opposed to increasing the number of partings per sheep) can result in more sensitive lice detection results (James et al., 2002b). Previous studies found 58% and 71% of lightly infested flocks were determined as having lice when five fleece partings were made on 5 and 10 sheep respectively (Morcombe et al., 1996).

The two stage method of lice detection is relatively easy and inexpensive to carry out when compared with other methods such as laboratory tests. However; the sensitivity of wool partings is dependent upon several factors including the prevalence of lice within the flock and severity of infestation, the number of sheep examined, number of partings per sheep and also the skill of the inspector (Pearse and Gardner, 1994). A further shortcoming of this method is that there need to be approximately 2000 lice per sheep for lice to be detected at a parting (James et al., 2001). This allows for light infestations to potentially go undetected and can later lead to severe wool damage as the lice population increases. Due to this issue, other methods of lice detection such as the testing of wool and wool grease on shears for traces of lice have been investigated.

A study by Morcombe et al., (1996) assessed the use of fleece partings, lamp tests and table locks tests as lice detection methods. Fleece parting is a simple and cost effective lice detection method that produces quick on-farm results, but has a low sensitivity. Fleece partings consisted of selecting 10 sheep from each mob showing the worst physical signs of lice and making five partings per sheep. Results showed this test to have a mob sensitivity of 0.71. In the lamp test 2g

samples of shorn wool from either 10 or 30 sheep were placed under lamps to repel any lice present in the wool. The lice move onto a black cloth placed under the wool. The number of lice was counted after 5 and 10 minutes. An increase in test sensitivity was seen when a higher number of fleeces were tested with sensitivity readings of 0.63 on 10 fleeces compared to 0.71 on 30 fleeces after 10 minutes and also when test times were increased from 5 to 10 minutes with results of 0.63 and 0.71 respectively from 30 fleeces. The test sensitivity levels are similar in both fleece partings and lamp tests. However, lamp tests may be less labour intensive.
The locks test involves dissolving 30g samples of lock wool in 10% sodium hydroxide. The solution is filtered and the remaining residue is examined under magnification to look for lice. The results showed 87% of lightly infested flocks tested returned positive results when using a locks test method at X40 magnification but only 8% returned positive results when examined at 4x magnification. When the locks tests at 40X magnification was used in conjunction with fleece partings, an increase in detection sensitivity was seen, as 91% of the lightly infested flocks were detected as having lice.

The study by Morcombe (1996) also investigated the ability and accuracy of flock owners to detect lice within a mob. Out of a total of 68 mobs evaluated, the 50 flock owners were able to categorise 12, 26 and 30 of the mobs to be infested, suspect infested or not infested respectively. Of the 26 mobs categorised by owners as suspect infested, 11 of these were confirmed to have lice through fleece partings, lamp tests and locks testing. No evidence of lice was found in the other 15 suspect mobs. Lice were found in all of the 12 mobs categorised as infested, through fleece partings, which showed the mobs to be lightly infested, <1 louse per parting (Wilkinson, 1988). In the 30 mobs categorised as not infested three of these mobs were found to have lice through locks testing at 40x magnification. However, these went undetected in the fleece partings and lamp tests. This suggests the infestations were at an early stage as lice are difficult to detect at low populations (Popp et al., 2012, James et al., 2002b). However the number of fleece partings per sheep could have been increased as this has been shown to obtain more specific results on lice presence and density within flocks (James et al., 2002b).

In 2009, an enzyme-linked immuno-sorbent assay (ELISA) was developed by CSIRO Livestock Industries, Australian Wool Innovation and the NSW Department of Primary Industries, to detect a specific louse protein and therefore detect lice (Popp et al., 2012). This highly sensitive test allowed for low lice levels to be detected but failed to become widely used by producers (Sales and Young, 2009, Popp et al., 2012) due to its cost and delayed results as this means off-shears backline treatments may no longer be an option. Backline treatments should be applied within 24 hours of shearing to be effective and laboratory results could not be returned within this time. Further development of ELISA to detect lice could potentially improve lice control and reduce regional lice prevalence (Popp et al., 2012).

A survey by Popp et al.,(2012) was carried out to examine the effectiveness and specificity of the ELISA laboratory test. Of 173 flocks examined by visual inspection 28 flocks were found to have lice (Popp et al., 2012). A subsample of 24 flocks that were believed to be louse free after visual inspection were further examined through ELISA testing. Four out of these 24 flocks returned positive results for lice and increased the estimated proportion of farms infested with lice from 16.2% to 18.5%, highlighting the limitations of visual detection. The true prevalence estimate considered the proportion of false negatives confirmed through ELISA testing and extrapolated results over the 173 mobs and estimated the true prevalence of lice infestation at 30% of the 173 flocks examined (Popp et al., 2012).

In 2009 the cost of an ELISA test was approximately $134 per sample (Sales and Young, 2009) which equated to approximately 50 cents per sheep based on a flock of 250. As the cost of lice treatment is also approximately 50 cents per sheep, it may be more economically viable for producers to treat for lice rather than paying for highly sensitive testing. This method may become cost effective in situations where lice infestations are suspected. Due to the high costs, this method has not been widely adopted (Popp et al., 2012). Therefore, due to ease of use and instant results wool parting remains the most common lice detection practice amongst Australian wool producers (Morcombe et al., 1996).

Biosecurity

As lice detection can be difficult, biosecurity measures to minimize the introduction of lice through purchased sheep or strays are extremely important. Lice can enter properties throughout the year through purchases and strays and can lead to previously uninfested flocks to become infested. Due to this the management of purchased sheep and strays is a key component of lice prevention.

Purchased sheep should be checked for lice before entering the farm unless buying from a supplier known to be lice free. If lice are present sheep must be quarantined from other flocks until the infested sheep are shorn and treated.

Double fencing of boundaries is often used as a biosecurity method to prevent strays coming into farms and is frequently used as a control method when neighbouring farmers are known to have lice. Improving fences does have high initial costs but may be a cost effective method over the long-term. On lice free properties farmers surveyed believed fencing to be a major defence against lice transmission, but its success highly depends on neighbour cooperation (Horton and Champion, 2001).

A survey of wool producers in South Australia found that overall 91% of the producers surveyed take precautionary actions in order to prevent lice infestations, with the most common method being securing fences (58%) (James and Riley, 2004). Other common preventative strategies included asking the previous owner about past treatments (16%), quarantine or segregation of purchased sheep (15%) and treating the existing flock (14%). However some of these results varied considerably between the high rainfall, cereal/sheep and pastoral regions within South Australia. The percentage of producers who quarantine and segregate purchased sheep was 6% and 11% in pastoral and cereal/sheep regions respectively, compared to 27% in high rainfall areas. Treatment of existing flocks as a precaution was high in Pastoral regions with 30% of producers using this method compared to 13% and 5% using this in the cereal/sheep and high rainfall areas. Some of the variability in these results can be attributed to the different production systems within these three regions. In high rainfall regions there is usually a high density of sheep run over small areas. Whereas in the cereal/sheep region there are usually less sheep which are run in conjunction with cropping systems so the managers tend not to be specialist wool producers. In Pastoral regions mobs are run over huge areas including bushland so fencing can be poor and mobs can be extremely hard to muster. Because prevention and eradication are extremely difficult in pastoral regions, producers tend to rely on annual treatments and treating purchased sheep, to control lice infestations (James and Riley, 2004). The decision on whether to treat purchased sheep can also depend on the number of sheep purchased. If a few rams are purchased then the wool losses through treatment and shearing would be minimal. In contrast, wool losses through treatment and shearing of several hundred ewes would be large and have a significant effect on profit.

Local lice action groups can also be a strategy of lice prevention with the aim of local lice eradication. The purpose of these groups is to get local producers working together to develop plans and strategies to achieve the goal of eradicating lice in the region. This allows farmers to discuss current issues and management strategies associated with lice infestations and provide each other support on how to manage and control these infestations. The success of these groups relies on farmers working together at each stage and having confidence in the eradication plan (Scarlett, 2001, Evans and Karlsson, 2001).

Lice Eradication

Ideally lice infestations can be detected or even prevented, however if lice are able to enter then infested flocks need to be treated straight after shearing to eradicate the infestation. Treatments can either occur on the day of shearing for backline options or no longer than six weeks after shearing for dipping treatment. Several different methods of lice treatment are available and all vary in cost, labor intensity, efficacy and susceptibility to development of resistance. This section examines the different treatment options available and their efficacy.

A study by James and Riley (2004) found that out of 167 farmers surveyed who had treated sheep after the previous shearing, 69% had used a backline treatment, 17% used plunge dipping and 16% used shower dipping as methods of lice treatment. Backline treatments are commonly used for lice control due to their ease of use and reduced labour when compared to other treatment methods such as dipping and showering (Table 1). The insect growth regulators diflubenzuron and triflumuron account for over 70% of the total lice control treatments in Australia (James et al., 2008) with 50% of Survey respondents in South Australia identifying insect growth regulator backline treatments as their method of lice control (James and Riley, 2004). However in recent years the suspected resistance to these insect growth regulator treatments has increasingly become an issue for sheep producers in Australia (Levot, 2012).

Backline treatments were first introduced to Australia in 1981 for synthetic pyrethroids (Bayvel et al., 1981) and currently dominate the lice control market (James et al., 2008). The development of backline treatments created an easy alternative to traditional dipping methods. Reduced labor requirements, decreased disease risks and no remustering after shearing all contribute to the huge practical advantage of this treatment (James, 2002).

Dipping is a traditional method of lice control and was commonly used before the development of backline treatments in the early 1990’s (James et al., 2008). The use of dips such as plunge, shower and cage can be effective methods of treatment application when used appropriately. These methods are considerably more labour intensive than backline applications as more care is involved to ensure adequate wetting of each sheep. Appropriate use of these methods involves maintaining chemical concentration throughout flock treatment as stripping can be a problem (see below).

A large proportion of plunge dips used are not long enough as a length of 9 metres is recommended (Lund and Levot, 2001b) in order for sheep to gain effective body coverage. In addition recommendations state that sheep should be pushed back and dunked at least twice after entering the dip to improve wetting (Lund and Levot, 2001b). This greatly increases the labour involved when compared to shower and cage dipping and requires two people to dunk sheep and one person to feed sheep into the dip. Whereas shower and cage dipping methods can be carried out either by two people or by one person and the help of a dog.

Shower and cage dips are less commonly used methods of treatment application. Shower dips are prone to mechanical issues that prevent them from working effectively and require a high level of maintenance (Lund and Levot, 2001b). Furthermore this method is affected more by stripping than plunge dips due to longer treatments of 12 minutes (see below). Both the mechanical issues and cost of shower dips negatively affects their widespread use. Immersion cage dips are more efficient than plunge dipping as both the amount of time in solution and dunking can be controlled by the operator. Due to this the system is less labour intensive than plunge dipping, however as the infrastructure is extremely expensive these systems are mainly used by contractors.

Diazinon is a broad-spectrum organophosphorus insecticide used for external parasite control on sheep and cattle (Aggarwal et al., 2013). A survey of farmers in South Australia found organophosphates to be most commonly used for shower and plunge dipping (James and Riley, 2004). A 2006 survey found that organophosphates, mostly diazinon were used by 84% of producers using plunge dips, 69% of producers using shower dips and 83% of contract dippers (Walkden-Brown et al., 2006). Stripping dips are an issue when using fat soluble chemical ingredients such as diazinon (Lund and Levot, 2001a). These chemicals will dissolve in the wool grease rather than in the dip solution itself resulting in decreases in chemical concentration with each sheep dipped. Chemical concentration needs to be constantly maintained and, if not, treatment will become less effective and may fail to control lice (James and Riley, 2004). Organophosphates are still used as a lousicide treatment, but when applied through shower and plunge dipping treatments on short wool, use of the recommended procedure may fail to maintain an adequate concentration to kill all the lice (Lund and Levot, 2001a).

Table 1. *Advantages and disadvantages of different treatment methods. Adapted from (LiceBoss, 2013).*

Treatment Method	**Advantages**	**Disadvantages**
Backline	Easy to use and not labour intensive. Don't need to re-muster sheep after shearing. Less risk of leaving sheep untreated as treated sheep can be recognised by dye. Easy to treat a small number of sheep such as stragglers. Easy to apply correct dose. Less risk of operator exposure to chemicals through splashing. No infrastructure required. No risk of transfer of disease during treatment.	Recommended to treat within 24 hours of shearing. Can often take over 6 weeks to kill all lice. Uneven chemical distribution means if not applied correctly it will not work. Uneven chemical coverage creates increased risk of resistance developing. Will not work effectively on poorly shorn sheep or sheep with dermo infections.
Dipping – Plunge, Shower and Cage	Some chemicals can kill all lice quickly. Even chemical distribution so less risk of developing resistance. Don't have to treat sheep immediately after shearing. May still work effectively on poorly shorn sheep and sheep with dermo if used correctly.	Labour intensive as sheep have to be dunked and pushed back. Sheep may need to be re-mustered. Concentration must be maintained as stripping can be a major issue. Hard to know if correct dose is applied. Plunge dips may not be long enough. Cage and shower dips require expensive infrastructure. Not easy to treat a small number of sheep. Operators are at a higher risk of exposure to chemicals through splashing and spray. Shower dips require a high amount of maintenance in order to work correctly. Potential for disease transfer from sheep to sheep through dip wash.

Traditional replenishment methods consist of pouring extra chemical directly into the dip after a certain number of sheep have been dipped as recommended on label instructions. This method creates large fluctuations in dip concentration throughout the dipping process and can result in poor lice control (Lund et al., 2005). Constant replenishment is an alternative method that continuously feeds a higher concentration of pre-mixed solution into the dip creating only small fluctuations in dip concentration.

Constant replenishment of plunge dips is now a widely used practice (Lund and Levot, 2001a) with concentrations commonly being up to 5 times that of the concentration needed to kill susceptible lice. This allows for any lice with a small resistance to be killed and allows for fluctuations in concentration during dipping. When using a constant replenishment method with equal concentrations of both the dip and replenishment solution following directions on the treatment label, results showed the dip concentration often fell too low, suggesting the method may need to be modified (Lund and Levot, 2001a).

A further study by Lund and Levot (2007) found that the concentration of diazinon in wool of merino sheep increased linearly with increases in dip concentration. This suggests that diazinon dissolved readily in the wool grease rather than the dip solution causing concentrations remaining in the dip to be low. An alternative constant replenishment method of adding a pre-mixed solution of 200mg/L was found to be effective at maintaining the dip concentration of 100mg/L. Due to increasing concerns about the use of diazinon and its safety, the product was removed from use in dips and jetting in Australia since 2009 (James, 2010a), but other chemical ingredients such as spinosad are also affected by stripping.

Treatment failure and poor eradication can be caused by numerous factors such as resistance, poor treatment application and inadequate chemical concentration. A survey (James and Riley, 2004) found wool producers reasons why they believe their treatment had failed. Of the respondents 44% believed this to be caused by poor treatment application, 23% by neighboring properties, 20% through poor mustering, 19% due to treating sheep at different times, 14% due to strays, 10% through chemical failure and 4% through poor shearing practices.

Chemical Resistance

The development of chemical resistance among lice populations is suggested to be a major cause of treatment failure.

There have been two outbreaks of resistance to chemicals used in backline treatments for lice control in Australia. The first outbreak was in the late 1980's to synthetic pyrethroids (James et al., 1993, Johnson et al., 1990, Boray et al., 1988) and the most recent was to the insect growth regulators diflubenzuron and triflumuron (James et al., 2008, Levot and Sales, 2008a, James, 2010a) which represent over 70% of lice control treatments currently used in Australia (James et al., 2008). Backline treatments have a high risk of developing resistance due to the way in which this treatment works (James, 2010a). Unlike dip and shower methods where sheep gain an even coverage over the body (Johnson et al., 1995), backline treatments apply a high chemical concentration in one narrow strip down the body from head to tail. This method relies on the chemical to spread from high concentrations on the back to lower concentrations around the body. However the concentration gradient allows for some lice to survive and develop resistance to the chemical used. If the chemical fails to spread and create an even concentration then it is possible there may be some areas where all lice are killed and other areas where only susceptible lice are killed and resistant lice survive. The effect of this is increased when backline treatments are poorly applied allowing for greater differences in chemical concentration over different areas of the body (James, 2010a, Johnson et al., 1995).

The development of resistance to synthetic pyrethroid treatments in the late 1980s was highly correlated with the subsequent increase in lice prevalence in Australia (James, 2002). In 1988 the first reports of possible resistance to synthetic pyrethroid treatments were made in New South Wales (Boray et al., 1988) and by the early 1990's high levels of resistance were reported across Australia (Levot, 1992, James et al., 1993). The severity of this resistance was reported by James et al., (1993) who found the prevalence of resistance to be 34% in lice population samples obtained from infested sheep at market inspections, 50% in flocks that were suspected to have resistance and 68% in flocks from Kangaroo Island. Resistance factors were found to be between 1 and 20 (James et al., 1993). The resistance factor is the concentration of insecticide that is required in order to kill resistant lice compared with concentration that will kill susceptible lice. A resistance factor of 10 means that 10 times the concentration needed to kill nonresistant lice was required in order to kill resistant lice. Strains of lice with resistance factors of 19.4 were found on sheep that had been treated 8 weeks earlier through dips of cypermethrin at 12 ppm, whereas susceptible strains of lice had been eradicated in dips of only 1 ppm cypermethrin (Johnson et al., 1990). These results highlight the resistance levels present in lice populations and difficulties with control of these resistant strains as pyrethroid based treatments often had little or no effect on reducing lice populations (Johnson et al., 1989, Johnson et al., 1990)

Resistance to synthetic pyrethroids led to the development of alternative insect growth regulators triflumuron and diflubenzuro in 1993 (Griffin, 1993). This allowed for the Australian market to move away from pyrethroid based backline treatments and for the increase in lice prevalence that developed to be controlled (Levot, 2012). However since 2003 resistance to insect growth regulators has been suspected due to apparent reductions in effectiveness of these treatments (James et al., 2008) and has led to several studies to determine if lice populations can become resistant to these chemicals. Moulting disruption assays have been used to determine if lice populations can become resistant to triflumuron and diflubenzuron treatments (James, 2002). Alternative chemicals such as tea tree oil, which has no reported resistance, could potentially be used to control resistant lice populations (James and Callander, 2012).

Residues

Treatment of flocks with no lice, not only increases unnecessary costs but also contributes to the issues of chemical residues in wool products (Russell, 1994) Before 1990 annual lice treatments were recommended and even enforced by state governments in Australia to control lice infestations (Popp et al., 2012, James and Riley, 2004) along with restrictions on stock movement from infested properties (James, 2010b). However in recent times wool producers have been discouraged from using annual treatments and advised to only treat for lice when detected as a means to reduce the use of chemical control and to reduce costs (Horton et al., 2009, Popp et al., 2012, James and Riley, 2004). Lice control treatments made up 63% of the total wool residue level in the 1999/2000 season (James and Riley, 2001) and it is estimated that almost 3 times the amount of chemical is used to control lice when compared to the amount used to control flystrike (McLeod, 1995).

With increasing awareness of environmental health and evolving market requirements, farmers are becoming more aware of potential disadvantages associated with extensive use of chemicals (James, 2010a). Overseas buyers in regions such as Europe, are increasingly attracted to products that are free from chemical residues (Russell, 2001) and this is a further incentive for Australian wool producers to reduce reliance on chemical treatments. As a result demand has built for environmentally friendly alternatives to these harsh chemicals (Russell, 1994, Savage, 1998). Low residue lice control treatments need to be developed if producers are to reduce reliance on chemical control whilst maintaining competitiveness in international wool markets (Russell, 2001).

Models and Decision Support

The significant impact of lice on Australian wool production has led to the development of predictive models to help identify the best management options. The use of such predictive models could be used to help manage lice infestations and also to decrease lice prevalence which is an important goal in the control of lice in Australia.

Deterministic models rely on standard formulae and parameters in order to simulate certain situations. These models produce a consistent result for a given set of variables entered. Stochastic models incorporate randomness using probability distributions to create an initial population and probability functions to determine ongoing changes to the population. The model follows rules but the randomness may result in slightly different results each time it is run.

The use of a deterministic model to aid in the control of lice infestations was first trialled by (Wilkinson, 1986). The model suggested that lice could be eradicated within 10 years. But Wilkinson assumed that eradication methods could be 90% effective, provided they were supervised by Department of Agriculture staff. However, these rates of eradication could not occur because this level of supervision was not available. Other models have been developed to predict effects on lice prevalence when using different lice treatments, changes in efficiency of eradication, reductions in annual treatments (James and Riley, 2001) and to predict effects of changes to management such as biosecurity (Brightling, 1989). These models have been developed with the aim of benefiting farmers with lice management decisions.

A study by Horton and Carew (2014) compared the use of stochastic and deterministic models for predicting the prevalence of lice in flocks. The models were based on the series of events shown in figure 1.2. The study found that the stochastic model produced more accurate results that were consistent with previous survey values. In contrast, the deterministic model which was similar to the other models developed previously, (Wilkinson 1986) produced more extreme results that were impractical for long-term decision making (Horton and Carew, 2014). This stochastic model makes it easier to allow for a wide range of management choices to be made based on the previous experience on each farm in the model. For example, properties with recent experience with lice may be more likely to treat their sheep than those not recently exposed to lice. The large number of interactions between management options on individual properties and neighbouring properties will affect the actions in later years on the same property. Due to this, these effects are harder to model using deterministic systems (Horton and Carew, 2014). However due to the variation within the stochastic model different results are obtained when the same values. This means that small variations between results may be due to variation within the model rather than actual changes in the model results. The updated version of the Lice Prevalence model is more complex than the previous version as it includes more specific lice detection and risk calculations.

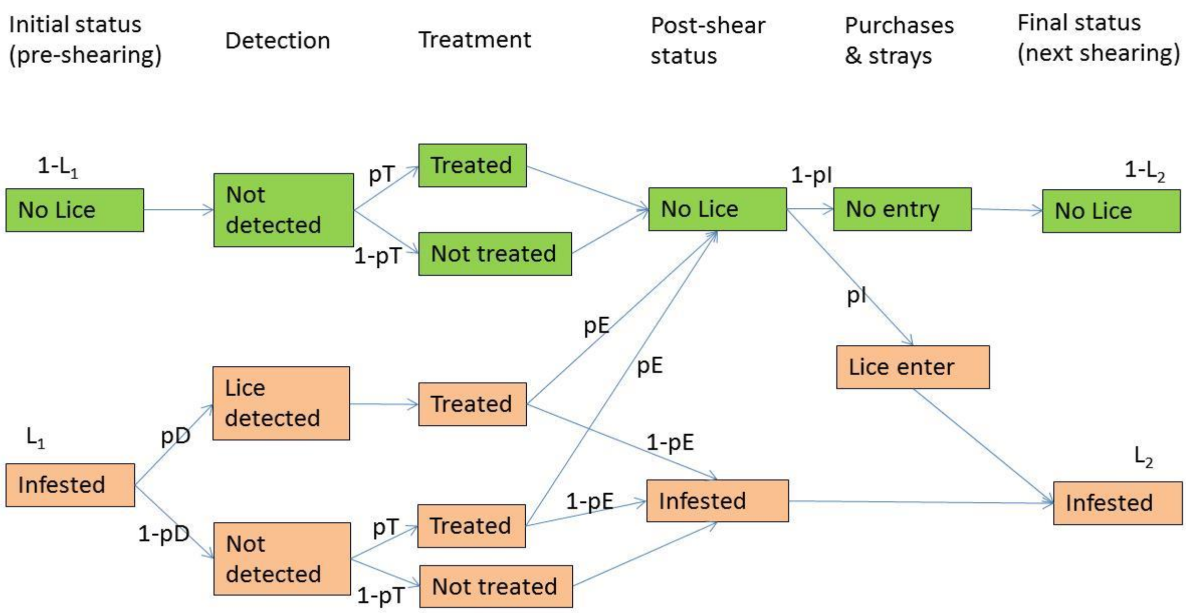

Figure 1. 2. *Lice prevalence stochastic model, series of events affecting lice prevalence from (Horton and Carew, 2014). pT is the probability of treating lice even if no lice are detected. pD is the probability of detecting lice when present. pE is the probability of eradicating lice if lice are present and a treatment applied. pI is the probability of introducing lice either through poor eradication or biosecurity. L1 and L2 are the probabilities that the initial flock and final flock status are infested respectively.*

Figure 1.2 (Horton and Carew, 2014) shows a series of events leading to the final status of a flock either being infested or free from lice. The lice Prevalence model described in Horton and Carew (2014) is based on the management options shown in figure 1.2, with minor differences in assumptions for the proportion in each category. Management options available in the model are the accuracy of detection of lice at shearing, factors affecting the decision on whether to treat if no lice have been detected, the effectiveness of treatment if applied, and the effectiveness of Biosecurity options. These are all management options that have been shown here to be important for lice control, but difficult for flock managers to control without extra labour or costs. The model assumes that if lice are detected then they will be treated, however treated sheep can remain infested. When flocks are free from lice post-shearing, the only way lice enter the flock is through purchased or stray sheep.

In the Lice Prevalence model, farms are split into different regions, each with a different lice prevalence that reflects the regional average for lice prevalence (Reeve and Thompson 2005). The differences in lice prevalence in each region allows for the effects of a low lice prevalence region (approximately 10%), to be compared to regions with high lice prevalence (approximately 40%). The model runs the simulation for 20 years and at the end of each year records the number of properties which have lice infestations and the associated costs. Results for individual years and for separate regions can be examined. Costs of the management options can be entered into the model and allocated to specific management practices. This allows for the overall costs from these treatments and the lice themselves to be evaluated.

From this study the stochastic model showed that improvement to biosecurity and eradication could provide the greatest reductions in dollar costs. Improvements to biosecurity included limiting the chance of lice entering either through purchases and strays. Improvements to eradication were simply through improving the methods used. The results show there is potential for improvement of current management practices to result in both a decrease in costs and lice prevalence, whilst also being a realistic option for farmers to achieve. From this study the Lice Prevalence model has been developed (Horton and Carew, 2014) but has only been used to analyse single changes in management options rather than interactions between these management options.

There are several benefits and limitations of predictive models for the control of sheep lice. Models can provide producers with information on lice management options and the associated costs and be a great resource to further aid on-farm decision making. However with the strengths of these models there are also shortcomings that limit their ability to be used as a management tool. The stochastic model developed by Horton and Carew (2014) relies on probabilities and assumptions made within the calculations. These assumptions are either based on published information and surveys or are chosen values which were consistent with current lice prevalence surveys if no published data was available. All assumptions are described in Chapter 3, but could be potential limitations to the practical significance of the results obtained.

Benefits and Limitations of the Lice Prevalence Model

The Lice Prevalence model can be used to examine eradication rate and biosecurity methods in combination with each other, and with other aspects of lice control, to determine if combined management options can further reduce the costs of lice control. This model was designed to provide farmers with essential information on the best methods of lice control to reduce costs associated with lice while also reducing lice prevalence. The model can assist wool producers to decide whether to treat or not treat their sheep if no lice are detected at shearing and support farmers who are trying to decrease chemical residue in their wool, use less chemical treatments or save on costs.

Decisions on whether to test for the presence of lice, to treat lice or maintain quarantine systems can all be evaluated by the Lice Prevalence model to determine the optimum outcome regarding cost and benefits of these management systems. By using the model, producers are able to allocate resources to different management options and determine which management strategy will be optimal on cost and lice prevalence and benefits for their farming system.

2. Introduction

Encouragement for producers to reduce reliance on chemical controls has not been met with satisfactory resources needed in order for farmers to make this shift away from chemical treatments without serious consequences on costs and lice prevalence. If lice prevalence within Australia and the use of chemical controls are to be reduced, further guidelines and resources need to be made available to support farmers with lice management decisions.

As this review has shown, the difficulty in detecting lice infestations, achieving good eradication rates and along with the apparent increases in lice prevalences across Australia, are all significant factors affecting lice control. These factors highlight the need for a set of guidelines and/or resources for farmers to use in the decision making process if the reliance on chemical control is to be reduced.

Practical significance of results from this study will indicate where potential improvements to lice prevalence and costs can be made within different regions of Australia rather than improvements for single properties. This study flows on from previous findings by Horton and Carew (2014) and aims to investigate if combinations of management options can be used to provide further reductions in lice prevalence and its associated costs than that of single management options. Resources such as this are essential for wool producers if wool residues, lice prevalence and lice-related costs are to be reduced.

3. Methods and Materials

The Lice Prevalence Model first developed by (Horton and Carew, 2014) is a predictive model designed to estimate the effects of specific management options on lice prevalence and its associated costs in different sheep production regions of Australia. The model was developed as a tool to aid in the decision making processes involved in lice management and to identify potential management practices that could provide reductions in both regional lice prevalence and costs.

The Lice Prevalence Model used in this study was a stochastic model based on 50,000 assumed sheep properties across Australia distributed across nine regions with different assumptions by region on lice prevalence, proportion of properties infested and number of sheep per property. Figure 1 is an adaptation of the Horton *et al* (2014) model and shows the series of events leading to the final status of a flock either being modelled as infested or free from lice. The available management options depicted in the model are: the accuracy of detection of lice at shearing, factors affecting the decision on whether to treat if no lice have been detected, the effectiveness of treatment if applied, and the effectiveness of quarantine and treatment of sheep entering the property either through purchases or strays. Lice detection methods embedded in the model include: signs of lice, detection and risk of lice being present. The model recommended that, if there were obvious signs of lice, then flocks should be treated. If there were no signs of lice the Model determined that flocks should be treated only when there was positive lice detection and/or if farm factors suggested a high risk of lice being present (Horton et al., 2014). The LP model was adapted from Horton, Bailey and Carew (2014) to include more specific decisions relating to whether to treat at shearing and lice detection factors, which include signs of lice, lice detection and risk. These methods are described below.

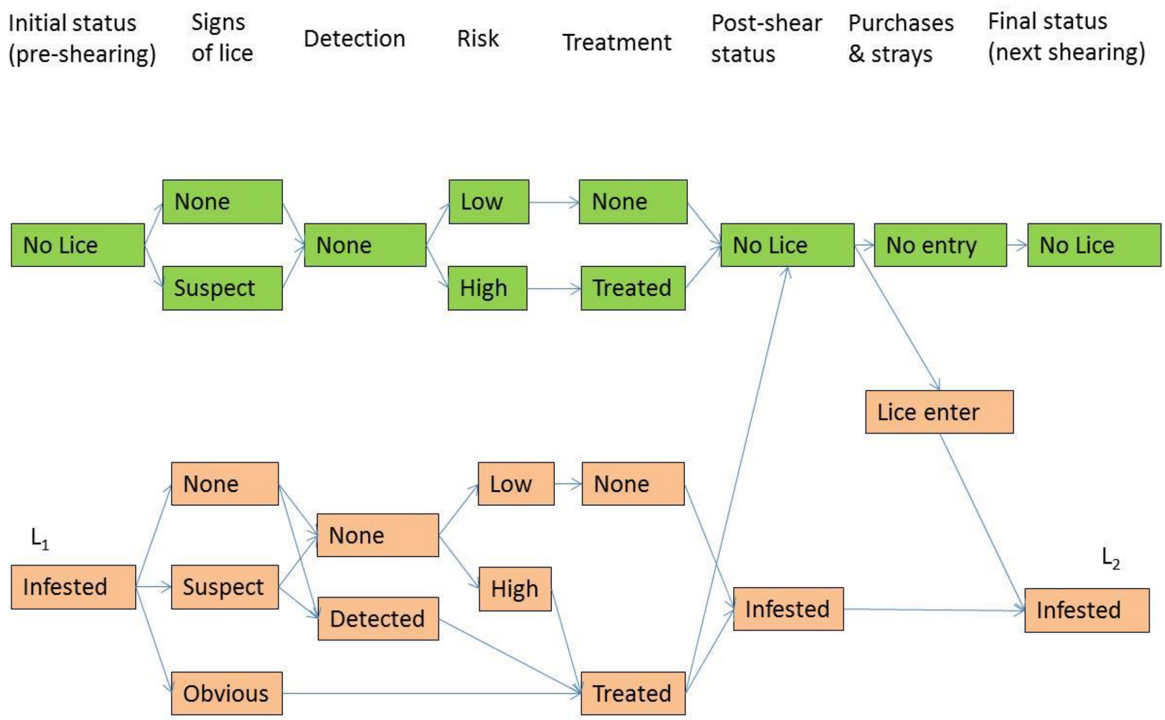

Figure 3 1. *Adapted from (Horton et al., 2014) Series of events affecting lice prevalence. L1 and L2 are the probabilities that the initial flock and final flock status are infested respectively.*

The model depicted as Figure 3.1 is constituted of eight stages in the predictive process, several of which had embedded assumptions as to the values or factors which a farmer might specify in using the Model to judge lice status of the flock. Those stages and their embedded assumptions are included below.

Stages of lice infestations

Initial status

In the model, the initial status of a flock is determined at shearing. Based on this, farms will be classified as either infested or having no lice.

Signs of lice

If no lice are observed to be present, the farmer may still suspect they have lice. If flocks are infested then there are three possible categories offered in the Model; farmers may suspect they have lice, consider a lice infestation obvious or be confident they are not infested (*none*). Approximately half of suspect flocks will have lice present (Morcombe et al., 1996). This indicates the importance of lice detection tests for suspect flocks as a variable within the model and how this can affect the accuracy of the model at predicting regional lice prevalence.

Detection

The Model indicates that a detection method may be used on suspect and non-suspect flocks to determine whether the flock should be treated. The model assumes that detection methods will not be applied to flocks that show obvious signs of lice. Where the infestation is obvious and farmers are certain they have lice, the model assumed flocks will be treated. The likelihood that treatment will be applied is calculated by the Model based on the detection of lice in suspect and non-suspect flocks, and the farmer's judgement of the risk of lice being present. If present, lice may be detected from suspect and non-suspect flocks if a highly sensitive detection method is used. It is an inbuilt assumption in the Model that lice will never be detected if no lice are present. If lice are detected then it is assumed flocks will be treated. If lice are not detected from these methods then the decision on whether to treat or not to treat may be based on the farmer's judgement of risk factors associated with lice infestations such as previous treatments, purchases and strays.

Risk

The risk of lice being present within a flock is determined by the flock owner and may take into account previous treatments, treatment efficacy, the flock's initial status (i.e. infested or no lice), possibility of a false suspects due to rubbing, sensitivity of detection methods used, and the procedures and rate of introduction of purchases and strays to the flock. Risk assessments can also be made using such approaches as the LiceBoss - Short Wool Tool. A risk assessment can be used to determine if a detection method needs to be used and how sensitive the detection method needs to be. In the case of risk assessment, an intervention level is set by the farmer to determine the level of risk at which flocks will be treated. If the risk of lice being present is above this intervention level then the Model assumes the flocks will be treated. If the risk is deemed below the set intervention level then the Model assumes flocks will not be treated.

Treatment

If flocks that initially had a lice infestation were assumed to be treated then the Model offers two options; flock will either be assumed to be free from lice or remain infested. When no treatment occurs, the Model maintains the lice status of the flock so flocks initially free of lice stay free, and flocks initially infested stay infested. If flocks that were initially free from lice were treated then they are assumed by the Model to remain uninfested. The Model recognises that some treatments, or some portion of treatment may be ineffective and infestation status may remain unchanged.

Post-shear status

The post-shear status of the flock in the Model is determined by the initial status of the flock, whether lice were detected or treated for, and whether a successful treatment occurred.

Purchases and Strays

Throughout the modelled year, the Lice Prevalence Model allows that lice can enter flocks through the assumed purchase of sheep or through strays entering the property. This may lead to flocks which are free from lice modelled as becoming infested.

Final status

The final modelled status of the flock is determined by the post-shearing status and whether or not lice have entered the flock through purchases and strays.

Lice Prevalence Model Assumptions

The lice prevalence model uses a series of equations, all of which have specific ranges, assumptions and limitations which affect calculations of lice prevalence and its corresponding costs. The model uses real-life data on flock status, efficacy of eradication, entry of lice and costs which are included in the equations. The rate of increase of the lice population is given by equation 3.1, with subsequent equations showing further information and assumptions included below. The LP model assumes lice prevalence is the same within regions. Specific management options are included on all properties within regions with the average of all properties having a specified value, but each individual property varying over a permitted range. When simulating specific management situations the model is run either with flocks being treated or not treated over a period of 20 years and does not include situations where properties move from treating in alternate years.

When calculating the costs and benefits of the different lice detection methods and biosecurity of purchases options the model assumes an average flock size of 2500 sheep with one fifth of the flock being replaced each year.

Regions

The Lice Prevalence Model used in this study is based on 50,000 assumed sheep properties across Australia. The number of properties assumed was obtained from a survey by Campbell et al (2014), and this total number of properties was subdivided into the correct proportions to represent each of the nine Australian regions shown in Table 3.1. The nine different regions were based on the findings of an Australian wide survey (Reeve and Thompson, 2005). These nine regions each have different lice prevalences, proportion of properties infested and number of sheep per property (Table 3.1). The Reeve and Thompson (2005) survey investigated wool levy payers which were randomly selected from different regions of Australia but did not include all major sheep production regions of Australian, and failed to include properties in regions such as north west NSW and areas of Victoria. The failure to include these regions in the survey may have resulted in underestimates of the fencing problems for pastoral sheep zones.   In the process of this research project, a study (Horton et al., 1998) was released which included the 2011 Australian lice survey results. The data from this more recent survey study was incorporated into the Lice Prevalence Model and used to calculate some of the latter results reported in the 'Results' section of this thesis.

Region code	Region	Number of properties	Median area (ha)	Median dse	Lice prevalence(%)
1	Qld, South West & South	63	7285	6000	37
2	Qld, Darling Downs	24	2320	3234	41
3	NSW, New England	179	874	3570	18
4	NSW, Central & S Tablelands	186	700	2971	10
5	NSW S + Vic N & Gippsland	183	719	2604	16
6	Vic Western + SA South East	378	671	3068	17
7	SA Upper southeast	71	1200	2630	15
8	Kangaroo Island	42	672	3750	26
9	WA (SW region)	209	1576	4405	30

Table 3 1. *Number of properties, property size, number of sheep and lice prevalence for each region from a 2005 survey by (Reeve and Thompson, 2005). Dse= dry sheep equivalent.*

Costs

All costs associated with lice infestations embedded in the LP Model were based on values reported by Sacket et al (2006) as shown in Table 3.2. All cost calculations were based on Net Present Values (NPV) over 20 years at a 7.5% discount rate. The discount rate of 7.5% was used to account for the inflation rate of 3.5%. The remaining 4% was allocated as an estimate of potential investment gains from funds over 20 years. Wool values were increased and decreased to analyse the effects of reductions in the number of neighbours contacted through strays on different quality wool (Table 3.2). The average losses due to lousy sheep in newly infested flocks and continually infested flocks were doubled and halved to analyse the effect of improved fencing on high value wool and low value wool respectively.

Factors	Cost (cents/sheep) average wool value	Cost (cents/sheep) high wool value	Cost (cents/sheep) poor wool value
Quarantine	14	14	14
Total treatment after shearing	83	83	83
Average losses due to lousy sheep in newly infested flocks	83	166	41.5
Average losses due to lousy sheep in continually infested flocks	184	368	92
Total long wool treatment*	150	150	150

Table 3 2. *Costs of Specific factors affecting lice prevalence for poor, average and high quality fleece. Adapted from(Horton and Carew, 2014). *Long wool treatment was used by 90% of the flocks in the model affected by continuing infestations.*

Lice detection

Lice spread through a sheep flock by direct contact of wool from an infested individual to an uninfested individual (Levot, 1995, Lymbery and Dadour, 1999, James et al., 2002b). Due to this, the rate of infestation within a population can vary depending on the conditions under which flocks are held. Increasing the number and duration of flock yarding for management purposes such as drenching and crutching can potentially increase the rate of spread of lice due to direct contact of sheep.

The LP Model calculates the proportion of the flock infested with lice and assumes an increase of 1.032 each day. The value for the number of days a flock has been infested is also included and assumes that at day zero, 1% of the flock is infested with approximately 10 lice per sheep. These values were included in the model calculations to simulate the spread rate, if a single heavily infested sheep was introduced to a clean flock. This rate of spread of lice is consistent with previous data (James et al., 2001). However these values used do not account for the differences between the spread of lice and population increase in experimental situations as compared with real life. For example in experimental environments mobs are usually regularly mustered and yarded in order for recordings to be made, and usually consist of a smaller number of sheep. Under experimental conditions, the rate of spread from one heavily infested sheep within a mob of 50 may be unrealistically high, compared to one heavily infested sheep in a 'real-life' mob of 500. Due to this likely over estimation from experimental data, a conservative rate of spread assumption was used in the Model.

There is limited published data on the rate of spread of lice over time. However a study by James et al (2001) which investigated lice infestations over time and average lice prevalence per part in individual sheep was used to estimate lice population increase and number of lice per part over time. The LP model assumes an initial lice population of 10, and a standard population increase of 1.05 lice per day (James et al., 2001). The population increase calculates how quickly lice populations develop regardless of the rate of spread within the flock. This calculation uses a logistic curve which initially increases exponentially and plateaus when each sheep has a large number of lice (Equation 3.2). This calculation is consistent with experimental studies.

The lice population, N, on a given day, d, after the start of infestation is

(Equation 3.1)

$$N_D = N_{d-1}(1 + \mathrm{r})$$

Where

(Equation 3.2)

$$r = r_{max} \frac{\log(K) - log(N_{d-1})}{\log(K)}$$

Where K is the maximum number of lice per sheep = 29,310

And r_{max} is the maximum rate of increase = 1.05

However, the rate of increase is lower in short wool, so that r_{max} is 1.00084 off shears, increasing linearly to 1.05 by 188 days after shearing (Lucas and Horton in preparation).

The detection options used in this study assume detection occurs before or at shearing. For lice detection only a single louse needs to be found in order to determine if lice are present or not. Each detection method has a specific level of sensitivity which is the probability of finding lice if lice are actually present within the flock. Due to this it is assumed that false positives do not occur.

The method used in this study for determining the sensitivity level of each lice detection test through partings is described by James et al 2002. The equation used is able to determine the HSe which is the sensitivity level.

(Equation 3.3)

$$HSe = 1 - \sum_{i=0}^{n} \left(\left[\frac{k}{k + \lambda} \right]^{kmi} P[r = i] \right)$$

Where n is the number of sheep inspected, k is an aggregation factor, m is the number of partings inspected and r is a hypergeometric random variable.

(Equation 3.4)

$$P[r = i] = \frac{\binom{I}{i}\binom{N - I}{n - i}}{\binom{N}{n}}$$

Where N is the total size of the flock and n is the number sampled. I is the total number infested in the flock and i is the number detected with lice (James et al., 2001).

(Equation 3.5)

$$\binom{N}{n} = \frac{N!}{n!\,(N - n)!}$$

The methods included in the Model include no detection, fleece inspection, at shearing tests and laboratory testing. All of these methods differ in sensitivity level and cost (Table 3.3). The ‘no detection' option assumes lice are detected after approximately 180 days of infestation through obvious signs of lice. Inspection through fleece partings allow for a simple inspection method using the 5x5 parting option and a more accurate method using the 10x10 parting option. Fleece parting calculations were based on labour costs of $25/hour, a flock size of 500 sheep and the assumption five partings on one sheep takes approximately one minute. The sensitivity of fleece partings were obtained from results found in studies (Morcombe et al., 1996, James et al., 2001). For these methods it is assumed fleece partings will be done on sheep with at least 6 months wool and partings are carried out by experienced farmers.

The detection tests assumed to occur at shearing include the Lamp test and the Locks NaOH test both of which are methods described by Morcombe (1996). The Lamp test involves using 2g samples from the fleece of 50 sheep during shearing, which are placed under light on a dark surface for 10 minutes. If lice are present they will move away from light and can be seen on the dark surface after the allocated time. The Locks NaOH test involves dissolving 60g locks wool samples from the fleece of 100 to 150 sheep in a sodium hydroxide solution. The solution is then observed under a microscope for the presence of lice exoskeletons. The sensitivity of both these methods was estimated from data reported by Morcombe, (1996) and assumes flocks tested are suspected to have lice. Costs of these tests were calculated using an assumed labour cost of $25/hour and the assumption that the collection of fleece and locks wool samples takes approximately 30 minutes for 50 fleeces. These tests were based on mob sizes of 500 sheep with benefits spread across whole flock.

The sensitivity and costs of the ELISA testing options were based on results from two earlier studies (Sales and Young, 2009, Popp et al., 2012). The ELISA half price option was included as a less expensive alternative to the standard ELISA testing because initial results indicated this method was never cost effective.

The six lice detection tests described here were compared against different eradication rates, biosecurity of purchases and biosecurity of strays options. Specific costs and sensitivities were included in each of the lice detection methods used (Table 3.3). These detection methods were used on flocks that were both suspected to have lice and flocks that were not suspected to have lice but not those classed as certain to have lice. Through only using lice detection methods on flocks that are suspected to have lice, it is possible for some lice infestations to go undetected causing lice prevalence to increase compared to testing both suspect and non-suspect flocks. However through testing only suspected flocks for lice it is possible for costs to be reduced.

Detection Method	Number of Sheep	Partings per Sheep	Cost (Cents/head)
None	0	0	0
Partings 5x5	5	5	0.4
Partings 10x10	10	10	1.6
Lamp test	65	1	3.2
Locks NaOH	100	1	25
ELISA half price	200	1	30
ELISA	200	1	60

Table 3 3. *Sensitivity, detection days and cost of each lice detection method.5x5=five fleece partings on five sheep.10x10= ten fleece partings on ten sheep. 10x20= ten fleece partings on 20 sheep. NaOH=sodium hydroxide test. ELISA half price = half the cost of a normal ELISA test. Number of sheep= number of sheep used in each testing option. Partings/sheep= test equivalent of parting individual sheep in a flock size of 500. Cost is based on a flock size of 500 sheep.*

In table 3.3 the number of sheep and partings were adjusted to align with the results reported by Morcombe (1996). This allowed for the detection methods in this study to have comparable results to the partings methods under the same conditions.

The lice detection methods used the original version of the LP Model (version 1) were calculated based on the number of days after which lice are assumed to be detected using a specific detection method (detection days). The detection days calculation did not include differences in the rate of spread of lice within flocks. Due to this an updated version of the LP model (Version 2) was developed as part of this study and used for later analysis. Version 2 of the LP Model included calculations that accounted for an increasing proportion of sheep infested over time. All results for single management option were obtained using the original version of the LP model (Version 1). Version 2 of the LP model was used to obtain all combination results in this study.

Intervention

The assumptions in the LP Model about decisions on whether to treat or not to treat if no lice are detected are based on the farmer's perceived risk of lice being present within a flock. The risk of lice being present within a flock is based on risk factors such as previous treatment, risk of treatment failure, entry of lice through purchases and strays and signs of lice within the flock. The intervention level is used to help determine if treatment should occur.

It is assumed farmers have the equivalent of an intervention level based on their attitude to risk and their ability to assess the risk of flocks being infested. If the risk of lice being present is above a certain intervention level then the model assumes treatment will occur. If the risk is below the intervention level then the model assumes treatment will not occur. The intervention level in the model was set at 20%. This level was based on findings from Horton *et al* (2014); which showed the use of a 20% intervention level provided the most consistent results to published surveys (Reeve and Thompson, 2005),when compared to higher and lower intervention levels. Intervention levels included in this study ranged from 0 % to 100%.

Users of the LP Model (V2) are able to enter a specific intervention level which is set at an average level across all regions with a standard deviation of half the intervention level for different properties.

Eradication rate

The eradication rate is the assumed percentage effectiveness of the lice control treatment applied and is therefore the probability that a single treatment of all sheep will eradicate all lice on the property. The model ranges from low eradication efficacy and low cost options to high eradication efficacy with higher costs (Table 3.4), with users being able to increase or decrease this rate along with the costs of obtaining a certain eradication rate. Each eradication rate and its associated costs were estimated from the use of different chemical control options (included below).

Chemical costs shown in table 3.4 were based on costs of different chemical types on the Lice Boss Tool (Levot, 2013a). These costs obtained from the Lice Boss Tool (Levot, 2013a) were increased to account for increased labour costs, associated with some methods such as dipping and also to ensure all sheep are mustered and treated correctly (Levot, 2013b).

Eradication Rate	Added Cost (cents/head)	Total Cost (cents/head)	Chemical Type
50	-51	32	Synthetic Pyrethroid
65	-23	60	IGR
75	0	83	“Average Method”
85	40	123	diazinon Dip
95	61	144	Imidacloprid
100	104	187	Cage Dip OP

Table 3 4. *Cost added to model, total cost and chemical type of each eradication method.*

Table 3.4 shows the costs and efficacy of each lice control treatment. The 50% eradication option was obtained from synthetic pyrethroid backline treatment. This treatment option is low cost however lice have a high resistance to these products. The 65% eradication rate is also a backline application but uses an Insect Growth Regulator which has less resistance than backline synthetic pyrethroid treatments. The ‘Average Method’ used in the model has a standard eradication rate of 75% which costs 83 cents/head and corresponds to the national average eradication rate which is currently between 65 and 75% eradication (Horton and Carew, 2014). The 85% eradication rate is obtained through the use of the chemical ingredient diazinon applied by dip application and accounts for the increased labour required for dip applications. The 95% eradication efficacy option simulates the use the chemical ingredient Imidacloprid since no resistance to this product has been reported. The 100% eradication option is obtained using diazinon applied by cage dipping together with increased labour to ensure every sheep is treated appropriately.

Biosecurity of Purchases

The biosecurity of purchased sheep options include fleece inspection, quarantine and treatment of purchased sheep. The method used depends on individual farmer’s situations such as the number and type of sheep purchased and the time of purchase and how this fits into the shearing and lambing routines of the property. If sheep purchased have short wool, less than 6 weeks growth then treatment can occur. If wool is longer than 6 weeks growth farmers are able to quarantine purchased sheep until shearing occurs where they can be treated. If there is more than 6 months wool, sheep can be inspected through fleece partings to determine if lice are present. Farmers may also decide to shear and treat purchased sheep. Farmers may choose to not use any biosecurity measures for purchased sheep.

Standard number of properties contacted through purchased sheep is 0.562. (Horton et al., 2014). This value can either be increased or decreased depending on the biosecurity measures used. Reductions in contacts are calculated by multiplying the standard purchase contacts by the percentage efficacy of biosecurity such as the sensitivity of detection and efficacy of treatment. All biosecurity of purchases costs were based on replacing one fifth of the flock each year, e.g. purchase 500 ewes each year to maintain a total flock of 2500.

Biosecurity Inspection

Inspection of purchased sheep uses fleece parting methods similar to those used for lice detection (Table 3.3). Purchases inspection includes three parting options all of which have different costs and levels of sensitivity (Table 3.5). Inspection through fleece partings were the only lice detection options used for purchased sheep as other detection methods, such as the 'Lamp test' are unavailable as they require shearing before detection can occur. If purchased sheep are shorn then it would not be advantageous to use a lice detection test as this would result in unnecessary costs on top of the standard costs to treat purchased sheep.

Fleece Partings	Cost (Cents/head)	Parting sensitivity (%)	Standard purchase contacts	Decrease in purchase contacts
5x5	0.4	42	0.562	0.236
10x10	1.6	56	0.562	0.314
10x20	3.2	63	0.562	0.354

Table 3 5. *Cost, sensitivity and reduction in purchase contacts for each fleece parting option. Purchase contacts= number of properties contacted through purchased sheep. Reductions in purchase contacts= reduction in number of properties contacted through purchased sheep depending on sensitivity level of fleece parting options.*

All inspection methods for biosecurity of purchased sheep were based on inspecting sheep with the most signs of wool rubbing in a purchased mob size of 500. As inspection of purchased sheep is a benefit to the whole flock, the costs and benefits calculated for lice detection inspections are spread across the whole flock of 2500 sheep.

Biosecurity Quarantine

Purchased flocks can be separated from the original flock for up to six months to stop the spread of lice. The model assumes if lice are present then obvious signs of lice will be present after six months. The six cents/head option is the standard cost for separation of one flock for up to six months. The 20 cents/head option was included to account for the cost of separating multiple flocks for up to six months including ewes and rams (Table 3.6).

Quarantine Option	Number of flocks	Cost (cents/head)	Sensitivity (%)
Q6	Single flock	6	80
Q20	Multiple flocks	20	80

Table 3 6. *Number of flocks quarantined, cost and sensitivity for each quarantine of purchased sheep option.*

The costs of the quarantine methods were based on assumption properties will purchase ewes or rams each year. The calculations consider losses incurred from being unable to gain interest on money spent on the purchase of sheep six months before required. For example at an interest rate of 5%, if sheep are purchased for $5000 six months before required then $125 could have been earned from investment. If this cost is spread over a flock of 2500 then it results in a cost of approximately 6 cents per head. This cost was multiplied by three to determine the cost of 20 cents per head to quarantine multiple flocks for up to six months.

Through quarantine of purchased sheep, it was assumed a reduction in the number of properties contacted through purchasing sheep could be reduced by 80%.

Biosecurity Treatment of purchases

Treatment of purchased sheep with a short wool treatment can occur if there is less than six weeks wool growth, otherwise sheep must be shorn before treatment can occur.

Table 3.7 shows the standard, added 60 cents and added 260 cents methods which all have the same eradication efficacy but differing costs. The standard treatment method costs one fifth of the normal treatment costs. The additional 60 cents per head is added to the standard treatment cost to allow for the cost of shearing purchased sheep if necessary. If shearing costs $3 per ewe then one fifth of shearing costs will be 60 cents per ewe on the property. The additional 260 cents per head method was included as this allows for the cost of double shearing and treatment of purchased flocks and subsequent wool losses.

Eradication Rate	Decrease in purchase contacts	Total cost (cents/head)	1/5th Cost (cents/head)	Added 60 (cents/head)	Added 200 (cents/head)
50	0.281	32	6.4	66.4	266.4
65	0.3653	60	12	72	272
75	0.4215	83	16.6	76.6	276.6
85	0.4777	123	24.6	84.6	284.6
95	0.5339	144	28.8	88.8	288.8
100	0.562	187	37.4	97.4	297.4

Table 3 7. *Eradication costs, reduction in purchase contacts, standard treatment and added cost treatment options for the treatment of purchased sheep for each eradication rate.*

The method used depends on the time at which sheep are purchased and how this relates to annual shearing. If purchased sheep are shorn and treated with less than 12 months wool, then they may have to be shorn and treated again in order to follow the regular shearing routine of the property. This scenario can occur if purchased sheep have more than six months wool and the regular shearing time is in six months' time and can result in two lots of short wool.

If sheep are purchased close to annual shearing time then a separate shearing of purchased sheep may be necessary however double shearing may be avoided. If sheep are purchased several months either before or after annual shearing then double shearing may be necessary and result in high wool losses. Treatment may also differ depending on the type of sheep purchased such as ewes and rams. For example purchased rams will need to be quarantined for at least 6 weeks as a dipping treatment is not cost effective for a small number of sheep, therefore a backline treatment will be used which can take up to 6 weeks for all lice to be eradicated.

Biosecurity against Strays

A value of $20,000 was used for all reductions in the number of stray sheep contacted and was based on contract fencing cost of $10.00 per meter for 2km of boundary fencing (Table 3.8). There is difficulty in estimating the percentage reduction gained from 2km of improved fencing, due to this the proportion of total boundary fences improved was used to estimate possible reductions. Small properties in the model have an average size of 700ha (table 3.1) which relates to approximately 11km of boundary fencing. A length of 2km of boundary fencing is 18% of the total boundary fence; therefore on average sized properties a minimum reduction in the number of neighbours contacted through strays of 20% was used. This reduction can be increased through specific targeting of problematic fences; hence 40 and 60% reductions were included on all sized properties.

% Reduction in strays contacted	$ Cost for 2km of fencing	Standard contacts	Average contacts
0	0	0.721	0.721
20	20,000	0.721	0.577
40	20,000	0.721	0.433
60	20,000	0.721	0.289

Table 3 8. *Dollar cost of improved fencing, standard stray contacts and average stray contacts at each percentage reduction in strays option. Reduction in neighbours = reduction in number of neighbours contacted by stray sheep. Average contacts= average number of neighbours contacted by stray sheep with each reduction in strays option.*

On smaller properties the 2km of fencing covers a higher proportion of the total boundary fencing when compared to medium and large sized properties. Due to this the potential benefit of this re-fencing is reduced on medium and large sized properties when compared to that of smaller sized properties. However through specifically targeting problematic fences it may be possible to increase the benefit of this fencing on all sized properties.

Standard number of stray contacts is the number of neighboring properties contacted through stray sheep and is set in the model at 0.721 (Horton et al., 2014). As in biosecurity of purchases, this standard value can be increased or decreased depending on management options. Reductions in stray contacts are calculated by multiplying the standard stray contacts by the percentage reduction in strays through improved fencing e.g. 20, 40 or 60%.

Different sized properties

Reductions in the number of neighbouring properties contacted by strays were analysed on small, medium and large properties individually. These results were obtained through averaging the lice prevalence and net present values obtained from the model for the regions that correspond to the different sized properties. Table 3.1 shows the average property sizes used in the model and allows for regions to be categorized into small, medium and large sized properties. Small properties include regions 3, 4, 5, 6 and 8, with an average size of 700ha and an estimated boundary fence of 11km. Medium sized properties included regions 2, 7 and 9 with an average size of 1500ha and boundary fence of 16km. Large properties were found in region 1 and had an average size of 7000ha and an estimated 34km of boundary fencing.

Data Available

The Lice prevalence model produces the lice prevalence and cost results (Net Present Value) either over a 20 year period or at the end of 20 years. The NPV is the cost (cents) per sheep and does not depend on flock size.

All initial results for model testing and validation (chapter 4a) were obtained using version 1 of the lice prevalence model. These results only include single management factors and show lice prevalence and costs (cents/sheep) in the 20th year of the specified management.

As the LP model is a stochastic model each simulation produces different results even when the same values are entered by the user. Due to this the level of variation between results was measured to determine if differences in results were due to random variation within the model or due to management options. Simulations were run using the same values 10 times in order to determine the mean, standard deviation of the sample and the coefficient of variation. Low, high and average eradication rates were tested 10 times and included to determine if results differ at extreme values.

All combination results and the single factor eradication results (chapter 4b), were obtained using version 2 of the LP model which included specific costs and benefits of each eradication rate. Version 2 of the model allowed for costs of lice infestations to be converted into a net present value for each individual year and accumulated over 20 years so costs and benefits could be analysed over the long-term rather than over individual years.

All biosecurity of purchased sheep and biosecurity of strays options were based on an average flock size of 2500 sheep and replacing one fifth of flock each year. All biosecurity options were simulated using an average eradication rate of 75%. Biosecurity of strays options were analysed on different sized properties and at different wool values. These results were obtained by averaging the costs and lice prevalence results for small, medium and large sized properties (table 3.1). Wool values used are shown in table 3.2.

4. Model Testing

Single management options and model variation

The model was run using a range of values in order to test the outputs of extreme values to ensure the model functioned as expected.

Increasing eradication efficiency reduces lice prevalence and costs of lice (Figure 4.1). Even with 99% eradication, lice prevalence is still at 8%. This result shows even with optimum lice eradication treatments for 20 years flocks will still be infested due to lice being able to enter flocks through strays and purchased sheep.

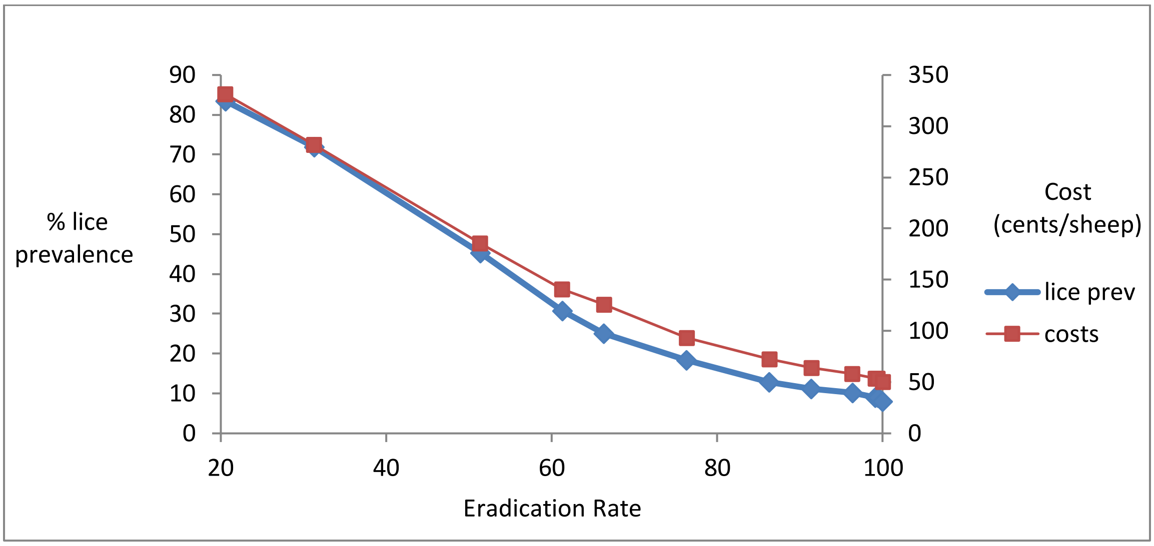

Figure 4. 1. *Lice prevalence and costs at different eradication rates. Eradication rate = percentage of lice eradicated within flock. Lice prevalence = percentage of Lice in flock.*

Figure 4.2 shows the effects on lice prevalence and costs associated with lice infestations at different number of detection days. The number of detection days increases with decreasing sensitivity of lice detection methods. If lice can be detected early (low number of days after infestation) the prevalence and costs are decreased compared with systems where lice are not detected for long periods of time after entry. However, only small reductions in lice prevalence and costs can be obtained from using highly sensitive lice detection tests.

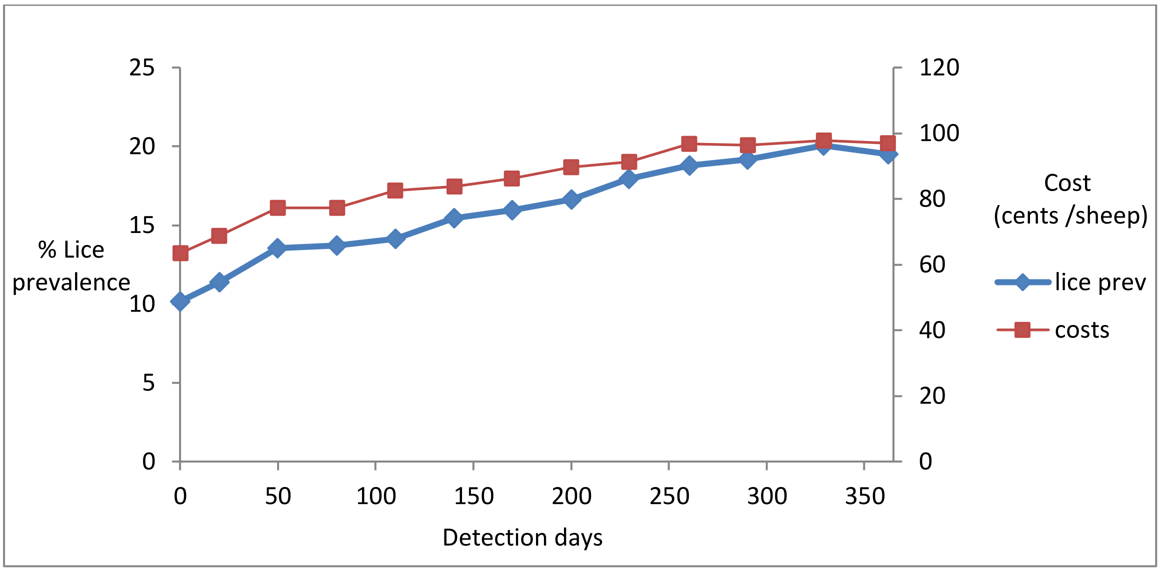

Figure 4. 2. *Lice prevalence and costs at different detection days. Detection days= number of days lice are present in a flock before detected by a lice detection test.*

Figure 4.3 shows at low intervention levels costs are high due to unnecessary treatments. This is because at low intervention levels for example 0% intervention, all flocks are treated unless they have zero chance of having lice. The cost of treatment stays relatively stable between 95 and 99 cents per sheep as intervention levels increase from 5% to 70%. This indicates that by changing intervention levels alone, costs cannot be reduced greatly. The best intervention level is shown to be about 10% as this level shows the lowest costs whilst having relatively low lice prevalence.

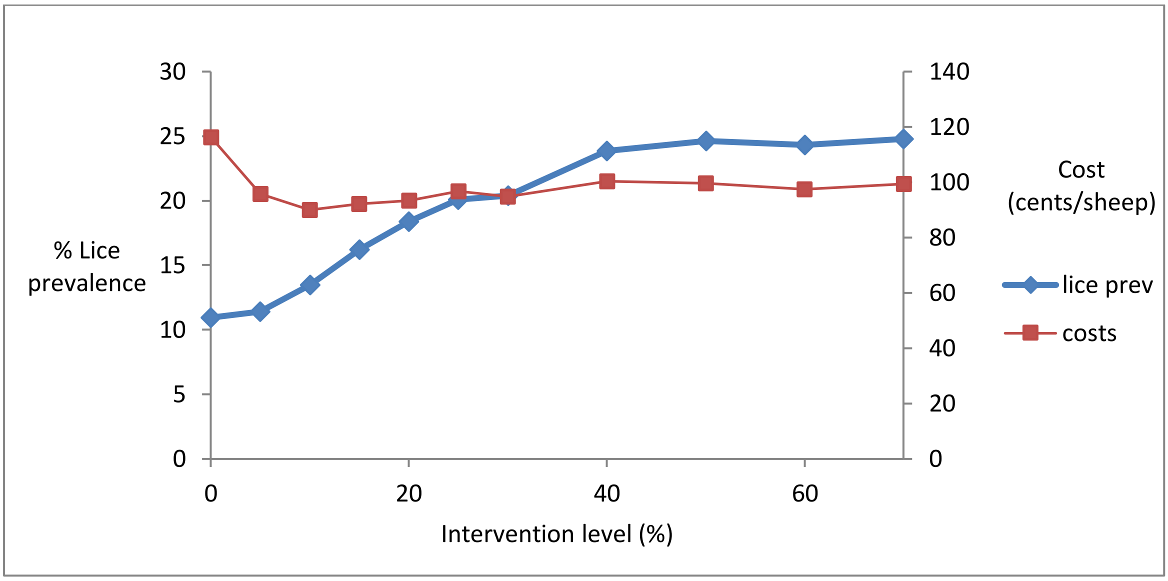

Figure 4. 3. *Intervention level= Calculated probability of lice having entered flock (depending upon risk factors) at which treatment for lice will be applied, when no lice have been detected.*

Figure 4.4 shows as the number of properties contacted increases, both lice costs and lice prevalence rapidly increase.   This suggests that considerable reductions in lice prevalence and costs could be made through improving quarantine of purchased sheep.

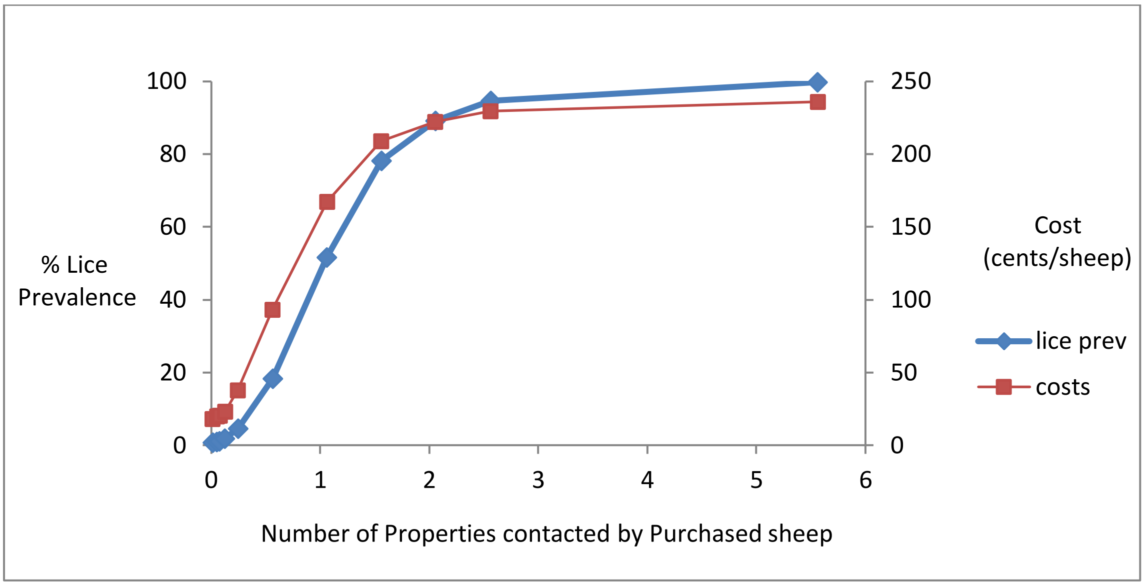

Figure 4. 4. *Costs and lice prevalence at different number of properties contacted by purchased sheep.*

Figure 4.5 shows both costs and lice prevalence to increase rapidly as the number of strays contacted increases. These results indicate that large reductions in cost and lice prevalence can be made through decreasing contact with neighbouring sheep through strays.

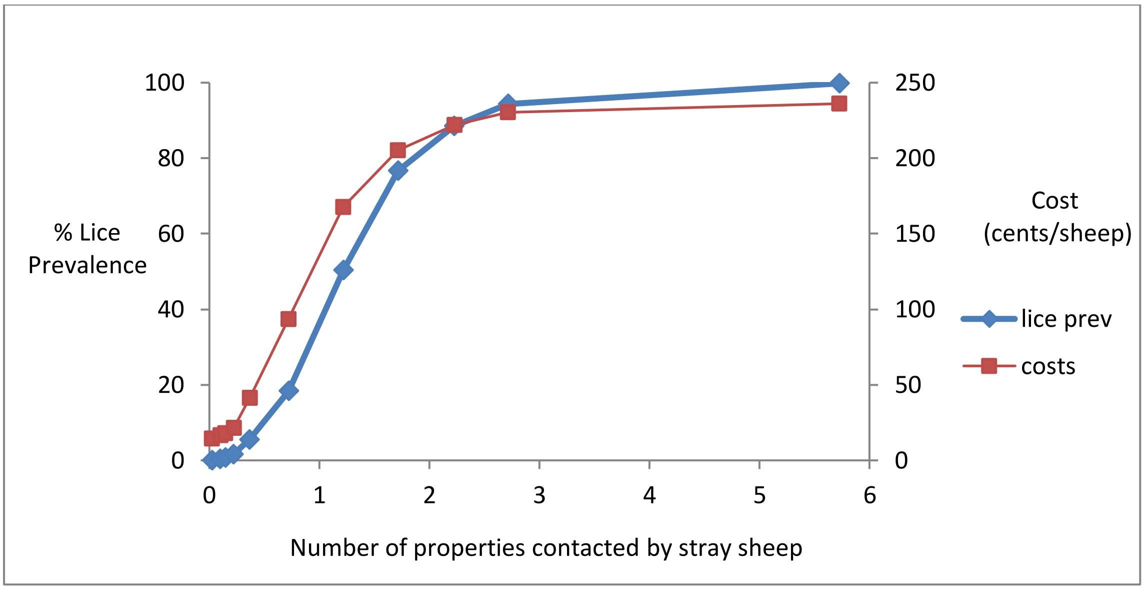

Figure 4. 5. *Costs and lice prevalence at different number of neighbouring properties contacted by stray sheep.*

Model variation

Table 4.1 shows the variation between results obtained from model simulations at low, high and average eradication rates. The standard deviations indicate the amount of variation caused by different model runs rather than due to management differences. The standard deviation for both costs and lice prevalence appears to decrease when lower values are obtained but results in an increased coefficient of variation. This indicates the amount of variation increases slightly when lower costs or lice prevalences are obtained. The standard deviation and coefficient of variation results in table 4.1 indicate small differences between model outputs are due to variation within the model, therefore conclusions cannot be drawn from management options that differ by only 1 to 2%.

Table 4. 1. *Variation between results from model simulations at average, low and high eradication rates (n=10).*

	Eradication Rate	Mean value	Standard Deviation	Coefficient of Variation (%)
Cost	51	185.38	1.86	1.0
(cents/head)	75	93.01	1.82	2.0
	100	51.50	1.40	2.7
% Lice	51	45.37	0.45	1.0
Prevalence	75	18.40	0.34	1.8
	100	8.49	0.36	4.2

Eradication Results

In contrast to the results shown in figure 4.1, specific costs and benefits of each eradication rate (see table 3.4) were added to estimate the total costs of each eradication rate over a 20 year period.

By increasing eradication rates, lice prevalence is decreased over a 20 year period (figure 4.6). At average eradication rates of 65 and 75% lice prevalence is shown to remain stable at approximately 20% infestation (figure 4.6). At eradication rates above 75% lice prevalence appears to decrease over a 20 year period. Whereas at poor eradication rates of 65% and below lice prevalence increases over time.

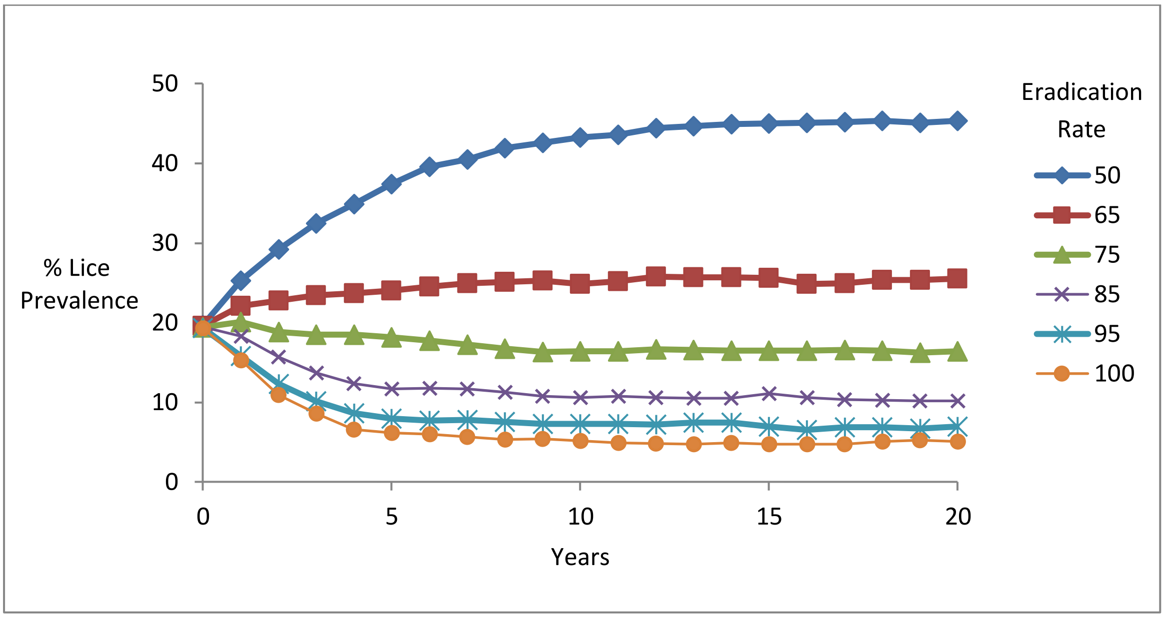

Figure 4. 6. *Average lice prevalence for each eradication rate over a 20 year period.*

The use of higher eradication rates results in lower costs over a 20 year period due to decreased costs associated with lice infestations (figure 4.7). The cost of using high eradication rates is initially higher than that of the lower eradication rates over the first few years but decreases over time. This is due to slow reductions in lice prevalence during this time and the increased costs of treatments required to obtain high eradication rates. Over time the costs of using a high eradication rate are reduced considerably when compared to that of using a poor eradication rate over a 20 year period due to reductions in lice prevalence.

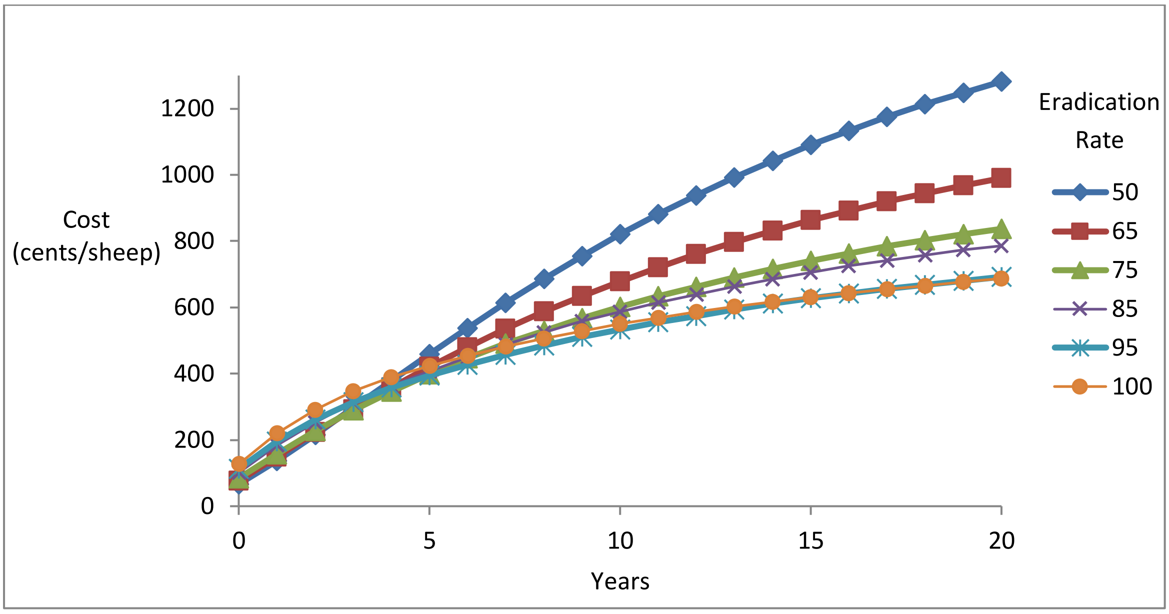

Figure 4. 7. *Net present value (NPV) for each eradication rate over a 20 year period.*

Both costs and lice prevalence decrease with increasing eradication rate (figure 4.8). The lowest costs and lice prevalences were found at higher eradication rates despite the increased costs of obtaining improved eradication rates.

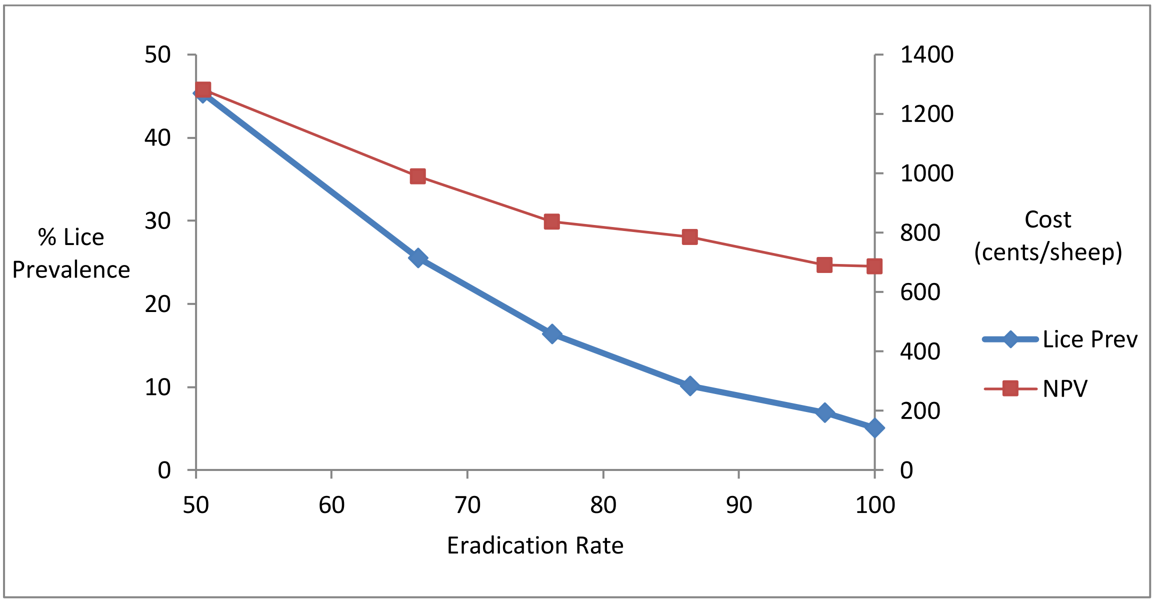

Figure 4. 8. *Net present value (NPV) over 20 years and lice prevalence for each different eradication option. Costs and benefits of lice treatments were added for each different eradication method.*

5. Eradication and Biosecurity

Eradication and minor factors

This section includes results on interactions between eradication rate and lice detection methods, intervention level and wool value.

Eradication x Detection

Suspect and non-suspect flocks

Detection methods have little effect on lice prevalence at low eradication rates and only appear to reduce lice prevalence at eradication rates of 75% and above (figure 5.1). Differences in lice prevalence between the different detection methods become most apparent at high eradication rates of 95 and 100%. At these high eradication rates the ELISA testing options clearly have the lowest lice prevalence with the no detection method showing the highest lice prevalence. These results suggest that only minimal reductions in lice prevalence can be made when using a highly sensitive detection test and only at high eradication rates.

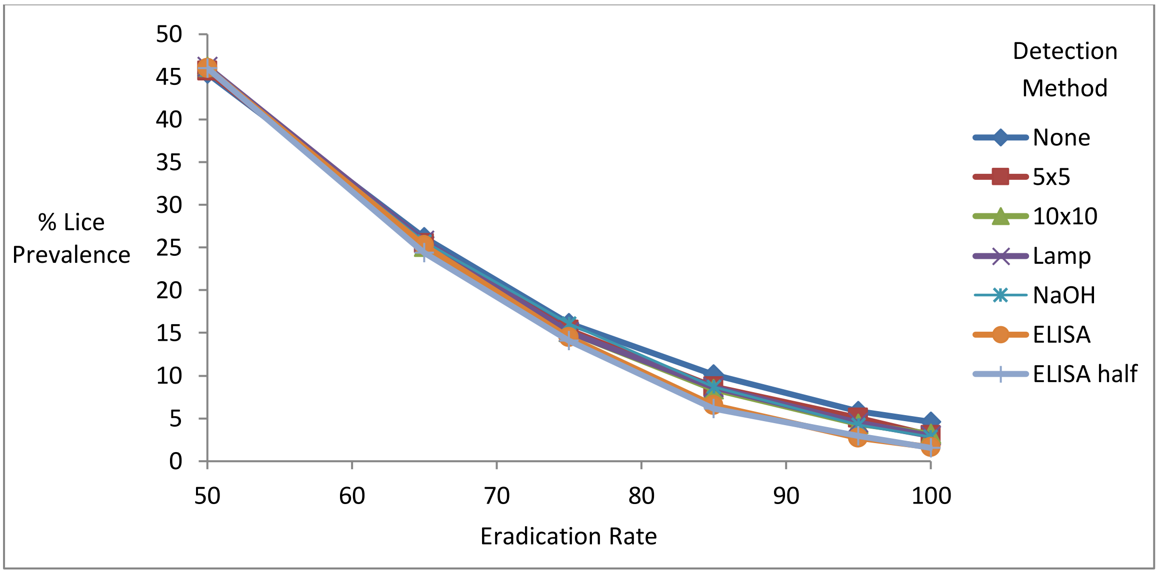

Figure 5. 1. *Lice prevalence for each lice detection option at different eradication rates on suspect and non-suspect flocks. Detection methods include ELISA testing, ELISA half (half cost of standard ELISA testing), NaOH test (dissolve locks wool with sodium hydroxide), Lamp test, 10x10 (10 partings on 10 sheep), 5x5 (Five partings on five sheep) and none (no detection test used).*

Lice detection methods 5x5, 10x10, lamp test and no detection show similar costs and appear to be the lowest cost options at each eradication rate (figure 5.2). More expensive lice detection methods result in substantial increases in overall costs but have similar impacts on lice prevalence to that of low cost lice detection methods.

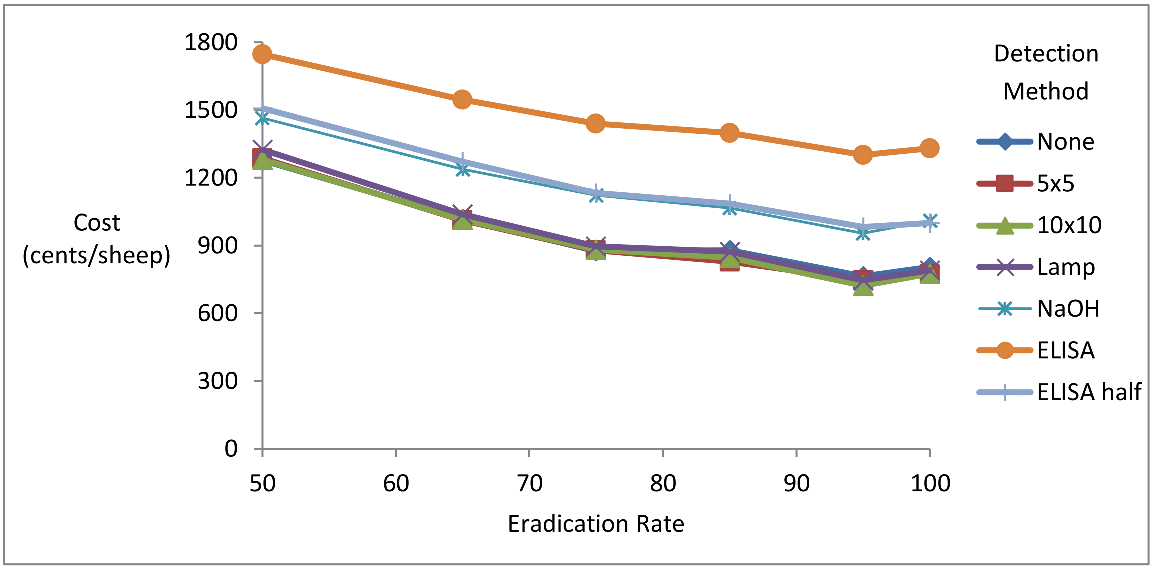

Figure 5. 2. *Net present value (NPV) over 20 years of each eradication rate at different lice detection methods on suspect and non-suspect flocks. Detection methods include ELISA testing, ELISA half (half cost of standard ELISA testing), NaOH test (dissolve locks wool with sodium hydroxide), Lamp test, 10x10 (10 partings on 10 sheep), 5x5 (Five partings on five sheep) and none (no detection test used).*

Suspect flocks only

At eradication rates of 75% and above, improved detection reduces lice prevalence and lice costs however only minimal reductions in lice prevalence can be seen at low eradication rates (Figure 5.3). At high eradication rates the no detection method shows the highest lice prevalence and ELISA tests appear to have the lowest lice prevalences. These results indicate that reductions in lice prevalence can be made through the use of highly sensitive lice detection methods at high eradication rates

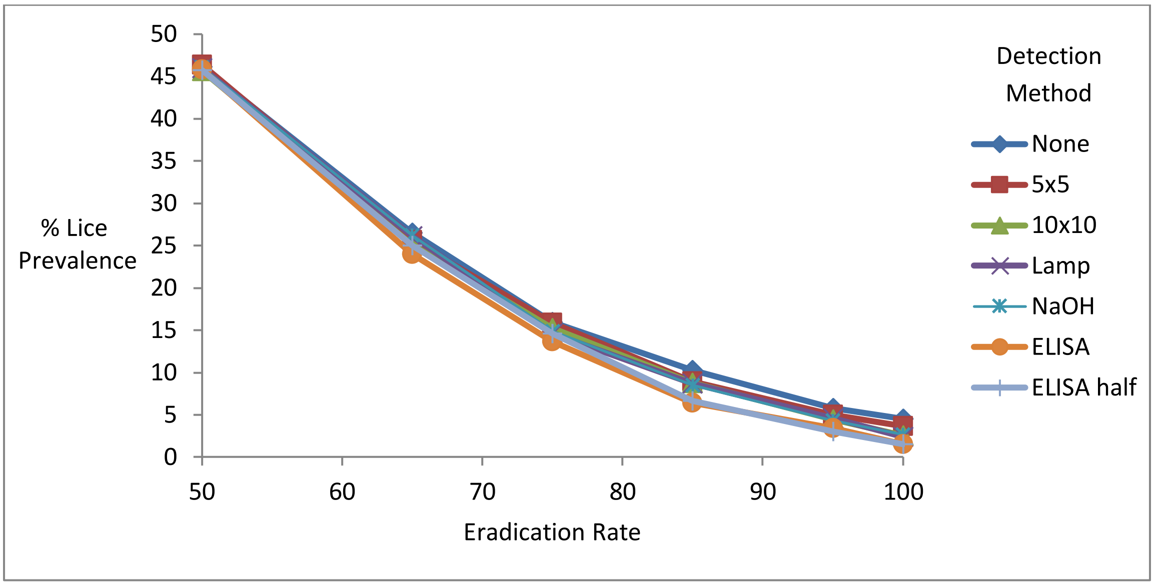

Figure 5. 3. *Lice prevalence for each lice detection method at different eradication rates for suspect flocks. Detection methods include ELISA testing, ELISA half (half cost of standard ELISA testing), NaOH test (dissolve locks wool with sodium hydroxide), Lamp test, 10x10 (10 partings on 10 sheep), 5x5 (Five partings on five sheep) and none (no detection test used). Suspect only= only flocks suspected to be infested were tested for the presence of lice.*

By only testing suspect flocks for lice the costs of lice have decreased when compared to testing both suspect and non-suspect flocks, due to reducing unnecessary treatments (figure 5.4). The 5x5, 10x10, lamp test and no detection methods again show similar results as seen in figure 5.1; however at high eradication rates of 85% and above the 5x5, 10x10 detection methods show the lowest costs. The ELISA test is the most expensive detection option at each eradication rate.

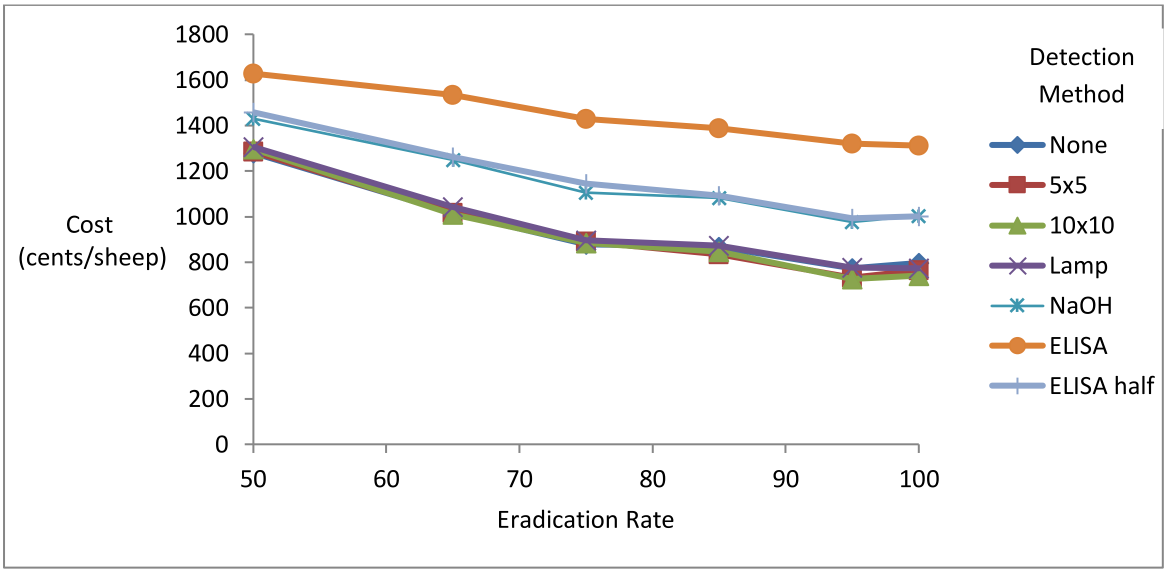

Figure 5. 4. *Net present value (NPV) over 20 years of each eradication rate at different lice detection methods on suspect flocks. Detection methods include ELISA testing, ELISA half (half cost of standard ELISA testing), NaOH test (dissolve locks wool with sodium hydroxide), Lamp test, 10x10 (10 partings on 10 sheep), 5x5 (Five partings on five*

sheep) and none (no detection test used). Suspect only= only flocks suspected to be infested were tested for the presence of lice.

Eradication x Intervention level

As intervention levels increase lice prevalence also increases except at very poor eradication rates (figure 5.5). The differences in lice prevalence for each intervention level become more apparent at higher eradication rates with the 0% intervention level showing the lowest lice prevalence and the 30% intervention level showing the highest.

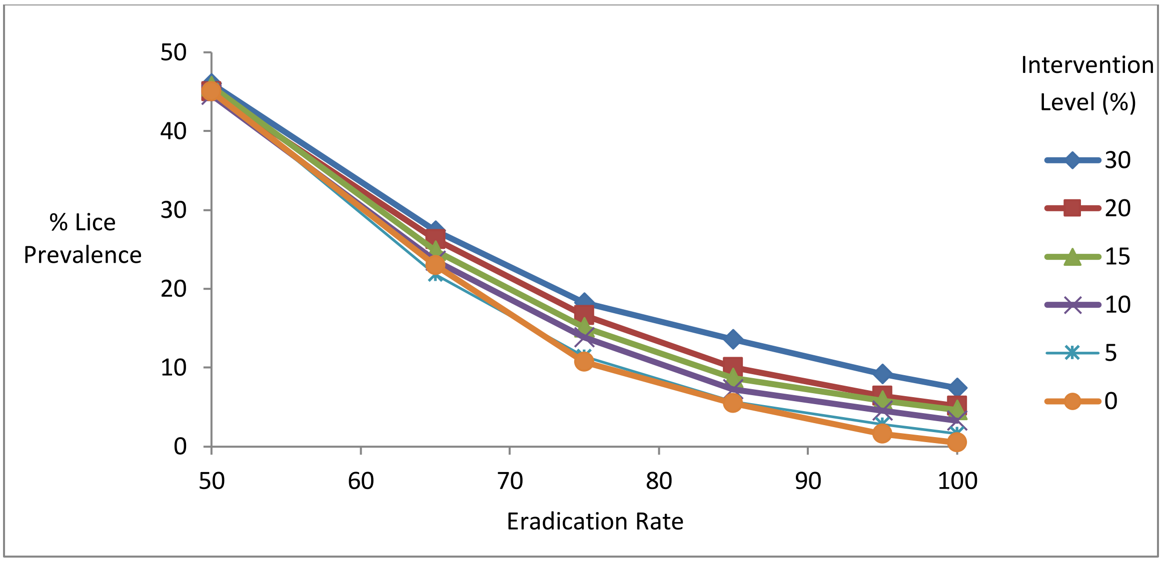

Figure 5. 5. *Lice prevalences for each intervention level at differing eradication rates. Intervention level (%) = Calculated probability of lice having entered flock (depending upon risk factors) at which treatment for lice will be applied, when no lice have been detected.*

The highest intervention level of 30% is the most cost effective option at each eradication rate; however at this intervention level lice prevalence is increased (figure 5.6). Large differences in costs can be seen between different intervention levels at higher eradication rates. Costs of the 0% intervention level are substantially higher than that of other intervention levels at higher eradication rates. Intervention levels of 10, 15 and 20% show reduced overall costs than that of lower intervention levels whilst also having reduced lice prevalence levels when compared to higher intervention levels.

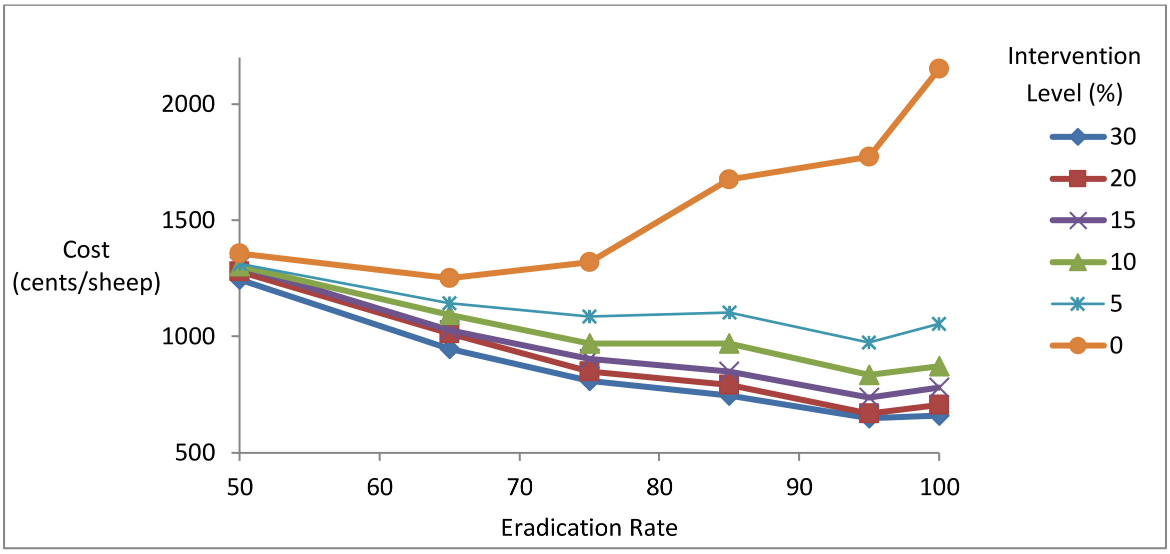

Figure 5. 6. *Net present values (NPV) over 20 years for each intervention level and eradication rate. Intervention level (%) = Calculated probability of lice having entered flock (depending upon risk factors) at which treatment for lice will be applied, when no lice have been detected.*

Eradication at High Wool Values

Improved eradication rates causes reductions in costs for all wool values, except for the most expensive method, which is not economic except at the highest wool value (figure 5.7). Lice prevalence levels for different quality wool do not change and have been shown previously in figure 4.8.

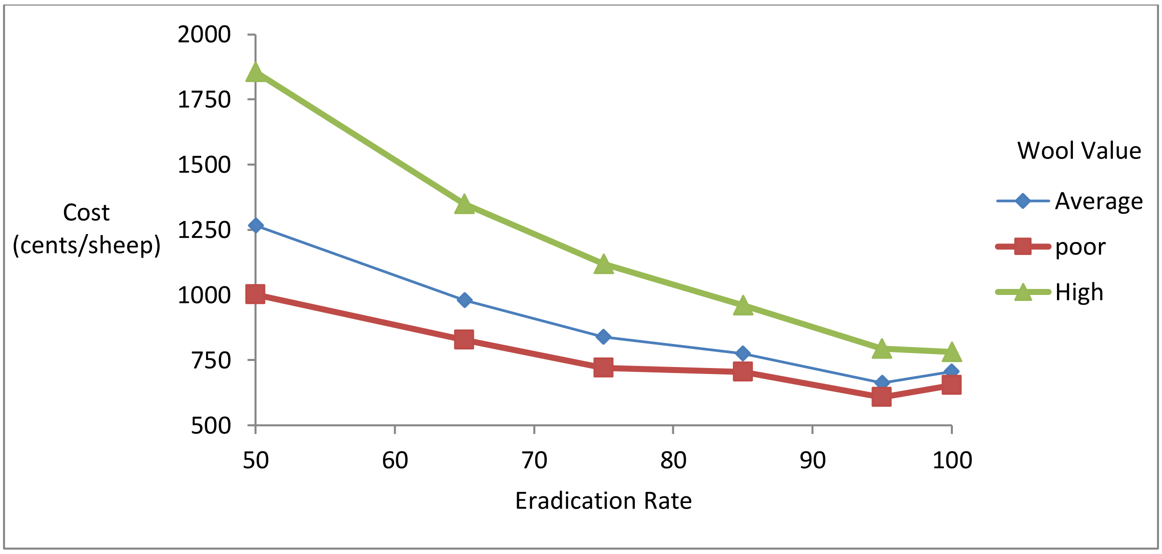

Figure 5. 7. *Net present value (NPV) over 20 years of average, poor and high value wool over different eradication rates.*

Biosecurity and minor factors

This section includes results on biosecurity of purchases and biosecurity of strays against lice detection methods and intervention level. Information on lice detection methods, intervention level and biosecurity of purchases and strays can be found in chapter 3.

Biosecurity of Purchases x Detection

Biosecurity of purchased sheep includes inspection through fleece partings, quarantine, treatment of purchased flocks and the option of no biosecurity of purchased sheep.

Suspect and non-suspect flocks

Lice prevalence is considerably reduced when using biosecurity of purchases methods compared to that of the no biosecurity of purchases (figure 5.8). Lice prevalence is further reduced by combining biosecurity of purchases with a lice detection test.

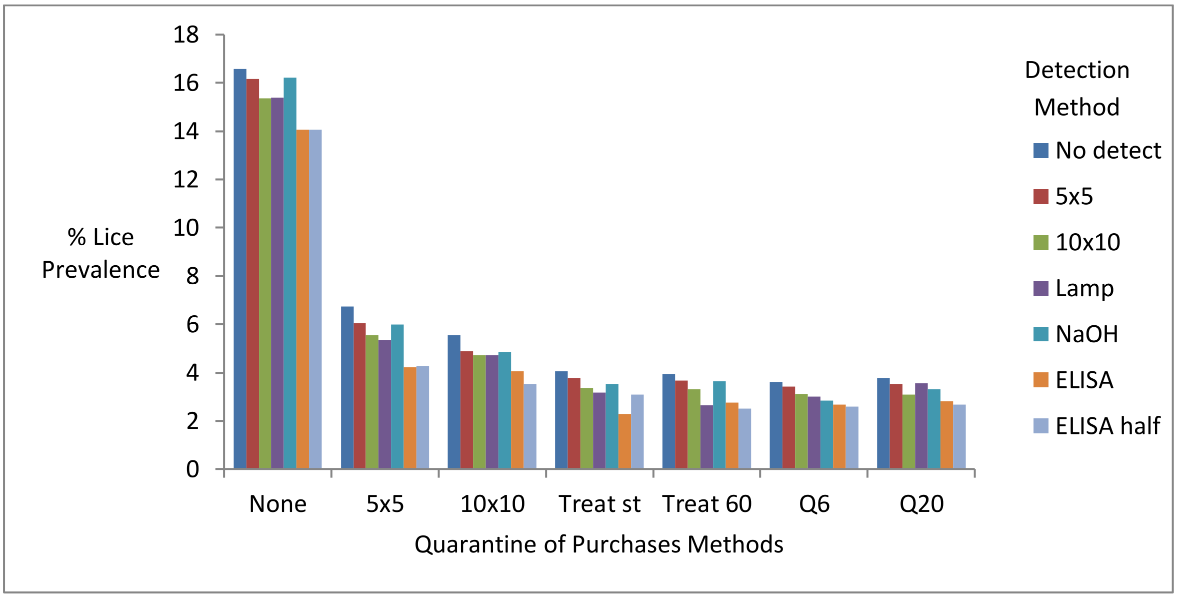

Figure 5. 8. *Lice prevalence for each biosecurity option for purchased sheep at different lice detection methods on suspect and non-suspect flocks. Purchases = number of properties contacted through purchase of sheep. Biosecurity options include inspection = 5x5 and 10x10, Quarantine= Q6 and Q20, Treatment of purchased sheep = treat st and treat 60 and none= no biosecurity of purchased sheep. Detection methods include ELISA testing, ELISA half (half cost of standard ELISA testing), NaOH test (dissolve locks wool with sodium hydroxide), Lamp test, 10x10 (10 partings on 10 sheep), 5x5 (Five partings on five sheep) and none (no detection test used).*

Costs decrease when lice detection and biosecurity of purchases are used in combination (figure 5.9). All biosecurity of purchases and lice detection methods show reduced costs when combined rather than when used as single management options. The lice detection methods of no detection, 5x5 and 10x10 appear to be the lowest cost options and the ELISA testing shows the highest costs for each biosecurity of purchases option. These results indicate further reductions in lice prevalence and costs can be obtained through using lice detection tests in combination with biosecurity of purchased sheep.

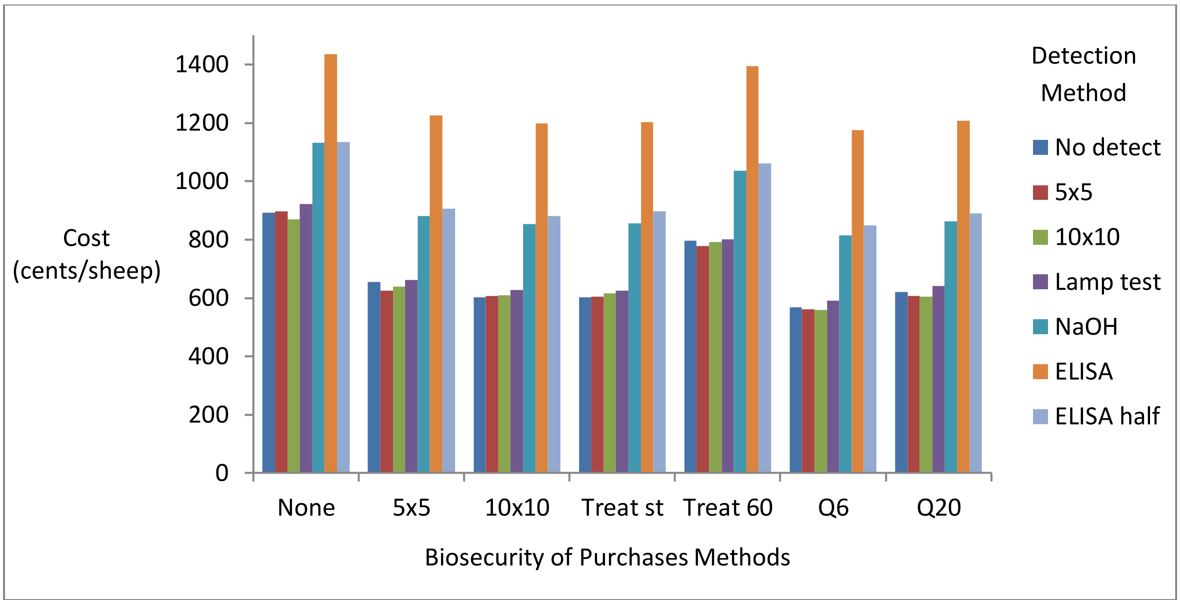

Figure 5. 9. *Net present value (NPV) over 20 years for each biosecurity option for purchased sheep at different lice detection methods on suspect and non-suspect flocks. Purchases = number of properties contacted through purchase of sheep. Biosecurity options include inspection = 5x5 and 10x10, Quarantine= Q6 and Q20, Treatment of purchased sheep = treat st and treat 60 and none= no biosecurity of purchased sheep. Detection methods include ELISA testing, ELISA half (half cost of standard ELISA testing), NaOH test (dissolve locks wool with sodium hydroxide), Lamp test, 10x10 (10 partings on 10 sheep), 5x5 (Five partings on five sheep) and none (no detection test used).*

Biosecurity of Purchases x Intervention Level

Lice prevalence is greatly decreased when a low intervention level is used (figure 5.10). Lice prevalence can be further decreased when a low level of intervention in combined with a low cost biosecurity of purchases.

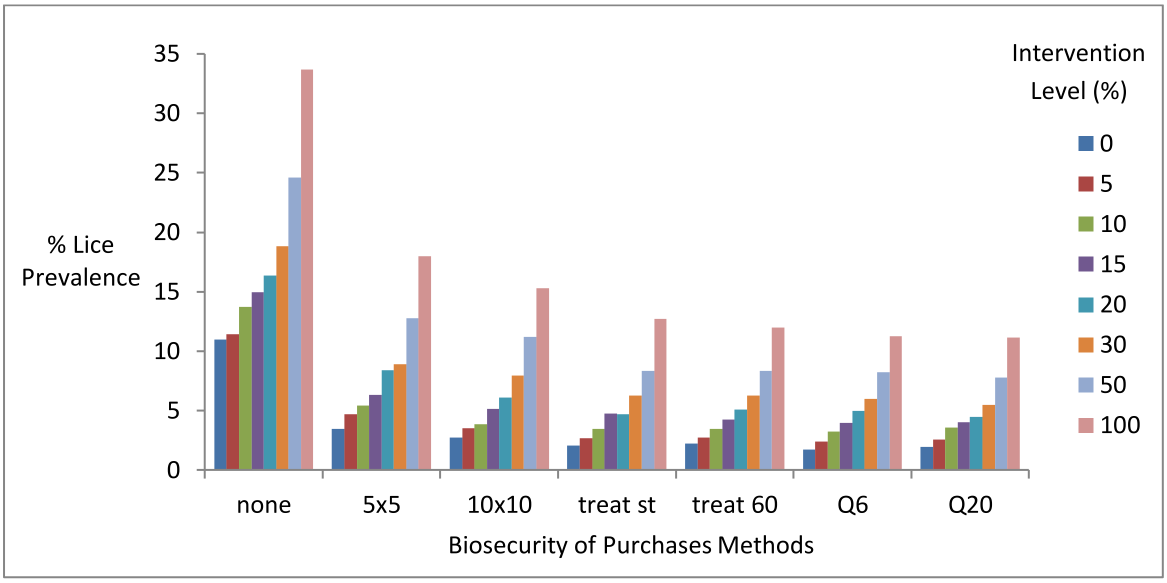

Figure 5. 10. *Lice prevalence for each biosecurity of purchases methods at different intervention levels. Purchases = number of properties contacted through purchase of sheep. Biosecurity options include inspection = 5x5 and 10x10, Quarantine= Q6 and Q20, Treatment of purchased sheep = treat st and treat 60 and none= no biosecurity of purchased sheep. Intervention level (%) = Calculated probability of lice having entered flock (depending upon risk factors) at which treatment for lice will be applied, when no lice have been detected.*

The use of low intervention levels shows higher costs for each biosecurity option (figure 5.11). All biosecurity of purchases options except treat 60, show lower costs than that of the no biosecurity option at each intervention level. Costs of lice decrease as the intervention level increases from 0 to 20 for each biosecurity of purchases method. As the intervention level increases from 30 the costs of lice increase for all biosecurity options.

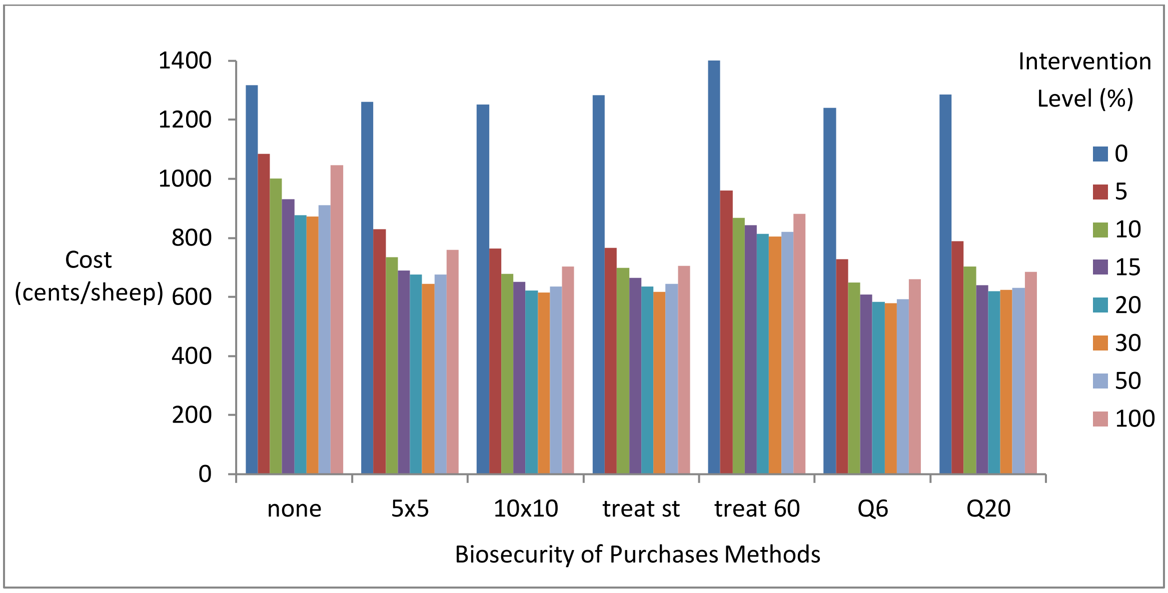

Figure 5. 11. *Net present value (NPV) over 20 years for each biosecurity option of purchased sheep against different intervention levels. Purchases = number of properties contacted through purchase of sheep. Biosecurity options include inspection = 5x5 and 10x10, Quarantine= Q6 and Q20, Treatment of purchased sheep = treat st and treat 60 and none= no biosecurity of purchased sheep. Intervention level (%) = Calculated probability of lice having entered flock (depending upon risk factors) at which treatment for lice will be applied, when no lice have been detected.*

Biosecurity of Strays x Detection

Reductions in the number of neighbouring properties contacted by strays were obtained through improving boundary fences by the addition of 2km fencing at a cost of $20,000. Reductions in stray contacts include 0, 20, 40 and 60%.

Suspect and non-suspect flocks

Lice prevalence is greatly reduced through reductions in the number of neighbours contacted, with the lowest lice prevalences for each detection method found using a 60% reduction method (figure 5.12). Lice prevalence is only minimally reduced when combining a biosecurity of strays option with lice detection methods

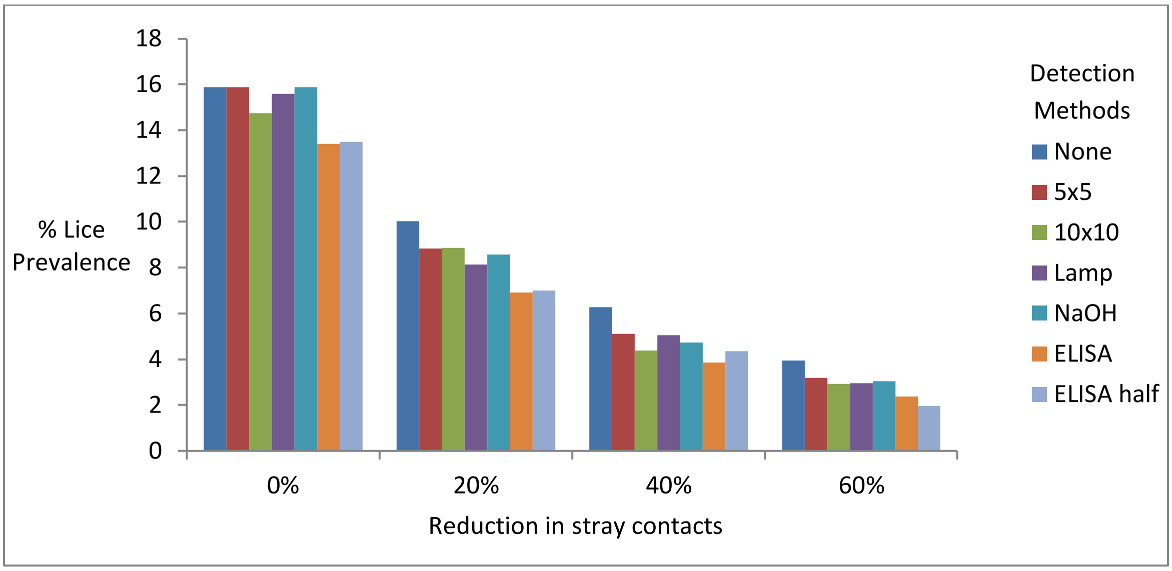

Figure 5. 12. *Lice prevalence for each reduction in strays at different lice detection methods on suspect and non-suspect flocks. Strays = number of neighbouring properties contacted by stray sheep. 20, 40, 60 = percentage reduction in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays and fencing costs added. Detection methods include ELISA testing, ELISA half (half cost of standard ELISA testing), NaOH test (dissolve locks wool with sodium hydroxide), Lamp test, 10x10 (10 partings on 10 sheep), 5x5 (Five partings on five sheep) and none (no detection test used).*

Lowest costs are obtained when using the 5x5 and 10x10 inspection methods at 40 and 60% reductions in strays (figure 5.13). Only small differences can be seen between the costs of the 5x5, 10x10, Lamp test and the no detection option at each reduction in strays. These results show that small reductions in cost can be made through using a 40 or 60% reduction in strays combined with a low cost lice detection method such as fleece partings.

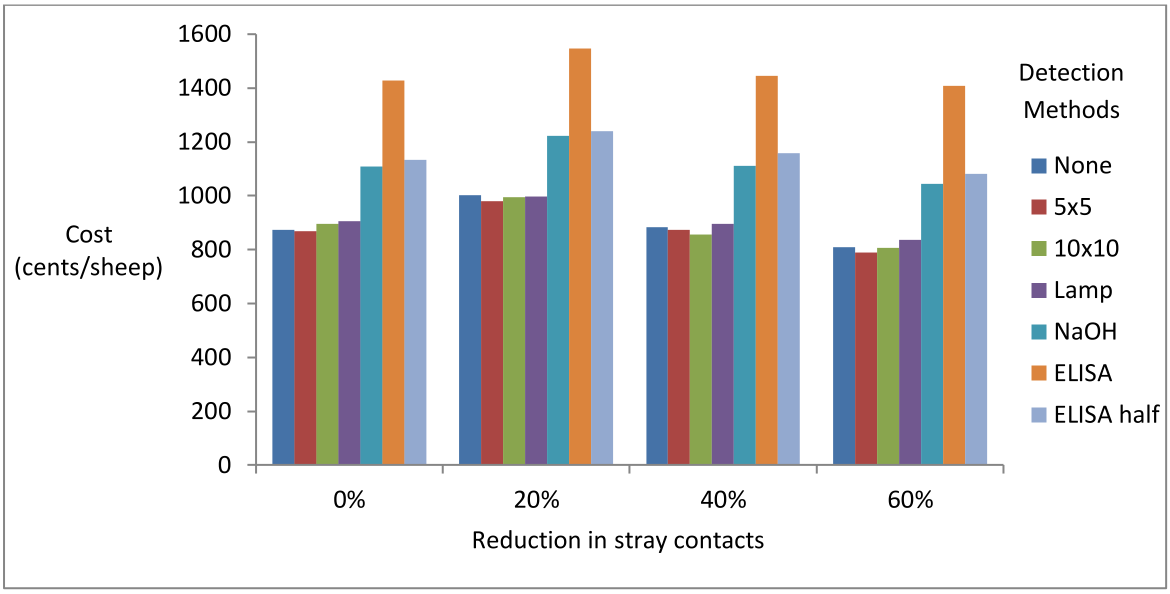

Figure 5. 13. *Net present value (NPV) over 20 years for each reduction in strays at different lice detection methods on suspect and non-suspect flocks. Strays = number of neighbouring properties contacted by stray sheep. 20, 40, 60 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays and fencing costs added. Detection methods include ELISA testing, ELISA half (half cost of standard ELISA testing), NaOH test (dissolve locks wool with sodium hydroxide), Lamp test, 10x10 (10 partings on 10 sheep), 5x5 (Five partings on five sheep) and none (no detection test used).*

Biosecurity of Strays x Intervention Level

Lice prevalence is greatly reduced when using a low intervention level in combination with a reduction in strays option (figure 5.14). When using a 60% reduction in strays it is possible to use a higher intervention level without causing huge increases in lice prevalence. Using a 100% intervention level with a 60% reduction in strays has very similar lice prevalence levels to that of using a 0% intervention level and having no reduction in strays.

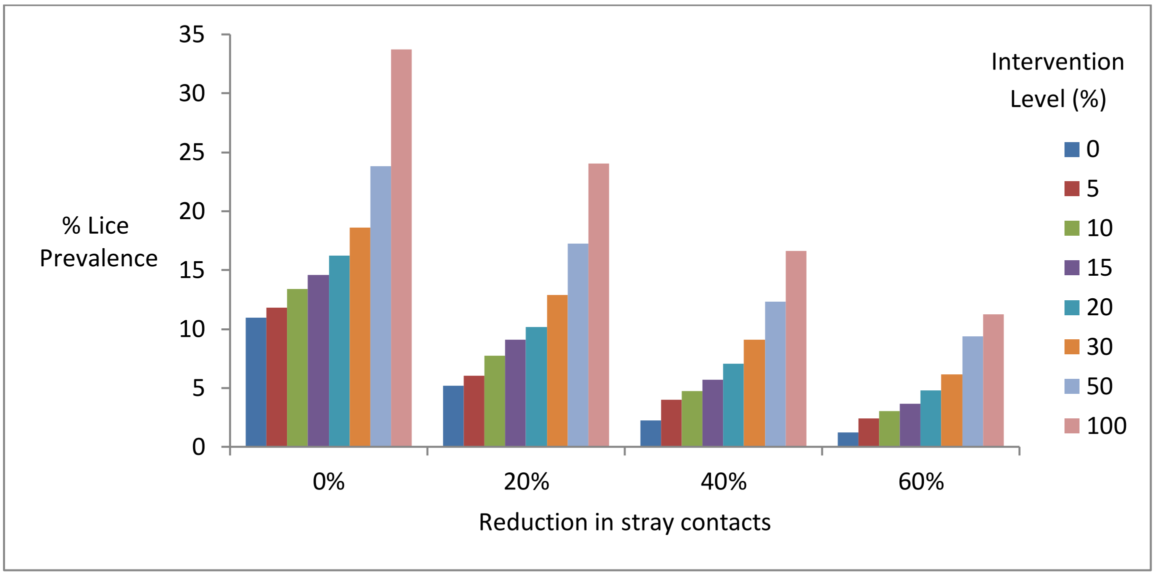

Figure 5. 14. *Lice prevalence for each reduction in strays at different intervention levels on suspect and non-suspect flocks. Strays = number of neighbouring properties contacted by stray sheep. 20, 40, 60 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays and fencing costs added. Intervention level (%) = Calculated probability of lice having entered flock (depending upon risk factors) at which treatment for lice will be applied, when no lice have been detected.*

For each biosecurity of strays option costs decrease as intervention levels increase from 0 to 30% (figure 5.14). Costs begin to increase as intervention levels increase above 30% for each biosecurity of strays option. The greatest reductions in costs are achieved when using an intervention level of 30% with a 60% reduction in strays.

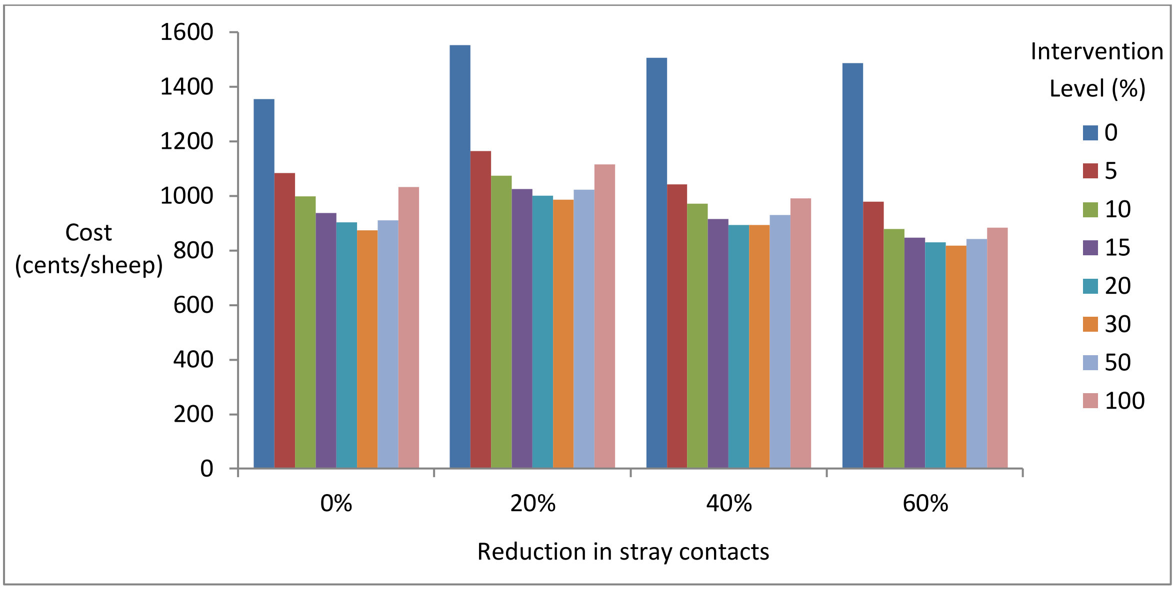

Figure 5. 15. *Net present value (NPV) over 20 years for each reduction in strays at different intervention levels on suspect and non-suspect flocks. Strays = number of neighbouring properties contacted by stray sheep. 20, 40, 60 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays and fencing costs added. Intervention level (%) = Calculated probability of lice having entered flock (depending upon risk factors) at which treatment for lice will be applied, when no lice have been detected.*

Eradication and Biosecurity Interactions

This section includes results of combinations of eradication rate and biosecurity of purchases and biosecurity of strays. Combinations of eradication rate and biosecurity of strays also include different sized properties and wool values. Information on the eradication rates, biosecurity of purchased sheep and biosecurity of strays found in chapter 3.

Eradication x Biosecurity of Purchases

Inspection of purchases

All inspection methods show reduced lice prevalence when compared to that of no lice detection of purchased sheep (figure 5.16). The largest reductions in lice prevalence are achieved at poor eradication rates when using a 10x20 parting method.

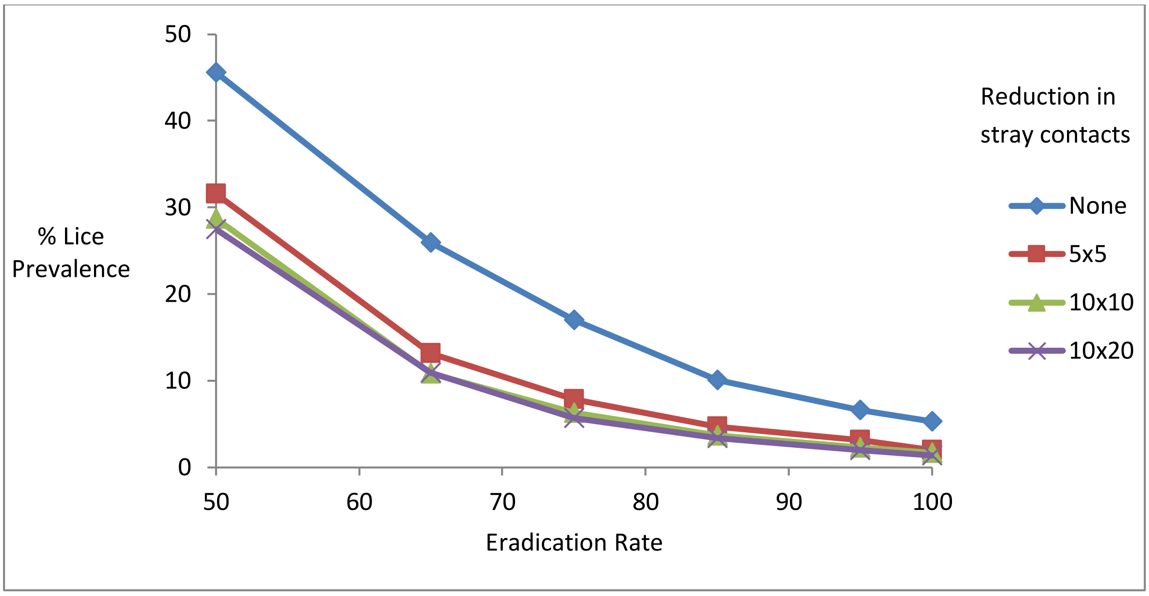

Figure 5. 16. *Lice prevalences of no lice detection and different parting methods at different eradication rates. None = no lice detection. 5x5 = 5 partings on 5 sheep. 10x10 = 10 partings on 10 sheep. 10x20 = 10 partings on 20 sheep.*

In figure 5.17 the results show costs decrease when inspection through parting methods are used. The greatest benefits at each eradication rate were found using 10x20 partings method. These results show a combination of 75% eradication rate and a 10x10 or a 10x20 inspection method can provide lower costs and lice prevalence than that of using a high eradication rate of 95% and no inspection method (figures 5.16 and 5.17).

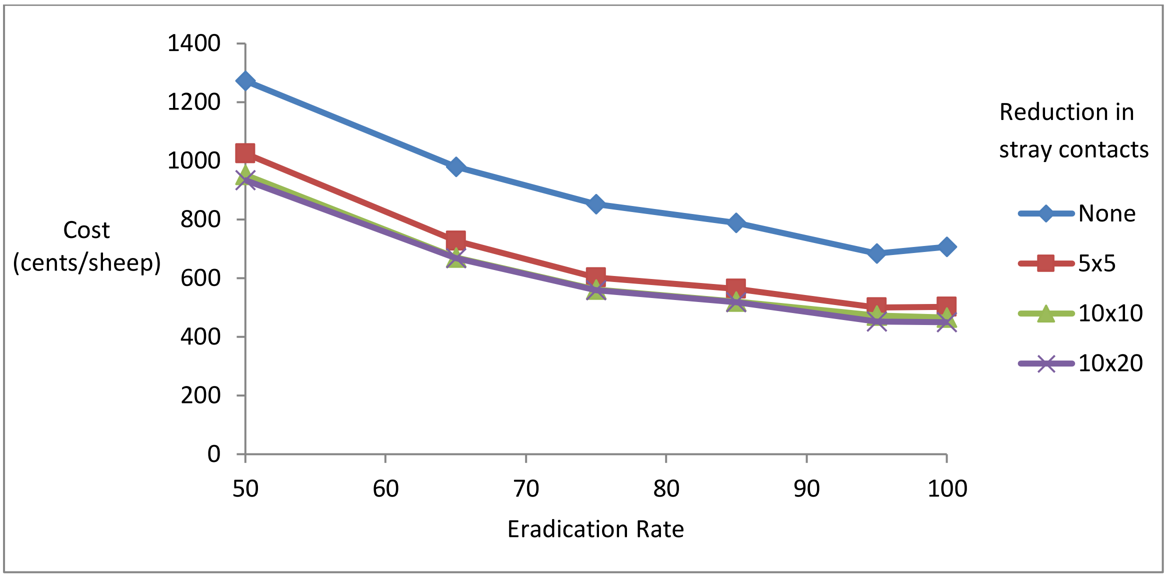

Figure 5. 17. *Net present value (NPV) over 20 years of no lice detection and different parting methods at different eradication rates. None = no lice detection. 5x5 = 5 partings on 5 sheep. 10x10 = 10 partings on 10 sheep. 10x20 = 10 partings on 20 sheep.*

Quarantine of purchases

Both quarantine options greatly reduce lice prevalence at each eradication rate when compared to that of no quarantine (figure 5.18). Greatest reductions in lice prevalence are obtained when using a quarantine of purchases option at low eradication rates.

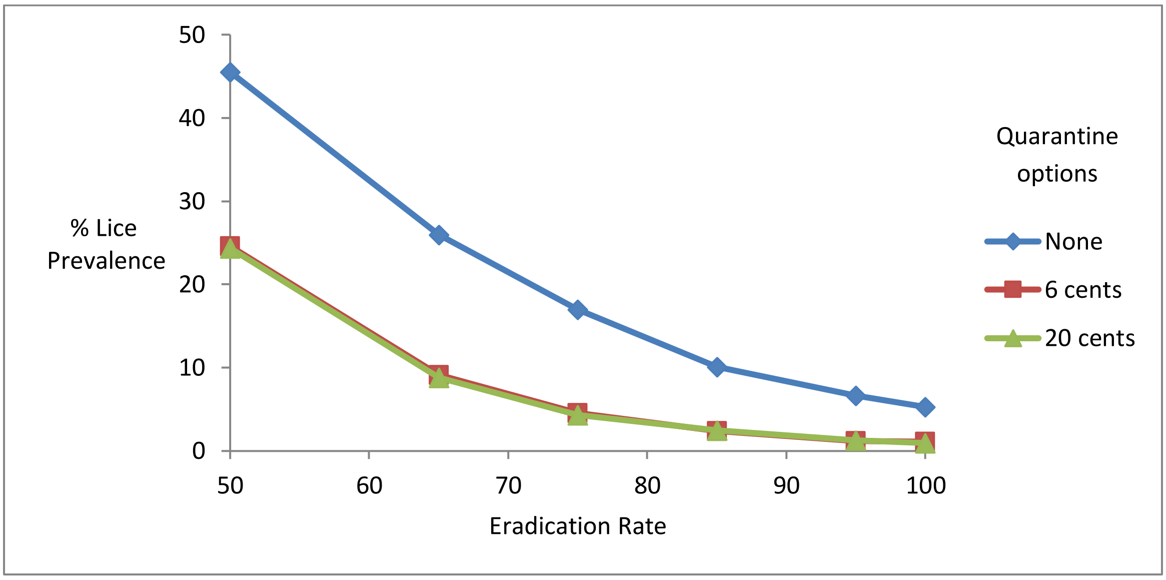

Figure 5. 18. *Lice prevalences for different quarantine options at each eradication rate. 6 cents= cost per head to separate a single mob from the original flock for up to 6 months. 20 cents= cost per head to separate multiple mobs from original flock for up to 6 months. None= no quarantine of purchased mobs.*

When using quarantine methods costs of lice are reduced at each eradication rate compared to that of no quarantine (figure 5.19). The quarantine option at 6 cents per head is the lowest cost option at all eradication rates. However there is only a small difference between the two quarantine methods. Lower lice costs and similar lice prevalences (figure 5.18) are obtained when using an eradication rate of 75% in combination with a quarantine option compared to that of using a single management option of 95% eradication. These results indicate combinations of management options can provide greater reductions in lice prevalence and cost compared to that of single management options.

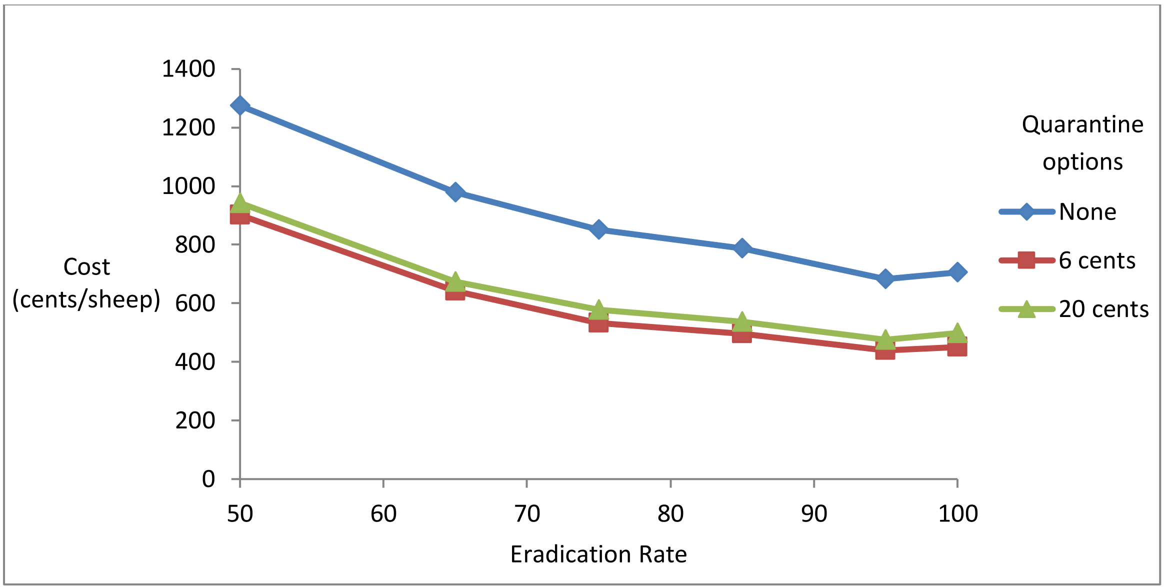

Figure 5. 19. *Net present value (NPV) over 20 years of no quarantine and quarantine of purchased sheep using two different costs methods for each eradication rate. 6 cents= cost per head to separate a single mob from the original flock for up to 6 months. 20 cents= cost per head to separate multiple mobs from original flock for up to 6 months. None= no quarantine of purchased mobs.*

Treatment of purchases

All treatment options show the same reduction in lice prevalence which is greatly reduced when compared to the no-treatment option at each eradication rate (figure 5.20). When using combinations of a 75% eradication rate with a treatment of purchases option lice prevalence is decreased when compared with using a 95% eradication rate alone.

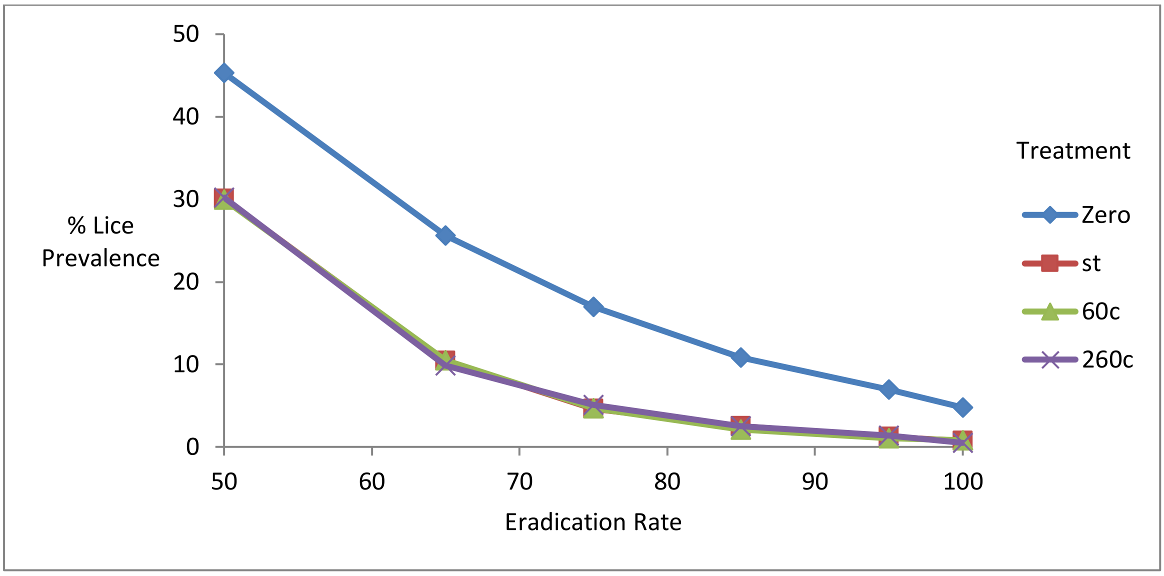

Figure 5. 20. *Lice prevelances of different treatment cost options at each eradication rate. St= standard treatment which is 1/5th of the costs to treat whole flock. 60c= cost of 60 cents per head to treat purchased sheep. 260c= cost of 260 cents per head to treat purchased sheep. Zero= no treatment of purchased sheep.*

The standard treatment and an additional treatment cost of 60c/head have reduced costs than that of the no treatment option (figure 5.21). The highly expensive treatment option of an additional 260c/head was not cost effective compared with the no-treatment option. Through using combinations of a 75% eradication rate with a standard treatment of purchases, cost of lice are lower than using an eradication rate of 95% alone.

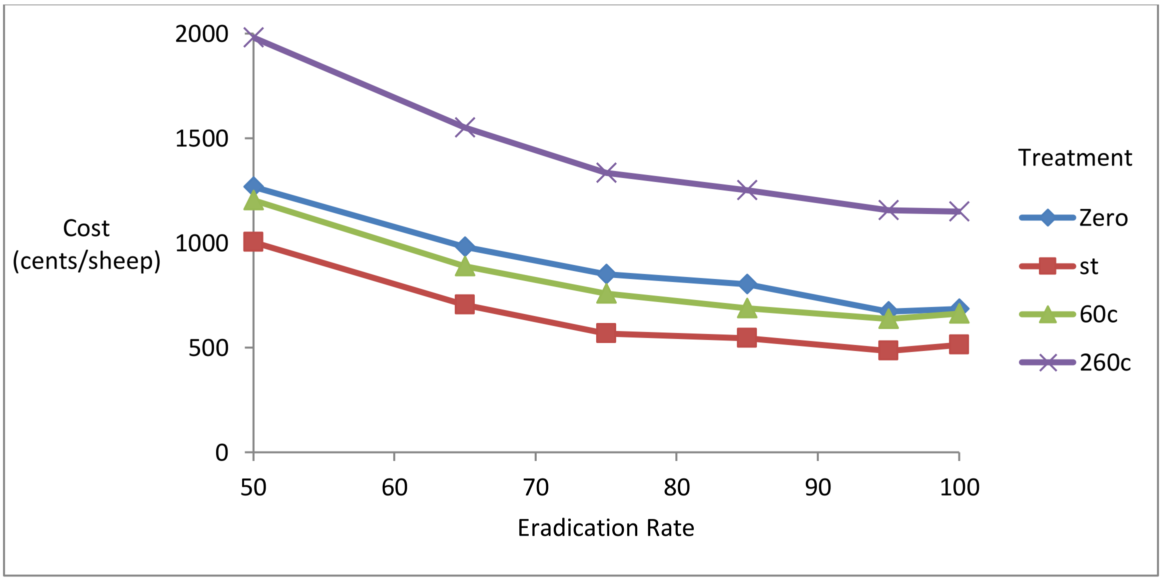

Figure 5. 21. *Net present value (NPV) over 20 years of different treatment costs of purchases at each eradication rate. St= standard treatment which is 1/5th of the costs to treat whole flock. 60c = cost of 60 cents per head to treat purchased sheep. 260c= cost of 260 cents per head to treat purchased sheep. Zero= no treatment of purchased sheep.*

Eradication x Biosecurity of Strays

All reductions in strays contacted show reduced lice prevalences at each eradication rate when compared to that of no reduction in neighbours (figure 5.22). The lowest lice prevalences for each eradication rate were found at 60% reduction in strays contacted.

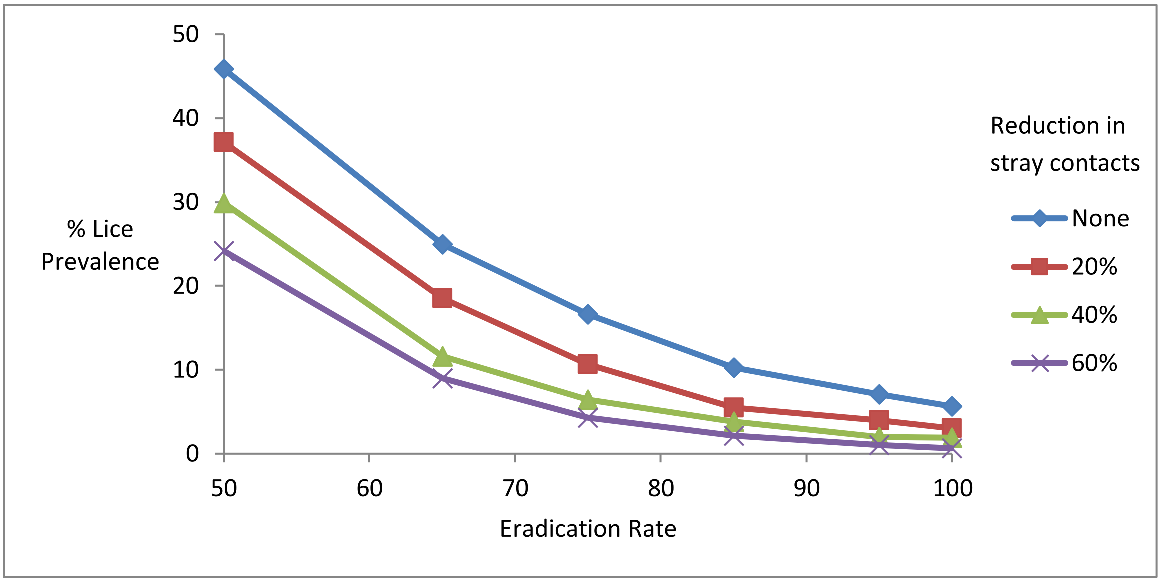

Figure 5. 22. *Lice prevalences at none, 20, 40 and 60% reductions in strays at each eradication rate. Strays = number of properties being contacted by stray sheep. 20, 40, 60 = percentage reduction in strays from addition of 2km boundary fencing at a cost of $20,000. None= no reduction in strays.*

A minimum reduction in strays contacted of over 40% is required in order for costs to be lower than that of no added fencing (figure 5.23). Obtaining a 20% benefit from the addition of 2km fencing is not sufficient despite reduced costs of lice infestations. At poor eradication rates reductions in strays of 40 and 60% are cost effective, however as eradication rates increase the costs of no reduction and a 60% reduction in strays contacted are very similar. Even though the costs of a 40% reduction may be slightly higher than that of no reduction option at high eradication rates, the 40% reduction greatly reduces lice prevalence (figure 5.22).

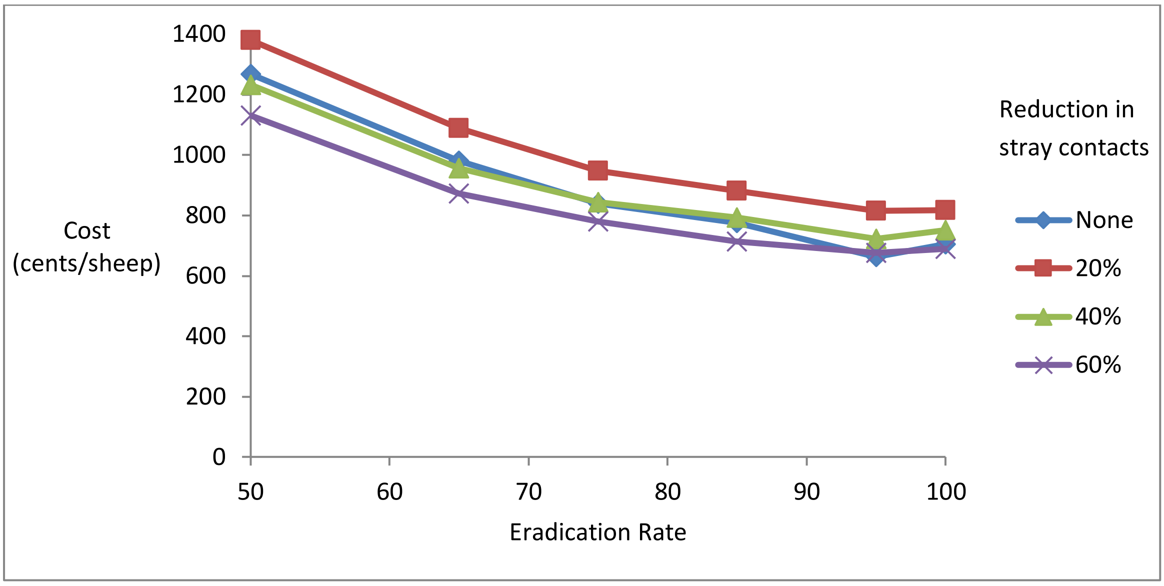

Figure 5. 23. *Net present value (NPV) over 20 years for 0, 20, 40 and 60% reduction in strays at each eradication rate after repairing 2km of fences at cost of $20,000. Strays = number of properties being contacted by stray sheep. 20, 40, 60 = percentage reduction in strays from addition of 2km boundary fencing at a cost of $20,000. None= no reduction in strays.*

Fencing benefit on different sized properties over 20 years

Large reductions in lice prevalence are obtained from a 40% reduction in strays contacted compared to no reduction in strays contacted on all property sizes (figure 5.24). The greatest reductions in lice prevalence are seen on large sized properties when a 40% reduction in strays is obtained. Lice prevalence shows an initial decrease over the first few years with a 40% reduction in strays on all property sizes, but remains relatively stable over the 20 year period with no improved fencing.

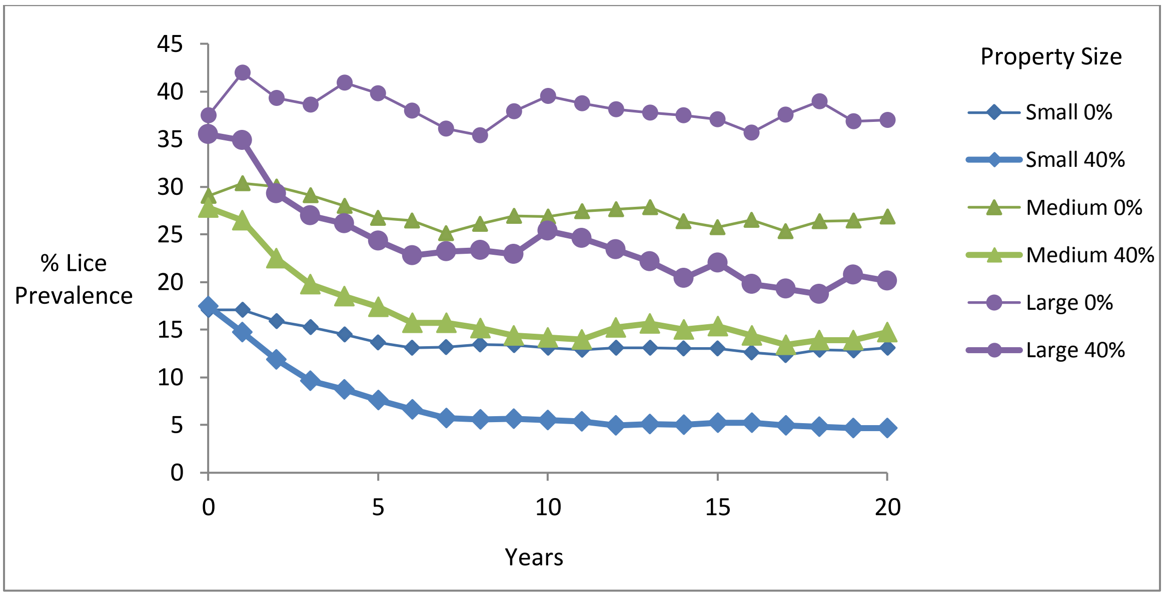

Figure 5. 24. *Lice prevalence over 20 years of none and 40 % reduction in strays contacted on small, medium and large*

sized properties at an eradication rate of 75%. Strays = number of properties being contacted by stray sheep. 40 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays.

On large properties costs of a 40% reduction in strays become lower than that of no reduction after approximately seven years (figure 5.25). On medium properties it takes approximately 15 years for the costs of a 40% reduction and no reduction to be equal. On small properties the overall costs of a 40% reduction is never lower than that of no reduction over 20 years. The intersection points of the two reduction options indicates large properties are able to recover costs of fencing in less time than that of medium and small sized properties.

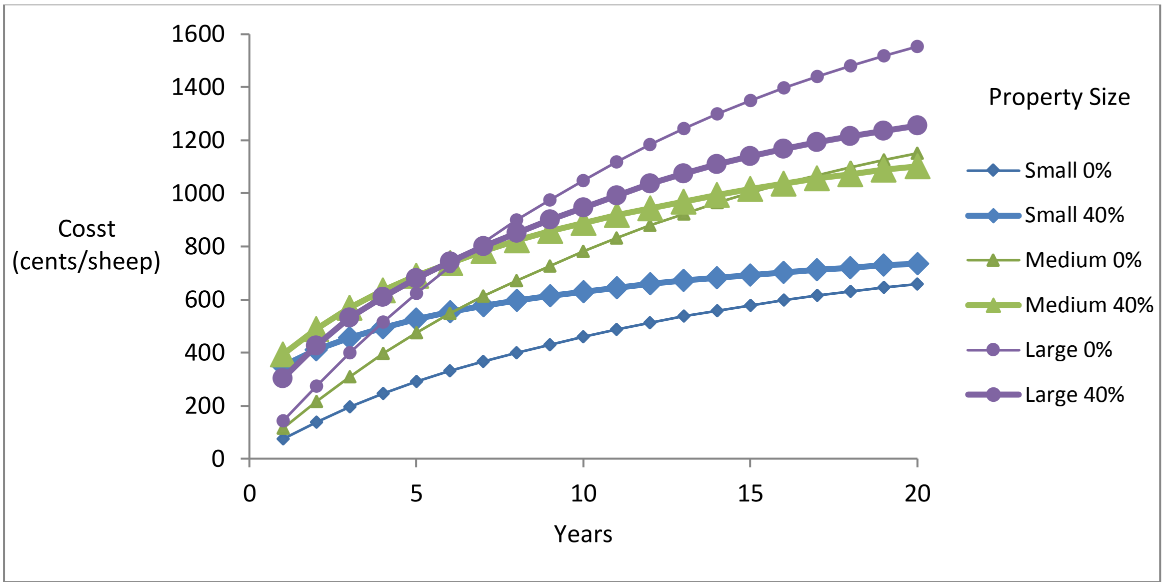

Figure 5. 25. *Net present value (NPV) over 20 years of none and 40 % reduction in strays contacted on small, medium and large sized properties at an eradication rate of 75%. Strays = number of properties being contacted by stray sheep. 40 = percent reduction in strays from addition of 2km boundary fencing at a cost of $20,000. None= no reduction in strays.*

Eradication x Biosecurity of Strays on Different Sized Properties

Small Properties

Lice prevalence on small properties decreases with increasing eradication rate for each reduction in strays option when compared to no reduction in strays (figure 5.26). The greatest benefits from improved fencing can be seen at poor eradication rates with a 60% reduction in strays showing the greatest reductions in lice prevalence at each eradication rate. no reduction in strays through improved fencing provides the highest lice prevalence at each eradication rate. As eradication rates increase only small differences in lice prevalence can be seen between the different biosecurity of strays methods.

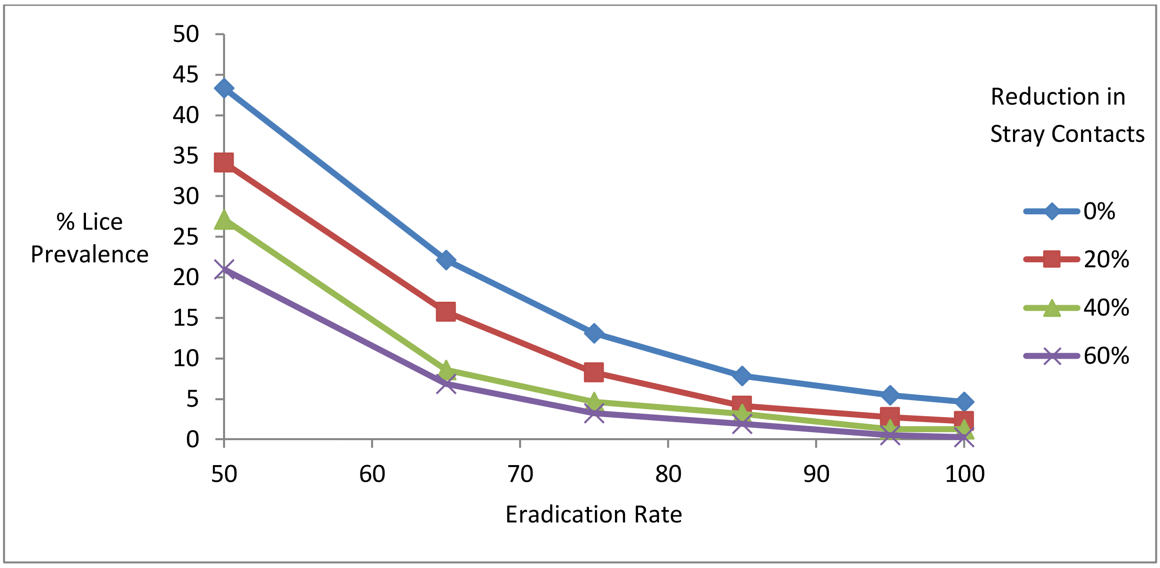

Figure 5. 26. *Lice Prevalence of none, 20, 40 and 60% reduction in strays contacted at each eradication rate on small sized properties. Strays = number of properties being contacted by stray sheep. 20, 40, 60 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. None= no reduction in strays. Small properties= average property size of 700ha.*

On small properties, the benefit from fencing is greater at lower eradication rates with both 40% and 60% reductions in neighbours showing lower overall costs than that of no fencing (figure 5.27). As the eradication rate increases the benefit of all reductions in neighbours is reduced with no fencing having the lowest costs from eradication rates of 75% and above.

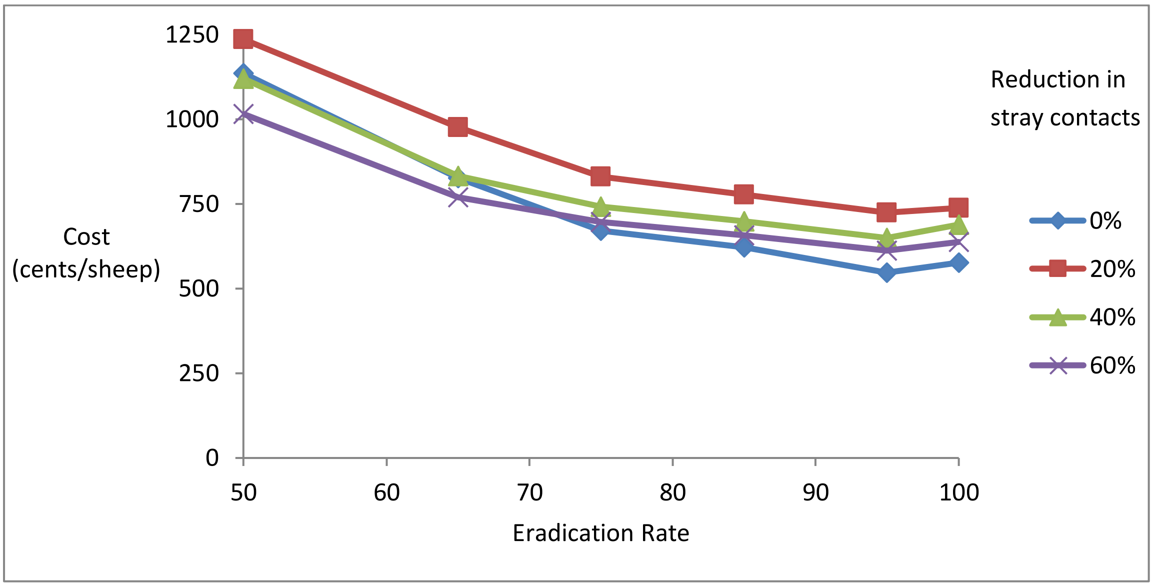

Figure 5. 27. *Net present value (NPV) over 20 years of none, 20, 40 and 60% reduction in strays contacted at each eradication rate on small sized properties. Strays = number of properties being contacted by stray sheep. 20, 40, 60 =*

percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. None= no reduction in strays. Small properties= average property size of 700ha.

Medium Properties

Large differences in lice prevalence for each different reduction in strays option on medium sized properties (figure 5.28). The 60% reduction provides the lowest lice prevalence at each eradication rate. In contrast to small properties, reductions in lice prevalence remain similar at each different eradication rate.

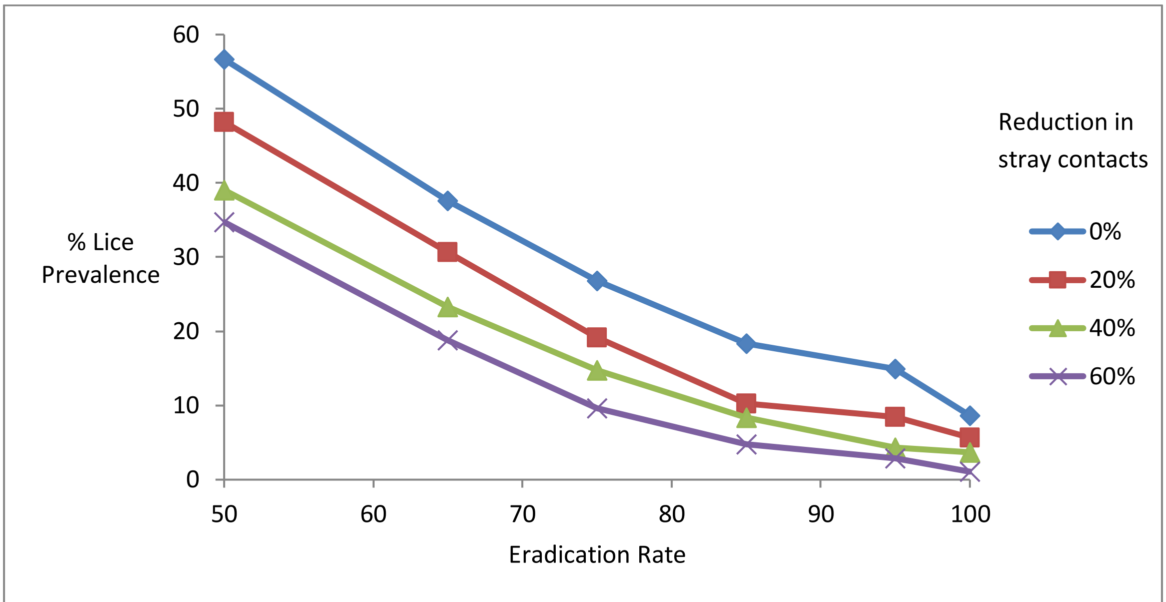

Figure 5. 28. *Lice Prevalence of none, 20, 40 and 60% reduction in strays contacted at each eradication rate on medium sized properties. Strays = number of properties being contacted by stray sheep. 20, 40, 60 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. None= no reduction in strays. Medium properties= average property size of 1500ha.*

On medium sized properties both 40% and 60% reductions in strays reduce costs of lice when compared to that of no fencing at each eradication rate (figure 5.29). The 20% reduction in strays is shown to never be cost effective however this option can still provide reductions in lice prevalence at each eradication rate compared to the no reduction in strays option (figure 5.28). A 40% reduction in strays will only provide minimal reductions in cost compared to that of the no reduction in strays option however large reductions lice prevalence can be obtained (figures 5.29 and 5.28).

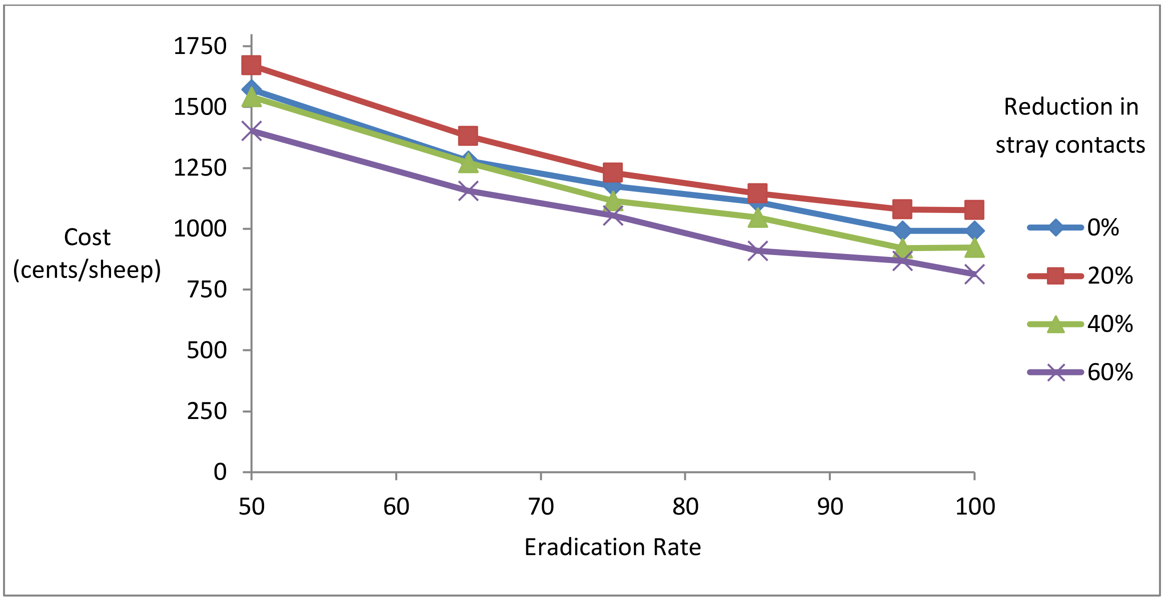

Figure 5. 29. *Net present value (NPV) over 20 years of none, 20, 40 and 60% reduction in strays contacted at each eradication rate on medium sized properties. Strays = number of properties being contacted by stray sheep. 20, 40, 60 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. None= no reduction in strays. Medium properties= average property size of 1500ha.*

Large Properties

All reductions in strays contacted result in reduced lice prevalences at each eradiation rate on large properties (figure 5.30). The results show larger properties have high lice prevalences when compared to that of small and medium sized properties (figures 5.26 and 5.28 respectively). Due to this the benefit of improved fencing may be increased on large properties.

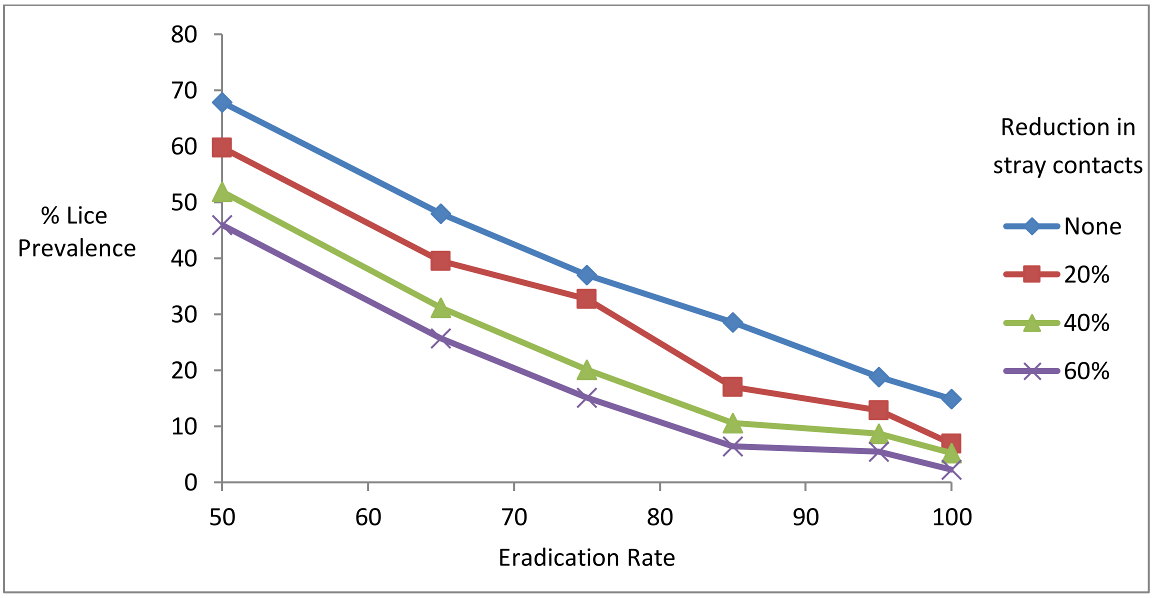

Figure 5. 30. *Lice Prevalence of none, 20, 40 and 60% reduction in strays contacted at each eradication rate on large sized properties. Strays = number of properties being contacted by stray sheep. 20, 40, 60 = percentage reductions in*

strays from addition of 2km boundary fencing at a cost of $20,000. None= no reduction in strays. Large properties= average property size of 7000ha.

On large properties the overall costs of 40% and 60% reductions in strays are below that of the no reduction option at each eradication rate (figure 5.31). The costs for no fencing and a 20% reduction in neighbours have very similar costs at each eradication rate with no fencing only having lower costs than the 20% reduction at eradication rates of 50% and 95%. The 40 and 60% reductions in strays contacted show similar costs at each eradication rate and are reduced compared to zero and 20% reduction options.

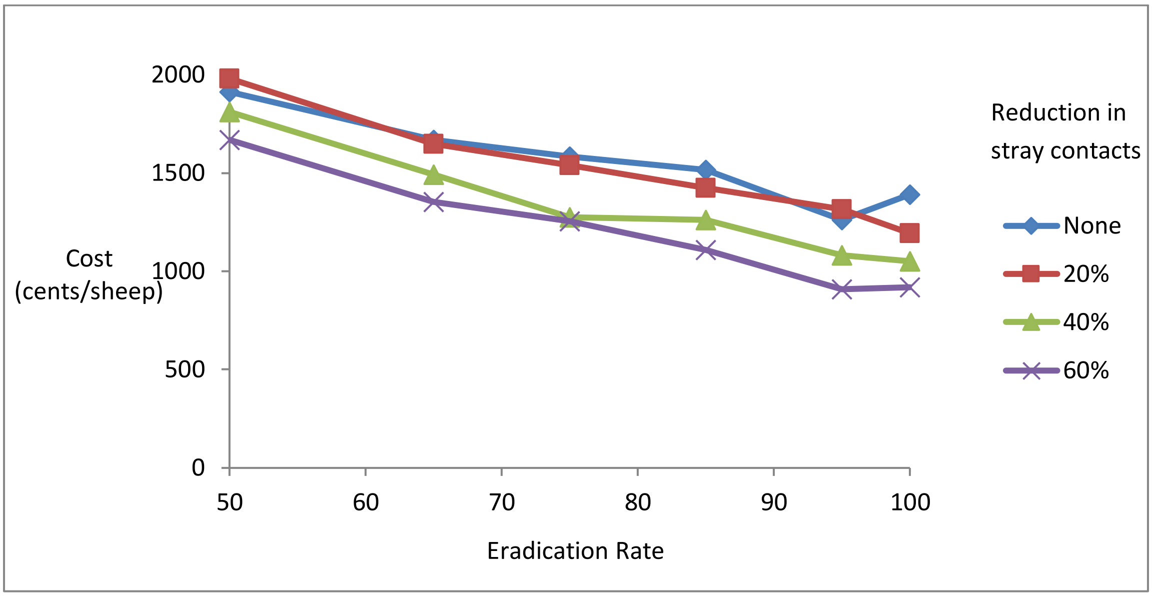

Figure 5. 31. *Net present value (NPV) over 20 years of none, 20, 40 and 60% reduction in strays contacted at each eradication rate on large sized properties. Strays = number of properties being contacted by stray sheep. 20, 40, 60 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. None= no reduction in strays. Large properties= average property size of 7000ha.*

Eradication x Biosecurity of Strays at Different Wool Values

Low Wool Values

At low wool values a reduction of 60% of neighbours contacted is the only fencing option that shows lower costs than no fencing at all eradication rates except 95% (figure 5.32). A 40% reduction in strays contacted is no longer of lower cost than no fencing as seen when using standard wool values (figure 5.23). Results for lice prevalence can be seen in figure 5.22.

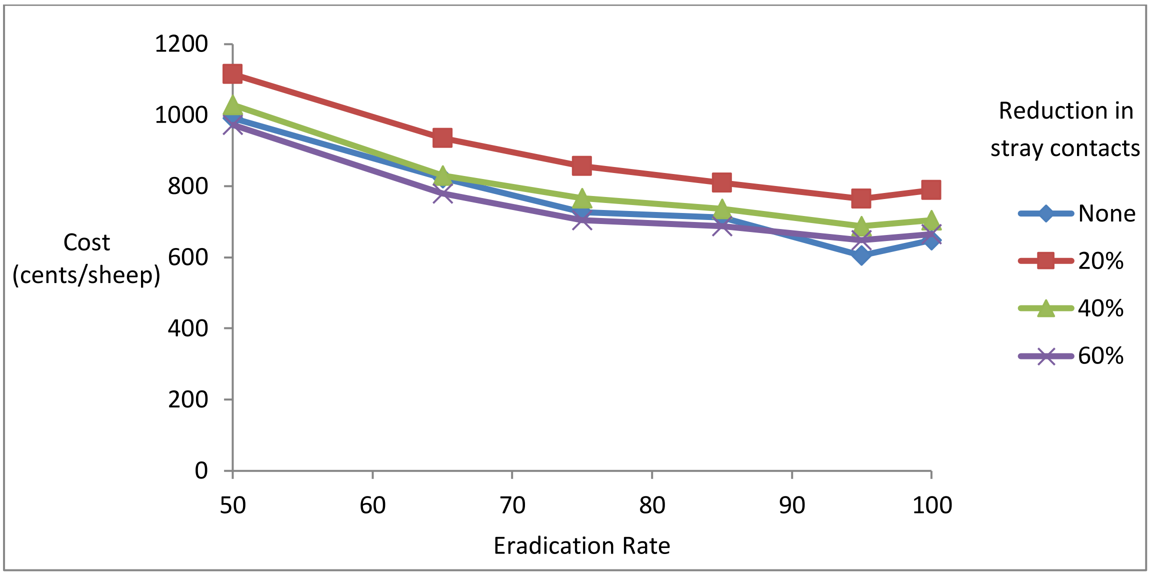

Figure 5. 32. *Net present value (NPV) over 20 years of none, 20, 40 and 60% reduction in strays contacted at each eradication at poor wool values Strays = number of properties being contacted by stray sheep. 20, 40, 60 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. None= no reduction in strays. Poor wool value=half of standard wool value.*

High Wool Values

Reductions in strays of 40 and 60% provide reduced costs compared with no fencing, at all eradication rates up until 95% where only a 60% reduction is cost-effective. At poor eradication rates a 20% reduction shows the same costs as the no fencing option; however as eradication rates increase above 65% a 20% reduction in neighbours is no longer cost effective against no fencing. Lice prevalences at high increased wool values are comparable to lice prevalence results shown in figure 5.22.

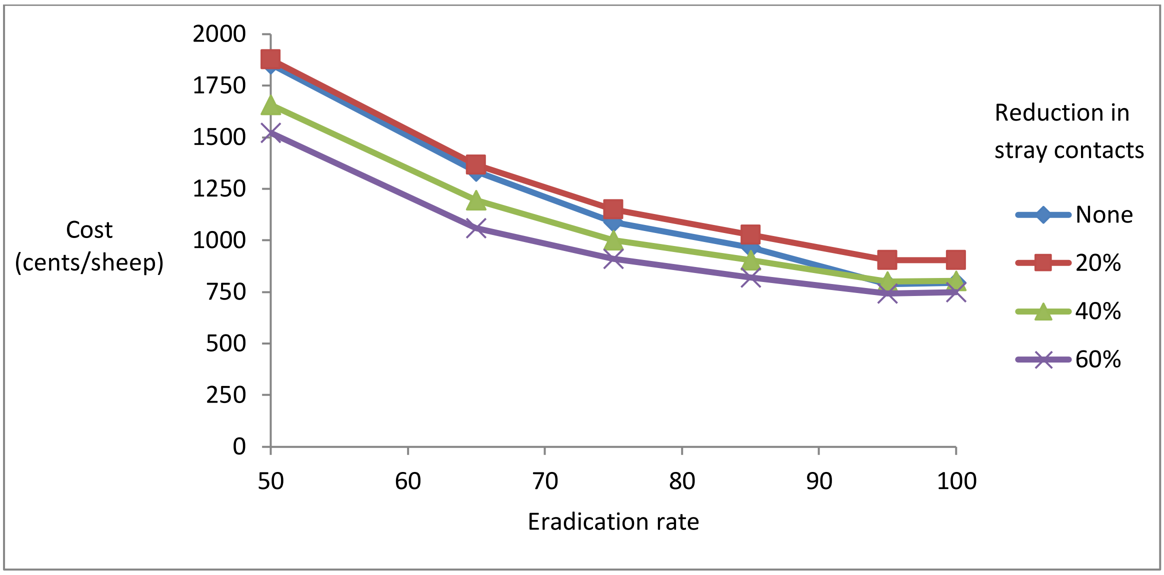

Figure 5. 33. *Net present value (NPV) over 20 years of none, 20, 40 and 60% reduction in strays contacted at each eradication at high wool values. Strays = number of properties being contacted by stray sheep. 20, 40, 60 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. None= no reduction in strays. High wool values= double standard wool values.*

6. Biosecurity Interactions

The biosecurity section includes the biosecurity of purchased sheep and the biosecurity of strays. Combinations of eradication rates and biosecurity have already been analysed so this section does not include variation of eradication. The options used for biosecurity of purchases and strays are described in chapter3.

Biosecurity of Purchases x Biosecurity of Strays

All reductions in strays reduce lice prevalence for each different biosecurity of purchases option (figure 6.1). Lice prevalence can be greatly reduced when using a biosecurity of strays option, however it can be expensive to obtain a reduction in strays of 60% (figure 6.2)

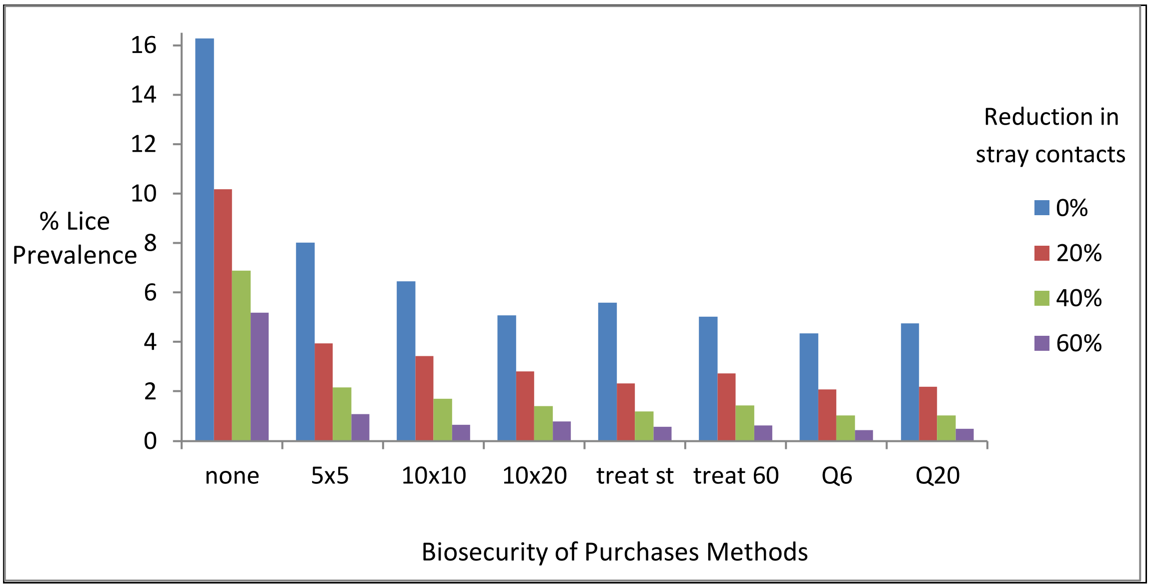

Figure 6. 1. *Lice prevalences at each biosecurity option of lice detection, separation and treatment of purchased sheep at different management options for strays. Purchases = number of properties contacted through purchase of sheep. Biosecurity options include Inspection = 5x5, 10x10 and 10x20, Quarantine = Q6 and Q20, Treatment = treat st and treat 60 and none= no biosecurity of purchased sheep. Strays = number of neighbouring properties contacted by stray sheep. 20, 40, 60 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays and fencing costs added.*

The no fencing option has lowest costs for each biosecurity of purchases methods except when biosecurity of strays is used as a single management option (figure 6.2). These results show that even a 60% reduction in strays is not cost effective when compared to the overall costs of no fencing, provided that biosecurity for purchases is improved. The cost of each fencing option differs with each different biosecurity method used. The lowest biosecurity options appear to be the 10x10 and 10x20 parting options and the Q6 separation method which all show very similar costs but even treat 60 and Q20 are better than doing nothing.

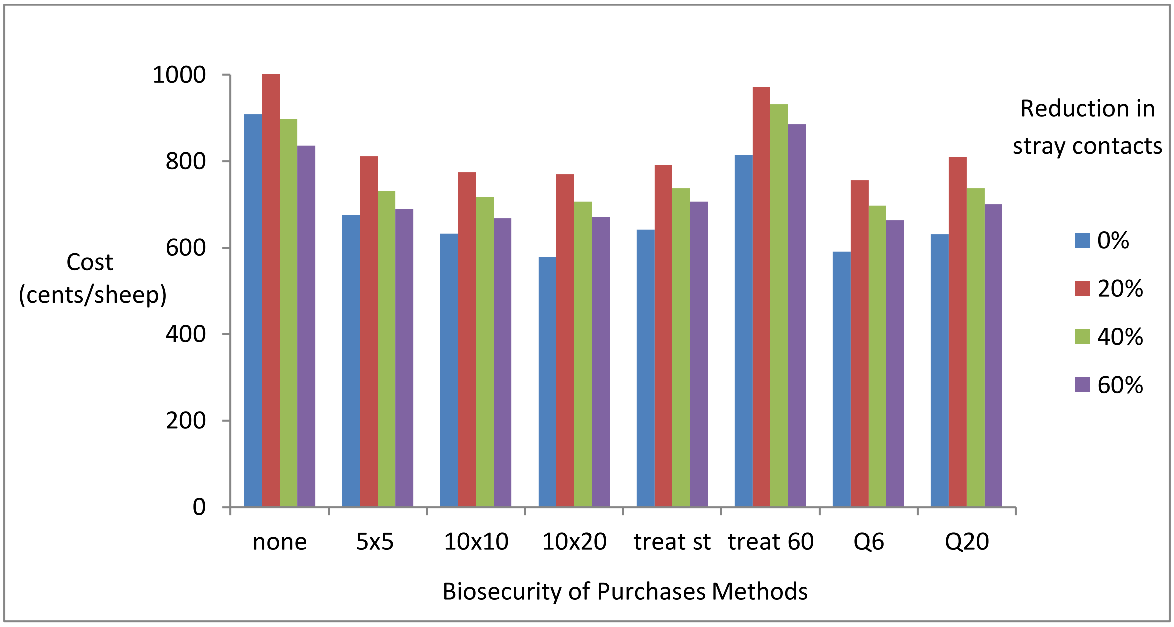

Figure 6. 2. *Net present value (NPV) over 20 years for each biosecurity option of purchased sheep against different management of strays options. Purchases = number of properties contacted through purchase of sheep. Biosecurity options include Inspection = 5x5, 10x10 and 10x20, Quarantine = Q6 and Q20, Treatment = treat st and treat 60 and none= no biosecurity of purchased sheep. Strays = number of properties being contacted by stray sheep. 20, 40, 60 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays and fencing costs added.*

Biosecurity of Purchases x Biosecurity of Strays on different sized properties

The effect of combining biosecurity of purchased sheep with reductions in strays contacted was investigated on small, medium and large sized properties in the model to determine if the benefits of improved fencing can be increased on different property sizes (see table 3.1).

Small Properties

All biosecurity options show reduced lice prevalence for each reduction in strays compared to that of no biosecurity on small properties (figure 6.3). The largest reductions in lice prevalence can be seen when the reductions in strays are used in conjunction with a biosecurity of purchases method.

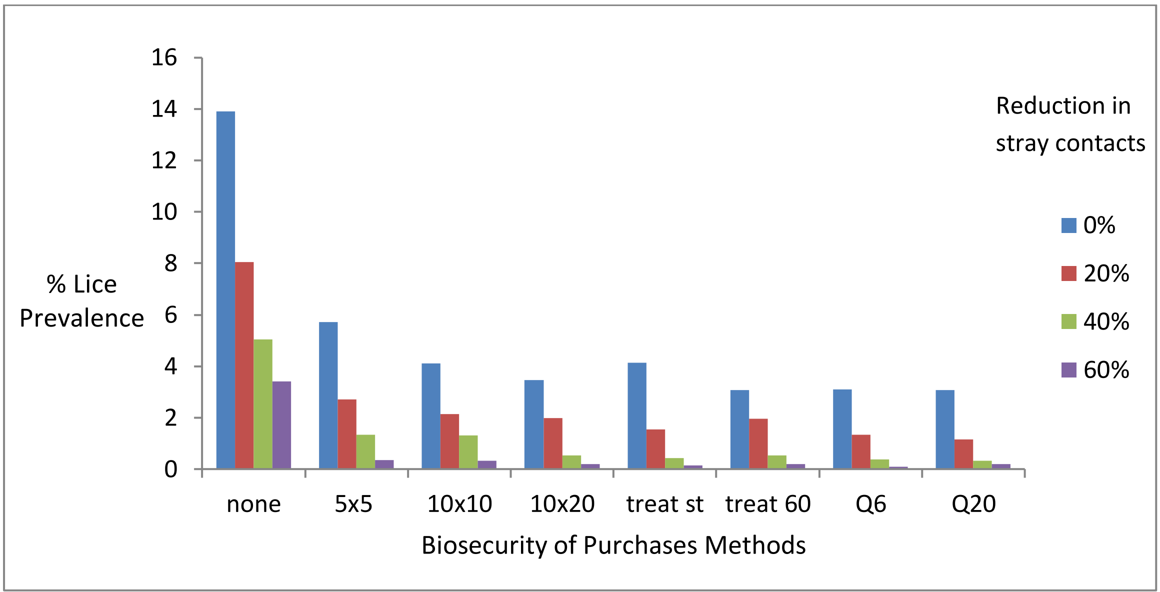

Figure 6. 3. *Lice prevalence for each biosecurity option at different reductions in strays contacted on small sized properties. Purchases = number of properties contacted through purchase of sheep. Biosecurity options include Inspection = 5x5, 10x10 and 10x20, Quarantine = Q6 and Q20, Treatment = treat st and treat 60 and none= no biosecurity of purchased sheep. Strays = number of neighbouring properties contacted by stray sheep. 20, 40, 60 = percentage reduction in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays and fencing costs added. Small properties= average property size of 700ha*

No reduction in strays is lowest cost option for each biosecurity of purchases method on small properties, except when biosecurity of strays is used as a single management option with a 60% reduction in strays providing the lowest costs (figure 6.5). All biosecurity options except treat 60 show lower costs than no biosecurity for each reduction in strays option, this could be attributed to the high costs of the treat 60 biosecurity method. The results show that the overall costs associated with lice can be reduced when compared to the no biosecurity option through using a biosecurity of purchases method in conjunction with a reduction in strays except for the biosecurity treat 60 option.

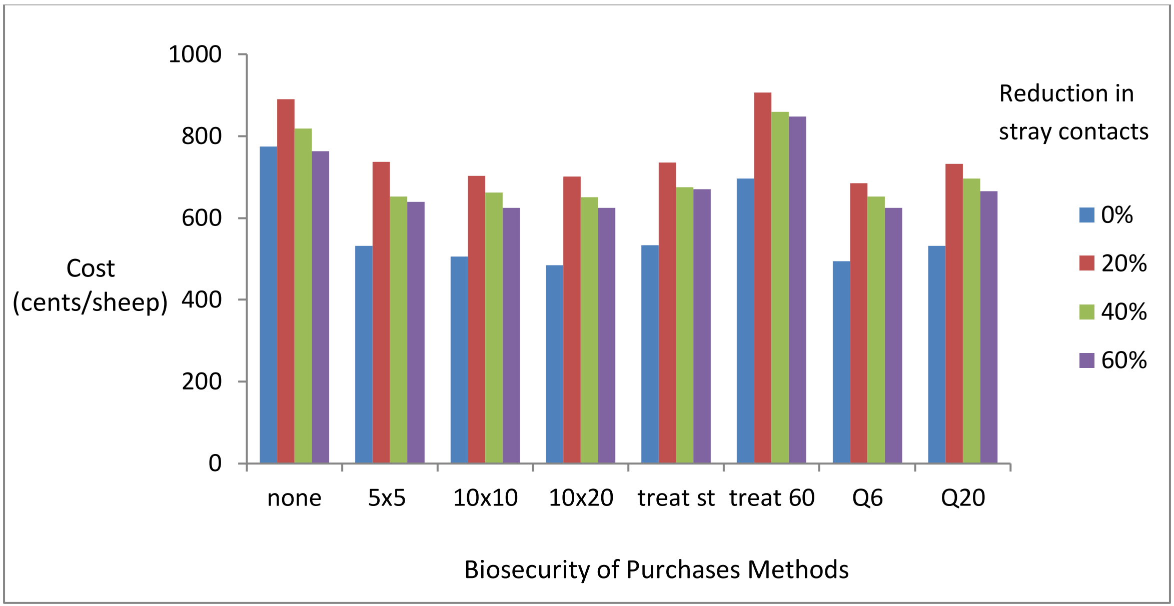

Figure 6. 4. *Net present value (NPV) over 20 years for each biosecurity option of purchased sheep against different management of strays options on small sized properties. Purchases = number of properties contacted through purchase of sheep. Biosecurity options include Inspection = 5x5, 10x10 and 10x20, Quarantine = Q6 and Q20, Treatment = treat st and treat 60 and none= no biosecurity of purchased sheep. Strays = number of neighbouring properties contacted by stray sheep. 20, 40, 60 = percentage reductions in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays and fencing costs added. Small properties= average property size of 700ha*

Medium Properties

Lice prevalence can be further reduced when biosecurity of strays is combined with biosecurity of purchases options on medium sized properties (figure 6.5). Lowest lice prevalences are obtained through using a 60% reduction is strays with a quarantine option.

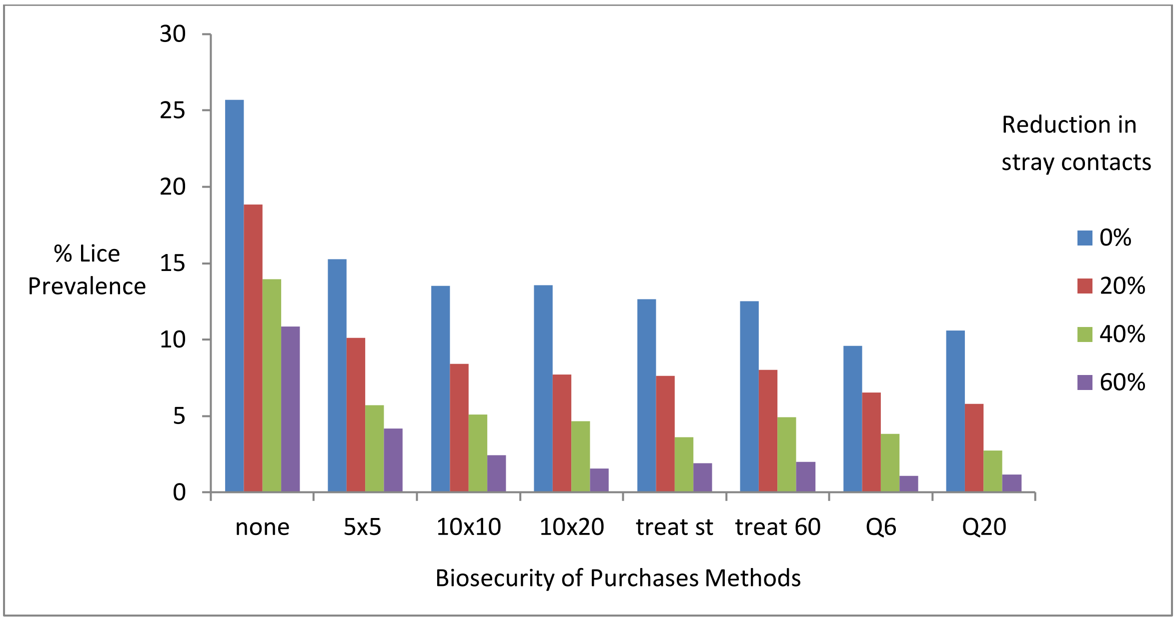

Figure 6. 5. *Lice prevalence for each biosecurity option at different reductions in Strays contacted on medium sized properties. Purchases = number of properties contacted through purchase of sheep. Biosecurity options include Inspection = 5x5, 10x10 and 10x20, Quarantine = Q6 and Q20, Treatment = treat st and treat 60 and none= no biosecurity of purchased sheep. Strays = number of neighbouring properties contacted by stray sheep. 20, 40, 60 = percentage reduction in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays and fencing costs added. Medium properties= average property size of 1500ha*

As seen on small properties (figure 6.4) reductions in costs of lice can be made on medium sized properties through combinations of biosecurity of purchases and reductions in strays options (figure 6.6). The overall costs of lice are increased on medium sized properties compared to the overall costs on small sized properties. The 60% reduction option appears to have lower costs than the no reduction option for each biosecurity methods except Q20.

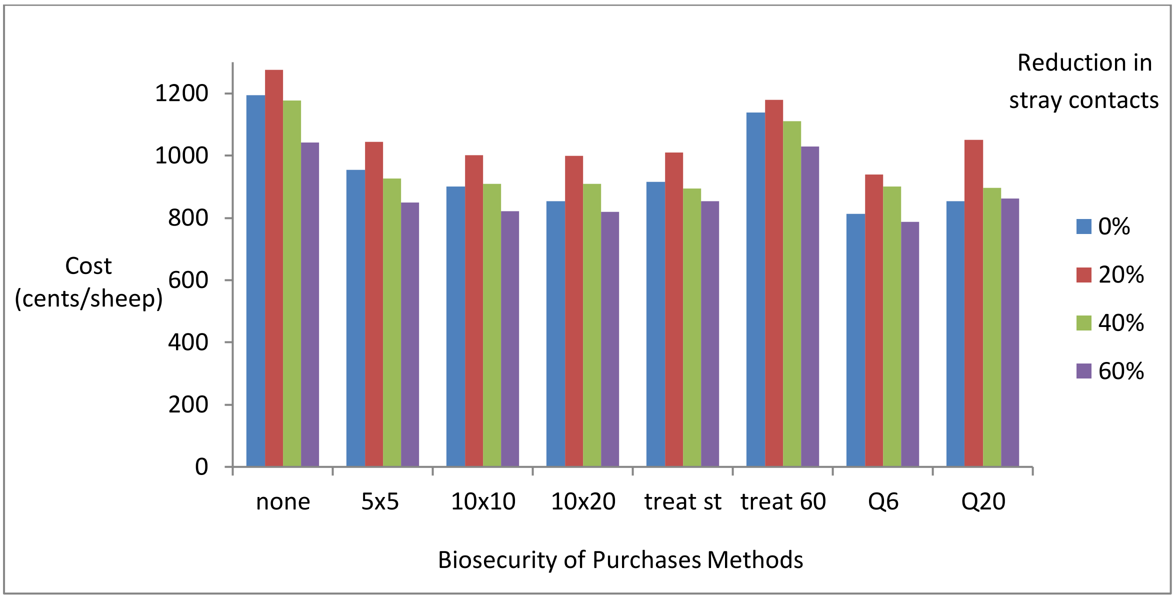

Figure 6. 6. *Net present value (NPV) over 20 years for each biosecurity option of purchased sheep against different management of strays options on medium sized properties. Purchases = number of properties contacted through purchase of sheep. Biosecurity options include Inspection = 5x5, 10x10 and 10x20, Quarantine = Q6 and Q20, Treatment = treat st and treat 60 and none= no biosecurity of purchased sheep. Strays = number of neighbouring properties contacted by stray sheep. 20, 40, 60 = percentage reduction in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays and fencing costs added. Medium properties= average property size of 1500ha*

Large Properties

Considerable reductions in lice prevalence are obtained from combinations of reductions in strays and biosecurity methods, compared to single management options on large properties (figure 6.7). The combination of treat 60 and a 60% reduction in strays provides the lowest overall lice prevalence.

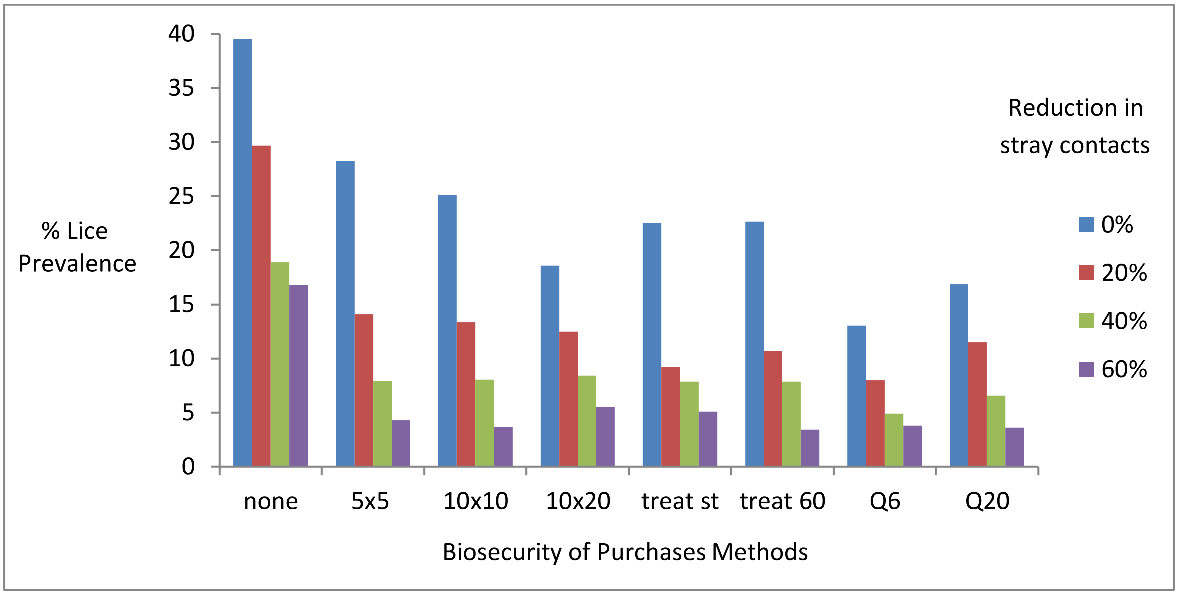

Figure 6. 7. *Lice prevalence for each biosecurity option of purchased sheep against different management of neighbours options on Large sized properties. Purchases = number of properties contacted through purchase of sheep. Biosecurity options include Inspection = 5x5, 10x10 and 10x20, Quarantine = Q6 and Q20, Treatment = treat st and treat 60 and none= no biosecurity of purchased sheep. Strays = number of neighbouring properties contacted by stray sheep. 20, 40, 60 = percentage reduction in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays and fencing costs added. Large properties= average property size of 7000ha*

On large properties combinations of biosecurity of strays and biosecurity of purchased sheep provide improved reductions in lice prevalence and cost than when used as single management options. All biosecurity methods except the treat 60 show lower costs for each reduction in strays when compared to the costs of the no biosecurity option. The treat 60 option showed slightly higher costs for the 40% reduction in strays than that of the no biosecurity method.

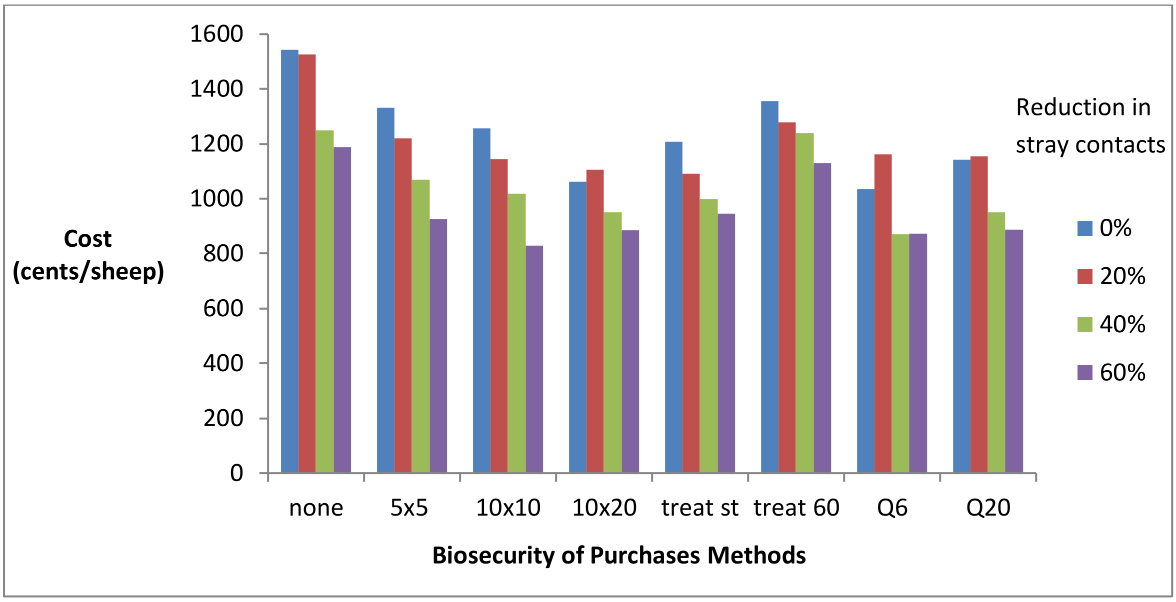

Figure 6. 8. *Net present value (NPV) over 20 years for each biosecurity option of purchased sheep against different management of strays options on large sized properties. Purchases = number of properties contacted through purchase of sheep. Biosecurity options include Inspection = 5x5, 10x10 and 10x20, Quarantine = Q6 and Q20, Treatment = treat st and treat 60 and none= no biosecurity of purchased sheep. Strays = number of neighbouring properties contacted by stray sheep. 20, 40, 60 = percentage reduction in strays from addition of 2km boundary fencing at a cost of $20,000. 0% = no reduction in strays and fencing costs added. Large properties= average property size of 7000ha*

7. Optimum Combinations

Table 7.1 shows the effects of combinations of management options to reduce lice prevalence and its associated costs. Combining an average eradication rate with a quarantine option shows better reductions in costs and lice prevalence than simply using a high eradication rate alone. This can be further reduced by using a high eradication rate in combination with a biosecurity of purchases option. Lowest lice prevalence was obtained when combining a 100% eradication rate with a 10x20 inspection before shearing, 100% intervention and a cheap quarantine of purchases option. However obtaining a 100% eradication rate can be difficult. The lowest cost was obtained through using a 95% eradication rate with quarantine of purchases, fleece inspection at shearing and a 100% intervention level and also provided a very low level of lice prevalence.

Table7. 1. *Combinations of management options to reduce lice prevalence and net present value (NPV) over a period of 20 years.*

Eradication Rate %	Biosecurity Option	Detection Method	Intervention Level %	NPV (cents/head)	% Lice Prevalence
75	-	-	20	893	16.3
95	-	-	20	763	5.97
95	-	10x20	20	752	4.77
75	St treat	-	20	607	4.05
75	St treat	10x20	100	545	4.40
95	Q6	10x20	100	407	0.64
100	Q6	10x20	100	421	0.48

The first two options in table 7.1 show the effects of using an average eradication rate and an improved eradication rate with no other management options. These two options were included to estimate costs and lice prevalence if current management systems are maintained and the lice prevalence and costs obtained are believed to be close to current values. Combinations of biosecurity of purchases, lice detection and intervention level were used with an average eradication rate of 75% to show reductions in lice prevalence and costs from these methods if eradication rate is not improved. These management options were also simulated at high eradication rates of 95% and 100% to show further reductions that can be obtained from improved eradication rates in combination with other management options.

It is clear that a combination of high eradication rates and a biosecurity of purchases option give excellent reductions in lice prevalence and its costs (table 7.1). Additional testing showed the use of a low cost detection method such as the 10x20 parting option could provide further improvement. The Intervention level was increased to reduce costs without causing excessive increases in lice prevalence.

8. Discussion

The results from this study show combinations of improved eradication rates and biosecurity of purchased sheep to have a great effect on reducing lice prevalence and costs. Further investigation found that these management options can be used in combination with other management factors such as lice detection methods and intervention level to gain further reductions in lice prevalence and its associated costs.

These findings agree with previous studies that indicate the importance of biosecurity in lice control (Brightling, 1989). Biosecurity of purchased sheep as a single management option showed the greatest reductions in lice prevalence and lice costs. Improved eradication was found to provide the second largest reductions in lice prevalence and costs. These results suggest that if only one management option is used then greatest reductions can be made through biosecurity of purchased sheep. It may not always be possible to use a low cost biosecurity of purchases option such as a standard treatment of purchases. In situations such as this improved eradiation rates can provide reductions in lice prevalence and costs as a single management option, especially when producing high quality fleece. Selecting improved eradication methods have been reported as key aspect of managing lice resistance (Levot, 2012). Lice detection methods had minimal effects on lice prevalence at low eradication rates and only provided small reductions when used at high eradication rates; however the use of highly sensitive lice detection tests were found to increase costs. Management of intervention level was found to provide large reductions in lice prevalence however caused large increases in costs at improved eradication rates. Both lice detection methods and intervention level were found to only provide minimal reductions in lice prevalence and lice costs when used in combination with one other management factor. However these options were found to provide further reductions when used with other combinations of management factors. Optimum reductions can be made through combining improved eradication rates and biosecurity of purchased sheep with low cost lice detection tests and high intervention levels.

The initial results from this study indicate a range of management options that could potentially provide both reductions in lice prevalence and costs. These results confirm the findings of Horton and Carew (2014), which suggested management of purchased sheep and stray sheep could provide the greatest reductions in lice prevalence and costs. Management of eradication rate, lice detection and intervention levels also showed reductions in costs and lice prevalence.

However these results only indicate the potential of single management factors rather than combinations of these management options.

The results in Table 4.1 show the level of variation between results under the same management conditions. These results indicate small differences between results of 1 to 2% are due to random variation. Differences between results of more than 5% can be attributed to differences in management options and can therefore be used to draw conclusions.

Intervention combinations

Through management of intervention levels it is possible to reduce costs without causing huge increases in lice prevalences if eradication rates are high (figure 5.5 and 5.6). At high eradication rates it is cost-effective and has only small effects on lice prevalence level to use a higher level of intervention. This is because the risk of lice being present after treatment is reduced when using high eradication rates, however this option relies on all properties improving eradication rates.

Through using a biosecurity of purchases option it is possible to use higher intervention levels and reduce the risk of unnecessary treatments without causing huge increases in lice prevalence (figures 5.10 and 5.11). At higher intervention levels there is a higher risk of lice actually being present in flocks, this can therefore be used to save money through minimising unnecessary lice treatments. With the use of higher intervention levels in these situations, reducing the risk of unnecessary treatments can also reduce the risk of lice populations developing resistance to treatments and reduce chemical residues in fleece. However the results in figure 5.11 show as intervention levels increase over 30 the risk of lice being present is high and costs associated with lice infestations increase and cause the overall costs to also increase. These results suggest large reductions in lice prevalence can occur if intervention level and biosecurity of purchases are used together to manage lice infestations.

Combinations of biosecurity of strays and intervention level also showed large reductions in lice prevalence but only minimal reductions in costs (figures 5.14 and 5.15 respectively). These results indicate that if a 60% reduction in strays from improved fencing can be obtained then it is possible to reduce unnecessary lice treatment through using a higher intervention level without causing huge increases in lice prevalence. The benefit of combining management of strays and intervention level is highest when using a 60% reduction in strays contacted.

Interactions of intervention level with biosecurity of purchases (figures 5.10 and 5.11) and biosecurity of strays (figures 5.14 and 5.15) are based on an average eradication rate of 75%. As previously noted the use of a high intervention level with a high eradication rate can reduce costs, it may be possible to achieve greater reductions in costs and lice prevalence through improving eradication rate when managing both intervention level and biosecurity of purchases or strays. Improved eradication is important

Lice detection combinations

Through only testing suspect flocks for the presence of lice, rather than testing both suspect and non-suspect flocks, costs can be reduced when combined with improved eradication (figures 5.2 and 5.4). When only using lice detection methods on suspect flocks the effect on lice prevalence is minimal however the reduction in costs was not enough to make highly sensitive lice detection methods cost-effective (figures 5.3 and 5.4). Both of these testing options show only small reductions in lice prevalence when used at high eradication rates and very minimal reductions when used a poor eradication rates (figures 5.1 and 5.2). These results indicate that the use of lice detection tests only provide minimal reductions in lice prevalence and only the low cost methods are cost-effective against no lice detection testing.

Lice detection methods can provide further reductions in lice prevalence when used in combination with a biosecurity of strays or a biosecurity of purchases option. Only minimal reductions in costs are obtained through the addition of lice detection tests to biosecurity of strays methods, however savings are improved when lice detection is combined with biosecurity of purchased sheep. Cost reductions can be improved through the use of low cost lice detection methods such as fleece partings. The results show low cost detection methods to have only a small effect on reducing overall costs when used in conjunction with a reduction in strays option.

Large reductions in lice prevalence can be obtained through using lice detection tests in conjunction with reductions in strays options but only results in small savings in costs (figures 5.12 and 5.13 respectively). Highly sensitive lice detection methods such as the ELISA tests cause large increases in costs compared to other lice detection tests with only the low cost detection methods providing minimal reductions in costs compared with of the no detection option. The benefit of combining management of strays and lice detection is greatest when increased reductions in strays contacted are used together with low cost detection test such as the 5x5 and 10x10 fleece parting options. These results are consistent with findings from a study by James et al.,(2001) that reported fleece partings to be an effective method of lice detection.

Eradication and Biosecurity Combinations

All biosecurity of purchases options showed reduced lice prevalences at each eradication rate compared to the no biosecurity of purchases options (figures 5.16, 5.18 and 5.20). Both biosecurity options of inspection through fleece partings and quarantine provided reduced costs at each eradication rate compared to that of the no biosecurity option (figures 5.17 and 5.19 respectively). For the treatment of purchased sheep only the standard and the added 60 cents/head treatment options provided reduced overall costs compared with the no biosecurity option (figure 5.21). The added 260 cents/head treatment option considerably increased costs at each eradication rate compared to all other treatment options; however this option accounts for extreme situations of economic losses due to double wool clip and short wool penalties.

Figures 5.18 and 5.19 showed a 75% eradication rate and quarantine methods for purchased sheep can provide greater reductions in both lice prevalence and lice costs than that of using an eradication rate of 95% as a single management option. This effect was also seen when combining eradication rate and inspection of purchased sheep (figures 5.16 and 5.17). The use of an average eradication rate of 75% in combination with fleece parting options can provide very similar lice prevalences and lower overall costs to that of using a high eradication rate of 95% and no biosecurity of purchases option. At an eradication rate of 75% the standard treatment of purchased sheep showed reduced lice prevalence and costs when compared to the use of a 95% eradication rate and no treatment of purchased sheep (figures 5.20 and 5.21).

The choice of biosecurity options for purchased sheep depends on individual farmer situations, with some farmers choosing to use no biosecurity methods. Shearing date can have a significant effect on the choice of biosecurity used. If sheep are purchased close to shearing then they can be treated and follow the regular shearing routine of the property. If purchased sheep have more than six weeks wool growth then farmers may decide to shear and treat sheep, use an inspection method or quarantine sheep until the following shearing. The type and number of sheep purchased can also affect the biosecurity option used such as when purchasing only a few sheep or rams.

Inspection of purchased sheep through fleece partings is a lice detection test that can be done on a sample of 10 to 20 sheep from a mob showing the worst signs of rubbing. This is a simple and cost effective detection test and only requires a small sample of a flock to be inspected. The option of quarantine of purchased sheep may depend on factors such as land availability and the time required to separate flocks for up to six months. Treatment of purchased flocks may be used as a biosecurity option if sheep are purchased within six weeks of shearing. For this treatment it is assumed that the treatment used for purchases is the same as that of regular treatments of the whole flock and therefore the eradication rates of regular treatment and treatment of purchases is the same. As eradication rates increase the costs of treating purchased sheep increases, however the effectiveness of these treatments also increases.

All biosecurity of purchases results are based on an average flock size of 2500 sheep with 500 sheep being replaced each year. Assumptions such as these used in the model will affect the accuracy of results obtained and may not be appropriate for some sheep operations such as stock traders. However these results can be used to highlight the importance of using biosecurity measures for lice control and the potential savings and reductions in lice prevalence that can be made from these management options. From these results it was found that combinations of eradication rates and biosecurity of purchases options are effective at minimising the introduction of lice into flocks and can be used to reduce lice prevalence and its associated costs.

On average sized properties all reductions in strays through improved fencing provide reduced lice prevalence at each eradication rate (figure 5.22). The results in figure 5.23 indicate at low eradication rates a minimum reduction in strays contacted of 40% is required in order to be cost effective against the no fencing option; however as the eradication rate increases only a 60% reduction in strays remains cost-effective. Greater benefits from fencing are seen at lower eradication rates, when infestations take longer to eradicate and hence incur higher costs. However reductions in strays that are only marginally lower cost than doing nothing can provide large reductions in lice prevalences especially when eradication rates are poor (figures 5.22 and 5.23).

The greatest benefit from fencing can be obtained on large properties if large reductions in strays can be obtained from 2km of improved fencing. Costs of lice increase from small to medium to large properties due to increases in lice prevalence. In regions with larger sized properties, lice prevalence is generally higher; therefore the risk of an infested sheep entering is greater. Due to this the overall costs of lice are higher and can result in the benefits of reducing costs associated with lice infestations to be greater on larger properties.

On small properties fencing can be advantageous at reducing costs however this benefit is only present at lower eradication rates when a minimum reduction in neighbours of 40% can be obtained (figure 5.27). On medium sized properties a minimum reduction of 40% strays is also required to reduce lice prevalence and costs (figure 5.29).

On large properties there is little difference between the cost of no reduction and a 20% reduction in strays (figure 5.31), however lice prevalence is reduced from a 20% reduction in strays (figure 5.30). These results indicate that 20, 40 and 60% reduction options tested on large properties can be advantageous at reducing costs associated with lice infestations and lice prevalence when compared to the no fencing option. However it may be difficult to obtain these levels of benefit on large properties with only 2km of fencing, therefore all fencing options need careful consideration in order to fence boundaries with the most problematic fences where the greatest benefits can be made.

Biosecurity of strays can be an effective option at reducing lice prevalence however the benefits of this option depend on the reduction in strays that can be obtained from 2km of fencing. The 2km of improved fencing used in the calculations is an arbitrary value as it is difficult to determine if a 60% benefit can be obtained from this amount of improved fencing. However it may be possible to obtain greater benefits from 2km of fencing or even obtain a similar benefit from a smaller proportion of improved boundary fencing. Therefore farmers may not need to spend $20,000 on fencing to achieve a reduction in strays.

The benefits of improved fencing were not considered across other farm enterprises therefore the costs could be reduced if fencing is required for other farm operations. The costs of fencing were only calculated for one property to improve fencing through installing a double boundary. Fencing costs could be halved between neighbouring properties if only a single fence is required. Both of these factors could be considered in the option of improved fencing to reduce strays and could further reduce costs.

Improving eradication rates can be difficult as lice infestations can persist after treatment and treatment failure can occur (Morcombe and Young, 1993). The results from this study have shown by combining average eradication rates with other management options such as biosecurity of purchases, lice prevalence and costs can still be reduced without improving eradication. These are important findings as this highlights the effectiveness of biosecurity management in lice control. With increasing demand for low reside wool products (Russell, 2001), and alternatives to chemical treatments (Russell, 1994), integrated management strategies such as improved biosecurity are essential in lice control. Biosecurity of purchases through quarantine has the potential to be used as an alternative to chemical treatments for lice control. Alternatives such as this are essential if reliance of chemical control is to be reduced and also to reduce the development of chemical resistance in lice populations.

Biosecurity interactions

Combinations of biosecurity of purchases and biosecurity of strays showed great reductions in lice prevalence (figure 6.1). However these combinations did not result in reduced costs and were only found to be cost-effective when used with combinations of other management factors rather than together (figure 6.2).

From the results obtained in this study it can be determined that the effects of biosecurity of purchases have a greater effect on reducing lice prevalence and its associated costs than that of biosecurity of strays. Through management of purchased sheep it is possible to achieve lower lice prevalence than when using biosecurity of strays options (figures 5.18 and 5.22). This is because if all properties in a specific region are using biosecurity of purchases options then regional lice prevalence can be reduced. Therefore the chance of stray sheep actually being infested with lice and entering a neighbouring property falls. Improving boundary fencing is also an effective method of reducing lice prevalence and lice costs however the impact of this management practice on regional lice prevalence is reduced therefore if a stray sheep does somehow enter a property then the chance of it being infested with lice is greater. Management of purchased sheep through inspection, quarantine or treatment is less costly than improved fencing and requires less upfront costs. This may have an effect on the type of biosecurity methods chosen if biosecurity practices are considered.

On medium and large sized properties a 60% and in some cases a 40% reduction in strays was cost-effective against no fencing. This effect was not seen on smaller sized properties however this may be due to regional lice prevalence rather than property size. Lice prevalence on all property sizes was further reduced by using combinations of purchases and strays biosecurity methods and can be seen in figures 6.3, 6.5 and 6.7, however these combinations did not result in reduced costs. The greatest reductions in lice prevalence are obtained on large properties as combinations of purchases and strays management practices have a large effect on the increased lice prevalences on larger sized properties (figure 6.7).

The results from this project are consistent with findings from previous studies which highlight the importance of biosecurity practices in lice control (Brightling, 1989) and suggestions that biosecurity methods for lice control need to be improved (James and Riley, 2004). A study by (Morcombe and Young, 1993) reported that lice enter properties at equal rates through purchased sheep and strays so improving either aspect is advantageous for lice control. However the findings from this study showed with $20,000 of improved fencing the use of biosecurity of strays and biosecurity of purchases together is not cost-effective.

9. Conclusion

The findings from this study highlight the importance of biosecurity of purchased sheep and strays in lice control. Combinations of biosecurity of purchased sheep with other management factors such as improved eradication rate, intervention l and lice detection test at shearing can provide reductions in both lice prevalence and cost, when compared to that of single management options. The results from this study highlight the use of such predictive models as tools to help identify possible management practices for improved lice control. Predictive models such as the lice prevalence model are important tools that are required if lice populations are to be adequately controlled with reduced reliance on chemical treatments.

Wool producers who struggle to control lice infestations without the use of chemical control may fail to maintain competitiveness in international markets as the demand for low residue wool increases. Chemical residue along with decreases in wool quality caused by lice infestations may have severe effects on the profitability of high quality wool producers in Australia.

The model allows for users to enter their current situation and see if improvements can be made through different management options. The model isn't designed for individual farmer use but rather for extension officers to use as a guide for regional lice prevalence control.

Assumptions made within the model could have affected the validity of results obtained and requires further study and development to improve the accuracy of model outputs. During the process of this project a study by (Reeve and Walkden-Brown, 2014) released the 2011 Australia lice survey findings and indicates an increase in lice prevalence. Therefore the results from this project could be underestimating lice prevalence and its costs. To provide results that are consistent with regional lice prevalences from these survey findings the data used in the model need to be updated.

Negative lice detection tests are not considered when calculating risk of flocks being infested and is only considered when a positive result is obtained. As negative detection results are not included in risk assessment it is possible for this to contribute to unnecessary lice treatments and costs.

All lice detection tests have sensitivity levels which are calculated on the probability of detecting lice in flocks that are suspected to be infested. The sensitivity of these tests is not known on flocks that are not suspected to have lice. Due to this it is possible for the lice detection test to determine if lice are present or not within suspect flocks however it cannot be used to determine if suspect flocks are free from lice. The sensitivity of detection tests on non-suspect flocks needs to be determined.

From this study it was found the lice prevalence model can be used to identify potential improvements in management practices that could result in decreased lice prevalence and costs. These findings show how predictive models can be used as management tools to aid decision making in lice control. From this study it is possible for further investigation into the use of predictive models for lice control and for the lice prevalence model to be developed for industry use.

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