TWO STUDIES ON THE CONTROL OF WILDLIFE-DERIVED TUBERCULOSIS:
FARMER VIEWS AND MODEL VALIDATION

A THESIS PRESENTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF VETERINARY STUDIES IN EPIDEMIOLOGY AT MASSEY UNIVERSITY, PALMERSTON NORTH, NEW ZEALAND.

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Abstract

The two studies included in this thesis are part of a larger research programme evaluating tools to aid in the eradication of bovine tuberculosis (TB) from cattle in New Zealand. The first study was a survey of farmer's attitudes towards the National Pest Management Strategy (NPMS) and tuberculosis control. The second study validated the population component of PossPOP, a spatial stochastic simulation model of TB in a wild possum population.

A postal questionnaire survey identified variation of attitudes of 404 farmers in four regions of varying TB status within New Zealand. Farmers were stratified by region, enterprise type, area TB classification and herd TB status. Of the farmers contacted by telephone prior to sending out the questionnaire 91% agreed to participate in the study and 83% of these farmers returned a completed questionnaire. The questionnaire contained questions on farmer demographics, TB status, herd TB history, farm management practices and attitudes towards the control of TB. Farmers with infected herds were generally positive about the control program and believed that TB could be eradicated from their herds. A number of farmers were concerned about proposed changes to the NPMS, such as the implementation of direct payment of TB testing costs by farmers and removal of compensation for infected cattle. An important finding was that the majority of farmers were not aware that the Animal Health Board was in charge of the NPMS.

PossPOP was built using the first 22 months' data from a longitudinal study of a possum population run at Castlepoint in the lower North Island of New Zealand. Data from the remaining 9 years of the study was used set for model validation. PossPOP was validated by comparing age distribution, sex structure and the proportion of births, deaths and immigrations in the modelled population against the field population. There was general agreement between the model and the field population and also published population patterns. PossPOP produced a stable population over time at different densities, with similar temporal patterns to the field population. Emergent biological properties were examined, such as rate of population rebuilding after a major population cull, the removal of immigration from both populations and age specific mortality. The field population grew much more rapidly following a cull compared with the PossPOP population due to home range expansion of possums that were living on the periphery of the study site, which was not programmed into the model. These results showed that while PossPOP models a small area, it reflects patterns of control over large areas making it a useful tool to evaluate large scale possum control strategies.

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"Education is a valuable thing but every now and then it is wise to remember that anything worth knowing cannot be learned" Oscar Wilde

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INTRODUCTION

Members of the *Mycobacterium tuberculosis* complex (*M.tuberculosis*, *M.bovis*, *M.microti* and *M.africanum*) cause Tuberculosis in mammals (O'Reilly and Daborn, 1995). The causal agent of bovine tuberculosis is *M.bovis*. Bovine tuberculosis was first described in 14 AD by Columella in Northern Italy. It was not until 1882 with Robert Koch's discovery of tubercle bacillus, that research into human and animal tuberculosis began (Wood et al., 1994). Under suitable conditions most mammals are susceptible to *M.bovis* infection, including humans (Thorns and Morris, 1983).

Bovine tuberculosis was probably introduced into New Zealand early in the 19th century and the first national control scheme for cattle began in 1945 (O'Neil and Pharo, 1995). The then Department of Agriculture initiated voluntary testing of dairy herds due to concern for human health regarding consumption of milk from infected cattle. The testing of cattle to control bovine tuberculosis commenced in the 1940s and progressed from voluntary testing to compulsory schemes for dairy herds (1945 – 1961), beef herds (1968 – 1970) and deer herds (1985 – 1990) (O'Neil and Pharo, 1995).

In March 1995 the Animal Health Board proposed a National Pest Management Strategy (NPMS) for the control and eradication of bovine tuberculosis. To understand their strategy knowledge of the epidemiology of tuberculosis in New Zealand is required.

In New Zealand tuberculosis has a complex epidemiology characterised by infection in 14 different species, both wild and domestic. The domestic species found naturally infected are cattle, sheep, deer, pigs, goats, cats and dogs. Naturally infected wildlife species include the Brushtail possum, ferret, hedgehog, stoat, weasel, rabbit and hare (Morris and Pfeiffer, 1995; Davidson et al., 1981 and Gay et al., 2000). Infected animal populations can act as one of two types of hosts – maintenance or spillover hosts (see Table 1 for detailed definitions). In New Zealand there are three maintenance hosts: cattle, possums and deer (both domestic and feral). Ferrets may also act as a maintenance host under certain circumstances (Caley, 2000). All other species that have been found to be susceptible to infection act as spillover hosts Table 1 (Morris and Pfeiffer, 1995).

Table 1. Definition of maintenance, spillover and reservoir hosts (Morris and Pfeiffer, 1995)

Host Type	Definition of host
Maintenance	the disease is maintained within the species with no external input and acts as a reservoir of infection for spread to spillover hosts
Spillover	the disease is not maintained within the species if there is no external input

In cattle, bovine tuberculosis lesions are granulomatous, caseous, calcified and paucibacillary (Corner, 1993). Respiratory infection with *M. bovis* produces a non-progressive disease with lesions that are initially small and self-limiting. Spread within the lungs is seen as a localised or generalised bronchopneumonia. Primary infection in the lung may disseminate by way of the lymphatic or circulatory systems (Collins and Grange, 1983). The principal transmission mechanism for tuberculosis in cattle is respiratory infection with the oral route of secondary importance (Lepper and Pearson, 1973).

Tuberculosis in deer presents as a granulomatous, calcified, purulent and multibacillary disease. Lesions are most commonly seen in lymph nodes and in some cases sinuses open to the skin or mucosal surfaces when large abscesses form in peripheral lymph nodes. Transmission of infection occurs via oral and respiratory route (Whiting and Tessaro, 1994; Lugton, 1997).

Tuberculous lesions in ferrets are oedematous, granulomatous and multibacillary. The majority of lesions are found in the mesenteric lymph nodes rather than in the lungs. The primary route of transmission is oral but may also occur through fighting and injuries incurred during mating (Lugton, 1997).

In possums tuberculosis is characterised as purulent or caseous and multi-bacillary (Corner and Presidente, 1981; Cooke et al., 1995). The two primary routes of transmission are horizontal and pseudo-vertical. Horizontal transmission is primarily through the respiratory route and is associated with behaviours such as courting, mating and competition between males (O'Reilly and Daborn, 1995). Pseudo-vertical transmission occurs from mother to joey through milk or close physical contact (Morris and Pfeiffer, 1995).

The impacts of possums on New Zealand are threefold. Possums damage native vegetation through selective browsing. They are opportunistic feeders with a diet of foliage, flowers, fruit, fungi and invertebrates (Cowan, 1995). Possums have also been found to prey on eggs and nestlings of threatened native birds for example the kokako

(*Callaeas cinerea*) and the kiwi (*apteryx*) (Sadleir, 2000). Finally, possums are a vector for *M.bovis* infection in cattle.

The Brushtail possum (*Trichosurus vulpecula*) is the major wildlife reservoir of M.bovis. It is a nocturnal, arboreal, herbivorous marsupial endemic to Australia and belongs to the order diprotodontia, sub-order marsupalia and family phalangeridae (Kirsch and Calaby, 1977). Possums were first successfully introduced to New Zealand in 1858 as the basis of a fur trade. The spread of possums was accelerated by the liberation of New Zealand-bred offspring across the country. The first scientific evidence of the negative effect of possums on native forest was collected in the 1940s. From that time possums have been considered a pest (Clout and Ericksen, 2000).

Natural transmission of *M.bovis* infection in possums was first identified by Bolliger (1948) in captive possums. In 1967 possums were identified as a vector of tuberculosis in domestic cattle and deer (Ekdahl et al., 1970). For these reasons possum eradication has become a priority. The majority of the $30 million spent on vector control in 1999-2000 was targeted at possums with a small proportion spent on ferrets and deer (Animal Health Board, 2000). The bovine tuberculosis National Pest Management Strategy (NPMS) involves the control of possums with the ultimate aim of eradication.

The occurrence of bovine tuberculosis in domestic and wild animal populations has wide-ranging implications for New Zealand. Humans are susceptible to infection with *M.bovis* and therefore it is a public health risk. In Australia in the 1930s *M.bovis* transmitted through contaminated milk products was responsible for 25% of tuberculosis cases in children. Introduction of pasteurisation eliminated this route of transmission (Cousins et al., 1998).

In the cattle industry bovine tuberculosis, if not controlled, leads to reduced farm productivity. Tuberculosis is a chronic disease that is usually not fatal. It results in decreased herd productivity due to the condemnation of carcasses at slaughter (Animal Health Board Inc, 1995). The level of tuberculosis may lead to the perception that New Zealand goods are inferior to those from countries with less tuberculosis and the presence of bovine tuberculosis may affect export markets.

It is for the above reasons that the NPMS was implemented to reduce the incidence and prevalence of tuberculosis in New Zealand. The eventual goal of the scheme is the eradication of *M. bovis* from New Zealand.

Study Objectives

Two independent studies were conducted into aspects of bovine tuberculosis control in New Zealand. The first study explored the attitudes of beef and deer farmers towards TB control while the second study validated the population component of a spatial stochastic simulation model of TB in a wild possum population.

In order for farmers to comply with the National Pest Management strategy they must have a basic knowledge of the NPMS. They need to have an overview of the entire scheme in order to determine their part in the strategy. Conducting a questionnaire was the most effective way of determining the extent of farmers' knowledge of and attitudes towards the NPMS. The Animal Health Board commissioned a project with the following objectives:

- to investigate farmers attitudes towards the control and eradication of bovine tuberculosis from farms in New Zealand and,
- to identify regional variations based on area classification and enterprise type.

The logic and the structure of each module in PossPOP had been verified by reviewing the program code and through the examination of the functioning program (Pfeiffer, 1994). Once the model was verified the next step was validation (Jorgensen, 1986). However, there has been no independent data set available against which to validate the model. The model was developed on the basis of the first 22 months' data from the longitudinal study of TB in possums conducted at Castlepoint in the lower North Island of New Zealand (Pfeiffer, 1994). This study was continued for 11 years from 1989 – 2000, and it was decided that the last 9 years of the study provided a suitable data set against which to validate the model. The aim of the study described in Chapter 3 was to validate the population component of PossPOP against data from the Castlepoint study.

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CHAPTER 1

A REVIEW OF THE LITERATURE

SECTION 1

THE STRUCTURE AND MANAGEMENT OF THE NEW ZEALAND TUBERCULOSIS CONTROL PROGRAMME: AN OVERVIEW

Introduction

The Animal Health Board (AHB) manages bovine tuberculosis (TB) control in New Zealand under the National Pest Management Strategy (NPMS) (Animal Health Board Inc, 1995). The strategy was written in compliance with the Biosecurity Act (1993). The first management strategy was introduced in 1995 and a revised strategy has recently been proposed (Animal Health Board Inc, 2001).

The long-term goal of the NPMS is to eradicate bovine tuberculosis from New Zealand. The short-term goal is to reduce or eliminate transmission of tuberculosis to and within domestic livestock species by reducing the number of infected herds through regular testing, abattoir surveillance and movement control, and by culling wildlife populations to prevent the establishment and expansion of areas with infected wildlife. The NPMS also encourages individual farmers to take action on their own properties to control TB (Animal Health Board Inc, 1995). The tuberculosis control strategies for domestic livestock are targeted at three different levels: individual livestock, individual herds and regions.

Control of TB at the level of individual animals

The tuberculosis status of individual animals is based on diagnostic assays (skin tests or gamma interferon assay), detection of gross lesions at post mortem examination, histopathology of suspect lesions, or the culture of *Mycobacterium bovis* (Table 2). The testing regime involves the use of one or more tests used in series.

Table 2. Criteria for the tuberculosis classification of livestock (Animal Health Board Inc, 1995)

Classification	Definition
Tuberculous animal	"an animal that is considered to be infected with *M. bovis* as a result of pathological investigation"
Reactor	"an animal considered to be infected with *M. bovis* as a result of a test"
Test positive animal	"an animal that responds to a test at specified criteria for a positive result to that test"
Test negative animal	"an animal that exhibits no positive response to a test"
In-contact animal	"an animal that is suspected of having been in contact with a reactor or tuberculous animal"

Tests for tuberculosis in cattle

The primary test used in cattle is the single intradermal tuberculin test (SIDT) using the skin of the skin fold at the base of the tail, the so-called caudal fold test. Bovine tuberculin is injected intradermally into the right or left caudal fold. The injection site is examined or "read", 72 hours (± 6 hours) after injection and a positive result is any palpable or visible reaction at the injection site (Animal Health Board, 2001f). The caudal fold test has moderate sensitivity, 72%, and high specificity, 98.8%. A high specificity test results in a low rate of false positive animals (Wood et al., 1991).

The comparative cervical test (CCT) is used to distinguish animals infected with *M. bovis* from those infected or sensitised to *M. avium* or other mycobacterium. It is available for use as a primary or ancillary test (most commonly used as an ancillary test). As an ancillary test it is not to be used within 60 days of the SIDT. The CCT is applied to the skin in the middle of the neck. Both bovine and avian tuberculins are injected into sites ?120 mm apart. The test is read 72 hours (± 6 hours) after injection by measuring the double fold skin thickness at each site. A positive result is indicated by reaction at the bovine site equal to or greater than at the avian site (Animal Health Board, 2001f).

The gamma interferon test (BOVIGAM? CSL, Melbourne) is an ancillary test that is used on both skin test positive and negative animals. A heparinised blood sample is taken 13 to 30 days after the caudal fold test. The interpretation of the test varies depending on results of skin test (Animal Health Board, 2001f). This test has a sensitivity of 95.2% and a specificity of 96.2%, therefore the gamma interferon test results in low false negatives and few false positives (Wood et al., 1991).

The last of the approved tests for cattle is the modified lymphocyte transformation test, used only as an ancillary test for cattle that have a negative caudal fold test. A heparinised blood sample is taken within 13 to 30 days of the last tuberculin test. The test identifies high, medium and low risk animals (Animal Health Board, 2001f).

Tests for tuberculosis in deer

The primary test in deer is the mid cervical test (MCT). Bovine tuberculin is injected intradermally into an area of the neck where hair has been removed. The results are determined 72 hours (± 6 hours) after injection. A positive result is a palpable or visible reaction at the site of injection. A negative result is a hard nodular reaction or "rice grain" size reactions, i.e., less than 5mm in diameter, or an increase in the double skin thickness of <2 mm (Animal Health Board, 2001f).

The comparative cervical test (CCT) is approved for use as a primary and an ancillary test but not for use in herds with Infected or Suspended status (see the following section). The test cannot be used within 90 days of a MCT. Both bovine and avian tuberculins are injected intradermally at sites greater than 120 mm apart, in the middle of the neck. Prior to injection the double skin fold thickness is measured and 72 hours (± 6 hours) after injection the skin thickness is re-measured at each injection site. A positive test is indicated by a reaction to the bovine tuberculin that is ?2mm and equal to or greater than the reaction at the avian site (Animal Health Board, 2001f).

The blood tuberculosis test (BTB) is used as a primary and ancillary test. BTB comprises the lymphocyte transformation assay and an ELISA. Heparinised blood is collected 13 to 33 days after the tuberculin test. Only animals that test positive to the MCT or the CCT are retested using BTB (Animal Health Board, 2001f).

The last of the approved tests used in deer is the ELISA tuberculosis test. This test is approved as an ancillary test to be used in parallel with a Mid cervical test. Blood is taken 13 to 33 days after a mid cervical test (Animal Health Board, 2001f).

Tuberculosis classification of livestock and consequences

Any animal that has a positive reaction to two sequential tuberculosis tests is classified a "reactor" and is slaughtered as soon as practical, but not longer than 30 days, after diagnosis. Whenever possible, reactors are slaughtered at a registered slaughter premise to ensure that: 1) the animal is subject to a post mortem examination, 2) there is control over sale/disposal of meat and 3) meat value is retained by AHB to offset compensation costs (Animal Health Board, 2001h). Reactors can only be moved direct to slaughter and must be identified by an official orange Reactor ear tag (Animal Health Board, 2001i).

Post mortem examinations are conducted for public health and epidemiological reasons on all animals processed at registered slaughterhouses. Examination of reactors is used as a serial test to determine if a reactor is infected with TB. However the abattoir examination has much lower sensitivity of 53% (Corner et al., 1990) compared with tests such as the SIDT (72%) or the gamma interferon assay (96.2%) (Wood et al., 1991). Animals that do not show lesions that are typical of or suspicious of tuberculosis are classified as clear of tuberculosis unless contradicted by further laboratory diagnostic tests (Animal Health Board, 2001a). Laboratory analyses are conducted for suspected cases with a maximum of 3 samples taken from a line from the same property. A limitation of this approach to determining the disease status of animals is that the least sensitive test is used as the final step in determining the disease status of a reactor. This approach is counter-intuitive and may result in infected animals and infected herds being misclassified. Compensation payments are made to owners of cattle classified as tuberculous. The compensation is 65% of fair market value as determined by the NZ Dairy Board for dairy cattle or the NZ Meat Board for beef cattle. Compensation is paid subject to certain conditions. No compensation is paid if: an owner wishes to slaughter a positive animal while awaiting a retest, an owner wishes to retain the meat for home consumption, the owner has not complied with a legal directive to slaughter a reactor, or, if pathological evidence of tuberculosis is detected in non-reactor cattle at slaughter. Owners of reactors are not liable for the cost of transportation of animals to slaughter or the slaughter fees if they are eligible for compensation. Animals bought from a movement-controlled herd at a discounted price are not eligible for compensation. Tuberculous deer are not eligible for compensation (Animal Health Board, 2001h).

Control of TB at the herd level

The tuberculosis status of herds is based on TB test results of individual livestock and abattoir surveillance. Herds are classified as "Infected" (I) if tuberculosis is identified or suspected in one or more animals. A herd is classified as “Clear” (C) if the entire herd passes at least 2 consecutive whole herd tests at an interval of at least 6 months and is free of any evidence of tuberculosis. The herd classification of “I” and “C” are used in conjunction with a numerical value that corresponds to the number of years that the herd has held that classification. For example I_2 is a herd that has been classified as infected for a period of two years (Animal Health Board Inc, 1995).

Additional herd classifications are “Works monitored” (WM), “Suspended” (S) and “Infected-High risk’. Herds where 45% to 90% (depending on area classification) of the herd go directly to slaughter each year are classified as “WM”. This classification indicates the herd is not under routine tuberculosis testing (Animal Health Board, 2001c). Where a clear herd awaits laboratory investigation of suspected cases or where animals have been added to a herd that have an unknown testing history, the herd is classified “S”. The criteria for classification of an Infected-High Risk herd is: 5 or more lesion cases have occurred in any test in a herd with less than 100 animals, or where there is a 3% tuberculosis lesion incidence at any test in a herd with more than 100 animals, or where 15 or more lesion cases occur in any one test in a herd with more than 500 cattle.

Herd testing frequencies are based on current herd and area classification. Clear herds are tested every one or three years, depending upon the area status of the farm. Infected herds must be tested at a two monthly or yearly interval depending upon the area classification (see below for description of area classifications and their effect on testing frequency) (Animal Health Board, 2001g).

Restrictions on movement of cattle and deer are applied to some herds and area classifications. Movement restrictions are applied to I and S herds. The level of restriction depends on the herd status and the reason for that status. Areas are declared as movement controlled if they have: herd breakdown rate of 0.01 herds, and/or TB lesion incidence of 0.001 per cattle/deer, and with consideration to herd management factors (Animal Health Board, 2001d). Conditions for the movement vary between herd types and are based upon the results of testing. In general, to move animals while under movement restrictions, a “permit-to-move” must be obtained for all cattle. In addition, the herd must have had a negative tuberculosis test. All such animals must be identified with the official movement control ear tags. Movements of non-reactor cattle directly to slaughter do not require a permit-to-move (Animal Health Board, 2001i).

To have an infected status revoked, a herd must have two consecutive whole herd tests, a minimum of 6 months apart, with no evidence of tuberculosis (Animal Health Board, 2001g). An infected herd after a clear herd test obtains a status of “infected” however with the clear test is noted, if a second test after 6 months shows no evidence of tuberculosis the herd takes on the status of “C1” (Figure 1).

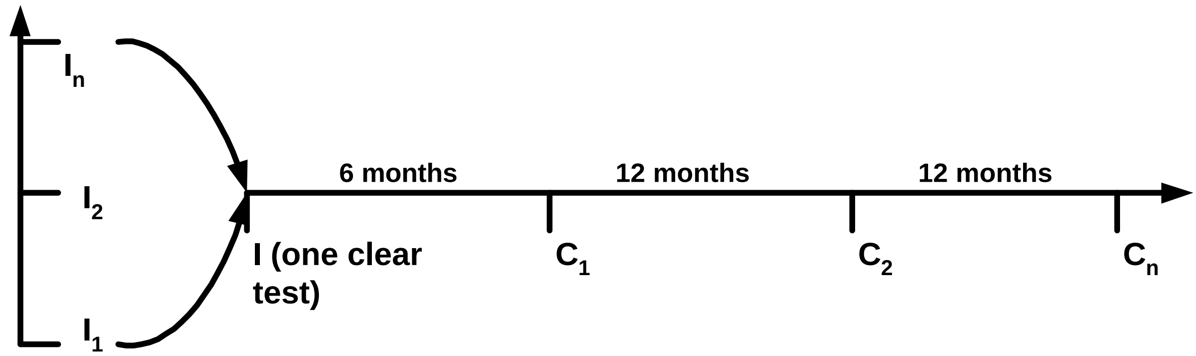

Figure 1. Structure of herd classification illustrating the transition from Infected to Clear (Adapted from: Animal Health Board Inc, 1995)

In the event of a herd breakdown status is set to “I” and an investigation is made into the causal factors. The investigation is undertaken within 14 days of the change in herd classification. The reason for the breakdown is assigned to one or more of five possible categories: 1) residual herd infection, 2) bought-in cattle/deer, 3) bought-in white tagged cattle/deer, 4) infected neighbouring herd, or 5) infected wildlife. Each category is given a ranking on a scale of “most likely, possible, not likely, definitely not” (Animal Health Board, 2001e). In order to determine the ranking of each of the categories different issues are considered. For example:

- identify possible sources of infected livestock,
- assess farm management practices which may have put the herd at risk of infection,
- investigate purchasing and off farm grazing policies,
- identify the extent of tuberculosis problem through testing of untested animals in infected and neighbouring herds,
- identify presence of potential vectors and their relative density,
- survey disease status and prevalence in vector species,
- request preventive vector control operation,
- trace and test any animals that left the herd since the last whole herd test. (Animal Health Board Inc, 1995).

The results of the breakdown investigation are used to develop a program to eradicate tuberculosis from the herd. Management and testing programs may be put in place if it is seen that the source of infection is residual infection or introduced with new cattle. If vectors introduce the infection then control operations are recommended (Animal Health Board Inc, 1995).

Control of TB at the regional level

Area classifications are based on risk of infection from tuberculous vectors and recent history of herd infections in the region. There are two primary regional classifications: tuberculosis vector risk areas (VRA) and tuberculosis vector free areas (VFA) (Figure 2). The boundaries between regions are based on geographical boundaries (rivers or mountain ranges) or distance from known or suspected focus of wild animal infection (Animal Health Board Inc, 1995).

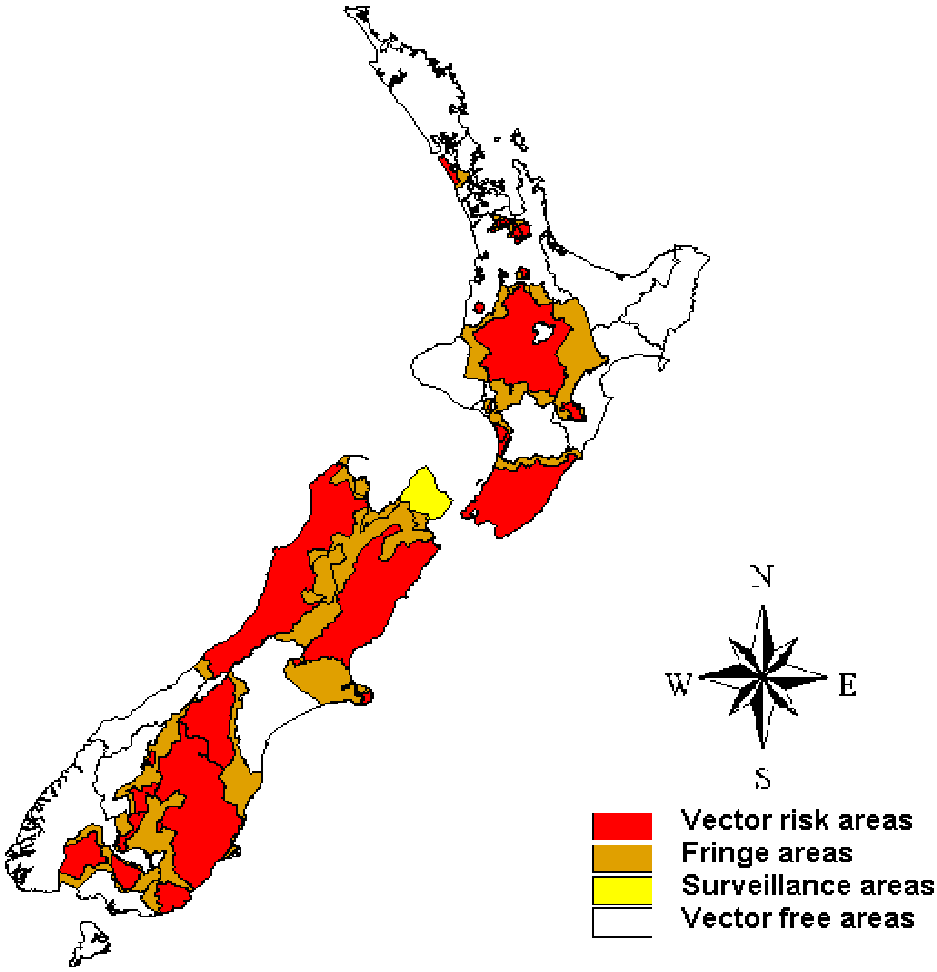

Figure 2. The distribution of vector risk, fringe, surveillance and vector free areas in New Zealand in February 2001

Vector risk areas are subdivided into endemic, buffer, control or eradication zones (Figure 3). Buffer zones are established on the periphery of the risk area to minimise the spread of tuberculous wildlife. Control and eradication zones are set up to control or eradicate tuberculosis from cattle, deer and wild animal populations. Within the VRA, subsections are classified as endemic if tuberculous vectors are identified and there is no vector control program in place (Animal Health Board Inc, 1995).

An area within a VRA may be declared a Movement Control area to help contain tuberculosis. Movement restrictions are placed on farmed cattle and deer and culling wildlife populations controls the spread of infected wild animals. A movement control area is declared where one or more of the following conditions are met: the herd breakdown rate is ?1% or, the incidence of tuberculous lesions is ?0.1% (Animal Health Board, 2001d). In a declared Movement Control area all animals greater than 3 months of age must have a negative pre-movement tuberculosis test, no more than 60 days prior to movement unless going directly to slaughter.

Movement control status of an area may be revoked if all the following criteria are met: the herd TB infection is < 1% and per head incidence is < 0.01. The criteria must be met for a minimum of two years and are expected to do so for an additional 12 months (Animal Health Board, 2001d).

For all cattle or deer ?1 month of age being transported within New Zealand a tuberculosis declaration card, completed by the owner, must be carried whether the movement is to grazing, sale or slaughter (Animal Health Board, 2001d).

Vector free areas are divided into fringe testing, surveillance testing and officially free areas (Figure 3). Fringe testing areas surround declared vector risk areas and are created to monitor whether infected vectors are contained within the VRA (Animal Health Board, 2001b). Officially free areas meet international specifications for freedom from tuberculosis, that is less than 0.2% infected herds for a minimum of three years. The remaining areas are designated as surveillance testing (Animal Health Board Inc, 1995).

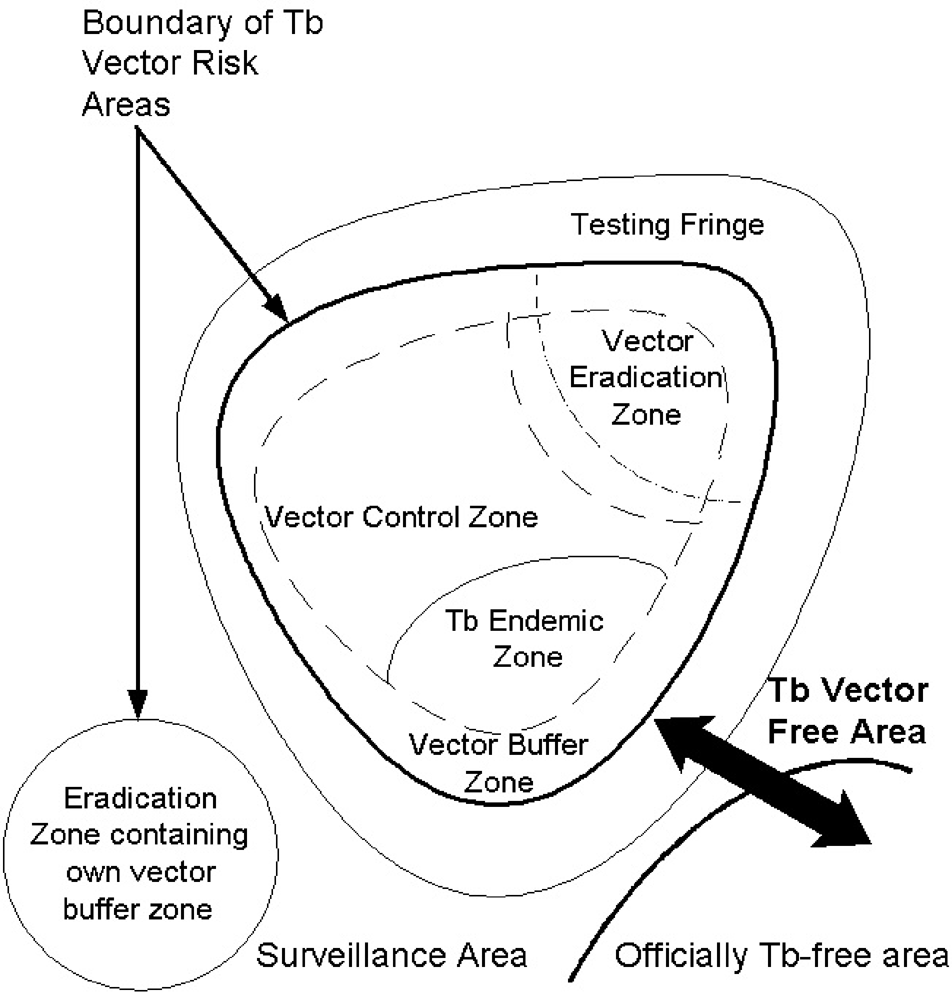

Figure 3. TB vector risk and vector free areas with corresponding subdivisions (Reproduced from: Animal Health Board Inc, 1995)

The frequency of herd testing is dependent upon three factors: 1) herd tuberculosis status, 2) area classification and 3) method of herd surveillance (Table 3).

Table 3. Testing frequency by herd status and area classification (Animal Health Board, 2001g)

Area [b]	Herd Status [a]	Testing frequency
VRA	I	2 to 12 months
	C	12 months
	WM	Works surveillance for herds with ?90% sent to slaughter each year
VFA- fringe	I	2 to 12 months
	C	12 months to 2 years
	WM	Works surveillance for herds with ?90% sent to slaughter in a year
VFA-Surveillance	C	Annual (C1, C2) to triennial (>C2)
	WM	In a triennial testing area where ?45% of herd go to slaughter each year or in biennial testing area ?60%

[a] I = herds classified as infected with tuberculosis, C = herds classified as free of tuberculosis, and WM = works monitored herds (not under routine testing conditions). [b] VRA = vector risk area, VFA = vector free area

The principal affect of area classifications is on vector control. Each area is subject to differing degrees of control and financial assistance (Animal Health Board Inc, 1995).

Vector Control

The primary goal in controlling infected wildlife vectors is a reduction in the risk of exposure to this source of TB to domestic livestock. Therefore, the objectives of vector control are to:

✍✍Establish and maintain areas around the periphery of a VRA that are free of vectors, that is, establish buffer zones,

✍✍Prevent the establishment and expansion of tuberculosis into wild animal populations that are free of tuberculosis, and

✍✍Reduce the size and number of VRAs through eradication of tuberculosis in areas where it is considered feasible.

Within Vector Risk Areas different types of vector control are conducted (see “Control of TB at the regional level”). Buffer zones are established around VRAs to minimise the spread of tuberculosis into areas free of infected wildlife. A range of vector control measures is used in control zones to reduce the spread of tuberculosis from vectors to domestic populations. Eradication of bovine tuberculosis from a VRA will be declared when the area has been free of vector-associated tuberculosis in all cattle and deer herds for a minimum of five consecutive years.

Vector control in VFA involves the prevention of spread of infection by limiting the vector populations and restricting infection to VRAs. In fringe testing areas wildlife populations are monitored either indirectly through cattle and deer testing or if livestock is insufficient by direct surveillance. Officially free and surveillance areas vectors are monitored indirectly through cattle and deer testing. An intense vector eradication scheme will be implemented if tuberculous wildlife are identified or suspected in VRAs (Animal Health Board Inc, 1995).

Methods of vector control depend on the species involved, the level of control required, the size of the area, vegetation of area, access to area, range of control techniques available and resources (funding) available. Three techniques are available: poison, trapping and shooting. All three are utilised in the management strategy. The basic guidelines for their use are that they must be “cost-effective, environmentally benign and acceptable on animal welfare grounds” (Animal Health Board Inc, 1995).

Poisons are used through aerial and ground distribution. There are a large number of poisons used, each with advantages and disadvantages (Table 4) (Eason et al., 2000).

Table 4. Advantages and disadvantages of poisons used for vector control (Eason et al., 2000)

Poison	Advantages	Disadvantages
1080 (Sodium monofluoroactetate)	Aerial and ground distribution, effectively reduces population size, biodegradable, cheap, presented in cereal based pellets or carrot	Adverse public opinion towards aerial distribution, use is highly regulated, can cause bait shyness, can kill non target species
Cyanide	Presented as paste or encapsulated pellet, cheap, 70-90% kill rate, pellets can be reused	Hazardous to users, for use only by licence holders, use of paste can result in cyanide shyness
Phosphorus	>90% kill rate, less public opposition than for 1080	Not efficient, possums can eat up to 2 kg and survive
Brodifacoum	Available to general public, effective against bait shy possums	Used only in bait stations, expensive, possums take 2 – 4 weeks to die, high risk to non target species
Pindone	Available to general public, cereal based pellets,	Not efficient, possums can eat up to 2 kg and survive
Cholecalciferol	Available to general public, achieves rapid population breakdown, low risk to birds	Expensive, not registered for aerial distribution

Trapping is the principal technique utilised for ferrets, but is not as widely used as poisoning for possums control. There are four types of traps used in New Zealand at present (Table 5) (Montague and Warburton, 2000).

Table 5. Advantages and disadvantages of trapping methods used for vector control (Montague and Warburton, 2000)

Trap type	Advantages	Disadvantages
Leg-hold traps	Many different types, efficient at capturing possums	Seen as inhumane by public, must be checked every 24 hrs
Kill traps	Can be checked infrequently, new traps are humane	Old traps were inefficient and inhumane
Cage and box traps	Humane, can be used in areas with protected species,	Trap weight and size make transporting traps difficult, expensive
Snares	Cheap, lure can be produced cheaply to increase efficiency	Skill is required for effective use, used primarily by hunters rather than control organisations, not commonly used, seen as inhumane by public

Shooting is most commonly utilised by individual farmers to reduce possum numbers. Shooting is conducted in twilight using spotlights to locate the possums by the red light reflected in their eyes. Shooting however is not practical for large or inaccessible areas and is labour intensive. Possum populations may become light shy if spotlighting occurs repeatedly over long periods (Montague and Warburton, 2000).

The pest management strategy encourages farmers to be personally involved in improving the disease status of their herds. Assistance is provided by AHB to implement vector control programs, especially for those with high-risk herds, through self-help programs and one-to-one programs (Animal Health Board Inc, 1995).

Culling of possums alone has not been sufficient to control the spread of tuberculosis in wild populations (Caley et al 1999). Since the implementation of the scheme in 1995, the total area classified as Vector Risk has increased from 23% (approximately 61,000 km^2) to 33% (approximately 88,000 km^2) of the total area of New Zealand in 2000. Ten of the 22 extensions to VRAs involve crown land (Animal Health Board Inc, 2001). This highlights the specific problem of diseased vector populations on Crown land and the need for vector control by the state authorities to prevent the spread of tuberculosis to farmed areas.

NPMS management structure

The Minister of Agriculture has responsibility for the Biosecurity Act of 1993 under which the NPMS is operated. The Biosecurity Act also provides the authority for carrying out actions under the Pest Management Strategy Order that are approved by the Chief Veterinary Officer (Animal Health Board Inc, 1995). The mandate for the NPMS is provided by the stakeholders and proving to the Minister that there is support for the strategy (Figure 4).

The Animal Health Board is responsible for developing the strategy and policy with respect to TB control. The board consults with stakeholders to gain general agreement on the strategy. However, the AHB is formally accountable to the Minister of Agriculture and is required to gain the Minister's approval for the scheme. The board's primary role is to successfully implement the strategy and is required to report annually to the executive committee on progress towards strategy objectives, financial accounts and the proposed annual budget (Animal Health Board Inc, 1995).

The executive committee is made up of stakeholders; that is, government appointees, local government representatives and representatives of industries with interests in tuberculosis control. The industry groups include: Dairy Farmers of New Zealand, New Zealand Meat and Fibre Producers, New Zealand Dairy Board, Meat New Zealand, New Zealand Deer Farmers Association and New Zealand Game Industry Board (Animal Health Board Inc, 1995).

The AHB disseminates information and receives feedback on current issues regarding the NPMS through regional committees (Figure 4). Regional committees are made up of Regional Animal Health Committees (RAHC), Locally Initiated Programs (LIPS) and Regional Council members. RAHC's are local groupings of industries and people affected by the NPMS. Members include representatives of industry such as the dairy and beef sectors, regional/district councils and any other group with an interest in tuberculosis control, for example the Department of Conservation (Barnett et al., 1999). Locally initiated program groups (LIPS) are groups of landowners that wish to initiate vector control work outside the vector control operations of the scheme and at their own expense.

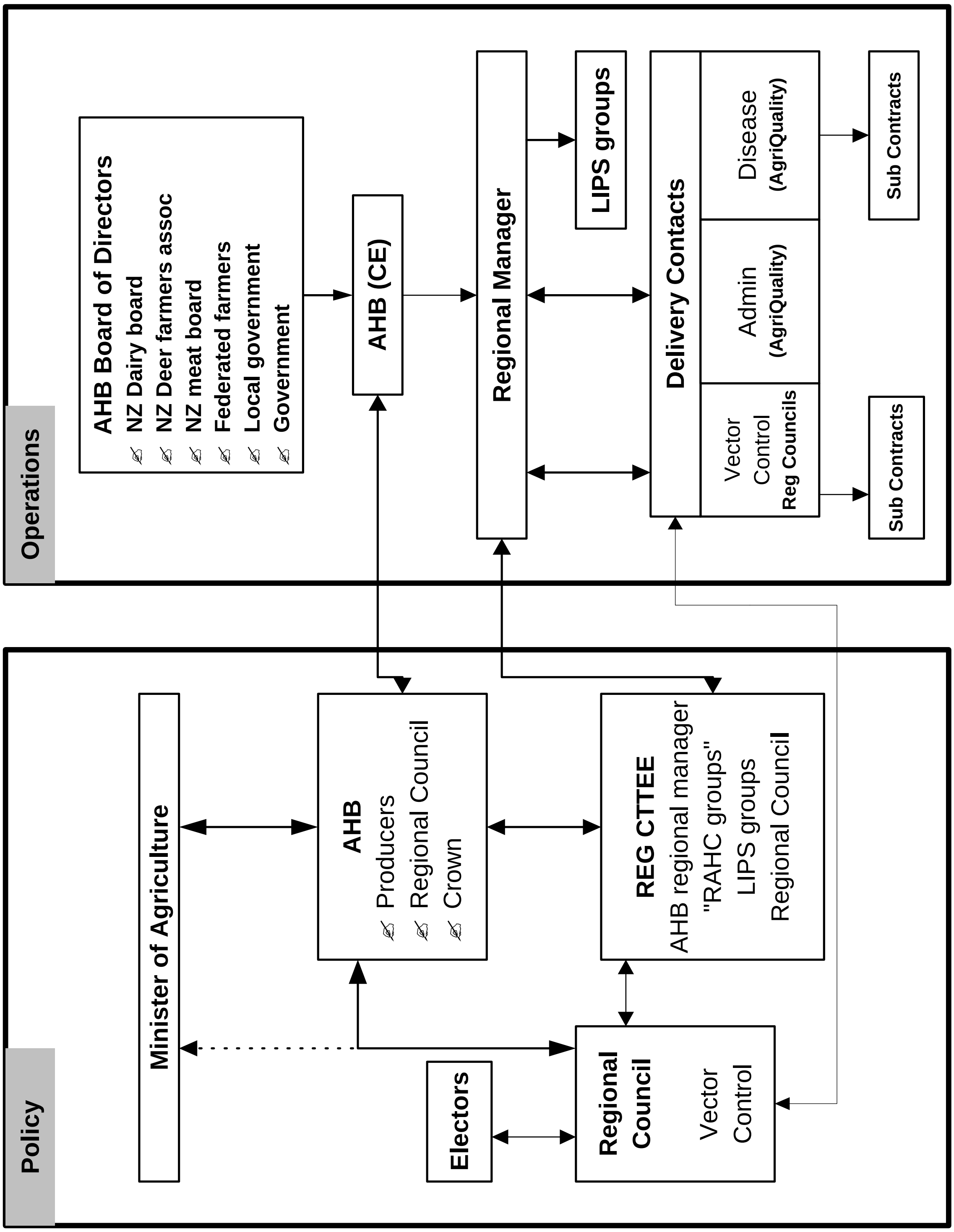

Figure 4. Diagram of the management structure of the NPMS for both policy and operations (Adapted from: Animal Health Board Inc, 1995b)

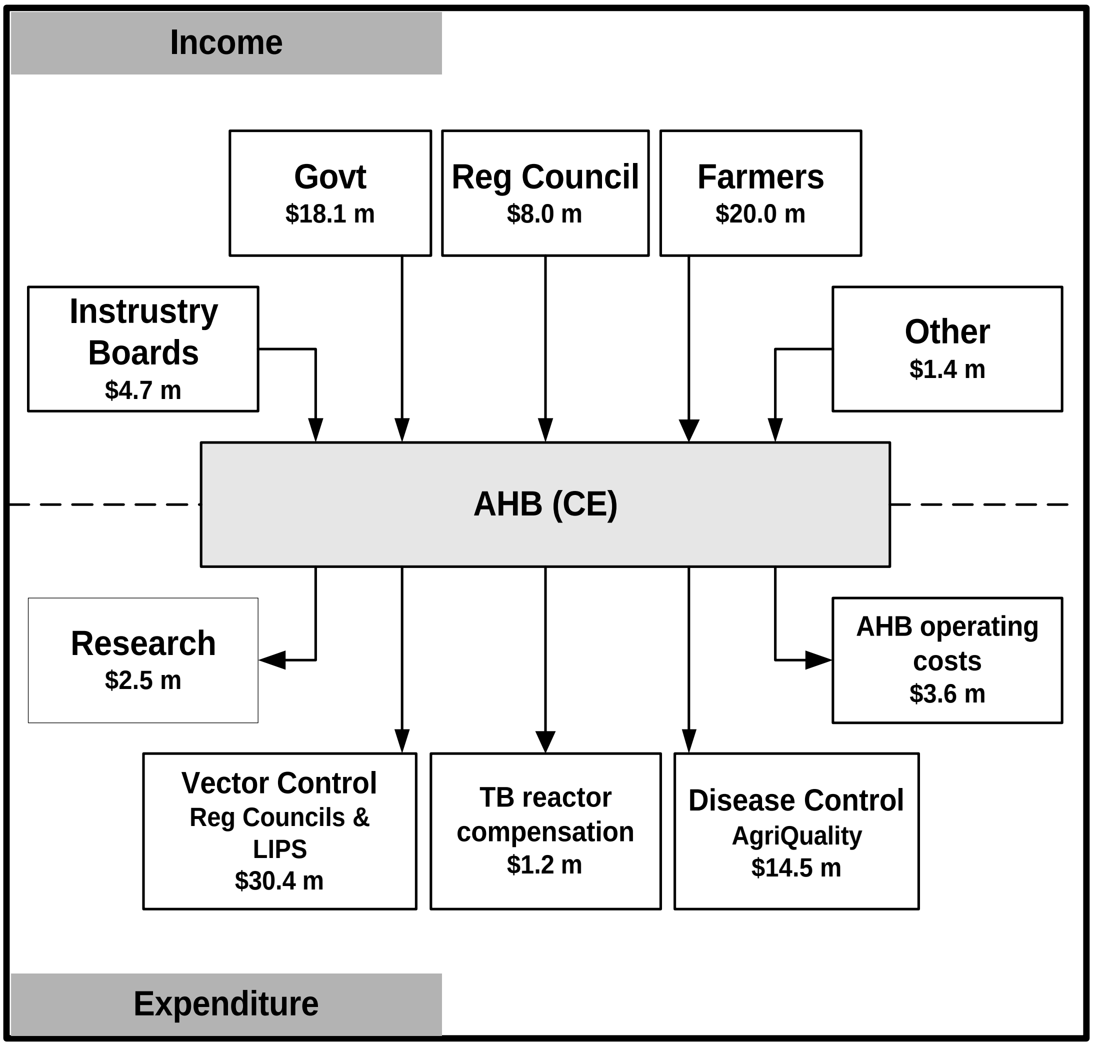

Figure 5. Funding structure of the National Pest Management Strategy (Animal Health Board Inc, 1995)

Funding of the NPMS

Producers, central government and regional governments fund the NPMS with the Animal Health Board acting as the agent (Figure 5). Farmers contribute to the strategy through a levy placed on all cattle sent to slaughter. However, on this basis an imbalance would exist between the funding contributed by the two cattle sectors, as 73% of all slaughtered cattle originate from the beef sector. Therefore to balance the contribution of the beef and dairy sectors the dairy industry provides an additional grant. The game industry contributes to the strategy on behalf of the deer industry. Regions contribute through the collection of levies on land (Animal Health Board Inc, 2001). The government contributes to the NPMS as they are seen as exacerbating the spread of vectors throughout New Zealand. They are seen as "exacerbators" for three reasons; 1) possums were for many years classed as a protected species, 2) when the

Government funding of the eradication scheme was reduced in the period between 1979 to 1981 (O'Neil and Pharo, 1995) the cattle and deer industries lost control of the battle to eradicate bovine tuberculosis from New Zealand and 3) the crown is also the largest single owner of land carrying vectors (Animal Health Board Inc, 2001).

There are five primary areas of expenditure in the NPMS, as illustrated in Figure 5.

- Disease control is sub-contracted to AgriQuality who conduct the cattle testing.
- Vector control is sub-contracted to regional councils and LIPS groups who conduct vector control on possums, ferrets and feral deer within their area.
- Compensation payments are handled by the AHB and paid to farmers with cattle that react to the tuberculosis tests (see previous section labelled "Control of TB at the level of individual animals").
- Short, medium and long-term research into areas relevant to the eradication of tuberculosis are funded by the AHB.
- Additional expenditure incurred in the operating expenses of AHB (Animal Health Board Inc, 1995).

The responsibility of farmers within the National Pest Management Strategy

Within the NPMS herd and landowners have obligations in two areas: disease control and vector control. Herd owners are obliged to provide access to their property, present livestock for testing and provide adequate facilities for an authorised person to conduct tuberculosis testing. Reactors must also be presented for removal and slaughter. Landowners must also provide access to their property for an authorised person to survey, monitor or destroy vector species (Animal Health Board Inc, 1995).

SECTION 2

THE DESIGN AND USE OF QUESTIONNAIRES:

A LITERATURE REVIEW

Introduction

Questionnaires are a practical method of obtaining information from many people or groups on a given topic (Czaja and Blair, 1995). There are many issues to be considered in the design and use of questionnaires that help to ensure optimum results.

Questionnaire Design

The first step in designing a questionnaire is to decide what information is being sought and the population of interest (Czaja and Blair, 1995). The population must be determined in reference to the information being sought. For example, if information on bovine tuberculosis is required the population will be all farmers that own cattle. However due to the large numbers of such farms a sampling frame must be established to select a subset of farms in certain geographical areas or that have herds of certain sizes (Czaja and Blair, 1995).

The principal issue in survey design concerns questions. Questions should be concise, clearly worded with the minimum number necessary to obtain the desired information (Martin et al., 1988). The terminology and jargon should be appropriate to the sample group. Double questions, where one question has two parts but only one possible response, should be avoided. Questions that involve a double negative, for example the question “Teachers shouldn’t smoke”, may lead to confusion if the respondent disagrees, ‘teachers shouldn’t not smoke’ could be interpreted as both agreement and disagreement. Leading questions may bias the respondent; for example, the use of “You do” should be replaced with “Do you”. Simple questions that avoid confusion will produce the best responses (Martin et al., 1988).

There are two types of questions: “open-ended” and “closed”. With open-ended questions the respondent is not given guidelines for their response. Open-ended questions allow the respondent to explain their response. The results of open-ended questions may be difficult to analyse. Closed questions have the possible answers listed and the respondent is asked to select their preferred response from the list. Closed questions do not allow the respondent to elaborate on their response but are easier to analyse (Martin et al., 1988).

The layout and structuring of the survey is also important. The sequence of questions should be logical and flow easily from one to another. Questions should be grouped by topic, temporal relationship of events, or another grouping relevant to the study. The respondent or an interviewer should easily complete the survey. There should be clear areas where a response is required and enough space for the response to be recorded (Martin et al., 1988).

A questionnaire should be pre-tested to identify weak areas, be it the wording of the questions, the content or layout (Martin et al., 1988; Czaja and Blair, 1995). The questionnaire should be pre-tested on respondents similar to those who will be involved in the final survey. Other features that can be tested include the length of time required to answer the questions, ease of understanding questions and the ease of following instructions. Lively and Nuthall (1983) produced a questionnaire to determine farmers attitudes to information. They consulted sociologists and agricultural economists on ways of improving the questionnaire and pre-tested their survey by conducting detailed interviews with six farmers.

Types of questionnaires

There are three basic types of questionnaires: face-to-face interview, telephone interview and postal (Czaja and Blair, 1995). Each approach has its advantages and disadvantages.

Face-to-face surveys are those where an interviewer speaks with the interviewee and asks predetermined questions, usually at a location convenient to the respondent (Czaja and Blair, 1995). The advantages of face interviews are that the interviewer can control the order of the questions, the speed of the interview, can pick up on the body language of the interviewee, and obtain more in-depth information. This type of questionnaire generates a high response rate. However within and between interviewer variation may arise but this can be avoided by training interviewers. Face-to-face surveys are expensive, due to the cost of travel, are time consuming to conduct and the need to find people at home (Haslett, 2000).

Telephone interviews are applicable for questionnaires with straightforward questions and that can be completed in 5-10 minutes (Haslett, 2000). The interviewer has control over the order in which questions are answered. The cost of telephone calls is a disadvantage although telephone interviews are usually cheaper than face-to-face interviews. Telephone interviews however contain a sampling frame bias arising from the assumption that everyone in the population of interest has a telephone (Czaja and Blair, 1995).

Postal surveys are the most practical method of surveying large numbers of people. Postal surveys are quick, cheap, contain no interviewer bias and they allow the respondent to consult records. However only simple questions may be asked and the responses have to be accepted as final as procedure does not usually allow for spontaneous responses (Haslett, 2000). Mail surveys have a sampling frame bias that arises from the assumption that in the population of interest all the people are literate. Mail surveys generally produce a low return rate, 40% – 50% (Martin et al., 1988), although return rates will be higher if the issue is important to the respondents.

A survey with a return or response rate of less than 70% or 80% is generally regarded as unsatisfactory (Martin et al., 1988) as interpretation is difficult and the results are hard to generalise. Low return rates may contain biases, respondents are self selected and may have different opinions, backgrounds or level of knowledge compared to those that do not respond.

The need for high return rates has resulted in the development of various methods for increasing the number of questionnaires returned. One method of increasing the response rate is to notify interviewees in advance of the study. For example, mailing out an introduction before a telephone or face-to-face interview, or ringing selected people to request their participation in a postal survey. Barnett (1999) initially contacted participants by telephone to obtain their agreement to participate in the study. Upon agreement they were interviewed face-to-face. Another method of increasing the return rate is to include a reply paid envelope with the questionnaire as used by Pollard (1999). Finally, the response rate for postal questionnaires may be increased by following up those that do not respond by sending reminder letters at regular intervals after the initial mail out. Bourn and Newton (2000) mailed out a reminder postcard one week after the initial mail-out and a replacement questionnaire was sent after 3 and 8 weeks to non-respondents.

Sources of error in surveys

There are two types of error that occur in surveys, sampling and non-sampling. Sampling errors are measurable and may be minimised, however non-sampling errors are not easily quantified.

Sampling errors can arise when collecting information from a fraction or sample of the population (Duoba and Maindonald, 1988; Statistics New Zealand, 1995). Sampling errors depend upon three factors: sample size, variability in characteristic of interest and sampling procedure. Increasing the proportion of the population that is sampled can reduce the effect of error related to sample size. However, it should be noted that little is gained by increasing the sample size beyond a certain point. The variability of the characteristic of interest also affects sampling error, the greater the variability the greater the potential for error. Sample design affects the magnitude of the error; samples that use information regarding the population are less likely to contain errors (Statistics New Zealand, 1995).

Non-sampling errors arise from a diverse array of causes and are not easily measured. There are two types of non-sampling error: random and bias. Random error effects cancel out if relatively large sample sizes are used. Random errors measure statistical variation in the data as measured by standard deviation (Czaja and Blair, 1995). Biases tend to create errors that are all in the same direction and accumulate over the entire sample. There are many types of biases that occur and different types of surveys have different biases (Table 6) (Duoba and Maindonald, 1988).

Table 6. Types of biases that arise in surveys (Duoba and Maindonald, 1988)

Type of bias	Description
Sampling operations	errors in sample selection, i.e. part of the population is omitted
Non-response	there may be a common element to those that do not respond
Adequacy of respondent	information can be obtained from others if respondent cannot be contacted however the proxy may not be as knowledgeable
Understanding concepts	some respondents may not understand what is wanted, i.e. misinterpret the question
Lack of knowledge	respondent may not know the information requested and invent an answer
Concealing truth	respondents may conceal the truth out of fear or suspicion
Loaded questions	questions that influence the respondents answer in a specific way
Processing errors	errors may occur in data entry, the computer program or coding
Conceptual problems	for a complex topic, the definition may need to be approximated to make questionnaire understandable
Interviewer error	interviewers may misread a question or distort the answers by using their own words

Ethics of surveys

There are two issues in conducting surveys that relate to ethics: informed consent and protection of confidentiality. The participant must be informed as to the nature and purpose of the study before they consent to participate (Czaja and Blair, 1995). Therefore the study must be introduced to the respondent either through the use of a cover letter for a mail survey or an explanation of the study for an interview. Aspects of the project such as the funding body, the major purpose, time required to complete the survey, the subjects covered and the use of the data should be explained.

When the respondent has agreed to participate in the study it is then the researcher’s responsibility to protect the respondent’s privacy. Information that could allow the identification of individual respondents should never be made available to others, nor should responses be discussed outside the research group (Czaja and Blair, 1995). As a gesture of appreciation it is also recommended that a summary of the findings of the study be sent to participants thereby giving feed back on the contribution of their information to the study. A note of thanks for their time and effort may also be added to the summary.

Data quality control

The first step in the analyses is to determine the validity of the data. Error checking should be conducted on the data. One method of quality control is the examination of outliers in order to determine if there have been data entry errors (Moore and McCabe, 1998). In addition the amount of errors that arise from data entry should be quantified. Randomly sampling 10% of the completed surveys and comparing the physical survey with the computer data allows the identification of data entry errors. An error rate of less than 1.5 per 100 cells was considered unlikely to affect the results of the analysis (Panichabhongse, 2001).

Once the error rate has been determined and is sufficiently low for the analysis to proceed, summaries are made of the data. Frequencies of responses for each question should be computed and stratified if the sample was based on a stratified sample, such as by sex, age, or other outcome variable such as presence of a disease. Graphical analyses, such as histograms or pie charts, can be used to present the data in a form that is easily digestible.

Questionnaires are becoming a more widely used and common place tool in the sciences. However with their use consideration must be paid to the issues involved with the creation, use and analysis of the data gained.

SECTION 3

AN INTRODUCTION TO THE POSSPOP SIMULATION MODEL AND PROCEDURES APPLICABLE TO ITS VALIDATION

Models

Models are “a simplified picture of reality” (Jorgensen, 1986). They are used in a range of activities from business to engineering and epidemiology. Their value lies primarily as methods for solving problems or for predicting outcomes. Models in science are used as an instrument to simplify complex systems, reveal system properties, reveal weaknesses in our knowledge and to test hypotheses (Jorgensen, 1986).

William Farr and others first used modelling in epidemiology as early as 1840. Mathematical representations were developed of patterns in the occurrence of epidemics with the hope of predicting them *a priori* (Susser, 1985). Using a model, Farr was able to predict the outcome of a Rinderpest epidemic in England (Hurd and Kaneene, 1993). Later modelling was used to address disease control problems in humans and livestock, such as malaria and helminth infections, with the models being developed concurrently with data collection and control policy recommendations (Hurd and Kaneene, 1993). In more recent times the use of computer simulation has allowed the relaxation of some of the assumptions of analytical modelling, thus decreasing the need for rigorous mathematics, enabling management of non-linearity and time dependence (Hurd and Kaneene, 1993).

Simulation Modelling

Simulation modelling was defined by Shannon (1975) as “the process of designing a model of a real system and conducting experiments with this model with the purpose of either understanding the behaviour of the system or evaluating various strategies (within the limits imposed by the criterion or set of criteria) for the operation of the system”. A simulation is the simplification of a real system through a set of assumptions about its operation. Emshoff (1970) describes simulation as “ a model of some situation in which the elements are represented by arithmetic and logical processes that can be executed on a computer to predict the dynamic properties of the situation”. Simulations do not produce exact solutions, which are available with analytical models, but generate representative samples of measures of performance (Winston, 1994). Models of real world systems contain three fundamental aspects: generality, realism and precision. A high degree of any two of these aspects excludes the possibility of a high degree of the third (Pfeiffer, 1994).

In epidemiology, the focus of simulation modelling is to describe and understand interactions of factors in biological systems that relate to a disease process (Hurd and Kaneene, 1993). Simulation modelling is used as a research tool to test hypotheses and identify areas of insufficient knowledge. In epidemiology there are two types of models: ‘associative’ and ‘process’. Associative models attempt to establish aetiology through the observation of risk factors with the occurrence of disease. However they do not take into account change in relationships over time (Hurd and Kaneene, 1993). Process models attempt to quantitatively describe the course of the disease in a population over time (Hurd and Kaneene, 1993).

Characteristics of simulation models

There are a number of characteristics of simulation models (Emshoff and Sisson, 1970) (Figure 6).

1) Static – Dynamic. A static model assumes that all variables and parameters are independent of time. A dynamic model is one where the system oscillates round a steady state (Jorgensen, 1986). Most epidemiological models are dynamic.
2) Aggregate – Detailed. An important characteristic of a model is the degree of aggregation, for example, should the events for every animal or every herd be represented in the model. The degree of aggregation is dictated by the objectives of the model.
3) Physical – Behavioural. The situation being modelled may contain physical processes, such as in a production line, and/or behavioural processes, such as mating or courtship.
4) Continuous-time – Discrete-time. Discrete-time models divide time into units of equal duration whereas continuous-time models treat time as a continuous variable (Hurd and Kaneene, 1993). Continuous-time provides a description of all the variables in the system for all time instants over the time interval of interest (Murthy et al., 1990). Therefore continuous-time is too detailed for most models and produces an unmanageable amount of output data.
5) Continuous-entity – Discrete-entity (Hurd and Kaneene, 1993). Discrete-entity models track one individual through the model at a time, whereas continuous-entity models treat the number of individuals in any state as a real number.
6) Deterministic – Stochastic. Deterministic models contain no random variables. Variables are fixed and no randomisation is inherent in the model, therefore multiple

runs of a deterministic model produce the same results (Winston, 1994). Deterministic models are useful in determining sensitivity of the systems to changes in particular parameters (Hurd and Kaneene, 1993). Stochastic models are probabilistic. They include elements of random variation and chance (Meerschaert, 1993). The value of some or all variables is selected from a distribution and therefore the results of the model vary with each run (Winston, 1994). Stochastic models reflect the realistic aspects of uncertainty that occur in the 'real world' (Hurd and Kaneene, 1993).

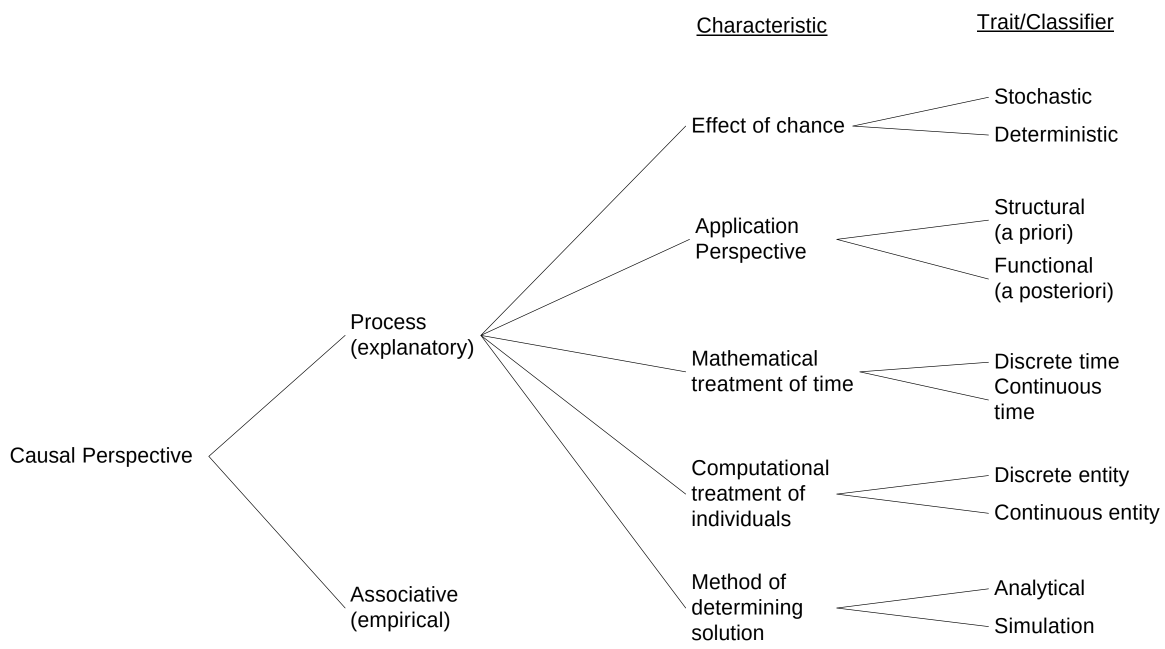

Figure 6. Classification method of process epidemiological models (Adapted from: "Hurd and Kaneene, 1993)

Development of a model

The development of a model is an iterative process that contains three phases: model design, model execution and execution analysis (Figure 7) (Fishwick, 1995).

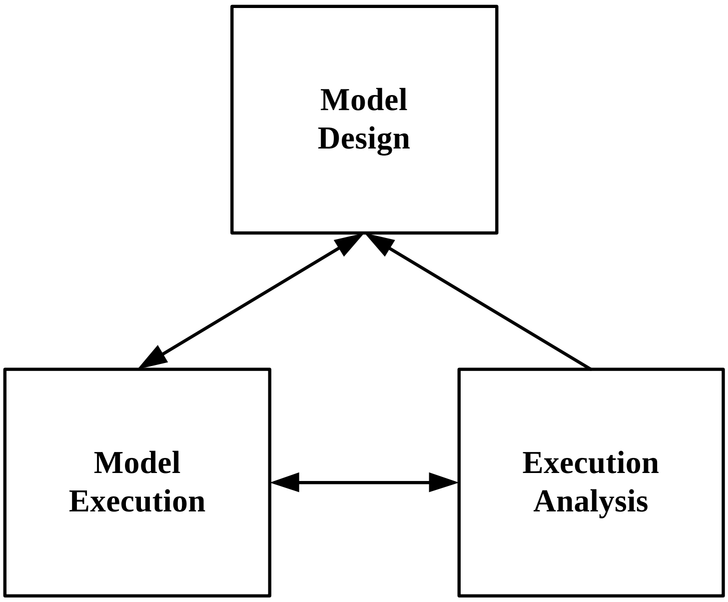

Figure 7. Process of model development (Reproduced from: "Fishwick, 1995)

The development of a simulation model is better understood as a five-stage process (Figure 8). The stages are determining goals, analysing the system, synthesising system data, checking the model and analysing the model (Anderson, 1974).

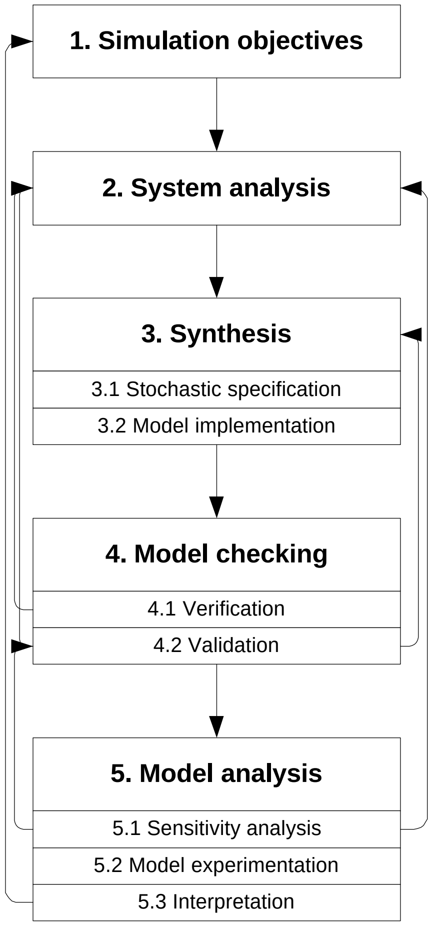

Figure 8. Five stage approach to model development (Adapted from: "Anderson, 1974)

In the design of a model the first step is to define the problem to be solved (Pfeiffer, 1994). The objectives for solving the problem should be set out and the relevant variables identified. Data on the system can be obtained from field observations or published data, or if no data exists then assumptions or approximations can be made. The final and hardest step in designing a model is to determine what modelling method of the many available should be used (Jorgensen, 1986). Although no one model will accurately describe a system, the most appropriate model, not necessarily the easiest to develop should be chosen. Once the type of model to be used has been chosen, then the model can be created and implemented.

In the creation of a model the simulation variables and parameters must be estimated. Real-world data is summarised to make it manageable as statistical descriptions of the system (Emshoff and Sisson, 1970). Frequency distributions are commonly computed, or if the variable has a cyclical trend, values are represented in time series.

Once the model has been created, it can be run and the results verified and/or the model debugged (Emshoff and Sisson, 1970). Verification determines if there are programming or logical errors in the model and that the model is operating as the modeller desired. Rykiel (1996) defines verification as “a demonstration that the modelling formalism is correct”. Questions such as “Does the model react as expected?” or “Does the model show long term stability?” are asked of the model (Jorgensen, 1986). Sensitivity analysis may also be used to give the modeller an overview of the most sensitive components of the model (Jorgensen, 1986).

Model validation

Emshoff (1970) writes, “The most vexing question asked about a model is, “How do you know it is valid?””. A measure of the degree of confidence that the user can place in the predictions of the model is required as no model will ever be a perfect representation of reality (McCarthy and Broome, 2000). Validation of simulation models is crucial to generate confidence in the behaviour of the model, especially if the model is used as a decision support tool (Higgins et al., 2001).

Validation is controversial in its definition, application and interpretation (Elliott J A. et al., 2000). Jorgensen (1986) defines validation as “an objective test on how well the model output fits the data”. Rykiel (1996) argues that there is ambiguity in the definition of validation between certifying operational capability and theoretical content. The definition used by Higgins et al. (2001) is that; “Validation refers to the process of testing a model on its agreement with observations independent of the observations used to structure the model and estimate parameters”. According to Rykiel (1996) this is a true definition of validation. The definition of validation should be separated from that of scientific hypothesis testing, which is determining confidence in inferences made about a real system based on model results (Rykiel, 1996).

Validation is important for building model credibility rather than for evaluating research models (Rykiel, 1996). Validation is often described as not straight forward or the most difficult step in modelling (Gentil and Blake, 1981).(Brown and Kulasiri, 1996) However, it is a necessary step for acceptance of the model in the user community (Mayer and Butler, 1993; Higgins et al., 2001).

In the validation process novel techniques must be explored (Higgins et al., 2001). A large number of papers have been published on methods of validating agricultural (Anderson, 1974) (Jones and Carberry, 1994), industrial (Gass, 1983) (Van Horn, 1971) and ecological models (Miller et al., 1976). Very few articles have been written on the methods of validation for epidemiological models. However methods and techniques used for model validation can be applied across all fields, as all simulation models operate on the same principals. There are many detailed reviews on validation which provide a good framework for validation (Van Horn, 1971; Anderson, 1974; Gass, 1983; Sargent, 1984; Power, 1993; Mayer and Butler, 1993; Brown and Kulasiri, 1996; Rykiel, 1996).

Validation is not straight forward as the systems being modelled are complex, and models contain assumptions, abstractions and aggregations that may result in errors (Higgins et al., 2001). However, researchers often do not include any reference to validation when they discuss models (Thrusfield, 1986; Winston, 1994; Padilla et al., 1996; Barlow, 1997; Barlow and Kean, 1998; Ward et al., 2000) and of those that do mention validation a detailed discussion of the methods is not included (Jorgensen, 1994; Smith et al., 2001).

In the validation of real systems three types of validity may be determined: replicative, predictive and structural validity. A model is; replicatively valid if it matches data already collected from the real system, predictively valid if it can match data before it is obtained from the real system and structurally valid if it not only reproduces behaviour of the real system but also reflects the way the real system truly operates (Gass, 1983).

There are four categories of validation techniques (Mayer and Butler, 1993):

1) "*Subjective assessment*" which involves the evaluation of the model by experts on the real system. One test that is used is the Turing test, where the model output and real data are given to experts who are asked to distinguish between them (Van Horn, 1971; Anderson, 1974; Sargent, 1984; Mayer and Butler, 1993; Rykiel, 1996). This method is prone to the personal bias of those evaluating the model and therefore should be used in conjunction with other more objective measures.
2) "*Visual techniques*" are typically graphical plots of both simulated and observed data. Most commonly they are time series plots. There are problems with this type of plot such as false agreement with the observed values. Therefore a preferable

alternative is a plot of the observed (y) versus predicted (y) with the line y = y marked.

3) "*Deviance measures*" are applicable when data can be paired (observed and simulated) according to time, location or treatment. Deviance is the measure of the difference between the simulated and observed values. Two commonly used measures are mean absolute error (MAE) and the mean absolute percent error (MA%E).
4) "*Statistical tests*". The application of statistical tests depends on the type of data available. Tests range from t-tests to non-parametric methods. Stochastic models introduce statistical problems for validation, therefore the mean of the generated population is usually used.

A model may also be validated through studying the models emergent properties. Emergent properties are variables that were not written into the model but emerged as a result of the combinations of other variables (Pfeiffer, 1994). An example of an emergent property in a model is the number of juvenile males in a population. This value is produced by combining the ratio of males to females and also the ratio of juveniles to adults in the model. Therefore the proportion of juvenile males in the model output can be compared to the number in a data set of the population.

The basis of validation is to obtain agreement between the output of the model and the independent data. Rykiel (1996) writes, "criteria for validation must be defined in the context of the model's purpose". It has been suggested that ideally model data and field data should be statistically independent for validation {#2460}. A statistically independent field data set has variables represented in the model but from a different population or time period. Statistically independent data are required as it may be possible to "force" a wrong model to behave in the desired way through selection of parameters that fit well with the data (Jorgensen, 1986).

In regards to a spatial simulation models, Higgins et al (2001) write, "these models are seldom validated". McCarthy (2000) writes, "data are usually scarce and any available data are used for setting parameters rather than for validation." Therefore alternative methods are used to produce a data set for validation. Anderson (1974) writes that there are four possibilities for data sets that may be used in the validation of agricultural models: "(a) historical data already employed in system analysis and synthesis, (b) historical data specifically not used earlier, (c) historical data that have evolved since earlier stages have been completed, and (d) data specifically collected for validation purposes by new system experimentation". He comments that often validation is confined to comparison of model output with the data used to formulate the model that is highly undesirable.

Where data sets are small or medium in size the data can be divided with one portion used to estimate parameters and the remaining portion to validate the model (Power, 1993). The two sections of the data may be split by time or for large data sets by random selection. It should be noted that in some circumstances validation cannot occur due to a small data set and no additional available data.

Models of tuberculosis

Models of the dynamics of bovine tuberculosis in the field of veterinary epidemiology have been used to investigate areas ranging from the spread of disease in populations to the effectiveness of control policies. Models have been developed on both badgers (*Meles meles*) in the United Kingdom (White E G, 1984; White and Harris, 1995a; White and Harris, 1995b) and Ireland (Martin, 1997), and Brushtail possums (*Trichosurus vulpecula*) in New Zealand. White and Harris (1995a; 1995b) produced models that focussed on the dynamics of tuberculosis and the assessment of control strategies in badgers.

Models of tuberculosis in New Zealand possum populations were created by Kalmakoff (1997), Pfeiffer (1994), Roberts (1992; 1996) and Barlow (1991b; 1996; 1997; 2000). The models contained different assumptions and were created for different purposes. Roberts (1992) examined the feasibility of the elimination of bovine tuberculosis by assessing the results of vaccination, culling and sterilisation. Roberts (1996) also assessed the feasibility of eradicating tuberculosis from possum populations. The models created by Barlow initially were used to study the epidemiology of tuberculosis in possum populations (Barlow, 1991b) and then were used to study the effects of various control policies such as poisoning, cull, sterilisation and vaccination (Barlow, 1991a). Barlow (1993) then used a mixed deterministic – stochastic model to describe the spread of tuberculosis in possum populations in order to assess the use of buffer zones around endemic areas. The effect of a hypothesised immunocontraceptive was investigated (Barlow et al., 1997) which was followed by an investigation of the effect of changes to tuberculosis testing policies (Barlow et al., 1998). Finally, Barlow developed a model that included heterogeneous mixing and non-linear disease transmission (2000). Pfeiffer (1994) produced a spatial stochastic simulation model (PossPOP), which included spatial heterogeneity of possum distribution and was used to investigate infection dynamics of tuberculosis and the effect of control strategies, such as culling, vaccination and sterilisation.

PossPOP

The following is a summary of PossPOP, a spatial simulation model developed by Pfeiffer (1994). It gives an overview of the model, how it operates and the assumptions in the model.

Description of PossPOP

PossPOP is a discrete stochastic simulation model designed to model bovine tuberculosis in a wild Brushtail possum (*Trichosurus vulpecula*) population in New Zealand. PossPOP is described as “a geographical model representing the ecology and infection dynamics of wild possum populations” (McKenzie, 1999). The model was developed to produce an understanding of the epidemiological processes involved in the behaviour of bovine tuberculosis in possums in the field and to formulate effective policies to control the disease in possums.

PossPOP models at the individual possum level. Each possum is represented as an object with the following attributes: birth date, sex, date of sexual maturity, pregnancy status, resident or immigrant status, memory of den sites used, date of tuberculosis infection and date of onset of clinical tuberculosis. Each day certain characteristics of each possum in the model can change according to the probability of events occurring. Many of the events in the model are subjected to random effects, generated through the use of random variables and specific probability distributions. Epidemiological studies were used to produce numerical estimates to describe these distributions. However in some cases biologically reasonable “guesstimates” were used (Pfeiffer, 1994).

Figure 9 shows the model interface that contains four tabs that allow the user to alter parameters in the simulation. The “general simulation” tab allows the user to set the length of simulation and the weather pattern. The “control strategies editing” tab allows the implementation of control strategies, which act on the population at particular intervals that are set by the user. Finally the “edit site and model parameters” tab allows the user to change variables such as dens per hectare, probability of survival for particular groups and the proportion of fertile females per month (Pfeiffer, 1994).

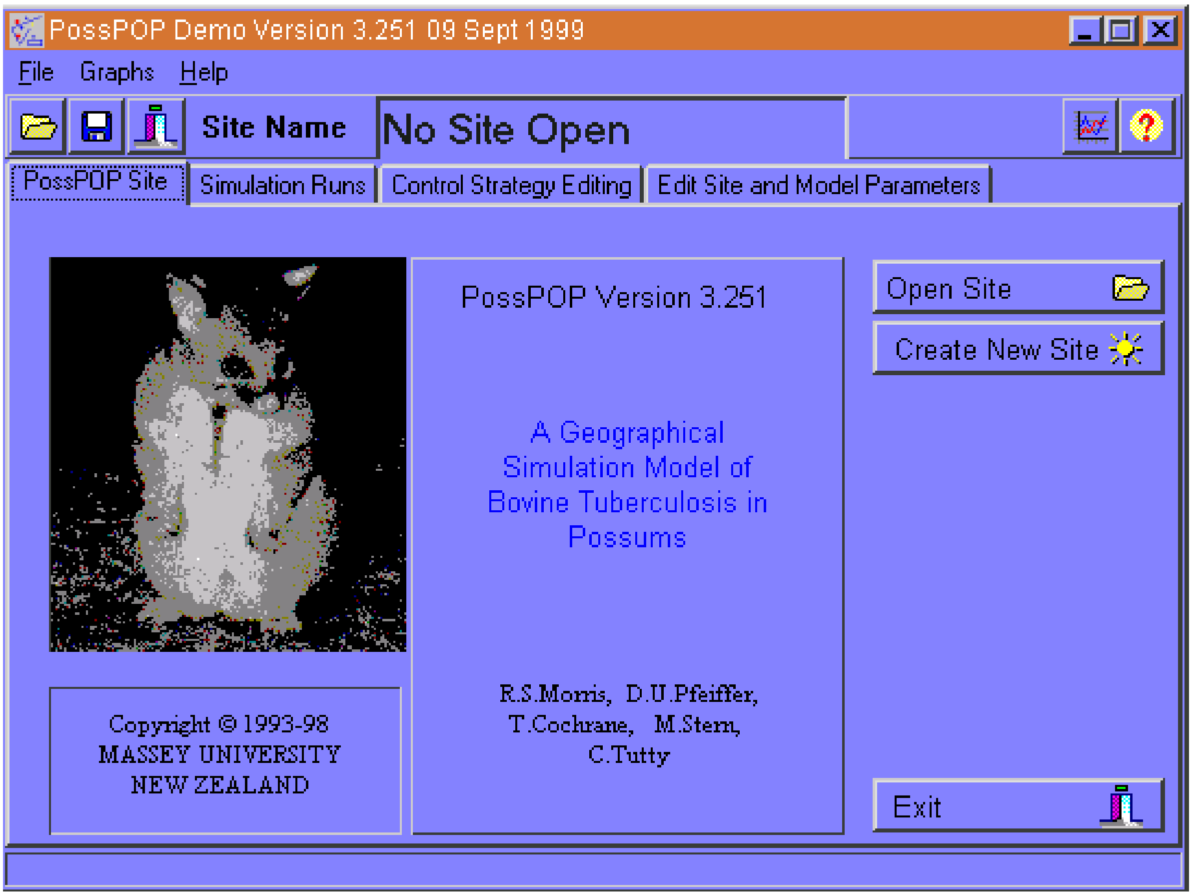

Figure 9. Illustration of the PossPOP program interface

Temporal and spatial scales

PossPOP contains a clock mechanism for synchronisation of the occurrence of events in the simulation run. The model uses a discrete-time approach with incremented intervals of one day (Pfeiffer, 1994).

PossPOP incorporates spatial heterogeneous mixing effects not often represented in epidemiological models. Heterogeneous mixing refers to the way in which individuals interact or move around the "area" of the model at the same rate due to variations in population density, vegetation and terrain. Heterogeneity is represented in the model by a spatial coordinate system on which the population can interact and disperse. The spatial behaviour of the model was represented by a map of potential den site locations (Pfeiffer, 1994).

Structure of PossPOP

In order to develop the parameters for the model the epidemiology of bovine tuberculosis needed to be understood. A review of the scientific literature and the results of a cross-sectional and a longitudinal study of a wild population of Brushtail possums in the West coast area of the North Island of New Zealand were conducted (Pfeiffer, 1994).

The model is divided into modules that represent distinct biological processes: den site selection, reproduction, transmission of infection, survival, ageing and immigration. Each module contains aspects of possum ecology that is important in regards to *Mycobacterium bovis* infection. In the model each possum is 'moved' daily through each module if the possums is classified as 'alive' (Pfeiffer, 1994).

PossPOP contains a "Run-in" period, a preliminary run that may vary in length between x and y days/years, which allows the establishment of a population and the disease levels. PossPOP was designed so that an analysis run cannot proceed until the "run-in" has been conducted. The population at the end of the run-in is then used as the start point for subsequent analysis runs (Cochrane, 1998).

Den site selection

At the beginning of a simulation, the available den sites are randomly allocated to each possum. An assumption is made that no den sharing occurs and therefore there is one possum per den. When a possum locates an available den it has a probability of accepting the den. If it rejects the den then it continues to search until it finds a suitable empty den or exceeds the "maximum den search distance". A count of the number of times an individual does not find a suitable den is kept. PossPOP contains a probability that a possum that does not find a den for a number of days will 'leap' to a new area (inside or outside the simulated population) or will die (Pfeiffer, 1994).

Reproduction

Sexually mature females search for a mature male denning in the proximity. Mating is based on direct contact between a mature male and female. With each encounter there is a probability of a successful mating. The female continues to search for a male until she becomes pregnant or reaches the "maximum mating search distance" (Pfeiffer, 1994).

Infection with Mycobacterium bovis

Possums are classified as being in one of three tuberculosis categories: susceptible (not infected), sub-clinically infected and clinically infected. The transition of sub-clinical to clinical infection is based on a probability that depends on seasonal environmental conditions. It is assumed that there is no reversion from sub-clinical to susceptible status. There are four mechanisms of transmission of infection from clinical to susceptible animals: social interaction due to proximity of den sites, contamination of den sites, courting or mating behaviour and pseudo-vertical transmission from mother to joey. It is assumed that there are ten contacts per possum per month through mating and spatial proximity. Three contacts per month are through temporal proximity that occurs through the use of contaminated den sites (Pfeiffer, 1994).

Survival of possums

The survival module represents both mortality and emigration or dispersal. There are four mechanisms of possum survival. Possums when dependent on their mothers are exposed to risk that varies with age (months) until independence. If a mother dies before the joey has reached independence the joey will also die. The remaining three mechanisms affect independent animals. Susceptible and sub-clinically infected animals are subjected to mortality that is dependent on age, sex and month of the year. Clinically infected animals have a separate mortality that varies by age and month of the year. The final mechanism is density-dependent mortality controlled by the proportion of days a possum is without a den. Possums without a den are exposed to more environmental stresses. It is assumed that the period that a possum does not have a den reflects density-dependent ecological pressures for possums (Pfeiffer, 1994).

Ageing Mechanisms

Every possum in PossPOP has a birth date and therefore will age during a simulation. There are three stages of physiological development: birth to independent, independence to sexual maturity and sexual maturity to death. It is assumed that the age of possums at each step is normally distributed. The age of a possum at independence and sexual maturity are sampled from a normal distribution. At independence a female possum copies its mothers den memory (Pfeiffer, 1994).

Immigration

In the model for each month and for each sex there is an average number of immigrants entering the population. Immigration is processed daily so the monthly mean number of immigrants is divided by the number of days in the month. Each sex class is sampled separately from Poisson distributions with the expected mean number of immigrants per day. Immigrants are assumed to be born in March of the previous year and therefore are assigned that as their date of birth. An immigration status remains until a possum finds a den, if no den is found within a given number of days the immigrant is removed from the population (Pfeiffer, 1994).

Creation and editing of population control strategies

A population control operation can be modelled in PossPOP. A population control operation modifies all or part of the population at a specified time and a specified interval. Control strategies can be based on culling, vaccination, sterilisation, or combinations of any of these three. The control may be applied once on the control “start date” and then may be applied again after an interval(s) of days, weeks, months or years. The percentage of the population to be affected may be specified, for example, a 95% population cull may be desired 3 years into the simulation with another cull 3 years later. The area to be controlled may be specified, the entire modelled area or smaller areas may be selected (Cochrane, 1998).

Cyclical effects

To introduce annual cyclical effects into the model a parameter setting of three different year types based on weather conditions in good, average and bad years are used in the model. Classifications of year types were based on the monthly averages of rainfall, temperature and temperature fluctuations in the winter months. The probability of survival and transition of sub-clinical to clinical were determined for each year type. In bad years the probability of survival is reduced in comparison to good and average years, for example, the cumulative annual survival in a good year is set at 0.6 while in a bad year it is 0.30 (Pfeiffer, 1994).

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CHAPTER 2

ATTITUDES OF NEW ZEALAND FARMERS TO BOVINE TUBERCULOSIS AND THE IMPLICATIONS FOR CONTROL STRATEGIES [?]

[?] Submitted to Animal Health Board as the final report for project R-20452B 07/12/00

Introduction

The current TB eradication scheme has been successful in reducing the incidence of TB in cattle and deer in recent years, however it is having less success in preventing the expansion of TB vector risk areas. For the scheme to maintain its current rate of progress new initiatives need to be developed and the most effective methods of promoting the scheme determined. Identification of variations in farmer attitudes between districts, enterprise types and TB status will help the current program to be more effective.

Methods

Survey

A questionnaire was developed that contained a series of questions designed to explore farmers' attitudes towards various aspects of the current TB eradication scheme (Appendix 1). There were 34 questions on six pages with a cover letter attached to explain why the survey was being conducted. Questions 1 to 4 collected demographic information on farm size, number of employees and number of stock. Questions 5 to 8 ascertained TB status and TB history. Farm management practices were elucidated from questions 9 to 19. Respondents' attitudes towards various issues were determined from questions 20 to 31. Questions 20 to 23 were asked only of farmers with infected herds. The final questions, 32 to 34, covered demographic details of the farmer.

Questionnaires were sent to a total of 404 farmers located in the Rangitikei, Tararua, Wairarapa, Tasman (Nelson area) and Tasman (Motueka area) districts of New Zealand (Figure 10). The districts were chosen to represent a cross section of geographic areas in the lower North Island and upper South Island with various TB infection histories.

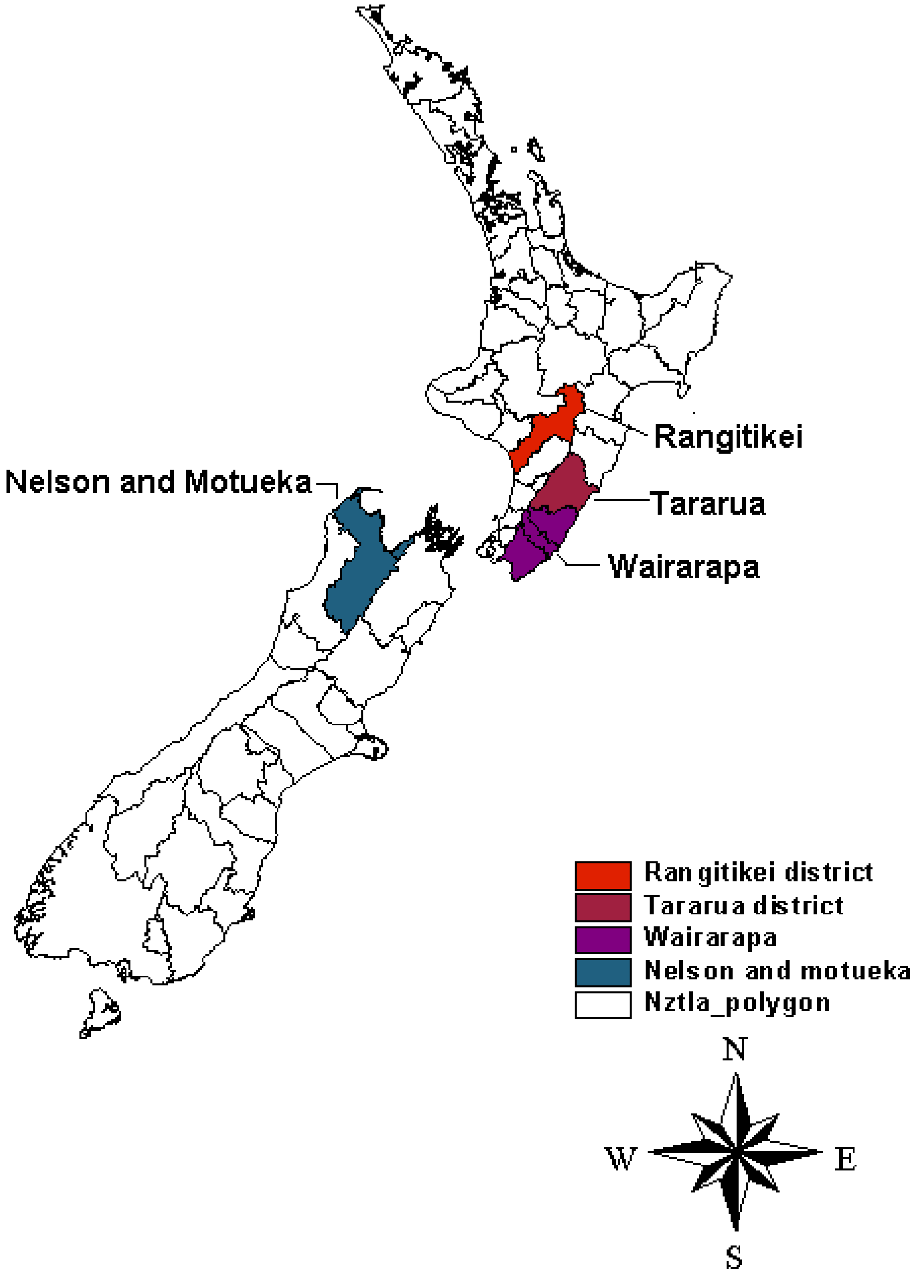


Figure 10. Districts sampled for the postal questionnaire

The method of selecting farms varied between districts. In Rangitikei and Tararua all herds classified as infected within the last 3 years were selected. The same numbers of uninfected farms were selected in each area by matching on area classification and enterprise type. In Motueka all herds classified as infected at the time were selected.

Uninfected herds were selected on the basis of their proximity to an infected property; neighbours were the closest property to an infected farm and non-neighbours were 7-9km away. The Nelson area of the Tasman district contained no infected herds. Uninfected herds were selected through a simple random sample. Infected farms in Wairarapa were selected to be representative of those in the region, uninfected farms were selected by matching on enterprise type. Carola Sauter-Louis conducted the survey of Wairarapa farmers in 1998 – 1999 as part of another study (Sauter-Louis, 2001).

The participation of selected farmers was requested by telephone with the exception of the majority of farmers in Wairarapa who were not contacted prior to receiving the questionnaire. A questionnaire was sent to participants accompanied by a reply paid envelope. A reminder letter was mailed to non-respondents with an additional copy of the questionnaire approximately three and six weeks after the initial questionnaire was sent.

Where closed questions were unanswered, overlooked or handwriting was illegible the respondent was contacted by telephone to determine their response.

Analysis

Descriptive statistics were used to identify trends and patterns in the data. Summary statistics such as the counts and percentages of respondents were calculated. Data was stratified to identify variations based on farm characteristics such as region, enterprise type, area classification and TB status.

Open questions were analysed by assigning each response to one or more of four or five themes developed for each question. Where the respondent mentioned a theme it was included irrespective of the tone of the comment. The themes were developed to assist analysis and reduce variations in the responses. Where responses were nonsensical or unrelated to the question they were classified as “Other”. There was also a “No response” category for those that did not respond. This categorical data was analysed to identify trends and patterns.

Due to the small number of deer enterprises surveyed, all deer classifications were analysed as one group. Deer includes deer breeders (B), miscellaneous deer herds (M) and deer (Deer) as classified in Agribase.

Explanation of terms

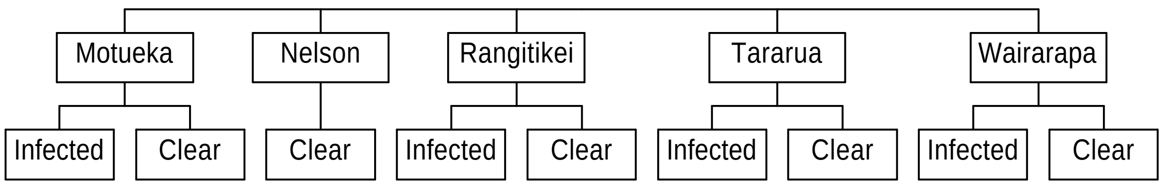
Area classifications: vector risk (RI), fringe (FR) and surveillance (SU).

Enterprise types: beef breeders (BB), beef dry stock (BD), dairy herds (DH), deer herds (Deer) and miscellaneous cattle herds (MS).

TB status: classified as infected at any time in the last 5 years (Infected), not classified as infected in the last 5 years (Clear / TB free).

Results

A total of 404 (91%) of the 443 farmers who were initially selected agreed to participate in the study. A further 13 farmers could not be contacted and 26 (6%) declined to participate following telephone contact. Of those farmers that agreed to participate, 335 (83%) returned their completed questionnaire while 69 did not respond. A summary of the number of respondents by district and TB status is presented in Table 7 and Figure 11.



Selected	9	69	75	31	31	44	44	70	70
Agreed	4	53	67	23	37	34	46	70*	70*
Responded	4	50	59	19	23	34	35	69	42

* All Wairarapa farmers were assumed to have agreed to participate in the study as only 35 of the 140 farmers were contacted by telephone prior to receiving the questionnaire.

Figure 11. Summary of the numbers of farmers, who were selected, agreed to participate and responded to the postal survey in each TB status within each district

Table 7. Number of respondents by TB status, region and enterprise type

Herd type	Beef breeder (BB)		Beef dry stock (BD)		Dairy herds (DH)		All deer herds (Deer)		Misc. cattle (MS)	Not specified
TB status	Non TB	TB	Non TB	TB	Non TB	TB	Non TB	TB	Non TB	Non TB
Motueka	14	4	16	3	0	2	3	3	7	2
Nelson	11	0	18	0	2	0	8	0	15	5
Rangitikei	14	11	7	5	2	3	0	0	0	0
Tararua	25	29	4	3	5	3	0	0	0	0
Wairarapa	14	34	3	13	23	22	1	0	0	1
Total	78	78	48	24	32	30	12	3	22	8

Demographic information (Questions 1-8)

Region

Farms were selected for the study based on the region in which they were located, their enterprise type and their TB status.

Figure 12 contains the percentages of returned questionnaires from clear and infected herd owners in each region. Infected farmers in Motueka, Tararua and Wairarapa had a high percentage of returned questionnaires, which is indicative of the level of interest in TB. Clear farmers were not as dedicated in returning their questionnaires. It should be noted that there were no infected herds in Nelson.

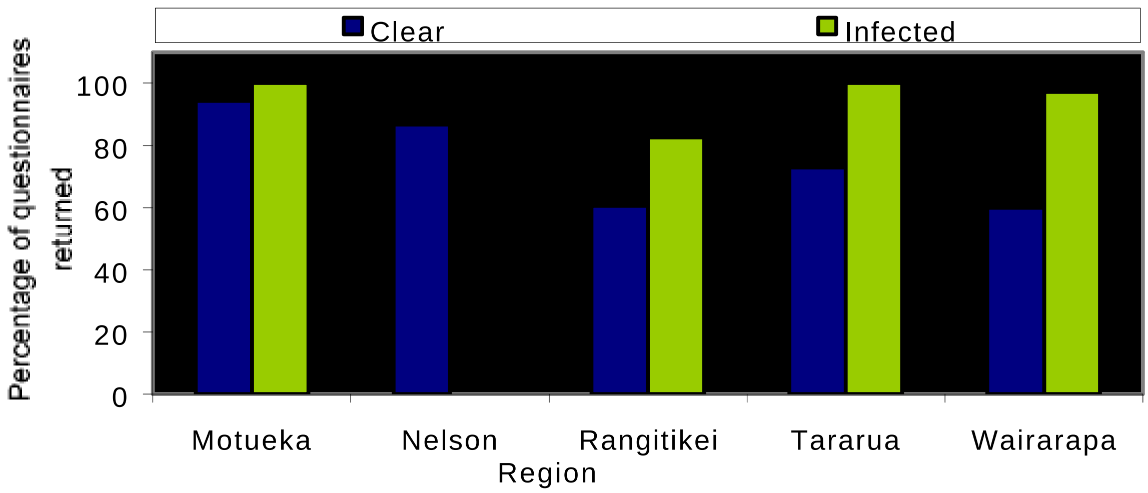


Figure 12. Percentage of returned questionnaires for each district by TB status

Enterprise type

Figure 13 shows that the numbers of infected and clear "BD" herds, "DH" herds and "Deer" were similar. However there was a greater percentage of infected than clear BB herds amongst respondents.

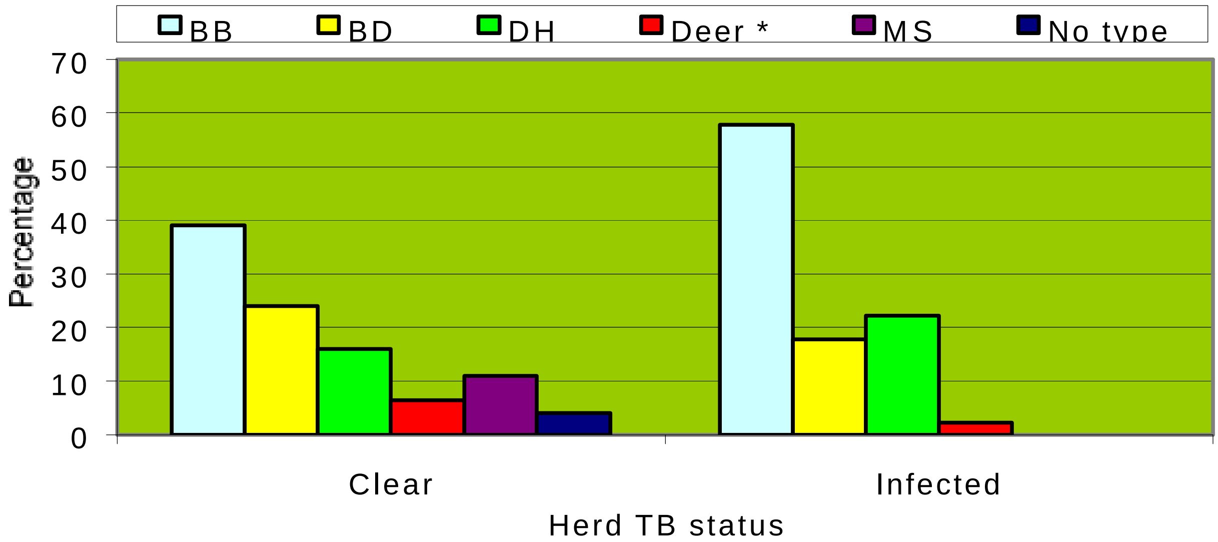


Figure 13. Percentage of each enterprise type stratified by TB status.

To determine the predominant farm types in each area, the percentage of each enterprise within a region was calculated. Table 8 shows that farms in the North Island regions (Tararua, Rangitikei and Wairarapa) were predominantly beef breeders. The second most common enterprise types varied, with dairy herds common in Wairarapa and beef dry herds in Rangitikei. The South Island had a greater spread of enterprise types. Motueka had approximately equal numbers of BB and BD. Nelson had a much lower percentage of BB (17%) than all other regions and a much higher percentage of MS herds (36%). There were many more deer herds in the South Island (n=14) than in the North (n=1).

Table 8. Percentages of enterprise types within each region.

	Enterprise types					
Regional code	BB	BD	DH	Deer	Other	Total
Motueka	33%	35%	4%	9%	19%	100%
Nelson	17%	31%	3%	14%	36%	100%
Rangitikei	57%	29%	12%	0%	2%	100%
Tararua	75%	10%	12%	0%	3%	100%
Wairarapa	43%	14%	41%	1%	1%	100%

Farm size

Respondents were asked to give the size of the home property and any other owned or leased land. The total effective farm size represented the sum of the effective areas of home farm, other owned land (less than 100km from home property) and leased land (less than 100km from home property).

Table 9 shows that farms with infected herds (TB positive at any time in the last 5 years) have a much larger median total effective farm area than farms with clear herds. Infected herds also have a greater median number of full-time workers then clear herds.

Table 9. Median and range of "total effective farm size" and number of workers both full time and part time stratified by TB status.

Farm TB status	Total effective Farm size	Full time workers	Part time workers
Clear	93 (2 - 3200) n=207	1 (0.5 - 25) n=137	1 (1 - 42) n=106
Infected	472.5 (18 - 15160) n=126	2 (0.25 – 11) n=120	1 (1 - 30) n=34

Farmers' age

The median age group of respondents was 40 – 50 years. This was also the most highly represented group (n = 107) followed by 50 – 60 years (n = 103). The distribution has a bell curve shape with the majority of farmers in the central age groups and smaller numbers in the extremities (Figure 14).

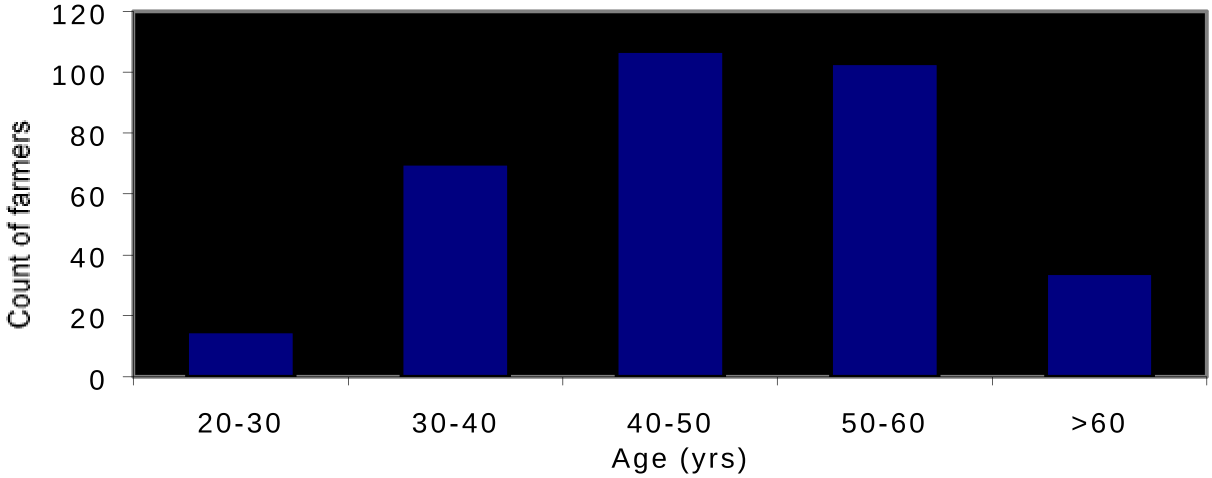


Figure 14. Frequency distribution of farmer age groups

Relationship to property

Figure 15 shows that 76% of farmers owned their own properties, 10% were managers and 5% were share-milkers. All other groups were represented by less than 5% of respondents.

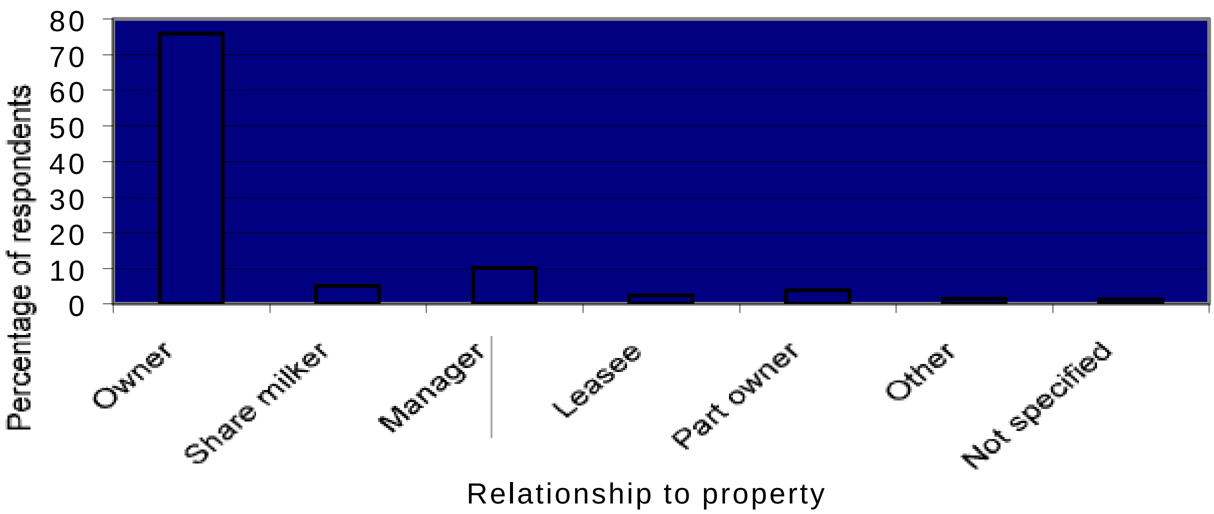


Figure 15. The distribution of respondent's relationship to the property

Demographic information shows that the group of farmers sampled was diverse and varied. This gives a broad sample upon which population attitudes can be extrapolated.

Farmer Attitudes

Factors contributing to TB infection (Item 20, farmers of infected herds only)

The question contained six possible answers including "other". Space was provided for respondents to identify what the "other" was.

Figure 16 shows that 52% of infected farmers believed that infected feral animals contributed to their TB status. The second greatest percentage (15%) of farmers believed that neighbours contributed. Bought-in stock and problems with the TB skin test were evenly represented with 12% and 10% respectively. Stock grazed on farm (2%) and off farm (3%) contributed a low percentage of the responses. The “other” category (6%) responses ranged from drought to domestic pigs.

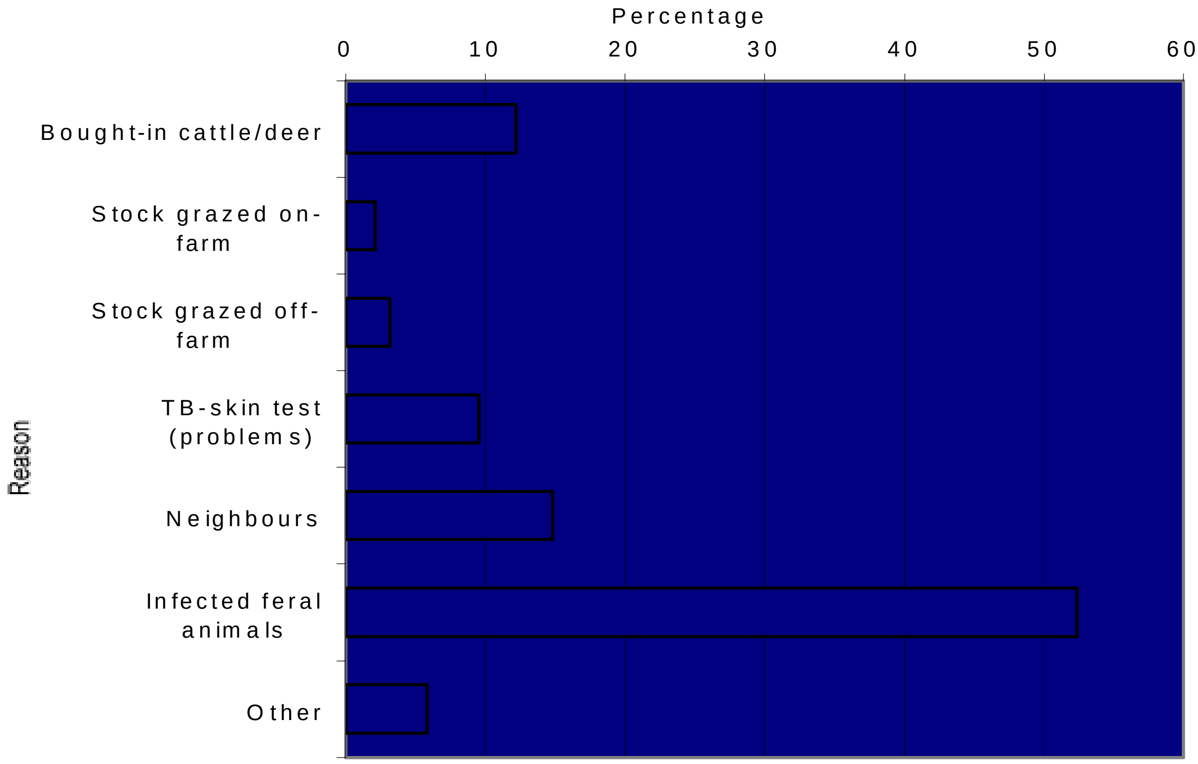


Figure 16. Distribution of reasons chosen to explain the factors contributing to TB infection of a herd

There is a strong belief that the source of infection is due to infected feral animals. This belief overlooks cattle to cattle spread of disease and the risk of introducing TB with new stock.

Importance of eradicating TB (Item 21, farmers of infected herds only)

Five options were available to represent the importance farmers place on eradicating TB from their own herd (crucial to not important at all).

81% of respondents believed that eradication of TB from their herds was crucial while 15% believed it to be important (Figure 17). Only 4% believed that eradication was moderate, minor or not important.

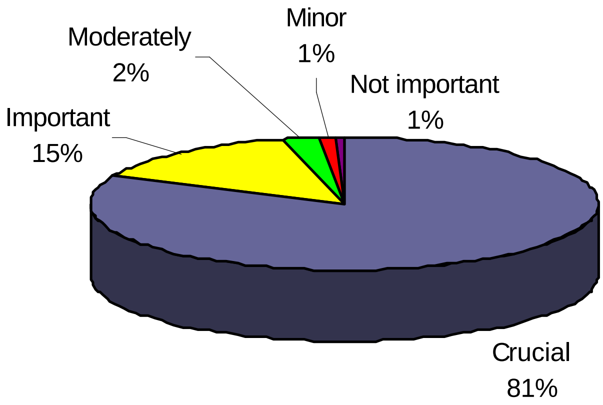


Figure 17. The importance of TB eradication to respondents with infected herds

The majority of farmers with infected herds believe that TB eradication is crucial, and therefore these farmers are supportive of the TB eradication scheme. The 2% of respondents who believed that the importance of eradicating TB from their farm was less than moderate indicates there is a small group of farmers who are not concerned about TB. It also indicates that there are some infected herds that are not being adversely affected by their TB status.

Can TB be eradicated from infected respondents' properties? (Item 22, farmers of infected herds only)

This question contained three options: "Yes", "No" and "Don't know".

Most farmers with infected stock (81%) believed that TB could be eradicated from their herd (Figure 18). Approximately equal percentages of respondents did not believe that TB could be eradicated (9%) or didn't know" (10%).

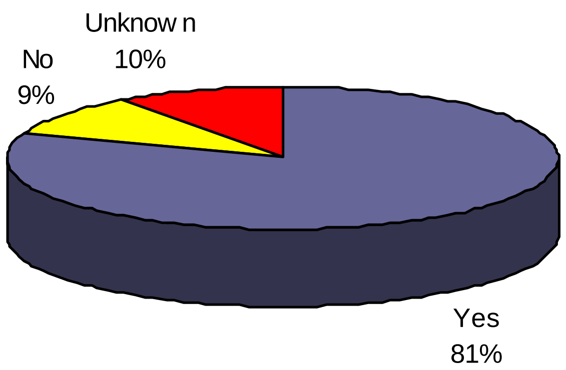


Figure 18. Distribution of responses from infected farmers on the likely success of TB eradication from their herd

Most farmers of infected herds are optimistic that TB can be eradicated from their properties. This is an encouraging result as it indicates that most farmers are motivated to become TB free.

Factors hindering TB eradication from infected herds (Item 23, farmers of infected herds only)

Space was made available for comments on why TB may not be eradicated from infected herds. Written responses were categorised into one or more of 5 themes (Table 10).

Table 10. Themes for categorising responses to factors hindering TB eradication from infected herds

Theme	Key words or phrases in the written response
Vectors	Vectors, control possums, keep numbers down and infected feral animals
Test	TB skin test, testing, inaccurate test
Program	Policy weaknesses, managing infected herds
Co-operation	Local issue, neighbours
Other	Question not answered or nonsensical response

The majority of respondents who thought TB could not be eradicated from their farm believed it was due to vectors (65%) (Figure 19). Test related issues were the next most common response (16%) and 6% believed eradication could not be achieved due to policy weaknesses.

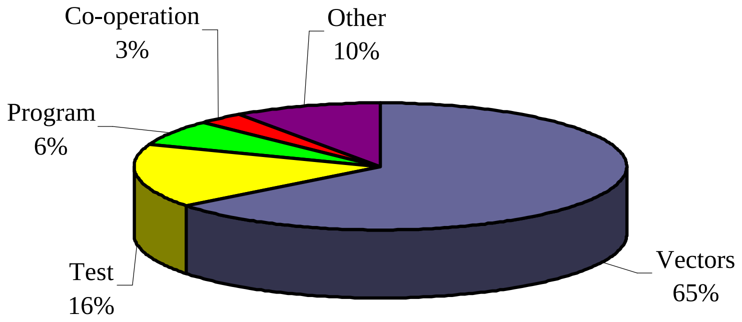


Figure 19. Factors that infected farmers believe are hindering eradication of TB from herds

Farmers who believed that TB could not be eradicated felt that feral vectors were the most important hindering factors due to the re-infection of herds. The distribution of results show that farmers give low weight to other issues such as sensible cattle purchases and controls on movement of stock.

What institutions or groups should be responsible for TB eradication? (Item 24)

Respondents were asked to choose from a list of 10 TB control entities, plus an "other" option. Farmers were also asked to rank their choice with 1 being the highest and decreasing consecutively down to the lowest ranking group. Ranking of responses was summarised using the reverse order to that given by farmers with 10 being the highest and 1 the lowest.

"All farmers", "government", "AgriQuality / AHB" and "MAF" were ranked by respondents as being most responsible for TB eradication (Figure 20). "Farmers with the problem", "all landowners", "regional councils", "DOC" and "others" all received a similar ranking that was just slightly lower than the former group. Regional Animal Health Committees (RAHC), veterinarians and farming action groups were the only groups that received a low ranking in terms of responsibility for TB eradication.

The greatest disparity between the percentage and rank occurred for MAF, very few respondents indicated they believed MAF was responsible however if selected it was ranked highly, 9 out of 10. It is likely that these responses came from people who do not distinguish between MAF and AgriQuality.

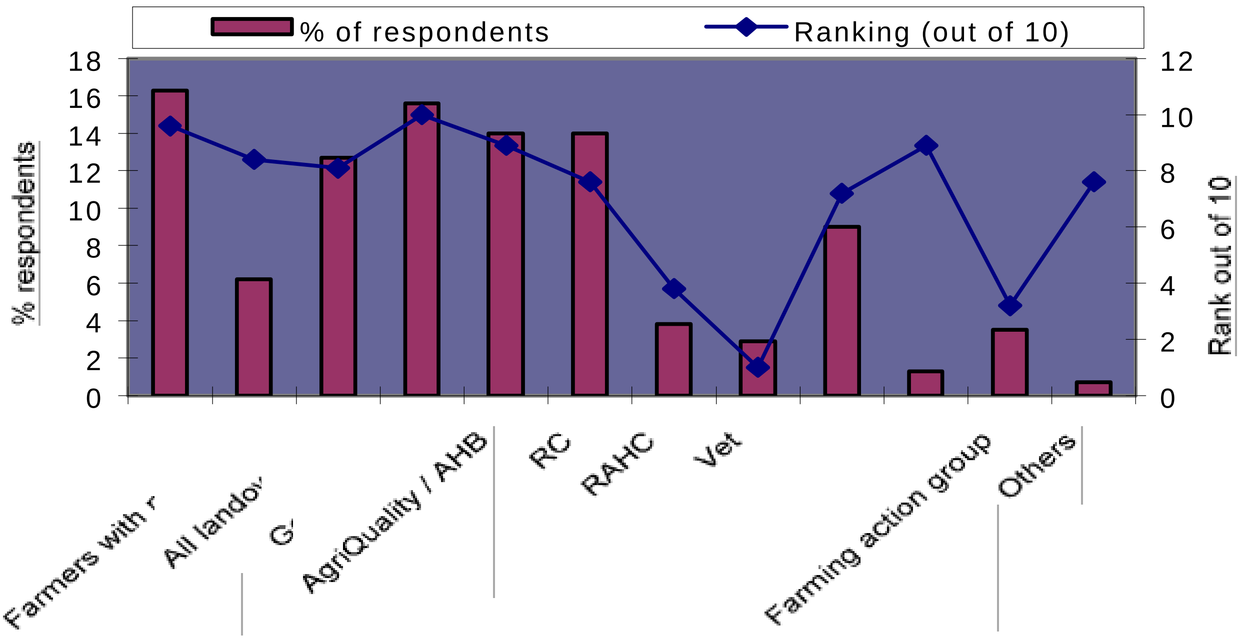


Figure 20. Groups and institutions perceived as being responsible for TB eradication and the average ranking for that group

Farmers did not identify one organisation as being solely responsible for TB eradication. The results of this question indicate that considerable confusion exists about who is in fact responsible for eradication of TB. This was associated with the large spread of organisations mentioned and the fact that no group stood out. Indications were that the Animal Health Board, which is primarily responsible for TB control, was not seen in that role, even though it was associated with AgriQuality in the questionnaire, because the two groups work closely together in their TB control roles.

If asked to carry out their own TB control, from where would farmers obtain help and what would the nature of the help be? (Item 25)

Participants were asked to select an institution that they would go to for assistance from a list of 9 possible institutions. They were also asked to describe the nature of the help they would like. Written responses were categorised into 4 themes plus “other” and “no response” as described in Table 11.

Table 11. Themes for categorising responses on forms of assistance for farmer conducted TB control measures

Theme	Keywords and phrases in response
Guidance	Information, testing results, advice / help, infection source and liasing with groups
Assistance	Physical help with testing, labour, personnel, practical help and material assistance
Vector Control	Pest control, wildlife control, poisoning, trapping and bait
Funding	Resources, money from an outside source, subsidies, free bait and incentives
Other	Responses that did not answer question or were nonsensical
No response	No response given to question

Figure 21 shows that of the farmers who gave a response, 55% indicated they would go to central government for funding, 36% to AgriQuality / AHB for advice. The regional council was seen as providing a range of services: most commonly vector control (29%), guidance (23%) and unspecified help (21%). Regional animal health committees (RAHC) were seen as providing guidance (41%). Neighbours were seen as a source for vector control help (45%). Veterinarians were seen as a source of guidance (35%).

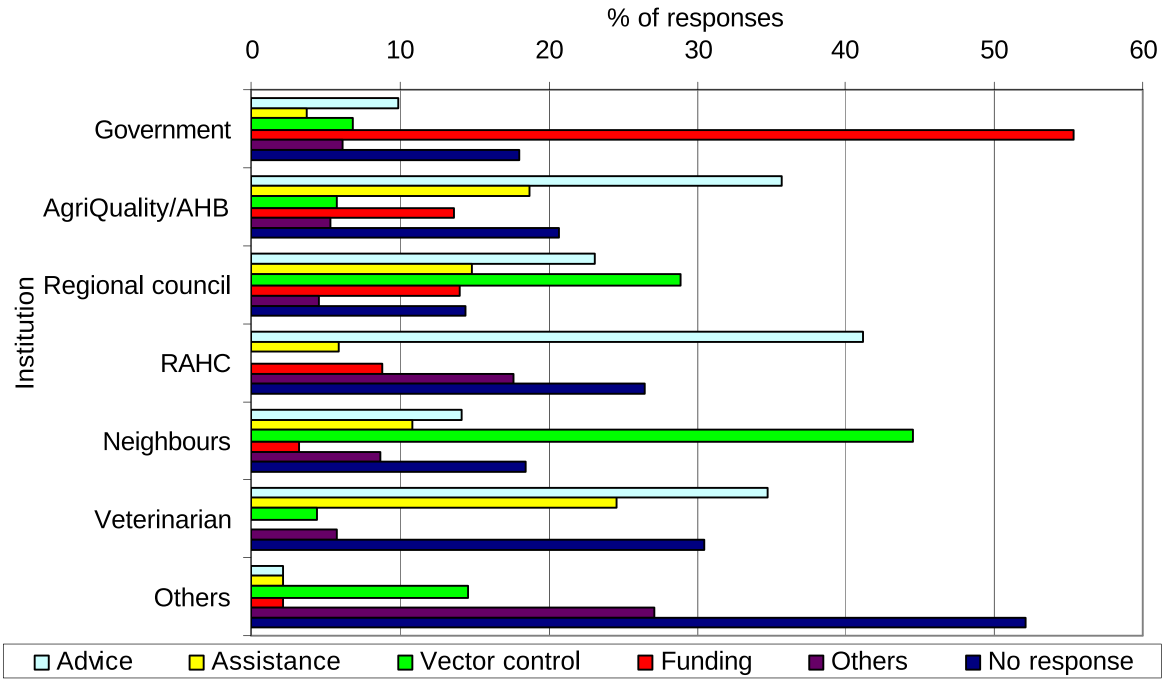


Figure 21. Types of assistance respondents would expect to receive from each institution if asked to carry out their own TB control

Respondents expected different types of help from different organisations. Most people would go to the most appropriate organisation for specific types of help, for example, AgriQuality / AHB for testing and guidance.

Should cattle movements be more strictly controlled? (Item 26a)

This question contained four possible responses: “more strict”, “same”, “less strict” and “not known”.

There was a marked difference between regions and TB status of the farmers in their attitude to movement control. The most common response from farmers with TB-free herds in the Motueka, Nelson and Wairarapa regions was “more strict” movement control (Table 12). Farmers of clear herds in the Rangitikei and Tararua districts believed movement control should remain the same. Owners with infected herds in all districts wished to maintain current controls.

Table 12. Most common response(s) to question on movement control by TB status and region

TB status	Region				
	Motueka	**Nelson**	**Rangitikei**	**Tararua**	**Wairarapa**
Clear	More strict	More strict	Same	Same	More
Infected	Same/More	-	Same	Same	Same

Attitudes toward movement control were closely linked to the occurrence of TB vectors and individual herd TB status. In surveillance areas respondents were content with the *status quo* whereas there was a divergence of opinion in other areas. In Wairarapa respondents from TB-free properties believed that movement control should be stricter. Farmers with TB-free herds were aware of their privileged status and did not want to become infected. The farmers of TB-free properties in the South Island also wanted tighter movement controls.

Written responses as to why cattle movement should or should not be more strictly controlled (Item 26b)

Participants were asked for the reasons why they chose their response to the question on movement control. The responses were categorised into one or more of 6 themes as described in Table 13.

Table 13. Themes for categorising responses on reasons for their response on strictness of cattle movement control.

Theme	Keywords and phrases from response
Containment	prevention of spread and infection, confinement of TB and eradication
Financial	money, funding, compensation or reduced slaughter weights
Vector	vectors are the problem, cause spread of TB or possum/ vector control
Test	testing cattle, accuracy of skin test or testing requirements
Co-operation	with rules and regulations, bypassing system, record keeping and honesty
Other	responses that did not answer question or were nonsensical
No response	no response given to question

Of TB free farmers that completed this question 59% of gave containment reasons for their answer to the question on movement control and 12% gave cooperation (Figure 22). The most common response for infected farmers was containment (39%) and the second most common response was financial (23%).

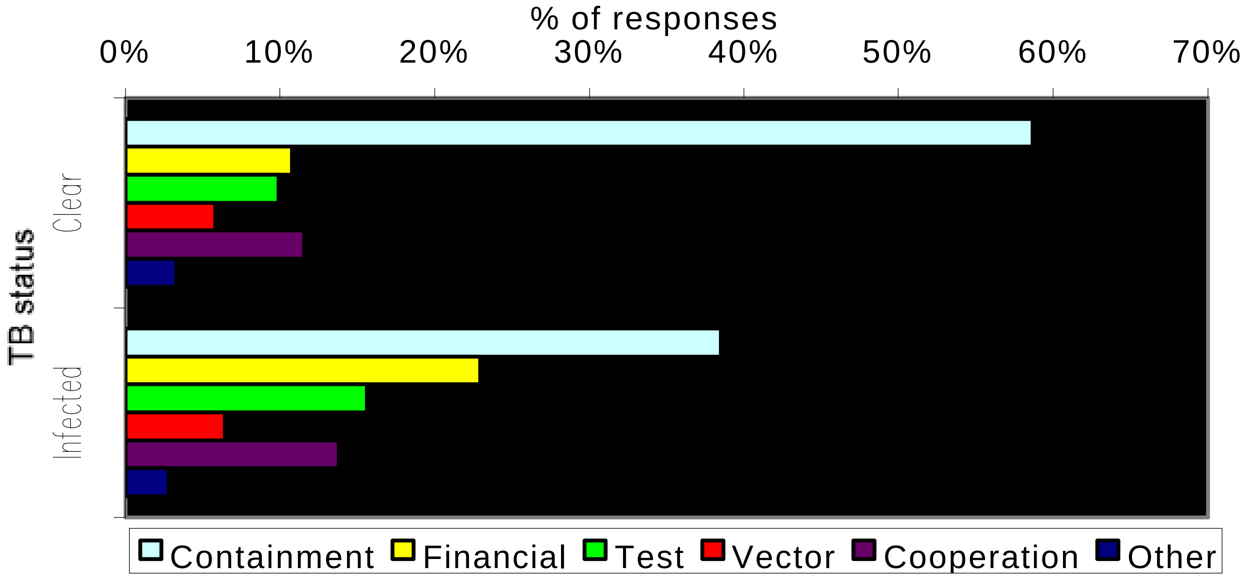


Figure 22. Percentage of themes for reasons for response on strictness of cattle movement

Clear farmers were much more concerned with preventing the spread of TB than farmers with infected herds. They were less concerned with funding and finance than infected herds and more committed to measures that will help them remain TB free.

What effect would removal of compensation have on the progress of TB eradication? (Item 27a)

Item 27a contained four possible responses: “quicker”, “slower”, “no change” and “don’t know”.

The attitude of deer farmers towards the removal of compensation was very different to that of cattle farmers. It was found that 47% of deer farmers believed the removal of compensation would hasten TB eradication (Figure 23). In contrast, only 22% - 31% of cattle farmers (beef breeders, dry stock and dairy herd) had the same belief.

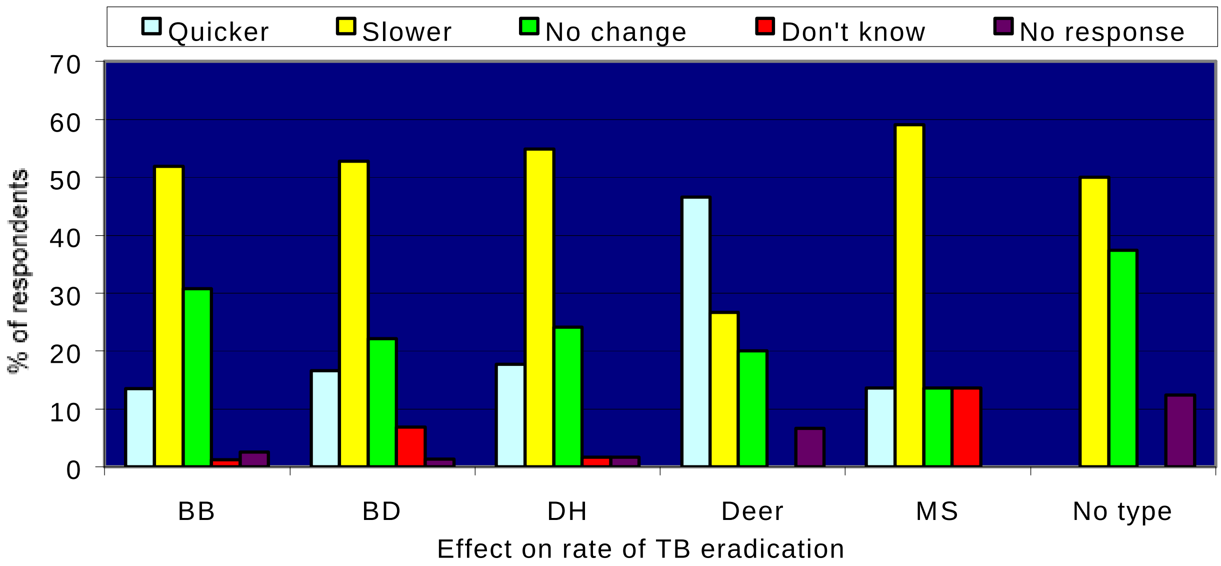


Figure 23. Percentage of responses on the effect of the removal of compensation on progress of TB eradication, by herd type.

Deer herd owners, who do not usually receive compensation, believe it is an unnecessary requirement for successful eradication. Cattle owners, who are eligible for compensation, believe it is important to maintain the financial pay-off for the removal of reactors.

Why was the response to compensation removal given? (Item 27b)

Participants were asked to explain their reasons for their choice of response to the previous item (Question 27a). Their responses were classified into one or more of six themes as described in Table 14.

Table 14. Themes for categorising responses on reasons for their response on removal of compensation.

Theme	Keywords and phrases from response
Co-operation	with rules and regulations, not testing whole herd, letting sick animals die on property or cheating the system
Financial	greater cost, out of cattle farming and decreased animal value
Effort	control / eradication of vectors, farmer attitude, motivation or incentive
Beyond control	nothing could be done about infection or compensation doesn’t affect TB
Other	responses that did not answer question or were nonsensical
No response	no response given to question

Figure 24 shows that 75% of respondents who believed eradication would be slower if compensation was removed, as farmers would no longer cooperate with testing requirements. Those respondents who believed TB eradication would be quicker most commonly (58.7%) gave "effort" as the reason, that farmers would put in more effort to remain TB-free. Financial considerations were fairly constant through all response groups.

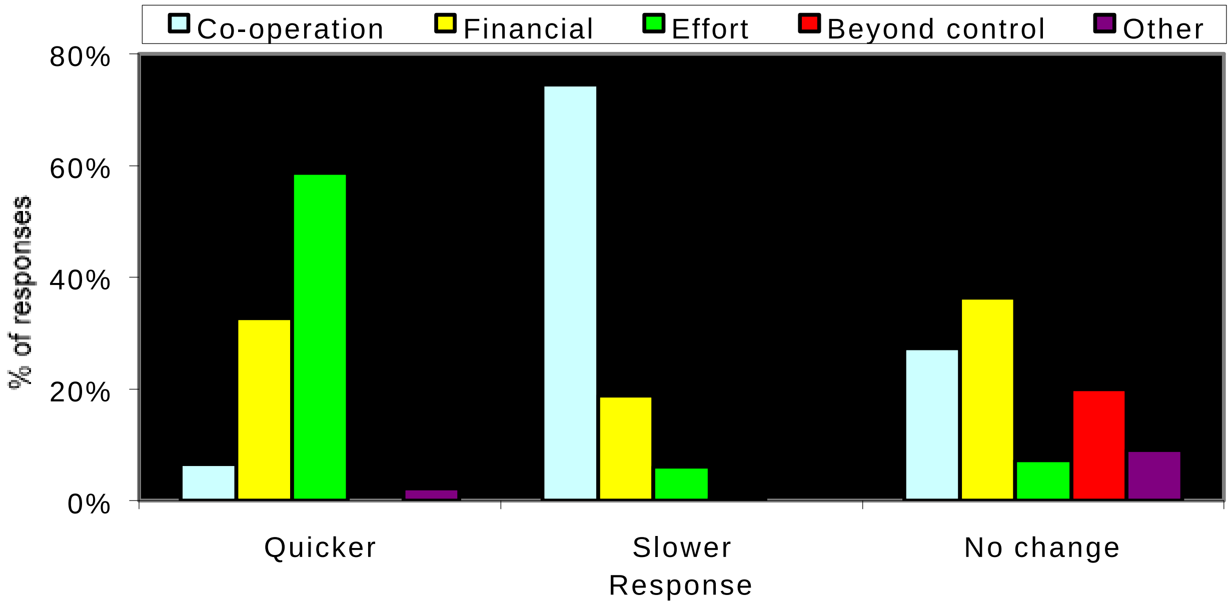


Figure 24. Frequency of themes for each response to removal of compensation

The "don't know" group was omitted from the graph for ease of interpretation. There were only 11 responses in this category and 10 of those had written responses classified as "other".

Would TB be eradicated more quickly if cattle farmers paid for TB testing directly? (Item 28a)

There were 3 possible responses to this question: "Yes", "No" and "Don't know".

Figure 25 shows that 67% of all respondents believed that direct payment of TB testing costs would not increase the rate of TB eradication. A surprising percentage of respondents that did not know what the effect would be (21%).

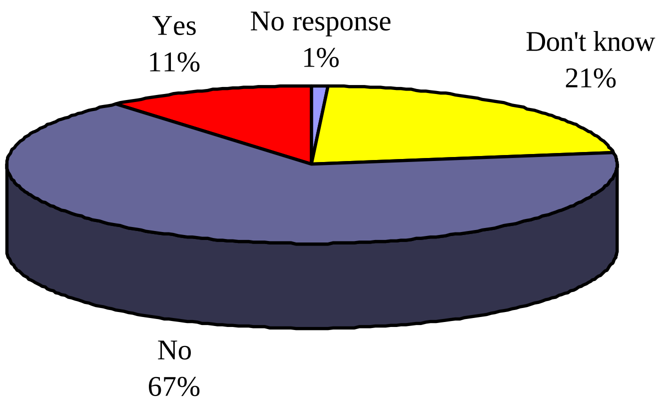


Figure 25. Responses as to whether TB would be eradicated faster if farmers paid their own TB testing costs

When the data was divided into enterprise types, “no” was the predominant response for all cattle enterprise types (Figure 26). The majority of deer farmers believed TB would be eradicated faster (54%).

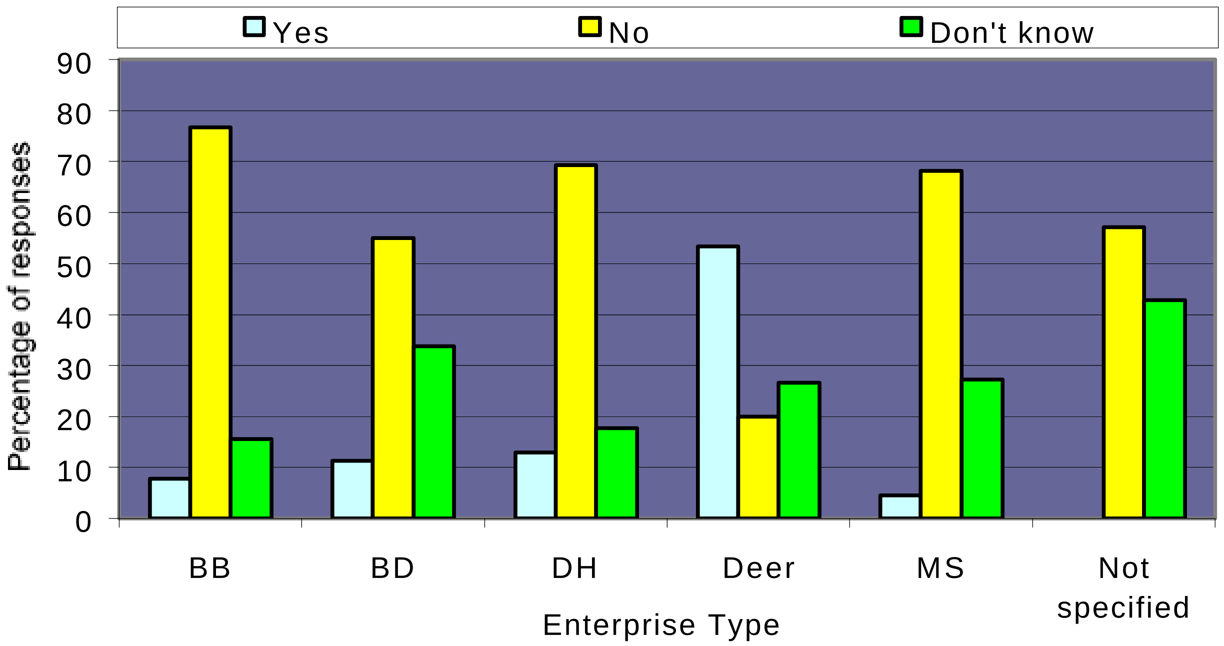


Figure 26. Percentage of responses as to whether TB would be eradicated more quickly if cattle farmers paid for TB testing directly grouped by enterprise type

There is a proportion of farmers that do not know what would be involved if they were to pay for TB testing themselves. This indicates that some farmers are not aware of the benefits they receive from subsidised TB testing.

The strong difference between deer and cattle farmers is most likely explained by the fact that deer farmers have always paid for TB testing directly. Cattle farmers however have paid indirectly by means of the levy on slaughtered cattle.

Why was the response to the direct payment of TB testing given? (Item 28b)

Reasons for the previous response to direct payment of TB testing costs were requested. Space was made available for a written response. Responses were grouped into one of six themes, shown in Table 15.

Table 15. Themes for categorising responses on direct payment of cattle TB testing

Theme	Keywords and phrases from response
Financial	cost, returns for cattle or out of cattle farming
Co-operation	less testing, avoid testing or not test whole herd
Motivation	make farmers think or do more work themselves
Beyond control	nothing could be done about infection or compensation doesn't affect TB
Other	responses that did not answer question or were nonsensical
No response	no response given to question

57% of those respondents who believed direct payment of TB testing costs would increase the TB eradication rate believed it would be due to "motivation" reasons (Figure 27). 42% of respondents who believed that TB would be eradicated more slowly gave "co-operation" reasons. Financial considerations were high in all groups and this was the primary consideration for farmers who did not know the effect of direct payment for TB testing (50%).

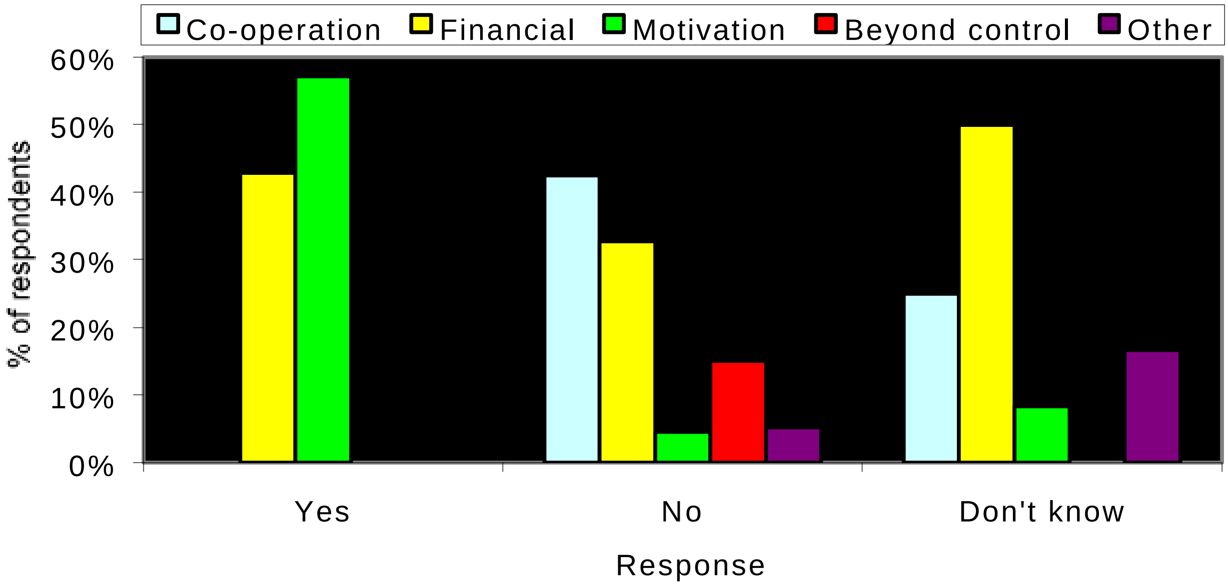


Figure 27. Percentage of written response themes stratified by their initial response on the effect of direct payment for TB testing

Farmers who believed TB would be eradicated more quickly, if TB testing subsidies were removed, believed it would be due to farmers' motivation to become TB free. Financial considerations were also high. Those farmers who did not believe removing subsidies would increase the rate of TB eradication believed that it would result in farmers evading the TB control system for financial reasons.

What individual farm efforts could play an important role in TB control? (Item 29)

This was an open question with space left for a response to be written. Responses were grouped into one of six themes as described in Table 16.

Table 16 . Themes for categorising responses on the effort individual farmers could play in TB control

Theme	Keywords and phrases from response
Vector control	possum control, trapping, spotlighting, poison or bounty
Responsible	farming practices, stock purchasing, testing, record keeping or clearing scrub / gorse
Co-operation	compliance with rules / regulations or co-operation with testing
Financial	cost or monetary considerations
Other	responses that did not answer question or were nonsensical
No response	no response given to question

The most common individual farm effort was increased vector control (51%) that involved farmers conducting their own control. The second most common suggestion was being responsible (27%) with farming practices i.e. buying and moving stock (Figure 28).

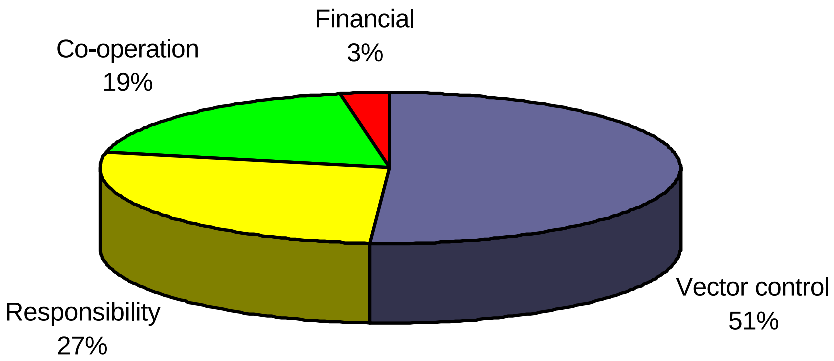


Figure 28. Distribution of responses to question on farmer efforts to eradicate TB

Farmers believe that TB exists in vectors and that they play a role in the spread of the disease. This is seen from the percentage of farmers who believe vector control is a way that individual farmers could play a role in TB eradication.

Respondents also believed that they must have responsible farm management practices such as in the buying and movement of stock. Specific responsibilities that were mentioned were presenting all stock for testing, keeping good records and clearing scrub and gorse.

How do farmers see TB being eradicated from New Zealand? (Item 30a)

This was the first part of a two-part open question; room was made available for a written response. Responses were categorised into one or more of 6 themes as described in Table 17.

Table 17. Themes for categorising responses on how farmers see TB being eradicated from New Zealand

Theme	Keywords and phrases from response
Vector control	removing possums / ferrets, poisoning or shooting
Regulation	tracking cattle, movement control, policy, penalties or vaccination
Program	technical, testing, test accuracy, education or research
Financial	more money spent
Other	responses that did not answer question or were nonsensical
No response	no response given to question

The majority of farmers that answered this question believed that TB would be eradicated through vector control (55%) and that infected vectors are the main problem interfering with national TB eradication (Figure 29). The second most popular response was regulation (17%), which included movement control and penalties for those who do not comply with regulations.

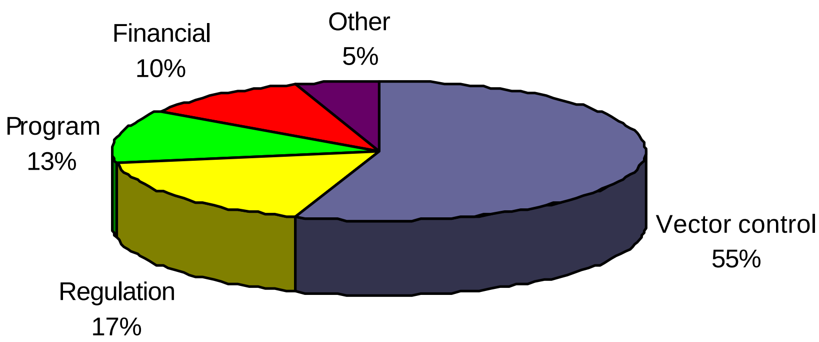


Figure 29. Methods for the national eradication of TB

What incentive do respondents believe would aid in eradicating TB? (Item 30b)

Item 30 was the second half of the two-part open question. This was also a written response question. The responses were grouped into 5 themes as described in Table 18.

Table 18. Themes for categorising responses on incentives farmers believe will aid in TB eradication

Theme	Keywords and phrases from response
Bounty	cash paid for killing possums / ferrets
Financial	benefits / penalties, money to farmers, provision of poison / ammunition
Funding	money for services or money to other organisations (not directly to farmers)
Other	responses that did not answer question or were nonsensical
No response	no response given to question

There were differences between herd types and area classifications. Farmers in fringe (FR) and risk (RI) areas favoured a bounty on vectors (34% and 40% respectively) whereas only 25% of respondents in surveillance (SU) areas believed the same (Figure 30).

There is a consistency in the percentage of respondents who believed financial incentives would aid nation-wide eradication of TB. "Financial" was ranked as the second most popular incentive in all area classifications.

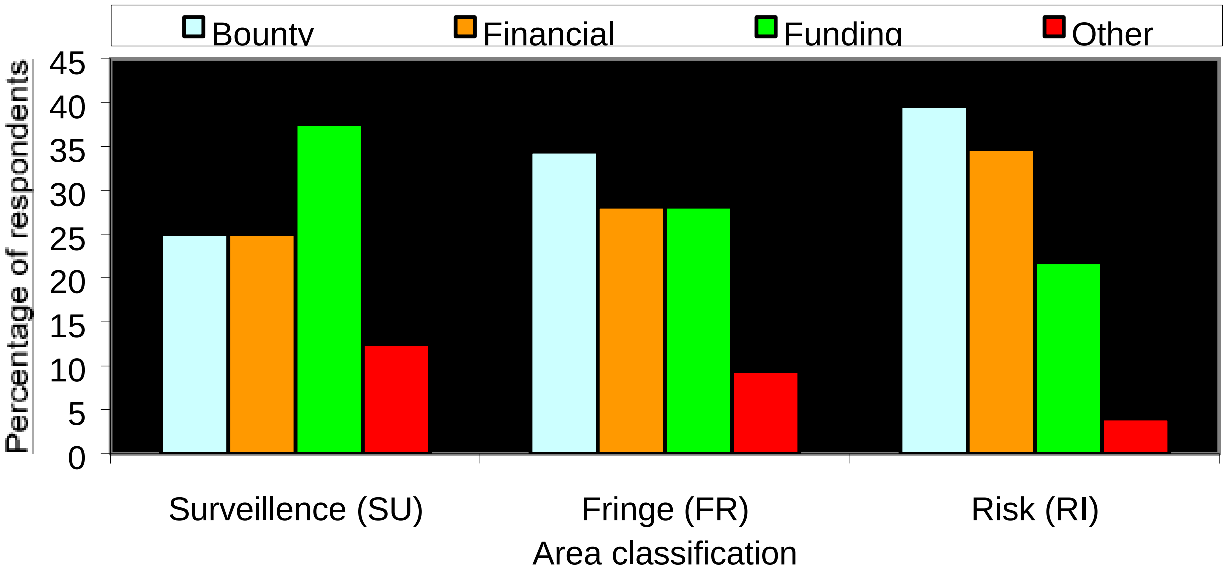


Figure 30. Response themes for incentives to aid TB eradication by area classification

There was a difference in preferred incentives for TB eradication between deer and cattle herd owners. Most deer herd (57%) owners regarded funding as a significant incentive to eradicate TB. By contrast, fewer beef breeders (25%), beef dry stock (16%) and dairy (4%) herd owners believed the same (Figure 31).

There was a consistency of the percentage of respondents who believed financial incentives were required to aid eradication. Across all enterprise types (except “MS” and “not specified”) financial incentives had the second highest percentage of responses.

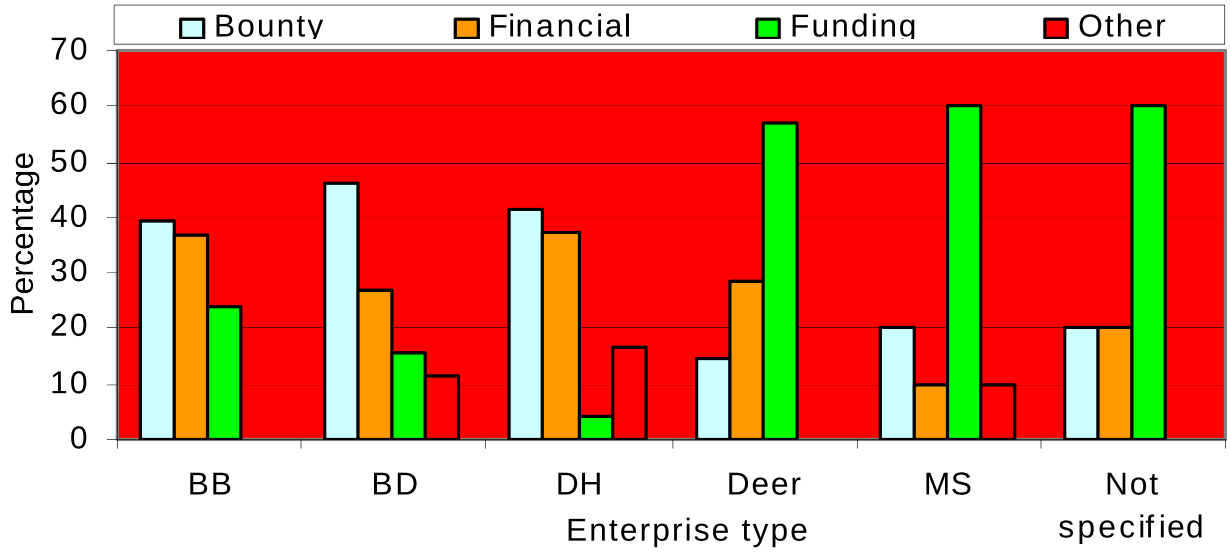


Figure 31. Percentage of written response themes on how farmers see TB being eradicated from New Zealand by enterprise type.

Incentives suggested to improve the national eradication scheme were dependent on area classification and enterprise type of the respondent. In vector risk and fringe areas farmers were in favour of a bounty to aid possum control. In surveillance areas additional government funding was seen as the most helpful action. This indicates that in vector risk and fringe areas possums are seen as the main problem in the spread of TB. In surveillance areas that are at risk of spread of TB, farmers see expenditure on intensified prevention as the highest priority.

Across enterprise types and area classifications financial incentives are ranked consistently. Therefore most farmers are in favour of financial incentives as a means of aiding national TB eradication.

Discussion

Differences in farmer attitudes were seen between regions, enterprise types, area classifications and TB status. Differences were seen in attitudes towards TB control and methods of eradication. The variations in opinions indicate that a singular approach which concentrates on general promotion of the TB eradication scheme would not be as successful as more focused information targeted at particular groups of farmers. Any attempt to design, market and implement a control scheme must take into account the diversity of interests and opinions if it is to be successful.

A broad mix of farmers was sampled, which gives a good basis for extrapolation of the data. High participation and return rates in this study provide confidence that all variations in the sample were identified. No additional biases were introduced through large numbers of non-respondents.

An important finding of the study was that the Animal Health Board was not perceived as being responsible for management of TB in New Zealand. The large spread of organisations selected as being responsible with no predominant group identified indicated that there was considerable confusion about who was in fact responsible. Unfortunately, the AHB and AgriQuality were combined as one organisation in the list of possible responses to the question on which organisation is responsible for TB eradication. Both of the organisations play a large role in the control strategy and a lot of information was lost, as we cannot know if the respondent chose AgriQuality or AHB or both. However the results suggest that the AHB needs to raise its profile amongst farmers with respect to their coordination function in the pest management strategy. In a similar vein, one quarter of farmers were unaware of the degree of assistance they receive through subsidised TB testing. Some respondents did not appear to know the true cost of testing per animal.

The attitude towards control policies of farmers in long-term infected areas, such as Wairarapa, was divided by TB status. Infected herd owners wished to remain with the *status quo* for movement control, while farmers with clear herds wanted stricter controls. Farmers in clear areas, such as Rangitikei and Tararua, were ambivalent about movement control. Respondents wanted movement restrictions to remain the same as at present. Farmers in emerging TB areas, such as Motueka and Nelson, were more aware of the problems associated with TB infection, as it is a new and topical issue. Farmers were aware of their herd contracting TB through cattle movements and therefore wanted movement to be stricter.

Clear farmers believed there was a need for stricter movement control. They saw the potential of infection and wanted to avoid the risk. Their most common reason for stricter movement control was to contain TB and prevent spread. Infected herd owners wanted movement control to remain the same. They were not as concerned about the risk of infection. When giving reasons for their response, containment of TB was the most common response followed by financial considerations.

Vectors were suggested as the reason for continued infection by farmers in long term infected areas who frequently expressed the belief that a bounty would have significant effect on nation-wide TB eradication. Farmers in clear regions saw vectors as the main obstacle to nation-wide eradication and the majority were also in favour of a bounty as an incentive to eradicate TB. Farmers in emerging areas saw a need to fund groups and organisations that provide services for vector control as a more critical measure than introducing a possum bounty to combat TB.

Farmers with infected herds believed TB could and should be eradicated from their herds. Farmers who did not think TB could be eradicated from their herd generally believed this would be due to vectors. Farmers with infected herds saw feral animals as the source of infection for cattle.

A poignant comment was made by a farmer with a TB free herd in the Nelson district "As with many things information never comes in straight forward understandable literature. Recent vector information for me was difficult to understand, are the people writing these so called information sheets being effective or just trying to justify their jobs." This indicates a need for better distribution of information in a form that is easily read and understood by farmers.

Cattle and deer farmers had opposing views on removal of compensation for reactors and direct payment for TB testing which relate to the historical development of control policies within the two industry groups. Deer herd owners, who do not receive compensation (Animal Health Board, 2001), believed it was unnecessary for successful eradication. Cattle owners, who are eligible for compensation, believed it was important to maintain the financial pay-off for removal of reactors. Deer farmers also believed that if cattle farmers were to pay directly for testing then TB would be eradicated more quickly as this would motivate farmers to put more effort into preventing infection. Cattle farmers did not believe that removing TB testing subsidies would increase the rate of TB eradication as this would negatively affect cooperation; for example, farmers would cheat the system by not testing the whole herd or hiding sick animals.

The range of general comments included in the questionnaire shows the diversity of opinions held by respondents. In terms of how the control strategy is working the responses ranged from, “Although extremely inconvenient I think the current testing program is a positive step to eradicating the disease” to “The latest compulsory tagging system is a huge misuse of resources and farmers time and money. The existing controls are quite adequate and at this stage resources should have been channelled towards vector control”.

The results of this study have significant implications for the design, marketing and implementation of the TB control scheme in New Zealand. They indicate the need to tailor aspects of the program to suit the perceptions of farmers in different geographical areas.

Acknowledgments

I would like to thank Robert Sanson, Catherine Cameron, Bryant Quarterman and Terry Ryan from AgriQuality for their help. I would like to acknowledge the collaboration of Dr. Carola Sauter-Louis, Dr. Joanna McKenzie and Dr. Leigh Corner from the EpiCentre.

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CHAPTER 3

VALIDATION OF A DISCRETE STOCHASTIC SIMULATION MODEL OF BOVINE TUBERCULOSIS IN WILD POSSUM POPULATIONS

Introduction

PossPOP is a discrete stochastic simulation model of bovine tuberculosis (TB) in Brushtail possums (*Trichosurus vulpecula*), designed at Massey University in the early 1990s (Pfeiffer, 1994). The aim of the model was to produce "a valid understanding of the epidemiological processes which influence the behaviour of the disease [bovine tuberculosis] in the field, and to contribute to the formulation of effective control policies" (Pfeiffer, 1994). The original model was based on data from the first 22 months of an 11-year longitudinal study of TB in possums run at Castlepoint in the lower North Island of New Zealand.

PossPOP contains a spatial element that uses possum dens as the spatial unit. The density of dens and possums in the modelled population is generated by means of a vegetation map that enables natural spatial heterogeneity to be incorporated into the model. PossPOP contains a large number of parameters that relate to population and disease dynamics. The model is divided into 6 modules that each possum is passed through in daily time intervals. These are: den site selection, reproduction, infection with *Mycobacterium bovis*, survival, aging and immigration (see chapter 4 for more detail).

PossPOP was verified and validated by Pfeiffer in 1993 (Pfeiffer, 1994) at which time the only data available for validation was that used to develop the model. Since that time the model has been extended and further data has become available from the longitudinal study. General consensus is that validation should be conducted using an independent data set (Power, 1993; Jones and Carberry, 1994; Jorgensen, 1995; Rykiel, 1996; Higgins et al., 2001). There is still no sufficiently detailed data available from a site other than Castlepoint, which includes spatial patterns of TB in possums and habitat data. We believed that validation of the model against data collected from the same location but during a subsequent time period was a valid process. This was strengthened by testing a number of emergent biological properties of the model against field data. Emergent properties were not programmed into the model, but arose through the interaction of built-in factors. One emergent property was the proportion of all deaths that occurred per age (Pfeiffer, 1994). Emergent properties provide a valuable test of whether or not the internal structure and parameter settings of the model accurately reflect reality.

Rykiel (1996) suggested that the modeller must specify three things when approaching model validation.

1 *Purpose of the model*. The purpose of PossPOP was to simulate Brushtail possum populations, the behaviour of bovine tuberculosis in possums and the effect of control strategies on the incidence and prevalence of disease in the population.

2 *Criteria that the model must meet to be acceptable for use*. The population produced by PossPOP must be stable over time with similar population dynamics to a natural population. The spatial and temporal patterns of uncontrolled disease must also be similar to that observed in the field.

3 *The context*. PossPOP was developed as a tool to evaluate the effect of different strategies for controlling TB in wild possum populations in New Zealand at a detailed scale representing the size of a large farm. This provided a means of identifying the most effective strategy to eradicate TB in different habitat conditions by accurately representing the spatial distribution of possum populations and TB hotspots.

Validation of PossPOP involved investigation of both the possum population and disease dynamics. This study related to the former, the latter being part of a separate study. The objective of this study was to validate the population component of PossPOP against an independent field data set to determine the degree of confidence that a user can place in the model.

Materials and Methods

Simulated data set

The simulated possum population generated by PossPOP was based on a 40-hectare vegetation map that included the entire Castlepoint study site (Figure 32). The area was comprised of 30% scrub and forest and 70% pasture. Simulations were run with at least 10 iterations for either an 8 or 10-year period. Runs were started in April of the 1st year to coincide with the start date of the Castlepoint study, which was April 1989. A run-in period of 5 years was included in the running of the model that allowed the establishment of the population. Data from the run-in was not considered part of the simulation run data that was analysed in this study.

The mechanisms that operate on the population dynamics of PossPOP are shown in Table 19. The mechanisms are fixed however the parameters may be altered.

Table 19. List of mechanisms and parameters that operate on the population dynamics of PossPOP (Cochrane, 1998)

Mechanism	Parameter type	Parameter name	Description
Possum movement	Not seasonal	MaxDenTravel	The distance a possum will travel in the neighbourhood looking for a den that is not occupied. Possums are moved out of their den each day and made to search for a different den
	Not seasonal	DenRejectProb	The probability that an empty den will be rejected
Emigration / leaps	Not seasonal	LeapProbDistrib	A table that determines the probability that a possum emigrates / leaps based on age
	Not seasonal	LeapDistDistrib	A distribution that determines the distance a possum leaps
Population density stress	Monthly	NoDenMortality	Probability a possum that has not had a den for a number of days will die
	Not seasonal	ResidentDen-Window	The period over which the “no den stress” is tested
	Not seasonal	ResidentDen-Threshold	The number of days out of the “ResidentDenWindow” that a resident possum can go without being subjected to a “no den mortality” test. If a possum does not die it leaps
	Not seasonal	ImmigrantDen-Threshold	The number of days out of the “ResidentDenWindow” that an immigrant can go without a den before “leaping” (if it leaps outside the modelled area it “emigrates” and is removed from the model)
Mating	Monthly	MatingProb	The probability that conception will occur during mating. A mature female possum who is not pregnant attempts to mate with all mature male possums until she is pregnant or has travelled the distance in “MatingBuffer” each day during the breeding season
	Not seasonal	MatingBuffer	The distance that a female possum travels to find prospective mates. This distance and the population density determine the number of contacts
	Not seasonal	MaleBirthProb	The probability that a male will be conceived
Immigration	Not seasonal	SinkModifier	This parameter modifies the [internal: external] population ratio that is used to determine the immigrant population size. A value greater than 1 will increase the rate of immigration.

Survival	Seasonal	SurvAdultFemales ; Surv Adult Males; Surv Imm Females; Surv Imm Males; Surv Joeys	These parameters are the monthly probability that each category of possum will survive.

The parameter settings for each simulation run are shown in Table 20 and Table 21. All simulations used the same parameter set “Sink12_J25”. Table 20 gives the parameters that vary during a year while Table 21 contains variables that remain constant throughout the year. PossPOP contains different sets of parameters for “bad”, “average” and “good” years. For this validation it was decided that only the parameter settings for “average” years would be used.

Table 20. Monthly parameter settings for an "Average year" from the parameter file Sink12_J25 that vary throughout the year

	Month											
Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Female Adult Survival	0.98	0.98	0.98	0.98	0.98	0.96	0.96	0.96	0.98	0.98	0.98	0.98
Male Adult Survival	0.98	0.98	0.98	0.98	0.98	0.96	0.96	0.96	0.98	0.98	0.98	0.98
Female Imm Survival	0.97	0.97	0.97	0.97	0.97	0.94	0.94	0.94	0.96	0.96	0.96	0.97
Male Imm Survival	0.97	0.97	0.97	0.97	0.97	0.94	0.94	0.94	0.96	0.96	0.96	0.97
No Den Mortality	0.05	0.05	0.05	0.05	0.05	0.05	0.30	0.30	0.15	0.15	0.15	0.05
Joey Survival	0.95	0.95	0.95	0.95	0.95	0.95	1.00	1.00	1.00	1.00	1.00	1.00
Mating Probability	0.00	0.00	0.20	0.20	0.20	0.05	0.00	0.05	0.05	0.05	0.05	0.00

Table 21. General parameter settings for parameter file Sink12_J25 applied consistently throughout the year

General Parameters	
Resident Den Threshold	10.00
Resident Den Window	30.00
Immigration Den Threshold	10.00
Male Birth Probability	0.50
Max Den Travel	125.00
Den Reject Probability	0.10
Sink Modifier	1.20

Simulation settings such as duration, immigration, control strategies and population density are shown for each run are shown in Table 22. Four separate runs were conducted: high and moderate density simulations were produced to determine the stability of the population, the population cull simulation was run to produce results that could be compared with field data, and the immigration simulation was run to determine the effect of removing immigration from the population.

Table 22. Settings for the PossPOP simulation runs

Settings	Moderate density simulation	High density simulation	Population cull simulation	Immigration simulation	
				No Immigration	Immigration
No. iterations	15, 10, 5	15, 10, 5	10	10	10
Duration of Simulation (Yrs)	10	10	8	7	7
Run-in duration (Yrs)	5	5	5	5	5
Immigration (Yes/No)	Yes	Yes	Yes	No	Yes
Control strategy	None	None	95% cull in 5th year	None	None
Dens per hectare					
Scrub	5	10	10	10	10
Pasture/scrub	4	8	8	8	8
Forest	4	8	8	8	8
Pasture	1.5	3	3	3	3
Possums per den (all vegetation types)	0.4	0.4	0.4	0.4	0.4

PossPOP contained a list of seven output tables, which could be selected by ticking a box. The output tables used for the following analyses were “Results” and “Survival”.

The “results” table listed every possum alive on the last day of every month and their corresponding demographic information. The “survival” table listed every survival event that occurred each day and the possum to whom the event occurred and their corresponding demographic information.

Table 23. Variables included in the "results" and "survival" tables

Results Table		**Survival Table**	
Output Variable	**Type of output**	**Output Variable**	**Type of output**
Iteration	Integer	Iteration	Integer
Day	Integer (number of days from start of simulation)	Year Type	A = average, B = Bad and G = Good
Id	Integer	Date	Date from start of simulation
X	Spatial coordinate	Poss Id	Integer
Y	Spatial coordinate	Sex	Male / female
Sex	Male / female	Age	Integer (possum age in days)
Maturity	Joey / immature / mature	Is Joey	Joey Id
Joey Id	Integer / No joey	Has Joey	Joey Id
Mother Id	Integer	Date Mature	Date
Independent date	Date	Date Independent	Date
Pregnant	Yes / No	X	Spatial coordinate
Conception date	Date	Y	Spatial coordinate
		Survival Event	Joey Mother Death, Death, Joey Death, Conceived, Immigrant Den Stress Leap, Local Den Stress Death Soon, Local Den Stress Leap, Immigrant, Joey Mother Emigrate, Possum Emigrate, Cull, Cull Mother Joey, Old and Mother Old

PossPOP output was imported into Access? where it was converted into monthly summaries for each parameter. In Excel? the average value across all iterations for each month or year was found for each parameter. Summary variables such as proportions and percentages were calculated.

Field data set

Figure 32 shows the Castlepoint study site that was located on the southeast coast of the North Island of New Zealand (longitude 176.22? E, latitude 40.85? S). Castlepoint was the site of an 11-year longitudinal study, from April 1989 until February 2000. Population and disease data were initially collected at monthly intervals until August 1994 when at least 99% of the study population was culled. Data on the rebuilding population was then collected bimonthly until the completion of the study. The data was divided into 3 sections representing different stages of the study. Castlepoint 1 contains the initial study population from April 1989 to October 1994, Castlepoint 2 covers the population regrowth after the October 1994 cull until February 1998 and Castlepoint 3 contains the period from May 1997 until the completion of the longitudinal study in December 1999. A regional culling program operated in the area surrounding the study site during this final period thereby significantly reducing immigration into the study site. The initial area of the study site was 24 hectares shown in Figure 32, until November 1994 when it was extended to 36 hectares, and February 1998 when it was extended further to 56 hectares.

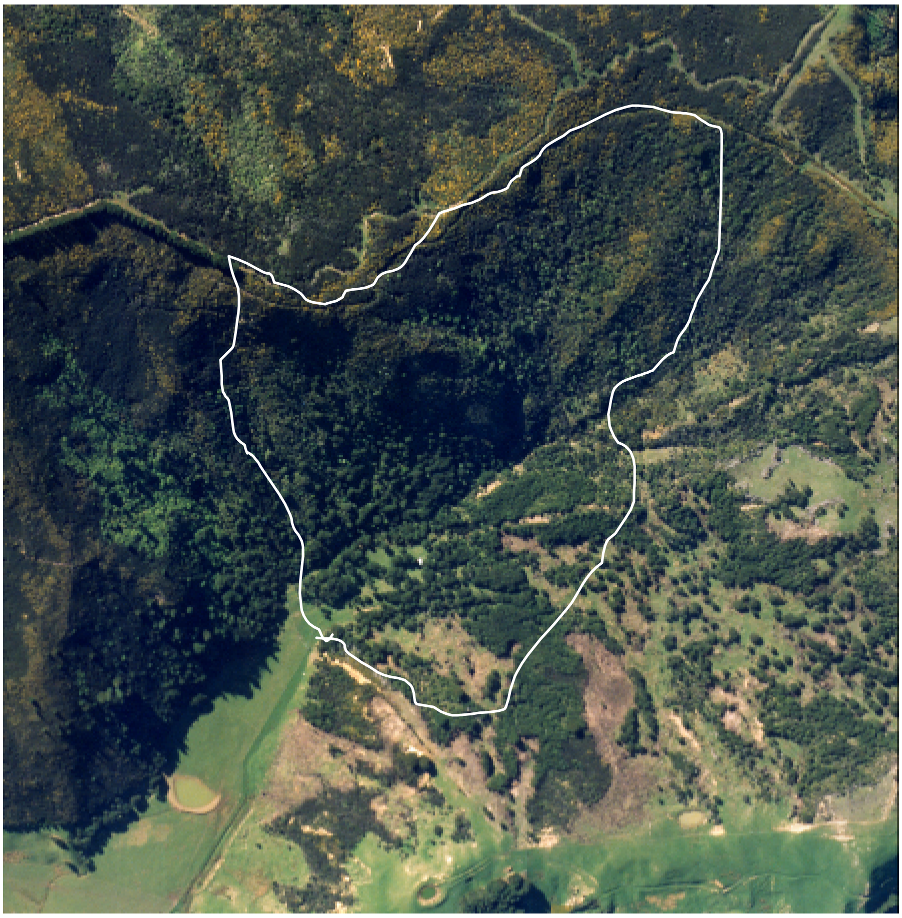

Figure 32. An aerial photograph of the 24-hectare Castlepoint study site where the longitudinal study of TB in possums was conducted (1989-2000)

A trap-mark-release regime was used to monitor the population of wild Brushtail possums. During each trapping possums were examined and data was collected on: location of capture, sex, maturity, weight, body condition, palpation for tuberculosis, tooth wear and presence of a joey or lactation. The number of possums trapped was used to estimate the population size through the use of the Jolly-Seber algorithm (Seber, 1982).

Validation of the model

The first stage of the validation process was to identify the optimum number of iterations required. Subsequently the model was validated by assessing four areas: stability of the population over time at different densities (moderate and high), comparing the structure of the model population over time with the field population, comparing the dynamics of the modelled with the field population and comparing emergent biological properties of the model with the field data.

To compare the field data to PossPOP, percentages were used due the disparity in population sizes. The Castlepoint population at its peak contained an estimated 285 possums whereas the simulated population had 1864 possums due to the larger area covered.

Identifying the optimum number of iterations

The optimum number of iterations was defined as the minimum number of iterations that incorporated the maximum amount of stochastic variation. This was determined by comparing the 95% confidence intervals of the mean population size at monthly intervals for a 10-year period using five, ten and fifteen iterations. The mean population size and 95% confidence intervals were calculated at the end of each month.

95% Confidence Intervals: $X \; ? \; (t \; ? \; Standard\ error)$

Standard error of the mean: $\dfrac{(Standard\ deviation)}{\sqrt{n}}$

Standard deviation: $\sqrt{\dfrac{Sum\ of\ (Individual\ value\ ?\ Mean\ value)^2}{Number\ of\ values}}$

Where X = mean, t = the value from the T distribution that corresponds with the degrees of freedom (n-1) and the degree of confidence required i.e. 0.05 for 95%, and n = sample size (Gardner and Altman, 1997)

The values for each set of iterations (5, 10 and 15) were plotted on the same graph to visually assess the optimum number of iterations. The model was then run with the optimum number of iterations for subsequent analyses.

Demonstrating stability of the simulated population over time

The stability of the simulated population over a 10-year period was tested using high and moderate population densities (see Table 22). Population on the last day of each month was averaged across all iterations and plotted over time for each population density. This was compared with a plot of the field population size over the 11-year study period.

Population structure

The age and gender structure of the simulated population over time was evaluated for the two population densities by calculating: percentage of females in the population; percentage of females in each age group; percentage of juveniles in the population;

percentage of males that were juvenile, and percentage of females that were juvenile. In the PossPOP output a “joey” was an animal younger than 4 - 6 months of age (mean = 5 months) and an “immature” possum was less than 1 - 2 years (mean = 18 months) (Pfeiffer, 1994). All “joey” and “immature” possums were grouped together into a classification called “juvenile” and therefore defined as any possum between birth and sexual maturity.

The number of simulated possums in each class on the last day of each month was averaged across all iterations. This figure was then divided by the average population at the end of the corresponding month, giving the percentage in a class in any month, which was then averaged to produce a yearly value.

Population dynamics

Dynamics of the PossPOP population were compared to the Castlepoint population using monthly values of the percentage of: (1) conceptions, (2) immigrations and (3) disappearances. PossPOP and Castlepoint data were plotted on the same chart and compared visually.

PossPOP output was imported into Microsoft Access 97? , where a count of each survival event by month was conducted for each year and iteration. This data was taken to Microsoft Excel 97? where the monthly values were averaged over all iterations to produce a mean monthly value. Calculations of the percentage of the population involved in each event for both the simulated and Castlepoint population are described below.

Conceptions

The number of conceptions per month in the PossPOP population was identified using the “survival” output table that included the event “conception”. The percentage of conceptions for the simulated population was calculated by dividing the number of conceptions per month by the total population present at the end of the previous month averaged across all iterations.

$$\textit{Percent conceptions} ? \frac{\textit{Number conceptions per month}}{\textit{Population at the end of the previous month}} ? 100$$

In the Castlepoint data, birth date of possums was estimated based on body weight. The estimated birth date minus gestation (eighteen days) produced an estimated conception date (Tyndale-Biscoe and Renfree, 1987). A count of conceptions was conducted for each month based on the conception dates. The percentage of conceptions was calculated for each month by dividing the number of conceptions by the corresponding Jolly-Seber estimated population for each month. The conception rates for each population were visually compared by plotting the values over time for each population on the same chart.

Immigration

The percentage of immigrants in the simulated population was calculated per month. The number of "immigrant" events in the PossPOP "survival" table was counted per month and averaged across all iterations. The percentage of immigrants was calculated for each month using the average population present at the end of each month.

$$Percent\ immigrations\ ?\ \frac{Number\ of\ immigrants\ for\ the\ month}{Estimated\ population\ at\ the\ end\ the\ month}\ ?\ 100$$

For the Castlepoint population any newly captured possum for which a mother could not be identified was classified as an immigrant. The number of immigrants was counted each month and the percentage calculated by dividing the number of immigrants by the Jolly-Seber estimated population for that month.

Disappearances

Possums that died undetected at the Castlepoint site could not be differentiated from those which dispersed away from the site, therefore the two groups were combined into one group called "disappearances". In the Castlepoint population, only a few possums were found dead therefore no date of death was available for most possums. The date a possum was assumed to have disappeared from the study population, if it was never trapped again, was taken as 120 days after it was last captured. A monthly count of possums classified as disappeared was conducted and calculated as a percentage of the estimated monthly population.

In the simulated population a series of survival classifications from the survival" table were grouped together and labelled "disappeared". Those classifications were: JoeyMotherDeath, Death, JoeyDeath, JoeyMotherEmigrate, PossumEmigrate, Cull, Old and MotherOld. A count of the number of disappearances per month was conducted and averaged across all iterations. This was then divided by the average population present at the end of the previous month to calculate the percentage of disappearances.

$$Percent\ disappearances\ ?\ \frac{Number\ of\ deaths\ or\ emigrations\ per\ month}{Population\ at\ the\ end\ of\ the\ previous\ month}\ ?\ 100$$

Emergent biological properties

Distribution of age at death

In the simulated population all deaths that occurred within the ten 10-year iterations were stratified into age groups. Age was given as the number of days after conception in the "survival" output table of PossPOP. Age was converted into years by dividing by 365 and then rounding the values to the nearest whole number for example 0.45 became 0 and 1.75 became 2. The percent of total deaths that occurred in each age group was calculated and presented as a bar chart. Possums at the Castlepoint study site were not aged beyond juvenile or mature and as a result the analysis could not be conducted for the field population.

Population regrowth before and after the population cull

The Castlepoint population was culled after 5 years in October of year 6 (1994), resulting in removal of 99% of the tagged possum population. In PossPOP a cull of 95% of the population was simulated during October of year 5 in the 8-year run. Calculating the monthly percentage change in the population compared the rate of population regrowth before the cull for both the simulated and Castlepoint populations. For example: population change in January

$$\%\ change\ in\ January\ ?\ \frac{Population\ at\ end\ of\ January\ ?\ Population\ at\ end\ of\ December}{Population\ at\ end\ of\ December}$$

After the cull the Castlepoint population was trapped at bi-monthly intervals from December in year 6 (1994). Growth rates during this period were calculated for 2-monthly periods in both the Castlepoint and simulated populations.

The growth rates for each of the Castlepoint and simulated populations before the cull were plotted on the same graph and those after the cull were also plotted.

Effect of removing immigration

In Castlepoint there was a two-year period from May of year 9 to December of year 11 (1997 to 1999) of the longitudinal study where the population outside the study area was substantially reduced in a regional culling program. As a result the immigration of possums into the study site was significantly reduced. This provided the opportunity to compare the effect of removing immigration in PossPOP with the field data. The model was run for seven years, once with immigration turned on and once with immigration off. The number of possums present at the end of each month of the simulation was compared visually with the Jolly-Seber estimation of the Castlepoint population in years 9, 10 and 11 using a scatter plot.

Results

Optimum number of iterations

The chart of the population means summarised across 5, 10 and 15 iterations is shown in Figure 33. There was very little difference in the means of the three groups.

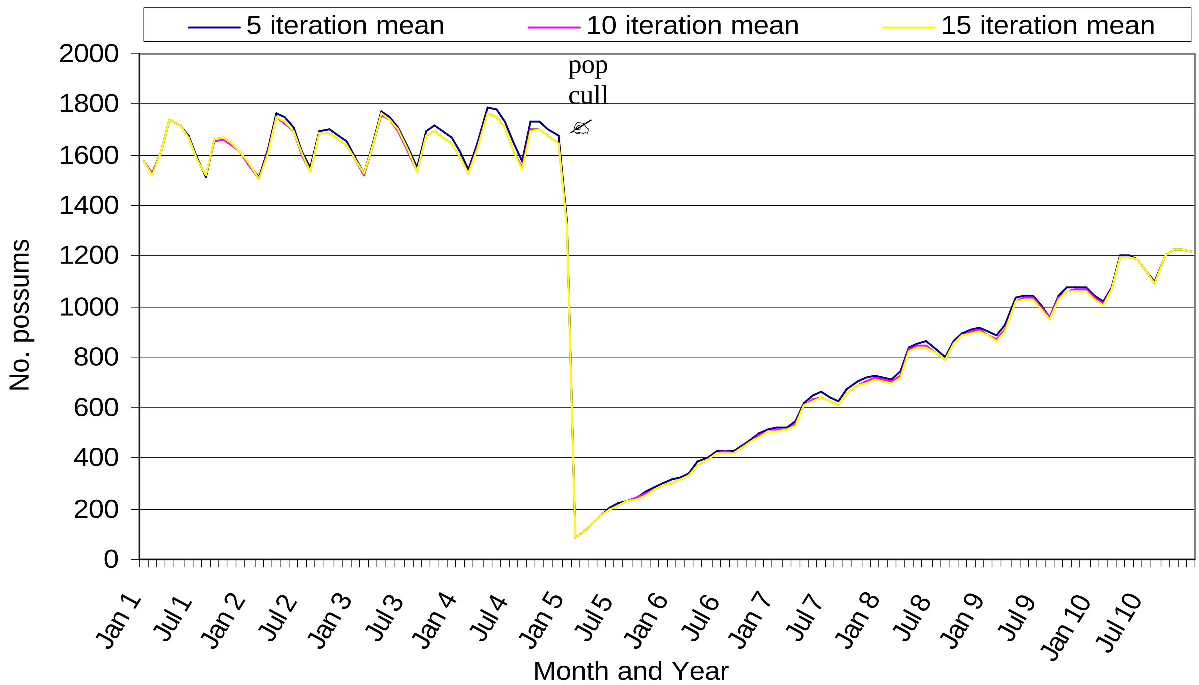

Figure 33. Monthly population means for the simulated high-density population using 5, 10 and 15 iterations

To illustrate the differences in the means for each group more clearly the chart was divided into two periods: before and after the 95% population cull. Figure 34 shows the comparison of the monthly population means for the 5, 10 and 15 iteration runs before the population cull while Figure 35 shows the same information for the period after the cull.

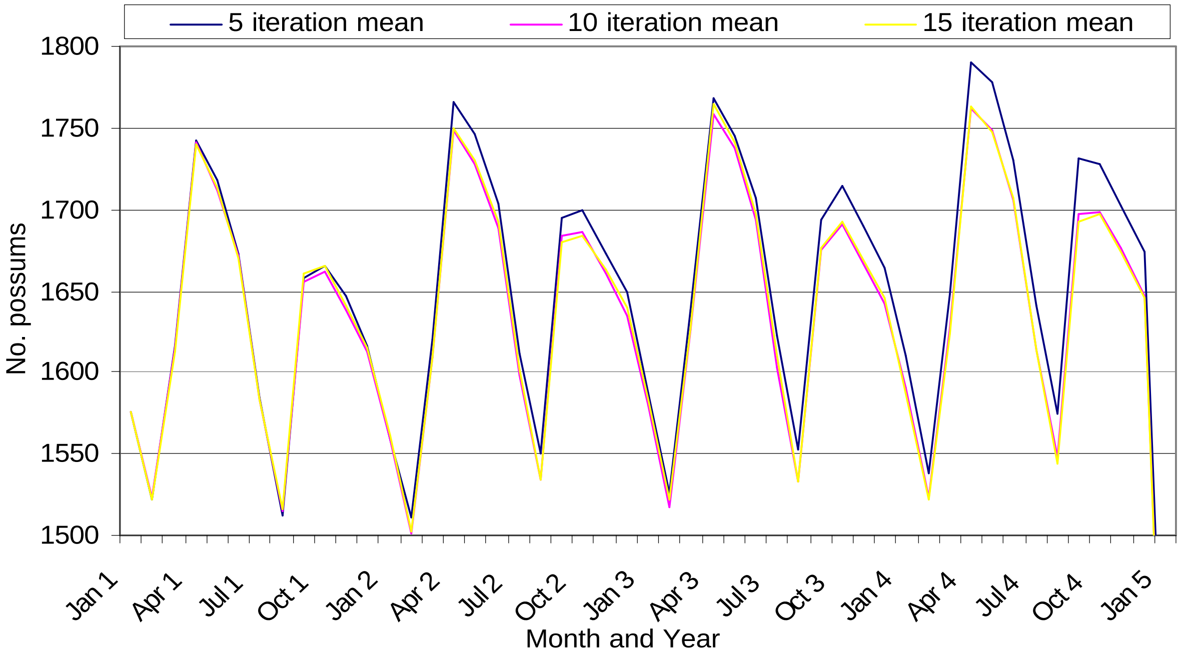

Figure 34. Monthly population means before the cull for the simulated high-density population using 5, 10 and 15 iterations (January 01 to January 05)

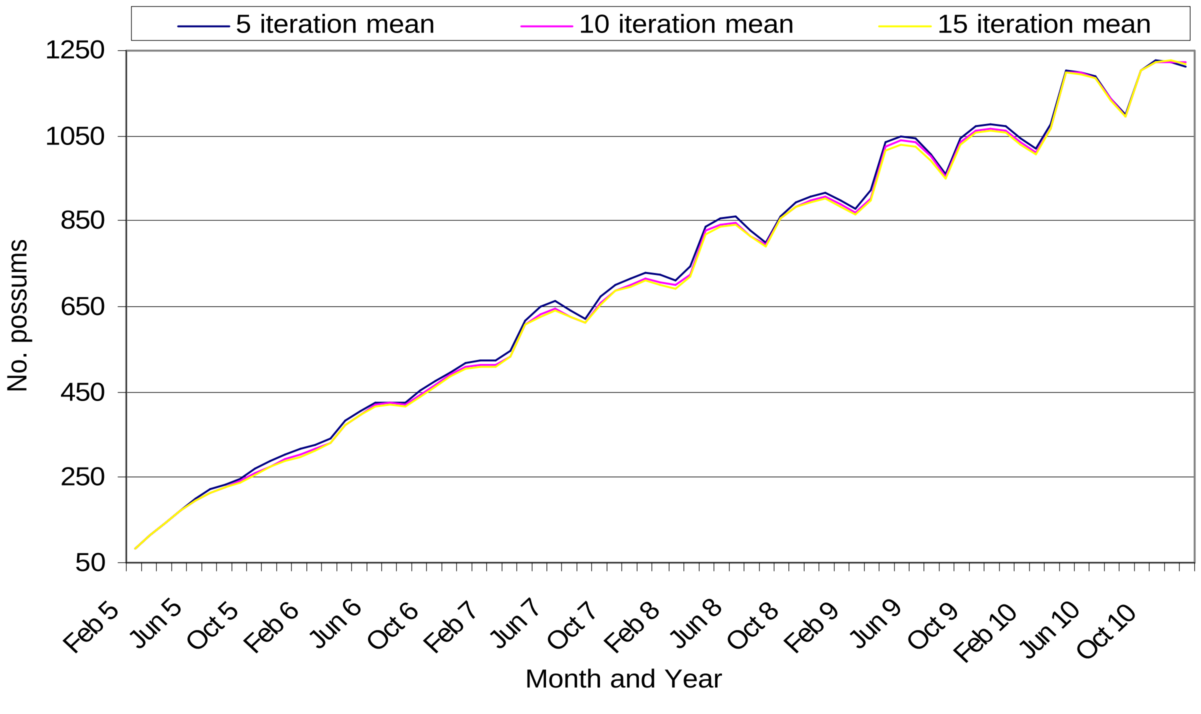

Figure 35. Monthly population means after the cull for the simulated high-density population using 5, 10 and 15 iterations (February 05 to December 10)

A graph of the range of the 95% confidence intervals (Upper CI – Lower CI) for the mean monthly population for each iteration group is shown in Figure 36. There is a marked reduction in range between 5 and 10 iterations but a smaller change between 10 and 15. Taking into consideration the resource requirements for running multiple iterations it was decided that the optimum number of iterations was 10, and this figure was used to run the simulated population for the remainder of the analyses.

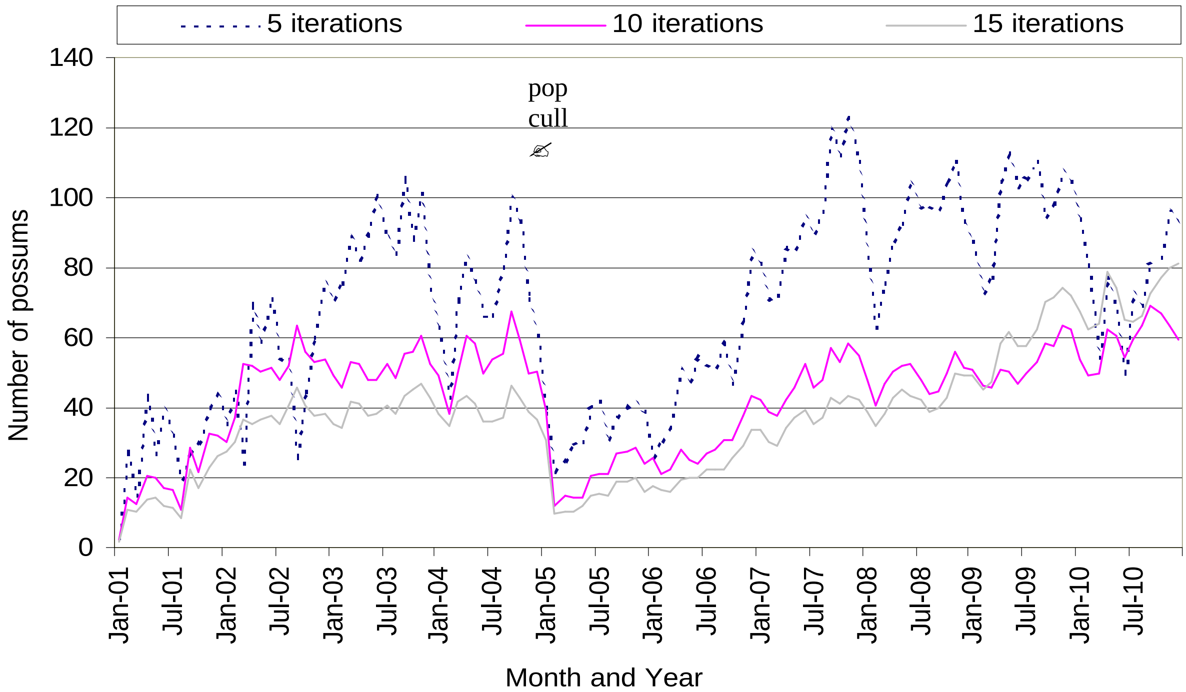

Figure 36. The 95% confidence interval range (Upper CI – lower CI) for the mean population each month using 5, 10 and 15 iterations for the high-density population.

Stability of the simulated population at different densities

Output shown in Figure 37 indicates the simulated population was stable over time at both moderate and high densities. The high and moderate population densities both showed seasonal fluctuations in population size. The percentage change in population between the lowest and highest points in the year for the high-density population was consistently 27% while the moderate population was 25%.

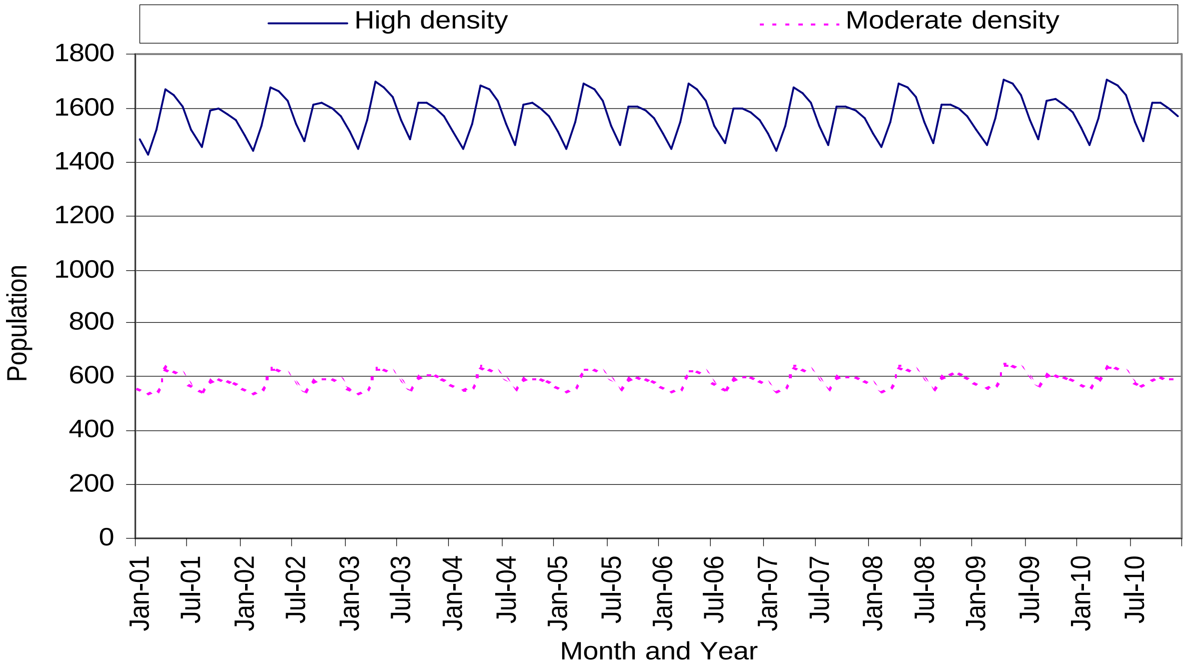

Figure 37. Monthly population size of the moderate and high-density populations over a 10-year simulation period.

Comparison of PossPOP population pattern with Castlepoint

Figure 38 shows the estimated population for the duration of the longitudinal study at Castlepoint. The population estimates for the first 3 months of the study are not very reliable, as the trapped population had not had time to build up. The population gradually increased in size from May of year 3 to May of year 6. In October and November of year 6 a 99% population cull occurred. After the cull and initial repopulation there was a decline in the population from May of year 9 when extensive depopulation occurred in the area surrounding the study site, which killed some possums in the study population and significantly reduced immigration into the study area.

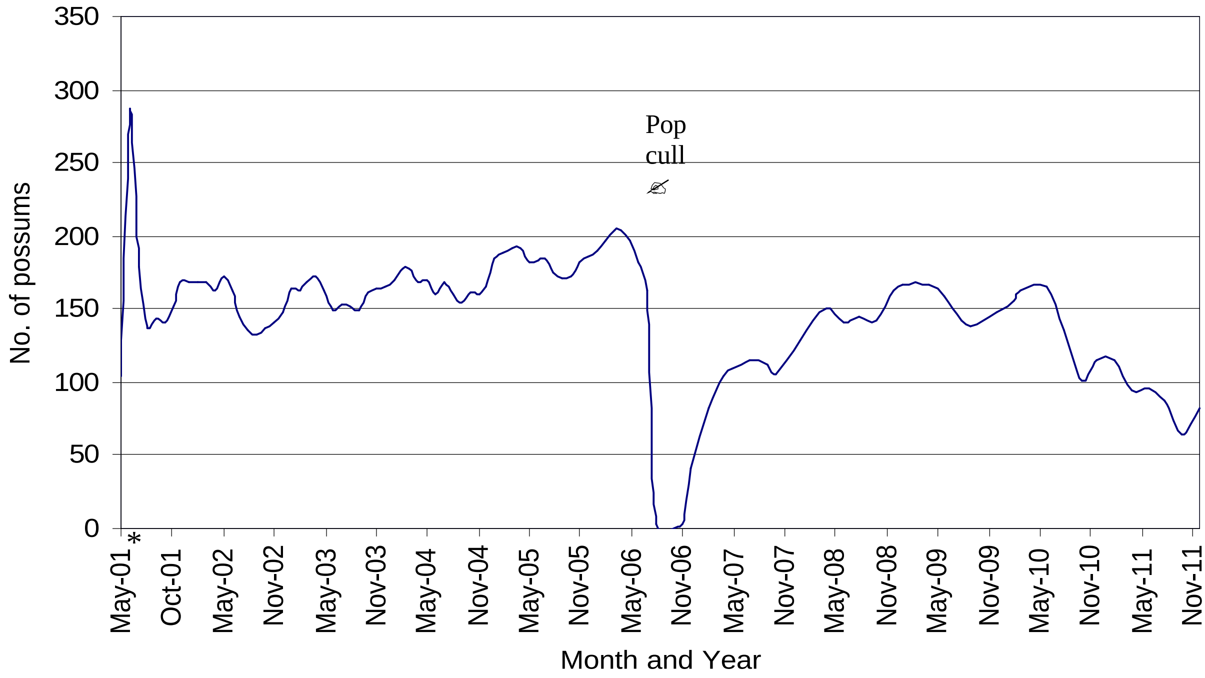

Figure 38. Jolly-Seber estimate of the Castlepoint population over time. * The population estimates begin in May 01 as no population estimate is produced by the Jolly-Seber estimation for the first trapping in April 01.

The PossPOP population was simulated to mimic the events that occurred in the Castlepoint population. Therefore a 95% population cull was programmed for October 1994 (Figure 39). The simulated population showed a similar seasonal pattern of variability to the field population in autumn. However, where the simulated population showed a second peak in October the Castlepoint population showed a trough. The simulated population did not incorporate directly through the parameter structure the annual variability shown in the field population.

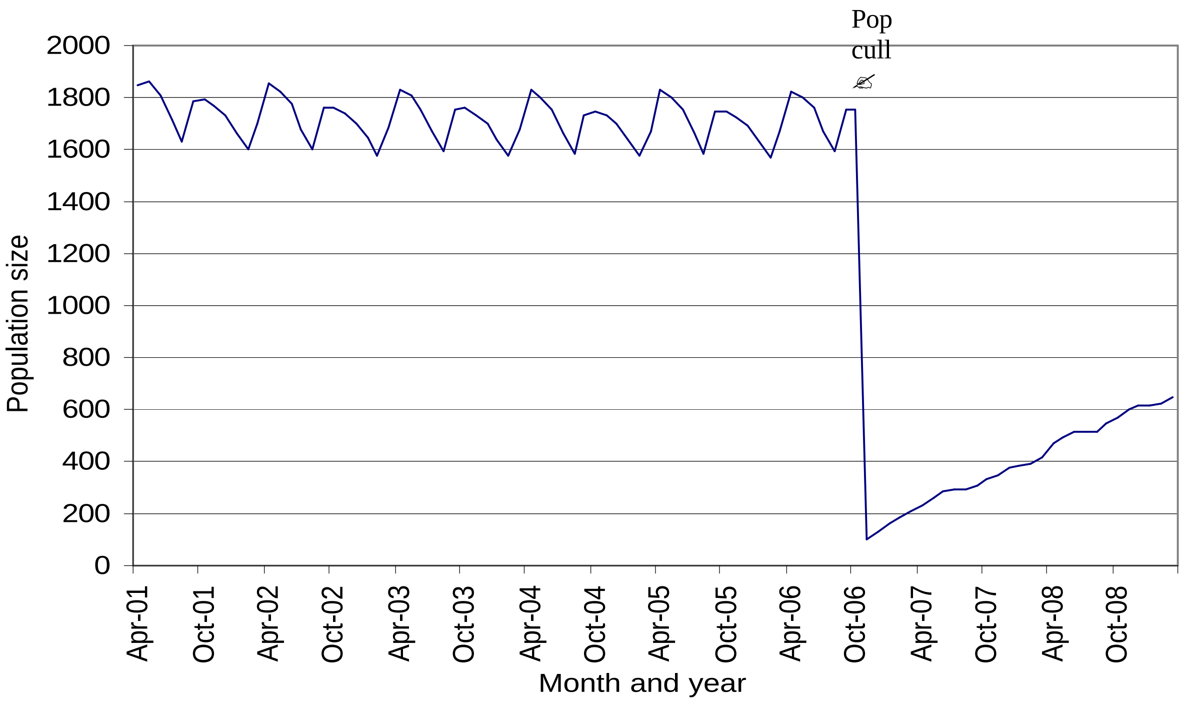

Figure 39. The high-density PossPOP population showing the 95% population cull

Figure 40 shows the percentage change in the population each month before the population cull for both the Castlepoint and PossPOP populations. While the decline of the two populations generally coincided in the winter months, the peak growth periods varied. Castlepoint had a larger percentage increase in the summer months and a smaller increase in the autumn months, whereas the simulated population had a large increase in both autumn and spring.

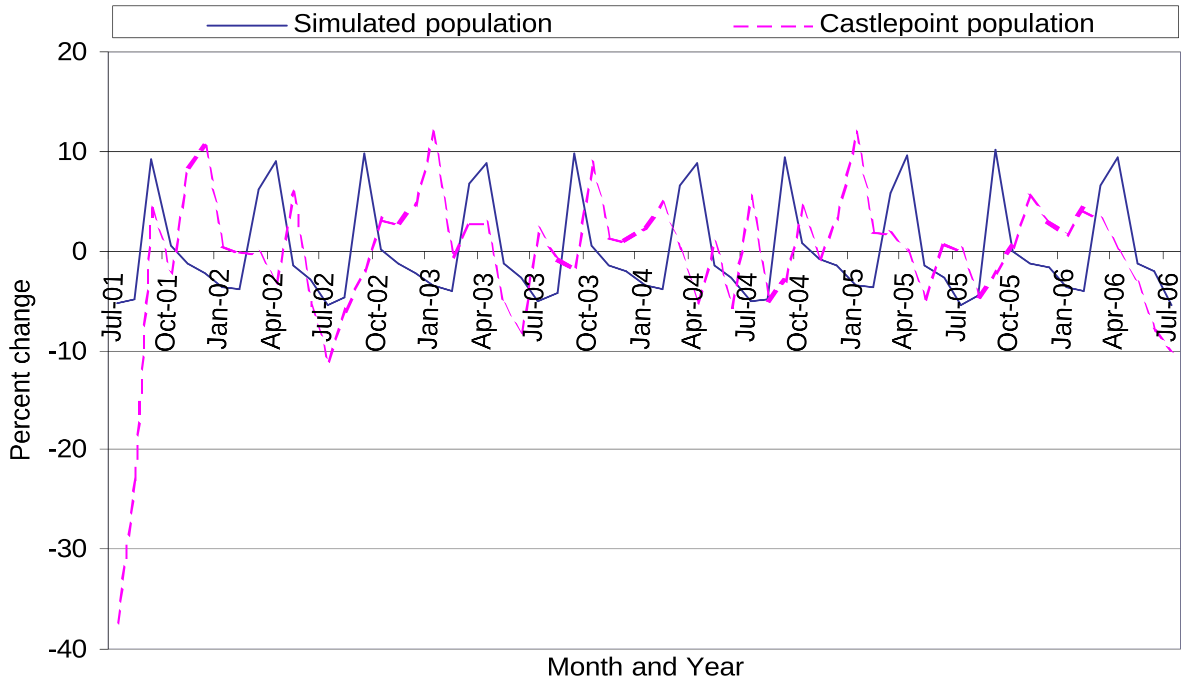

Figure 40. The percent population change each month for the PossPOP and Castlepoint populations

Population regrowth after the 95% cull

Figure 41 shows the percentage change in the population every 2 months after the population cull for both the simulated and Castlepoint populations. Castlepoint had a 60% larger population increase from December to February in year 7 after the population cull compared with the simulation. In the first year the population at Castlepoint increased 3,517% (3 –105 possums) compared with PossPOP, which increased 329% (100 – 329 possums) (Figure 38 and Figure 39). The simulated population continued to grow at the same rate for the remaining two and a half years of the simulation run by which time it had reached only 37% of the pre-cull population size.

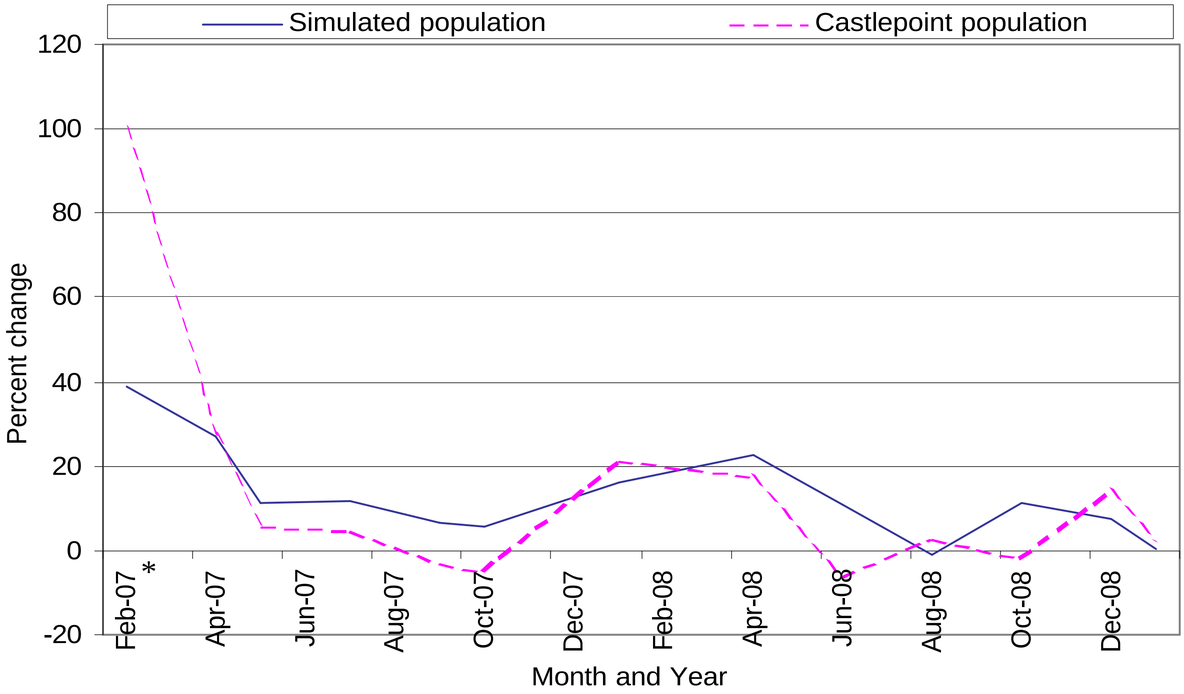

Figure 41. Percentage growth per month for the simulated and Castlepoint populations after each population was culled by 95% and 99% respectively. * The growth rate in the first month after the cull (November 07 – December 07) in the Castlepoint population was 1256% (3- 40 possums) was not included in the chart as it obscured the differences seen in the remaining months.

Population structure

Percentage of females

The percentage of females in the moderate and high-density populations in each year of the simulation is shown in Figure 42. In the moderate-density population the percentage of females was consistently greater and contained more variation than the high-density population. The greatest difference between the two densities occurred in the first two of years of the simulation, after which the values became more constant with the moderate density population having around 1% more females than the high density population.

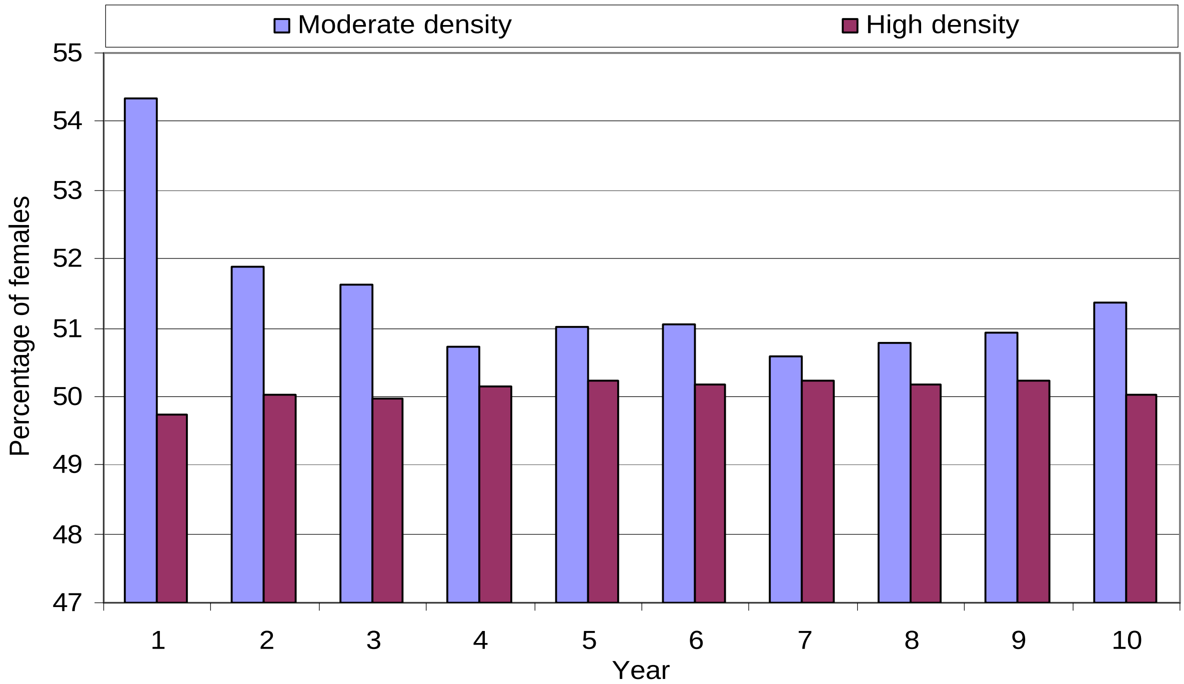

Figure 42. A comparison of the percentage of females in the total population for moderate and high-density populations

Figure 43 shows the percentage of females in the Castlepoint population per year. There was a wide fluctuation in the percentage of females, with an average of 40.8%. The population was moderately to greatly male biased in all years, which may be a reflection of the higher trap ability of males compared with females.

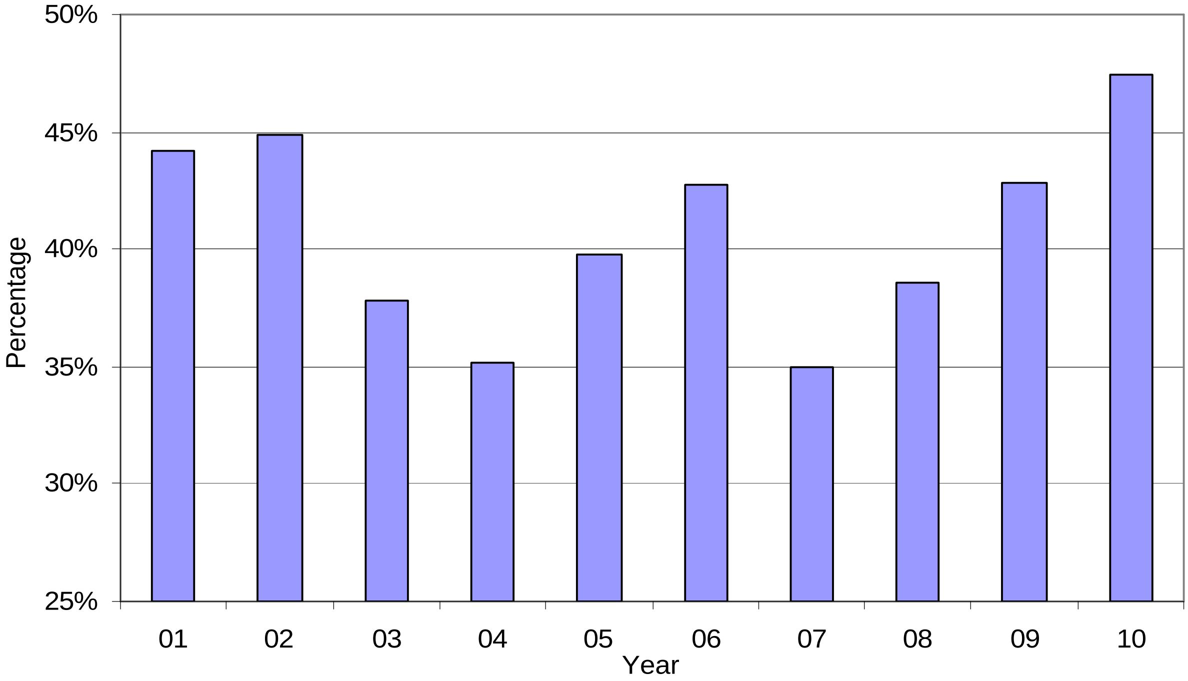

Figure 43. The mean monthly percentage of females in the Castlepoint population per year.

The percentage of females in each age group for the high-density population is shown in Figure 44. The high-density population showed that between birth and 6 years the percentage in each age group was approximately equal at 50% (?0.3%). The ratio of females was slightly higher at 51.1% in years 7 and 8. This variability was most likely due to the small number of possums in the older age groups.

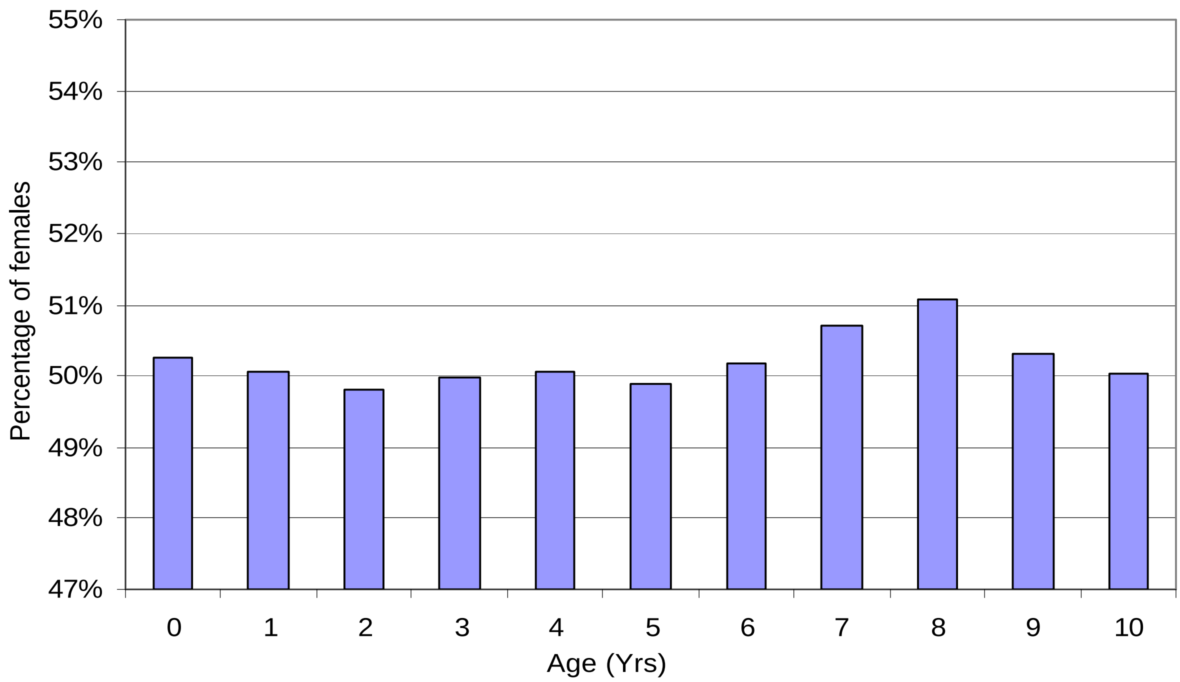

Figure 44. Mean percentage of females in the simulated high-density population stratified by age.

Percentage of juveniles in the whole population

Figure 45 shows the percentage of juveniles in the PossPOP population. Juveniles were defined as animals not yet sexually mature. Possums in PossPOP became mature on the basis of an age distribution that had a mean of 18 months and a standard deviation of 1.5 months (Pfeiffer, 1994). All possums born in the year of interest and a proportion of those born in the previous year were counted as juveniles resulting in approximately half the population being juveniles. There was a slightly higher percentage of juveniles in the high-density population than in the moderate. The difference between the two populations was small but increased over time until the 8^{th} year where it reached a maximum of 1.3% and then reduced again (Figure 45).

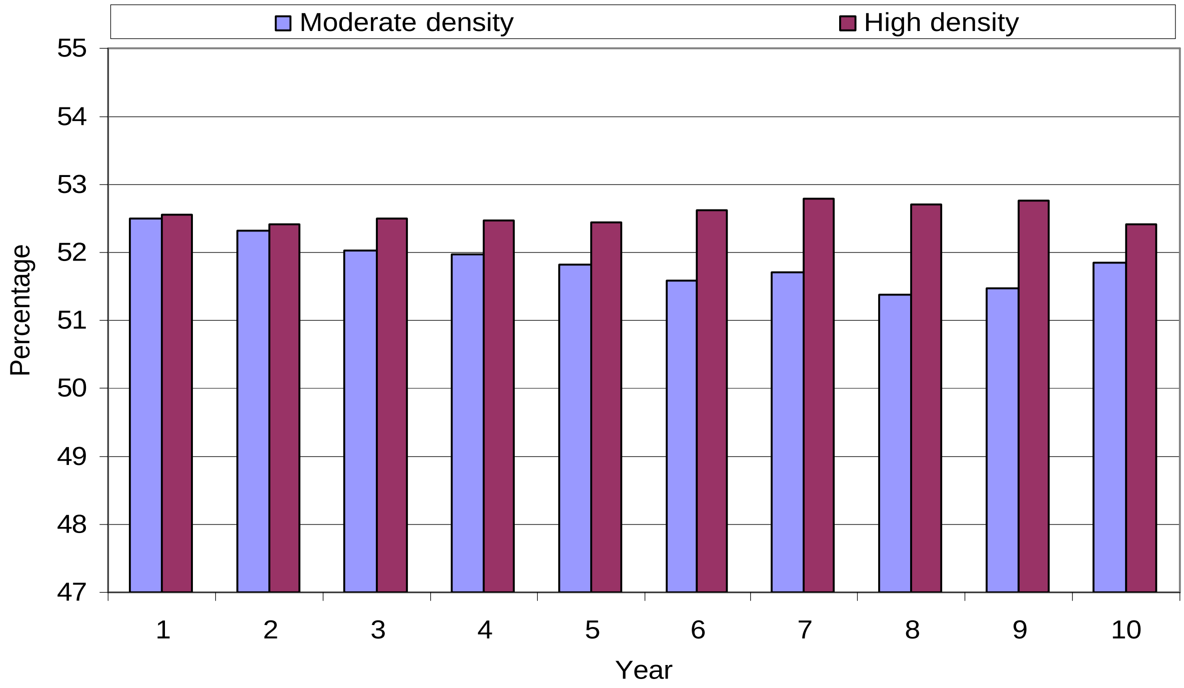

Figure 45. Mean monthly percentage of juveniles per year in the high and moderate-density populations over a 10-year simulation.

Percentage of males and females that were juvenile

Figure 46 shows the percentage of all males that were juvenile, in both the moderate and high-density populations. In half the years the moderate density population had a slightly higher percentage of males that were juvenile while in the other half the high density population was slightly higher.

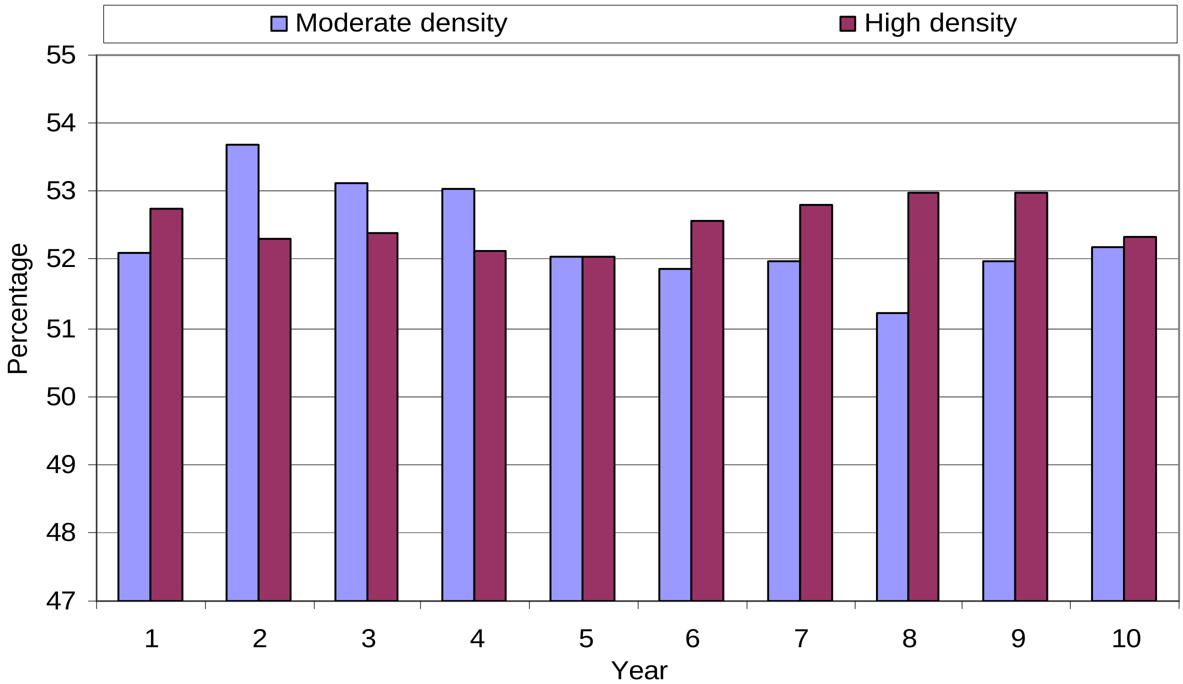

Figure 46. A comparison of the percentage of males that are juvenile for moderate and high-density populations

The percentage of females that were juvenile is shown in Figure 47. The high-density population had a higher value in all but the first year of the simulation. The difference fluctuated between 0.9% and 1.8% for the remainder of the simulation.

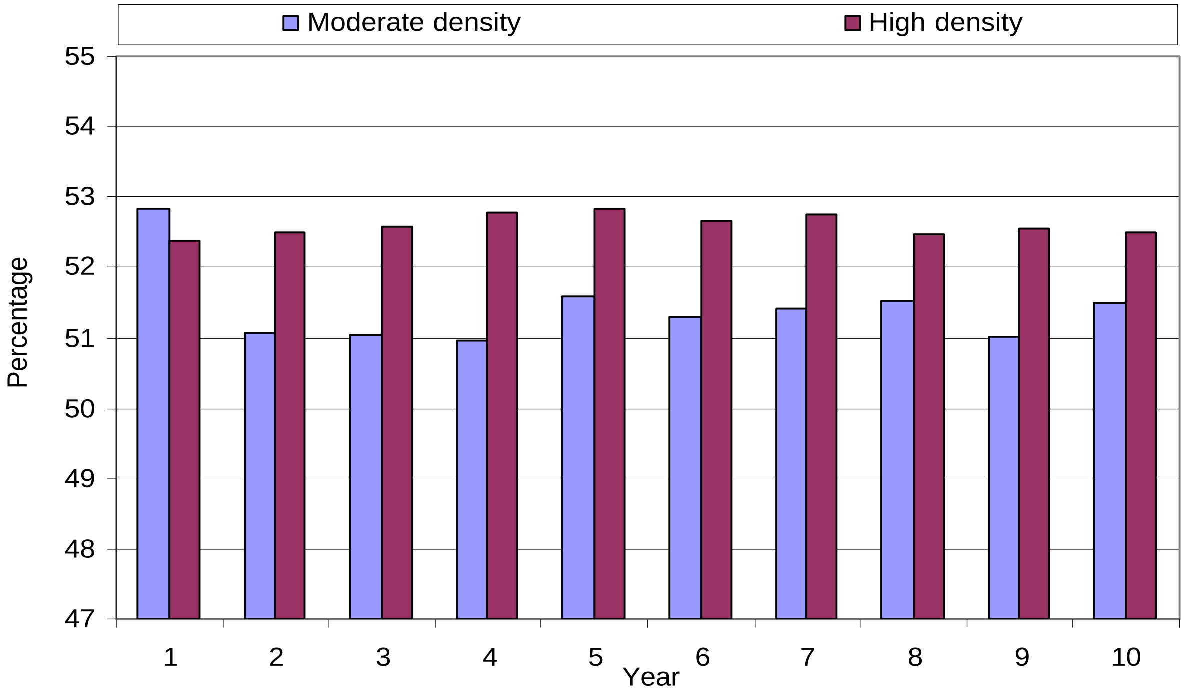

Figure 47. A comparison of the percentage of females that were juvenile in the moderate and high-density populations

The percentage of males and females that were juvenile was similar to the percentage for the whole population indicating a balance of juvenile and mature possums amongst both genders.

Population dynamics

Conception

The monthly percentage of conceptions for Castlepoint and PossPOP are shown in Figure 48. PossPOP had a similar conception rate to Castlepoint in March - April but a higher rate in September - October. PossPOP does not show the yearly variability in spring conceptions that is seen in the Castlepoint population in which the conceptions vary between 4% in year 1 and 8.4% in year 4. After the kill-out conceptions in both populations followed a different pattern, with the September - October peak being higher than the March - April peak.

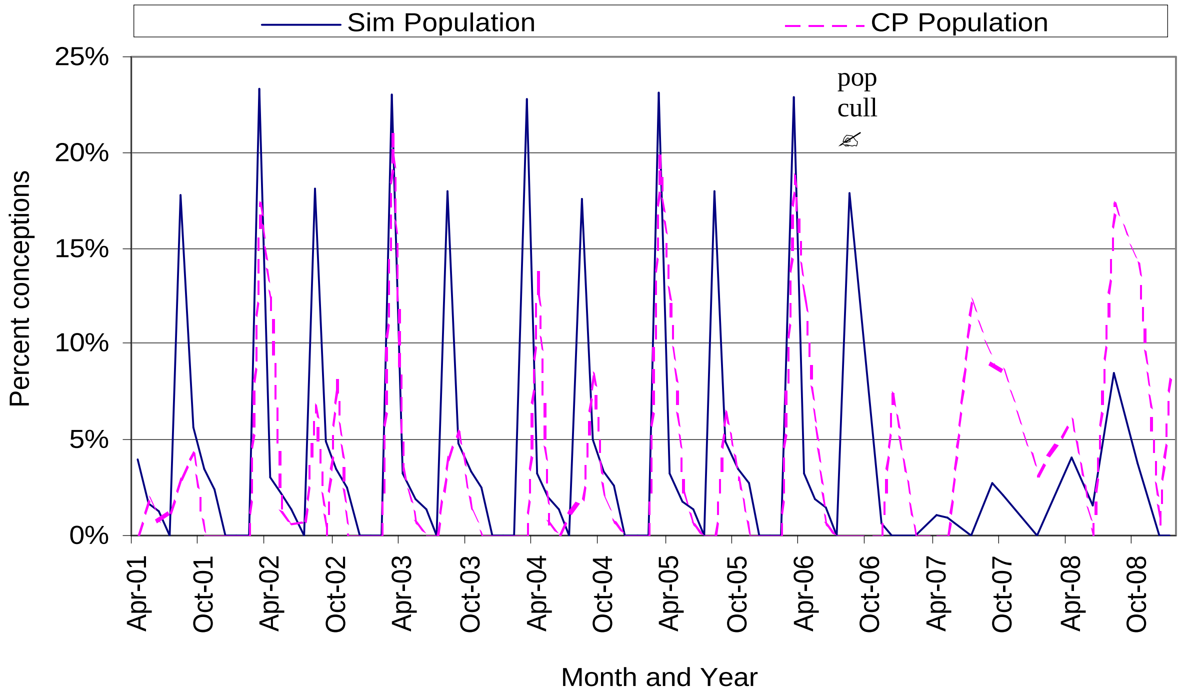

Figure 48. A comparison of the monthly conception rate in the high-density simulated and Castlepoint populations

Figure 49 shows the difference between the conception rate for the simulated and Castlepoint populations per month. Up until the population cull the differences between the simulated and Castlepoint populations followed a fairly regular pattern. The simulated population consistently had a much higher conception rate in August compared with Castlepoint, and a less consistent slightly lower rate in March. Therefore the percentage of conceptions was generally correctly modelled in the simulation in autumn however was overestimated in spring. Following the cull, the conception rate in the simulated population was consistently lower than that in the Castlepoint population.

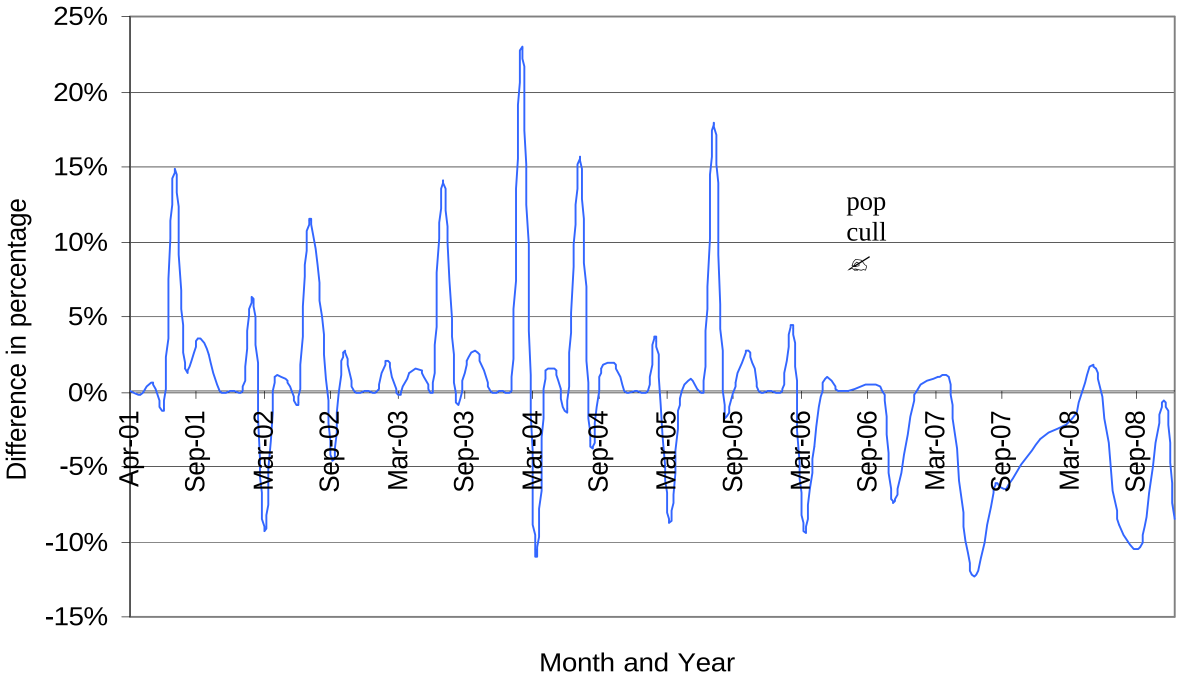

Figure 49. The difference in the monthly conception rates of the high-density simulated population minus the Castlepoint population.

Immigration

Figure 50 shows the proportion of immigrants into the population per month for both Castlepoint and PossPOP populations. In the six years prior to the cull PossPOP grossly underestimated the amount of immigration compared with Castlepoint. PossPOP values ranged from 0.06% to 2.4% and averaged 3%, while the Castlepoint values ranged from 0 to 20% with an average of 8% per month. Figure 50 shows that January consistently has the greatest difference between the two populations. The model did not match the seasonal pattern of immigration seen in the field population.

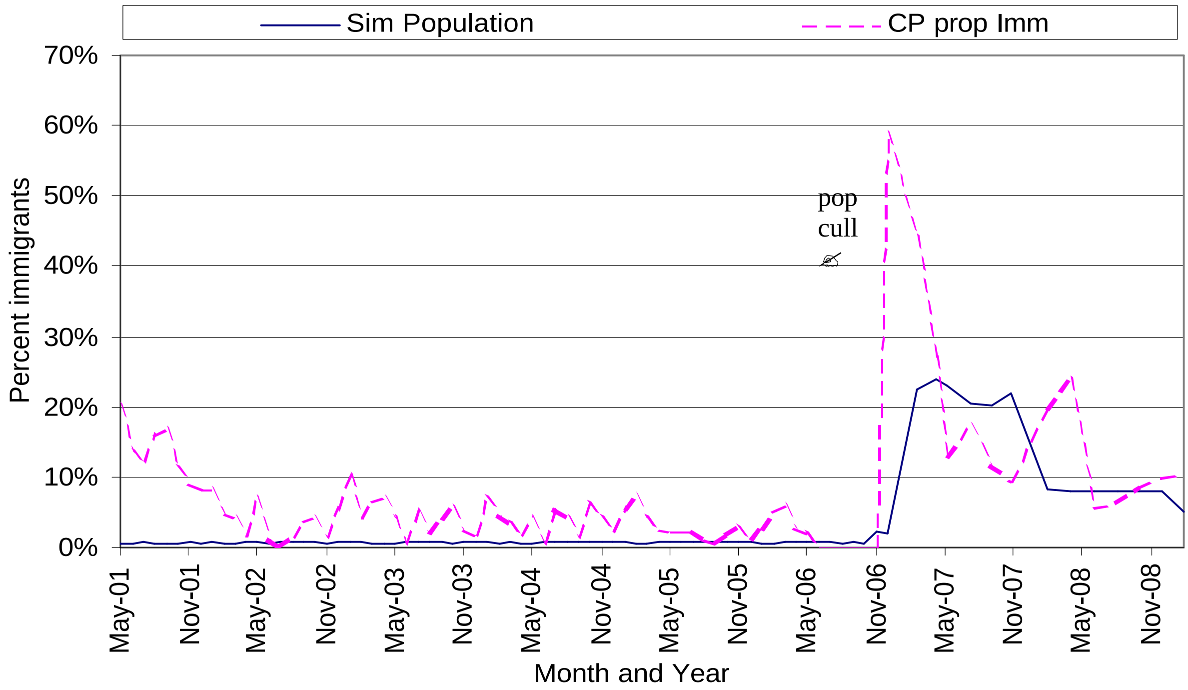

Figure 50. A comparison of the monthly immigration rate in the high-density simulated and Castlepoint populations.

The higher levels of immigrants seen in the first year of the study reflect the fact that the proportion of new possums trapped each month was initially high until the project had been implemented sufficiently long for the trapped and tagged population to grow to the point where it matched the true population and stabilised. After the cull the Castlepoint population had a dramatic increase in the percentage of apparent immigrants in the months following the cull. This is likely to be due to possums classified as "range expanders" who are adult possums that increase their home range into the area where the cull occurred, rather than juveniles that migrate over greater distances. Range expanders are not true immigrants in the way this term is normally used.

Disappearance

Figure 51 shows the monthly percent of disappearances for both Castlepoint and PossPOP. The simulated population on average had a slightly higher proportion of disappearances than was seen in Castlepoint. In PossPOP the proportion of disappearances varied between 0.04 and 0.18 (mean = 0.06) while in the Castlepoint population the range was 0.01 to 0.14 (mean = 0.05).

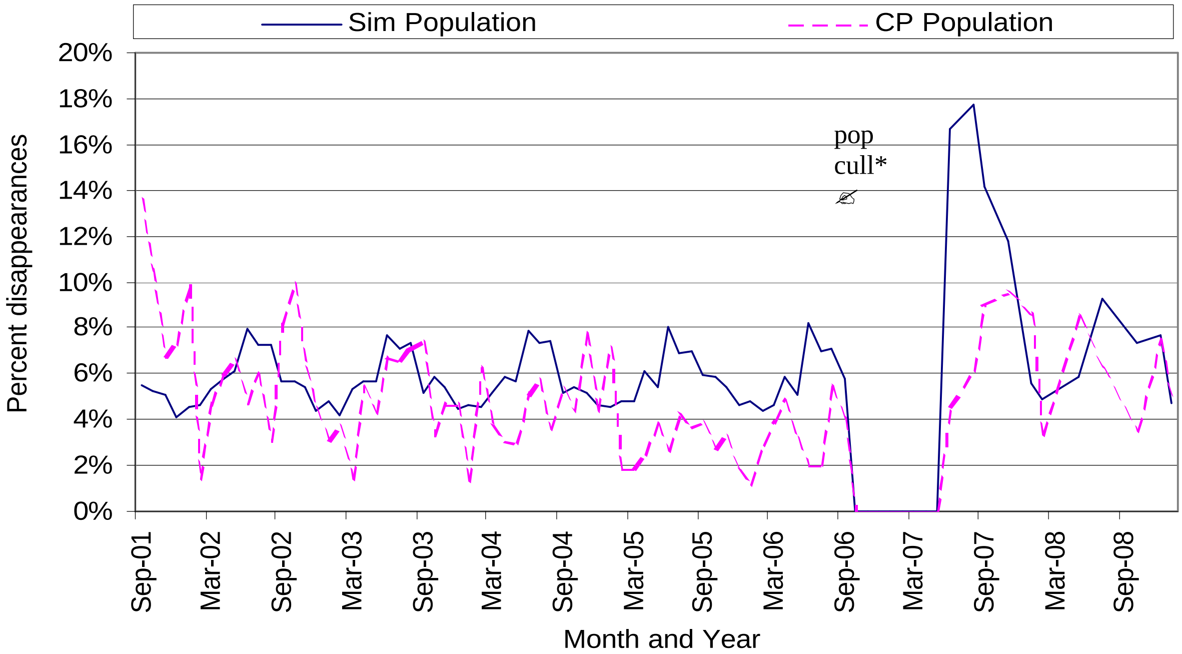

Figure 51. A comparison of the percentage of disappearances for the simulated and Castlepoint populations. * As a possum in the Castlepoint population was classified as having disappeared if it wasn't trapped for 4 months, no disappearance dates after the cull in October and November in year 6 was available until June of year 7.

The disappearance rate in the simulated population peaks in June – July each year. The rate was considerably higher in the simulated population during this period in the year after the cull because the total population at this time was greatly reduced (158 possums).

Emergent biological properties

Distribution of age at death for the simulated population

The distribution of age at death for the simulated population is shown in Figure 52. The greatest percentage of dead possums was one year old animals with a slightly lower percent of animals less than 6 months old. The curve is skewed to the right with the majority of dead possums (80%) aged between 0 and 2 years of age.

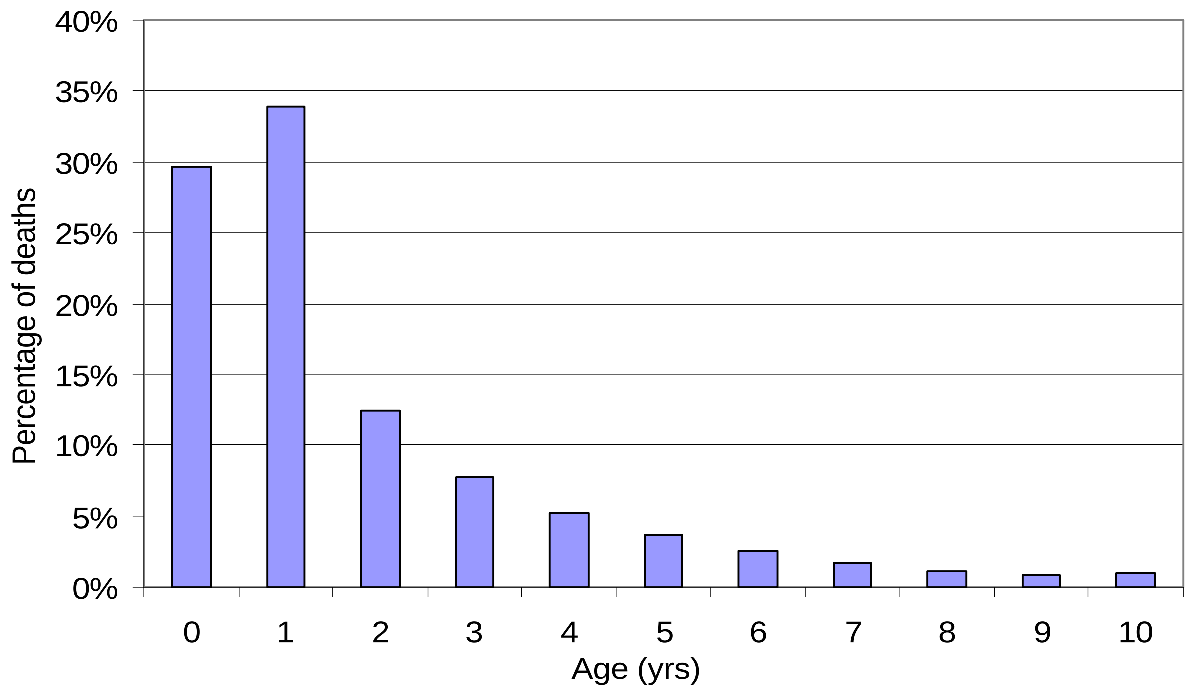

Figure 52. Distribution of age at death for the high density simulated population.

Removal of immigration

The effect of turning immigration on and off on the simulated population is shown in Figure 53. With no immigration the simulated population decreased by 6% relative to the simulation that included immigration, with a very gradual decline in population size over time. The removal of immigration from the Castlepoint population had a more pronounced effect, the population dropped off quickly and by the end of 2 years was 53% of the original size.

There are three mechanisms operating on the population: inwards movement of juveniles, outwards movements of juveniles and disappearances. This chart only shows the effect of removing the inwards movements of juveniles. An issue with the Castlepoint population is the reduced trap ability of possums when the population density is reduced.

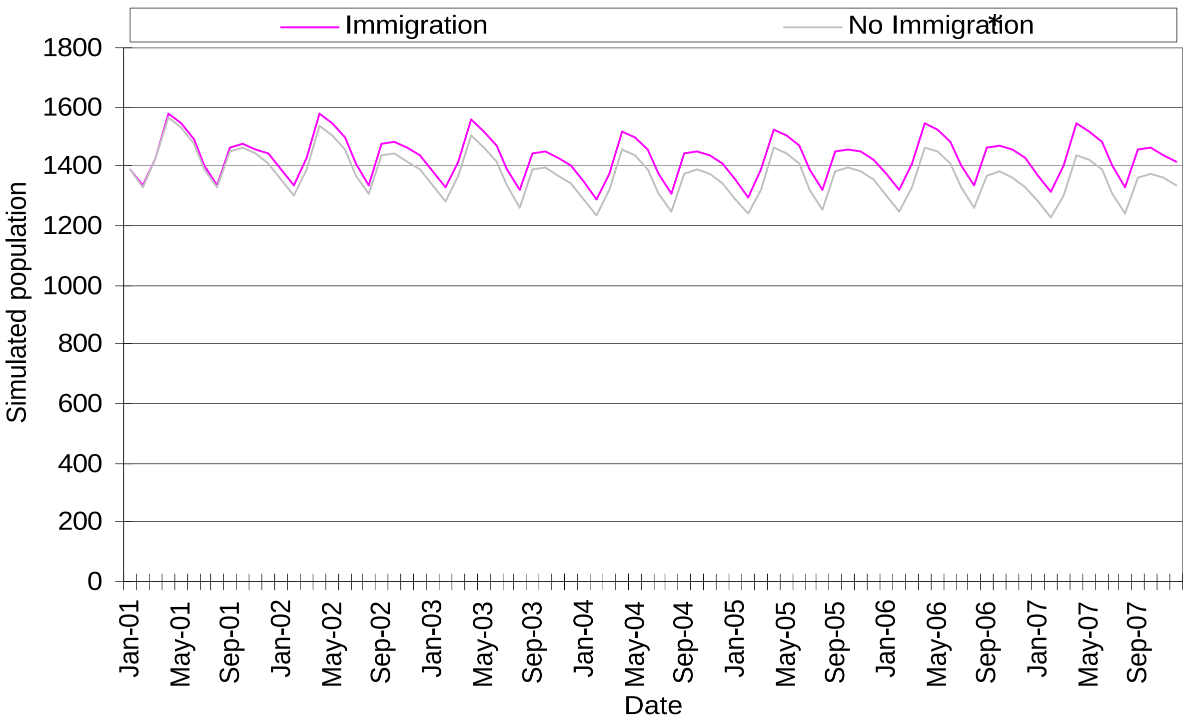

Figure 53. Comparison of the simulated population with and without immigration.

Discussion

Population stability and dynamics

The 11-year longitudinal study has provided data on longer-term temporal population patterns in a natural possum population located in dense scrub on farmland in the southeast of the North Island, known as Castlepoint. While PossPOP was developed from data collected during the first 2 years of this study, the remaining nine years provided a useful data set against which to validate the model. The nine years included cyclical population patterns, likely to be related to climatic effects. The study population underwent a major cull in year 5 with subsequent population regrowth, and the population controlled in the area surrounding the study site in the final 2 years. Although PossPOP has been designed to include the effect of annual climatic patterns on the population dynamics in the form of ‘good’, ‘average’ and ‘bad’ years, the model runs conducted for the validation were set for ‘average’ years. An assessment of the year types in the longitudinal study were made through a subjective exploration of population patterns in the longitudinal study together with knowledge of the climate during the course of the study. It was found that years 3 to 4 were ‘average’ years when compared with years 1 to 2 which were ‘bad’ years and 5 to 6 which were ‘good’ years. The data from years 3 to 4 are thus the most appropriate against which to validate the dynamics of the modelled population that was run for 'average' years. Data from the cull and subsequent population regrowth and the period of culling in the surrounding area provide variant data sets which were used to investigate emergent properties of PossPOP under conditions of perturbation, adding further strength to the validation process.

In this study only visual comparisons were used to validate PossPOP against the field data. Mayer and Butler (1993) suggest that a number of validation techniques are required to "appreciate the whole picture". While statistical analyses such as t-tests or deviance measures such as the mean absolute error (MAE) could have added strength to the validation of PossPOP, these analyses were not undertaken due to time restrictions. We are confident that the visual comparisons have provided major insights into the performance of PossPOP. Critical areas of the model have been identified which need investigation as they may influence PossPOP's ability to accurately model bovine tuberculosis in the possum population.

PossPOP produced a stable population over a 10-year period when run at two different densities, indicating that the population regulating parameters in the model were balanced. Comparison with the population dynamics of the field population showed that the factors influencing population growth and decline in the model were balanced. However there were significant differences in some factors that influence growth and decline between the modelled and field population. The conception rate was over-estimated in the model, particularly during the spring period (Figure 48 and Figure 49), and immigration was under-estimated (Figure 50). Comparison of monthly population growth rates in the two populations showed that the seasonal decline in each population coincided in the winter months (Figure 40). However, there were differences in high population growth periods. The highest population growth phase for the Castlepoint population most commonly occurred during December – February, whereas that for the PossPOP population occurred in April and again in September. This pattern reflects the strong influence of the birth peaks in PossPOP and the lesser effect of immigration. Whereas the Castlepoint population peaks reflect a stronger effect of immigration with a lesser effect of births in April. The Castlepoint population had a consistent pattern of a significantly lower disappearance rate during February-March. However it was not reflected in the simulated population that had a slightly higher disappearance rate during this time (Figure 51). Overall the disappearance rate in the simulated population was slightly lower than that in the Castlepoint population. This effect combined with the low immigration rate to offset the high conception rate in the model population.

The comparison of the simulation run in which immigration was turned off (Figure 53) with the last 2 years of the longitudinal study (Figure 38) shows immigration is under-estimated in PossPOP. In the last 2 years of the longitudinal study possums in the area surrounding the study site were culled as a part of a regional possum control operation. Therefore this comparison needs to be interpreted with caution as the major reduction that occurred in the Castlepoint population during this period was not only due to reduced immigration but also to some of the possums in the study population, whose home ranges were on the outer edges of the study site, being killed in the control operation. This was reflected in the higher disappearance rate during this period compared with previous years (Figure 51).

The differences in immigration and conception rates could have significant implications when modelling the dynamics of bovine tuberculosis within PossPOP. The low immigration rate could result in under-representation of TB infection in immigrant possums. This would have a particularly significant effect when modelling at the small geographic scale used in PossPOP. The high conception rate could result in an over-estimation of TB transmission via contact due to mating. Both these components of PossPOP need to be investigated, and if necessary adjusted so that they more closely reflect patterns in the field population. The slight difference in disappearance rate is unlikely to have a major effect on the dynamics of TB in the modelled population.

Population re-building after a cull

The pattern of population re-building following a major cull (95% - 99% population reduction) differed between the PossPOP and Castlepoint populations (Figure 37 and Figure 38). A much higher than normal spring conception rate followed the cull in the field population (Figure 48) and contributed to this rapid population re-growth. The Castlepoint population had an extremely high growth rate immediately following the cull (Figure 50), this is believed to be due to adult possums on the periphery of the study site expanding their home ranges into the site (Corner et al., In press). In contrast the PossPOP population increased much more slowly in a linear fashion and took 5 years to return to two thirds of its pre-cull population size. While the monthly growth rate of the two populations became similar after a period of 4 months (Figure 41), the initial surge in the Castlepoint population led to the population recovering in a much shorter time than the PossPOP population. This pattern reflects the fact that the population regulating parameters in PossPOP are set at the beginning of a run and do not change with natural population regulating factors such as local possum density. This is most noticeable in the low conception rate in the PossPOP population after the cull, which is most likely due to the mating distance being too small once the population has been reduced to a very low density after a major cull.

While PossPOP models a small geographic area, the pattern of population re-building after a cull is more representative of a cull over a large geographic area where the density of possums surrounding the smaller modelled area is low and thus immigration is low. The percentage of immigrants in the PossPOP population following the cull was significantly higher than that before the cull. PossPOP does not include the effect of range expanders after a population cull and therefore grossly over-estimated time taken for the population to return to its former size. This combined with the underestimation of juvenile immigration to produce a much lower population-rebuilding rate for a small area that has been subject to localised control when compared with such control of a natural population.

Population structure

Examination of the structure of the PossPOP population showed that the ratio of females to males in PossPOP matches published data. Efford (2000) writes, “the sex ratio of adult possum populations varies between moderately male biased and moderately female biased”. The Castlepoint population is male biased compared with the PossPOP population which is slightly female biased at 51.4% (moderate density population) and 50.1% (high density population) and therefore falls within the range determined through other studies. The Castlepoint population may appear male biased as males are more likely to be trapped (Coleman and Green W.Q., 1984). The bias of one sex in the population will have little impact on modelling dynamics of bovine tuberculosis, as there is no differentiation between the sexes in the disease module of PossPOP.

PossPOP appears to have a very high percentage of juveniles in the population (Figure 45) however this is due to the classification of juveniles in the model. Juveniles include all animals that are not yet sexually mature. PossPOP determines the age of a possum at sexual maturity by sampling a normal distribution that has a mean of 1.5 years and a minimum of 1 year and a maximum of 2. One would expect the percentage of possums new to the population in a year to be approximately 30%. However in this case a proportion of surviving possums born the previous year are also counted as juveniles thus increasing the percentage to approximately 50% (Figure 45).

Age distribution of dead possums

The age distribution of possums that died in PossPOP showed that the greatest percentage of deaths occurred in 1 year old animals (> 6 and < 18 months of age). This fits the pattern seen in field populations where survival of possums is low for those less than 1 year of age (Efford, 2000).

Optimum number of iterations

Due to the stochastic nature of the model, output varies between iterations. It is thus necessary to run the model for multiple iterations to capture this variability in output. A part of this validation process was to identify the optimum number of iterations, defined as the data set that contained the least variation around the mean while taking into account resource restrictions such as time. There was little reduction in variation between 10 and 15 iterations and therefore taking into consideration the time costs to run and summarise the data per iteration, 10 was selected as the optimum number of iterations.

In conclusion, validation of the population component of PossPOP has shown that the model performs consistently at moderate and high population densities and produces stable populations at the different densities. Comparison against an extended period of data from the Castlepoint field population and other published data of natural possum populations showed that the age and gender structure of the model population and the age distribution of dead possums were similar to that of natural populations. The study identified that while the population regulating parameters within PossPOP resulted in a stable population over time, the balance between immigration and births needs to be investigated as this could have a significant impact on the ability of PossPOP to accurately model TB dynamics and the effects of varying control strategies.

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CHAPTER 4

GENERAL DISCUSSION

This thesis is comprised of two independent studies that relate to different aspects of bovine tuberculosis (TB) control in New Zealand. The first study explored the attitudes of farmers with different TB status towards tuberculosis within five regions of New Zealand. The second study validated the population component of PossPOP, a simulation model of TB control in possums. Both studies produced results that have important implications for the national TB control strategy as described below.

Attitudes of New Zealand farmers to bovine tuberculosis

This survey included 404 farmers with a range of infected and uninfected deer and cattle enterprises from areas with varied TB histories (Chapter 2). The areas included a long-standing vector risk area (Wairarapa and Tararua), a relatively recently infected area (Rangitikei), a newly infected area (Motueka), and a TB-free area (Nelson). The broad mix of farmers and the high questionnaire return rate (76%) provide confidence that the results of the study represent a broad cross-section of farmer attitudes.

A combination of techniques was used in this survey to obtain a high return rate. All farmers selected to participate in the study were contacted prior posting of the questionnaire to obtain their agreement to participate in the study, reply paid envelopes were provided for participants to return their completed questionnaires and reminder letters were sent 3 and 6 weeks after the initial mail-out which included an additional copy of the questionnaire. Other researchers used one or more of these approaches such as Barnett (1999) who contacted farmers to attain their consent to participate in the survey by telephone before conducting a face-to-face interviews with farmers and Bourn and Newton (Bourn and Newton, 2000) who provided reply paid envelopes and sent reminder letters to participants.

There was a great deal of variation between farmers by area classification, enterprise type, TB status and region. The NPMS has been designed under the assumption that all clear or all infected farmers in particular areas should be treated the same. In the NPMS design herd type, herd TB status and area classification are taken into account when determining the frequency of herd TB testing while area classification is considered when implementing vector control programs (Animal Health Board Inc, 1995). In all other areas of the NPMS farmers are not differentiated by their location, farm type, herd TB status or area classification. The NPMS though successful is a “high resource input” scheme and as the number of infected herds decreases the benefits per dollar spent will decrease. Therefore the strategy must be revised to be as efficient as possible. The strategy must be tailored to those farmers that remain infected with TB and this can be achieved by taking into account the variations in farmers' attitudes.

The NPMS relies upon the cooperation and goodwill of farmers as indicated by the statement in the strategy document, "Your support for disease and vector control programmes is vital" (Animal Health Board, 2001). Many aspects of the strategy rely on the goodwill of farmers such as compliance with herd testing requirements, cooperation with livestock officers and observation of movement restrictions. Therefore if farmers feel that they are being represented in how the strategy is implemented the strategy will be more efficient by producing greater farmer co-operation. This can be achieved by incorporating farmers in the decision making process. Inclusion of farmers in the decision making process will result in the incorporation of adequate consideration of the variation between farmers into the design of the strategy.

The majority of farmers with infected herds believed that TB could be eradicated from their herds. Of infected farmers most (81%) believed that eradication of TB was crucial and could be achieved in their herd. However, there was generally a negative response to the proposed modifications to the strategy. The majority of farmers believed that the removal of compensation would result in slower eradication (53%) and direct payment for TB testing would slow the eradication process (67%), as farmers would not cooperate. These results closely correlate with those found by Sauter-Louis (2001) who conducted a face-to-face interview with farmers in the Wairarapa region to determine their attitudes towards the control of TB.

Attitudes of farmers to the degree of movement restrictions differed greatly from those found by Sauter-Louis (2001). In this study (for a mix of TB-free and infected areas) it was found that most of farmers wanted movement controls to remain the same (47%) or be more strict (38%). Sauter-Louis (2001) found in the Wairarapa (an infected area) nearly half of the farmers interviewed were in favour of less strict movement control. Farmers with clear herds who wanted stricter restrictions were concerned about the risk of infection to their herds and wanted to avoid infection. Infected herd owners who wanted restrictions to remain the same were more concerned with the containment of infection to areas already infected. Farmers appear to be driven by their own situation, for clear farmers it is to remain clear and for infected farmers it is to prevent spread of infection while allowing stock movement to continue.

Farmers' showed confusion when questioned on which organisation they believed was responsible for eradication of TB. Many institutions and organisations were selected with no organisation mentioned more frequently than the others. Sauter-Louis (2001) also found this pattern of response. A majority of farmers in the study did not identify the Animal Health Board (AHB), which has the responsibility for management of TB in New Zealand, in this role. This result may have been influenced by the way in which the organisations were listed in the questionnaire. The Animal Health Board (AHB) and AgriQuality were grouped together as one, which may have led to some confusion amongst participants. However, the results suggest that the AHB needs to increase its farmer profile.

More farmers saw "all farmers" (16%) as being responsible for eradicating TB from infected herds than believed it was the responsibility solely of infected farmers (6%). This study concurs with the findings of Sauter-Louis (2001) in that farmers see TB eradication as a national effort rather than an individual effort.

Farmers identified vectors as being important in the spread of bovine tuberculosis. A reduction in the prevalence of tuberculosis in wildlife vector populations will aid in the reduction of the number of infected herds in New Zealand. Farmers in newly infected areas when compared with farmers from long term clear or infected areas showed a clear distinction in views on methods of national TB eradication in order to combat the spread of TB by vectors. Farmers in newly infected areas saw TB being eradicated from New Zealand by funding groups and organisations that provide services to farmers such as vector control whereas farmers in clear and infected areas more commonly believed a possum bounty would have a significant effect on the control of TB in New Zealand.

A number of respondents expressed a desire to receive information about the TB programme in a format that they could understand. It is clear from the survey that while most farmers are optimistic about the ability to eradicate TB and support the current TB control programme, they require more information on measures that they can take to reduce the risk of TB in their herd.

Validation of PossPOP, a stochastic simulation model

PossPOP is a simulation model of TB in possums that was developed from the first 2 years of data from the 11-year longitudinal study of TB in possums conducted at Castlepoint during the years 1989 – 2000 (Corner, 2001). Pfeiffer (1994) verified and preliminary validated PossPOP, however due to insufficient data the model output was tested against an "antithetic run" where the simulation was run using random variates. Since that time the model has been advanced and has greater agreement when compared with field data.

While it is generally agreed that model validation should be conducted using an independent data set (Anderson, 1974), there is still no sufficiently detailed data, (which includes spatial patterns of TB in possums and habitat data), available for any site other than Castlepoint. Data from the nine years of the study following the period used to develop the model provided a useful data set for validation. While the test data originated from the same geographic location there were significant variations in climate and resulting variations in population patterns during the subsequent period that could be used to validate the patterns in the model. In addition, a major population cull in year 5 of the study and subsequent rebuilding period plus a period of culling in the area surrounding the study site provided variant data sets against which emergent properties of the model could be validated under conditions of perturbation, adding further strength to the validation process. This study involved validation of the population component of the model (Chapter 3). The disease component will be validated in a subsequent study.

PossPOP produced a stable population over time at two different densities and in a manner that was generally consistent with the field population. Detailed investigation of the individual factors contributing to population dynamics showed that while the factors contributing to population growth and decline in the model were balanced there were some significant differences between the simulated and field populations. Conception rate was overestimated in the model population and this was balanced by an underestimated immigration rate. The number of immigrants is based on a Poisson probability distribution of the number of immigrants per month (Pfeiffer, 1994). We determined that the distribution was based on numbers of immigrants, rather than the number of immigrants as a proportion of the whole population. Therefore when the population size increased the number of immigrants remained the same. This can be rectified by altering the scale of immigration to act as a proportion of the population size.

PossPOP has provided insights into population rebuilding after a major population cull. The pattern of population rebuilding after a cull was found to differ between the field and PossPOP populations (Chapter 3). The field population showed a dramatic initial increase in population size that was most likely due to the inward movement of possums from the periphery of the study site. This is not considered to be immigration as defined in the model, as the possums involved in this initial growth phase most likely had a part of their home range overlapping the study site (Efford, 2000). Immigration in the model is considered to be a possum moving to another area to establish a new home range. This range expansion of boundary possums following a cull is not included in PossPOP, which assumes that the modelled area is part of a larger area all arranged the same. While the monthly growth rate of the two populations became similar after a period of 4 months (Chapter 3, Figure 10), the initial surge in the Castlepoint population led to the population recovering in a much shorter time compared with the model population. While PossPOP models a small geographic area, the pattern of population re-building following a cull is more representative of a cull over a large geographic area, where the large area of low density results in a much lower immigration rate. It less accurately models the rebuilding process following a cull on the perimeter of an operational area where range expansion is more likely to occur.

The difference in population rebuilding following a cull can be partially explained by the rigidity of the population regulating parameters in the model. The population behaves according to the parameters set at the beginning of the simulation run with den availability being the only population-regulating factor operating during a model run. Immigration, conception and death rates do not change even when the population is drastically reduced. This was most noticeable in the low conception rate in the PossPOP population following the cull, which was most likely due to the mating distance being too small once the population had been reduced to a very low density.

Of all the factors influencing population dynamics, the differences in immigration are likely to have the most significant effect when modelling the effects of culling programs on the dynamics of TB in the model population. The insights gained in this study have led to a clearer understanding of the field situation that is being represented by the model and are important to interpreting model output. The PossPOP population structure was not only similar to the field population against which it was validated but also agreed with published data. The percentage of females in the simulated population of 51.4% was similar to that reported by Efford (2000) who found that the “sex ratio of adult possums varies between moderately male-biased to moderately female-biased”.

The distribution of the age at which possums died in the modelled population showed that animals in their first 18 months have the highest mortality rate. This was similar to that reported by Efford (2000) who found that mortality was high for possums 1 year of age. This adds to developing confidence in the model.

Directions for further research

The investigation of farmer's attitudes provided insight into differences seen between regions, enterprise types, TB status and are classifications. This investigation could be refined to determine how farmers believe the NPMS should be run in a effort to include farmers in the decision making process.

PossPOP has been partially validated in the work covered in this thesis. There is additional work to be completed on the model before the next phase of validation. Areas that were identified as being in error such as, the poisson distribution for determining the monthly number of immigrants which used numbers of possums rather than a proportion of the population. Once these areas have been addressed then there is scope to validate both the disease portion of the model and also the effect of control strategies. Both these areas are vital in order to produce confidence in the model in its entirety and in decisions made based on the output.

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Appendix 1 – Questionnaire

A copy of the questionnaire mailed to cattle and deer farmers in Rangitikei, Tararua, Nelson and Motueka in 2000.

CONFIDENTIAL

TUBERCULOSIS QUESTIONNAIRE

Further to my telephone call, thank you very much for your co-operation in our study. I would like to request your personal help in efforts to further strengthen the national TB control program, by completing the attached questionnaire. Your farm has been specially selected for this study.

Reasons for the questionnaire:

This study is being undertaken as part of a masters degree, conducted by researchers at the EpiCentre, Institute of Veterinary, Animal & Biomedical Sciences at Massey University.

Tuberculosis is a major problem in New Zealand at the present time. Although the number of infected herds of cattle and deer are rapidly decreasing, a worrying number of farms continue to have on-going TB problems - despite active efforts to control the source in wildlife. A project to offer intensified support for individual farms with TB problems was conducted on 35 farms in the Wairarapa district by Dr. Carola Sauter-Louis under the supervision of Professor Roger Morris. Some interesting results have been found from that study, which show that increased advice can help farmers get off movement control, as a result, we want to get the views of farmers in two additional regions, Rangitikei and Tararua.

The aim of the questionnaire is to obtain information on general farm management practices and attitudes regarding TB control. The information collected will be used to develop and refine TB management recommendations to farmers to achieve better TB control.

Confidentiality of information supplied:

We assure you that all information you provide in the questionnaire will only be used for research purposes by the EpiCentre, Massey University, and will not be published in any form that would allow identification of any individual or property. We will also ensure that you receive feedback on the results of the study.

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Questionnaire: TB control and farm management practices

Name:

Date: ______/_______/_______

Introduction and general farm information

(Please write your responses in the white areas of the questionnaire)

What is the size of your farm? Please fill in the size of your farm (both total size and effective size) and other land used by you. (Where stock is shifted by truck, land is classified as ‘Other’, please indicate the distance, in km, from your home property to these areas)

		Total size (in ha)	Effective size (in ha)	Distance from home property (in km)
Owned Land	Main property			
	Other owned land			
Leased land	Locally leased			
	Other leased land			

2. How many labour units are working on the farm?

Full-time workers_____________

Part-time workers_____________

3.Which of the following categories describe your enterprise type (multiple answers are possible, please give approximate percentage of total farm income)

Enterprise type ✝	*% of gross farm income*
Cattle breeding ☐	
Cattle finishing ☐	
Dairy herd ☐ Town supply ☐ Seasonal supply ☐	
Sheep flock ☐	
Deer breeding ☐	
Deer finishing ☐	
Velvetting deer operation ☐	
Others (e.g. goats, pigs, plantations) ☐ Please specify:__________________	

4. How many animals do you run on your farm? (Please give the numbers as at the 30th June 1999 for each of the groups)

Species	Sex	Age 0 –1 Year June 1999	Age 1-2 Years June 1999	Age > 2 Years June 1999
Cattle	Female			
	Male			
Deer	Female			
	Male			
Sheep	Ewes			
	Hoggets			
	Rams			
Others				

5. Current TB status of your herd: (Infected means the herd has the status "I" at present in the AHB system of herd classification.)

	Infected
Cattle	Yes ☐ No ☐
Deer	Yes ☐ No ☐

6.Within the last 5 years were your cattle or deer at any time classified as a TB infected herd?

Yes ☐ No ☐

7.To your knowledge within the last 5 years, was any of your neighbours' stock classified as infected with TB?

Yes ☐ No ☐

8. How important is off-farm grazing to your farm?

Crucial	Important	Moderately	Minor	Not important at all
☐	☐	☐	☐	☐

9. How important is trading of cattle and deer (e.g. through private sales, yard sales, but not to slaughter) to your farm?

Crucial	Important	Moderately	Minor	Not important at all
☐	☐	☐	☐	☐

10. How do you replace your herd? Please tick the appropriate box and indicate the percentage each type contributes to the total breeding replacement of your herd.

	Female replacements		Makes up for ____ % of total replacement	
	Cattle	Deer	Cattle	Deer
Own breeding			%	%
Buying in			%	%
Other (please specify) ____________________			%	%

11. How often do you purchase cattle/deer?

Every year ☐ every now and then ☐ never ☐ other (please specify) ☐ ______________________

12. From how many herds do you buy cattle/deer in a normal year?

1 to 3 herds ☐ more than 3 herds ☐ from sale yards or similar source ☐

13. Did you buy any white-tagged cattle/deer? Yes ☐ No ☐

If yes, what were your main reasons for buying white-tagged animals?

____

____

1a. Grazed in stock; if cattle/deer were grazed-in over the last 12 months, please fill in the following questions

14. Are cattle belonging to other owners grazed on your farm? Yes ☐ No ☐

15. From how many other farms do you receive grazed-in stock? ______________________

1b. Stock sent for off-farm grazing; if cattle/deer were grazed off farm over the last 12 months, please answer the following questions

16. Within the last 12 months, did you send any of your stock for off-farm grazing? Yes ☐ No ☐

17. What stock classes were sent for off-farm grazing? ______________________________

____

____

18. During what months are cattle grazed off farm? ______________________________

____

19. Did you assess the TB risk to these stock? Yes ☐ No ☐

If 'Yes' by what means?

____

____

2) Herds classified as TB infected in the last five years (if your herd has not been classified as infected turn to section 3)

20. Which of the following factors do you consider as having contributed to your current or past TB infection? (Please tick the box, if you think it contributed to your TB problem)

	Contributed? ✝
Bought-in cattle or deer	☐
Cattle/deer grazed on-farm	☐
Cattle/deer grazed off-farm	☐
Problems with TB-skin test	☐
Neighbours (incl. DOC and RC land)	☐
TB infected feral animals	☐
Others (please specify) ______________________	☐

21. How important is it to you to eradicate TB from your herd?

Crucial	Important	Moderately	Minor	Not important at all

22. Do you believe TB can be eradicated on your farm? Yes No Do not know

23. If 'no' what are the factors hindering the progress?

____

____

____

3) Attitudes

24. Who do you see as having responsibility for eradicating TB from infected farms? (tick them please and rank them in terms of your priority, with '1' being the highest priority.)

	Responsible?	*Priority*
All farmers		
Only farmers with the problem		
All landowners		
Government		
AgriQuality/AHB		
Regional council		
RAHC		
Local farming action group		
Local veterinarian		
DOC		
Others (please specify)		
______________________		

25. If you were asked to do your own TB control or preventative measures on your farm where would expect to get help from, and what would be your expectations about the nature of this help?

AgriQuality/AHB		______________________
Regional council		______________________
Government		______________________
RAHC		______________________
Neighbours		______________________
Veterinarian		______________________
Other (specify)		______________________
None		______________________
None of these, I would get out of farming cattle		

26. Do you think movements of cattle from MC farms should be more strictly controlled? (e.g., only animals to slaughter)

More strict Same Less strict Not known

Why?____

____

____

27. If compensation for reactors was removed altogether, what do you believe the effect on TB control would be?

TB eradication achieved Quicker ☐ Slower ☐ No change ☐

Why?____
____

28. Do you believe that control of TB in cattle would be achieved more quickly if cattle farmers, like deer farmers, had to pay testing costs directly? Yes ☐ No ☐ Do not know ☐

Why?____
____

29.Where do you think individual farm efforts could play an important role?

____
____
____
____

30. How do you see TB eradicated from NZ? What criteria/measures/incentives for farmers would you like to see being put into place?

____
____
____
____

31. How much do you spend annually on possum/ferret control for TB prevention control?

In terms of money?	$______________
In terms of time?	________________ hours

4) Farmer's personal details

32. Male ☐ Female ☐

33. What age group are you in? < 20 years ☐ 20 – 30 ☐ 30 – 40 ☐ 40 – 50 ☐ 50 – 60 ☐ >60 ☐

34. What is your relation to the property?

Owner ☐ Share milker ☐ Manager ☐ Other (please specify) ☐ ___________________________________

5) Permission for access to TB testing data from AgriQuality database

I give permission for Professor Roger Morris, Veterinary epidemiologist at Massey University to have access to my TB testing data from AgriQuality for 1998-1999 and previous seasons, for the specific purpose of relating findings in this questionnaire to herd TB history. The data will be treated confidentially and destroyed after analysis has been completed.

Signed:____

Comments: we would like to hear from you any comments or additional information on the current TB control Policy. What could be improved or what could be changed about the policy?

If you have any questions please feel free to contact me any time

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Institute of Veterinary, Animal and Biomedical Sciences
Massey University
Palmerston North

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021 114 5859 (evenings)

Thankyou very much for your cooperation, it is very much appreciated.