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A New Tb Surveillance Paradigm and Model for Game Estates

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Summary

Project and Client

Characterisation of game estates and modelling of the utility of potential sentinel species for Tb detection on such estates were investigated by Landcare Research, Lincoln, for the Animal Health Board (Project R-10615) between July 2003 and June 2004.

Objectives

- To determine the effectiveness of the current Tb surveillance system for game estates.
- To assess the likely cost, sensitivity, and utility of the complementary use of sentinels.

Methods

- All 12 game estates belonging to the New Zealand Association of Game Estates (NZAGE) were characterised by interviewing the owner or manager. Of the 12 estates surveyed, five were located within vector risk areas. This survey was also used to develop a picture of the 'total Tb surveillance effort' on each estate.
- A computer-based simulation model was developed to explore the potential utility of a complementary surveillance system, focussing in particular on the use of sentinel pigs (either resident or released).
- A new paradigm for Tb surveillance was developed by exploring the concept of complementing deer-based surveillance with information from possums and other species of wildlife.

Results

- Game estates in the NZAGE focussed primarily on hunting of trophy deer species (red and fallow deer being the most common). The size of hunting estates varied from 162 ha to 1800 ha, and averaged 756 ha.
- Ten of the 12 estate operators interviewed were happy to make trophy heads available for Tb assessment, when possible. On all estates, some non-trophy deer were culled each year, with an average of about one-third of the herd being killed each year. These culls would also be available for surveillance purposes. Most estates also undertook some form of vector (possum, ferret, cat) control.
- Eight of the 12 game estates had wild pigs present on the estate. Many of those pigs are either harvested or have the potential to be harvested. Eight estates were interested in the idea of released pigs as a Tb surveillance tool. The remaining four were unsure, but none completely ruled out the idea.
- Modelling of pig scavenging rates predicted that for estates of 400, 900 and 1600 ha (three areas chosen to cover slightly less than the range of areas of actual estates surveyed), an average of 5, 10, and 16 pigs, respectively, would need to be present as sentinels for five years to be 95% certain of detecting Tb in possums.
- The model also showed that there would be a 50% probability of Tb being detected after one year with 5, 8, and 12 pigs on estates of 400, 900, and 1600 ha respectively.
- A group of 10 released sentinel pigs would cost a minimum of $1000, and possibly up to $5000, plus the costs of recovery, necropsy, and mycobacterial culture.

Conclusions

- Given the professional nature of most of the estate operators interviewed, the AHB will meet little resistance developing formal Tb surveillance regimes for each estate.
- A key first question in defining the type of surveillance required on game estates is how much surveillance is needed to detect the presence of Tb in local wildlife. On similarly enclosed deer farms managed for venison production, the AHB by default accepts the level of surveillance provided by whatever density of deer the farmer chooses to hold. There is no discernible reason why game estates should be required to provide a different level of surveillance.
- Necropsy of trophy and cull animals provide an obvious 'first tier' of deer-based surveillance on game estates, but this will rarely provide the desired level of surveillance. A new paradigm of 'complementarity' is needed in which deer-based surveillance is augmented by 'second tier' information from other sentinel species.
- Possum surveys can provide the most direct measure of Tb presence, but their utility depends on prevailing density and necropsy and culture costs. Possum surveys would be most useful where possum populations are being maintained at low density by an annual kill, and where all killed possums are recovered for necropsy.
- Annual surveys of a high proportion of resident ferrets and resident pigs, where available in adequate numbers, would provide a high level of complementary surveillance.
- Use of released pigs as sentinels is likely to be more expensive than use of resident pigs or ferrets, but provides an option of last resort where other sentinels are scarce. The method has the potential to provide a high degree of certainty that Tb is absent, but requires retrieval of a high percentage of the released pigs.

Recommendations

- The AHB should decide formally what level of surveillance is required on game estates. We recommend that the 'default' level of surveillance required be set as a number of 'annual deer test equivalents' (based on the size of the deer herd and the testing frequency that would apply to that herd if it were managed as a conventional deer farm). Where the desired level of surveillance cannot be attained practicably by 'first tier' surveillance (direct testing or necropsy of the deer herd), we recommend implementation of a new paradigm of complementarity, based on 'equivalency' between sources of surveillance information.
- 'First tier' surveillance should be based on skin testing wherever practicable, backed up by necropsy and culture of trophy and cull animals. A system that takes into account the age (and therefore the length of exposure) of cull animals should be developed. Necropsy of a deer that has been present for several years provides more surveillance information than does a skin test of an animal that was skin tested the previous year.
- To make up the expected shortfall in total surveillance effort on game estates, the priorities should be as follows:
    1. Surveys of possums, at least where possum numbers are being maintained at low density through annual culls of 30-40% of the possum population;
    2. Surveys of resident pigs and ferrets, coupled with some assessment of the proportion of each population surveyed;
    3. Use of released sentinels.
- Because estates differ in the nature of their operations, and in the availability of alternative sentinels, we recommend that the AHB should develop estate-specific surveillance plans. This will require that the relative sensitivity of different species as sentinels is better quantified and explained to estate owners, because it is central to the concept of surveillance equivalency.

1. Introduction

Characterisation of game estates and modelling of the utility of potential sentinel species for Tb detection on such estates were investigated by Landcare Research, Lincoln, for the Animal Health Board (Project R-10615) between July 2003 and June 2004.

2. Background

The big-game hunting industry, which caters for recreational hunters, is increasingly valuable to the New Zealand economy (currently the industry contributes up to $15 million annually; J. Guild, pers. comm.). Some of these ‘safari operations’ or ‘game estates’ are effectively low-density deer farms, but at the other extreme they integrate into free-range operations in which the animals are not fully confined by fences. The current Tb surveillance system or protocol for such estates calls for post-mortem inspection of a high proportion of the deer population each year. Because animals on game estates are not easily mustered, sampling a high proportion of the herd is not always compatible with the primary aim of estate operators, which is to provide a ‘truly wild’ hunting experience for their clients. As a result, the protocol has not been applied with consistency.

The failure of the current surveillance protocol for game estates therefore creates a surveillance vacuum in which Tb could easily persist undetected for long periods. This means that Tb vector managers sometimes may have little direct information on Tb presence on game estates with which to guide their vector management programmes. Likewise, game estate operators who wish to know more about the Tb status of their herds cannot find this information easily. Initial contact with game estate operators was made by Kevin Crews (AHB National Disease Control Manager, central New Zealand). Landcare Research was then contracted by the AHB to (i) characterise the nature of individual game estates and the Tb surveillance conducted on them; (ii) model the utility of using released sentinels such as pigs as a first step in formalising a surveillance protocol suitable for individual estates; and (iii) to identify practical solutions to the inadequacies and inconsistency in current Tb surveillance on such properties.

3. Objectives

- To determine the effectiveness of the current Tb surveillance system for game estates.
- To assess the likely cost, sensitivity, and utility of the complementary use of sentinels.

4. Methods

4.1 Game estate characterisation

To determine the general nature of safari parks or hunting preserves, we focused on the New Zealand Association of Game Estates (NZAGE) as the sole national association of such operations. The NZAGE was founded in 1997 and currently has 12 members. Estates in the NZAGE are expected to adhere to a code of Industry Agreed Standards (IAS) that was developed in 1998. The IAS document covers aspects of game estate management such as sustainable land use, fair hunt, facilities for stock and for clients, personnel, equipment, sound commercial practice, and animal health. For the latter, operators are expected to 'manage or remedy disease conditions'. Bovine Tb is specifically mentioned, with the requirement to keep records of all animal movements for disease control purposes, Tb testing records, and records of wild animal control. On many estates, the trophy animals provided are often reared elsewhere, then brought in and released. The IAS requires that these releases come from properties that have had clear whole-herd Tb tests for at least 2 years (C2).

Seven of the game estates were visited and the owner or manager interviewed in person, while the managers of a further five were interviewed by telephone. Each operator interviewed was asked the following questions:

1. Is your estate located inside a VRA?
2. What is the size of your fenced enclosure?
3. What types of habitat are found in your enclosure (bush, tussock, etc.)?
4. Which game species are present on your estate?
5. What is the size of the herds for each of the species?
6. How rapid is the turnover of each species (annual, biannual etc.), i.e. how long is each population inside the enclosure?
7. What is the fate of individual animals (left in situ, go to taxidermist, etc). Could carcasses be placed in a farm chiller for later inspection of the nodes of interest?
8. Which wildlife species are present on your property (feral pigs, possums, ferrets, feral cats, others)?
9. What is your response to the use of sentinel species, particularly pigs, as part of your overall Tb surveillance?
10. What are the grazing regimes and grazing unit equivalents on your property? Do you graze cattle inside your fenced enclosure?
11. Any other notes or comments.

The answers to these questions were used to develop a picture of the 'total Tb surveillance effort' on each estate by qualitatively assessing the potential contribution of different aspects of surveillance such as the fate of trophy and cull animals, presence of resident sentinels, and current levels of vector control, taking into account the abundance of animals, and acceptance by estate managers/owners of each method of surveillance.

We focussed in particular on the presence (and abundance) or absence of two key sentinel species (pigs and ferrets) on estates, and the acceptability and practicality of a surveillance system based on surveys of resident pigs or ferrets, or of released pigs when residents are absent. We also documented any difficulties involved in undertaking surveillance using hunter-killed animals, where they were identified.

As the responses from operators include some commercially sensitive information, property-specific summaries of their responses are not included in this report, but will be provided in confidence to the Animal Health Board as a separate appendix not for public release.

4.2 Modelling – the sensitivity of sentinel pigs

To explore the utility of a complementary surveillance system based on use of sentinel pigs (either resident or released) we developed a computer-based simulation model. The objective of this modelling was to predict the number of pigs needed to have a high probability of detecting the presence of Tb in the wildlife on a particular estate, assuming that pigs become infected through scavenging the carcasses of possums (or any other animals) that have died of Tb. A related question was to determine the minimum time to detection of Tb for a given sample size of sentinel pigs. The accuracy of the model's predictions obviously depends very largely on the accuracy of the key assumptions that underpin it. Some of the empirical data underpinning these key assumptions are sparse, so our predictions are of necessity provisional.

A stochastic spatial model of pig movements was developed. This model, 'PigDetect', represents pig home ranges in two-dimensional space. Pig home range utilisation in the model conformed to a circular bivariate normal distribution and ranges in the model were allowed to overlap at random (because it is uncertain how ranges of released pigs might be arranged in an actual game estate situation). The model also simulated the presence of a single, randomly located focus of infection in possums that produced two infected possum carcasses per year. Model pigs could 'scavenge' possum carcasses if the carcasses fell within the pig's home range. The probability that an individual pig scavenged a carcass declined as a half-normal function of the distance between the carcass and the centre of the pig's home range (Fig. 1).

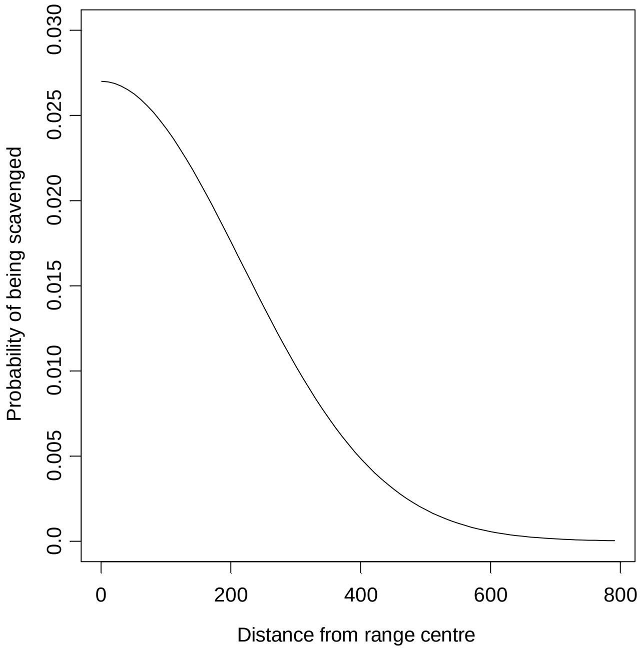

Fig. 1 Probability of a carcass being scavenged as a function of distance from the centre of an individual pig's home range.

The half-normal function has two parameters: g(0), representing the probability of a carcass located in the centre of a pig's range being scavenged, and σ, an index of home range size. Since pig home ranges overlapped, one carcass could be exposed to multiple pigs. Hence the model allowed pigs to 'compete' for possum carcasses by assuming that scavenging events occurred in continuous time and followed a stochastic Poisson process. Once a carcass was 'scavenged' by an individual pig, that carcass was no longer available to be scavenged by other pigs. (This is likely to be a conservative assumption, which we discuss further in section 6.1).

The infectivity of simulated possum carcasses was also assumed to decline at a constant rate based on the rate of decay of possum carcasses at Mt White, Canterbury, in winter (Barber 2004). Carcasses older than approximately 42 days (i.e. about 50–75% decayed) were deemed not to contain viable Tb and, hence, scavenging by pigs did not result in Tb infection.

Field estimates of the parameters g(0) and σ came from two sources. We used information about movements of radio-collared pigs collected at a site near Lake Taupo as part of project R-10558 (Nugent et al. 2004) for the likely size of, and variation in, pig home ranges. The estimate of the scavenging probability g(0) was calculated from detailed data on the scavenging rate of possum carcasses by pigs placed at known locations at the Mt White site (Barber 2004). An estimate of g(0) was made from these data by simulating the scavenging rate of pigs with a known g(0) and finding the value of g(0) that matched the observed scavenging rate from the Mt White data using inverse prediction methods. The simulated scavenging rate using this estimate of g(0) slightly underestimated the observed scavenging rate up to about 40 days (Fig. 2). Imprecision in this relationship occurs because of uncertainty in the estimates of pig density at Mt White (6–10 pigs/km^2). Hence we conducted inverse prediction over a range of pig densities and incorporated this uncertainty in the estimate of g(0) into the simulations.

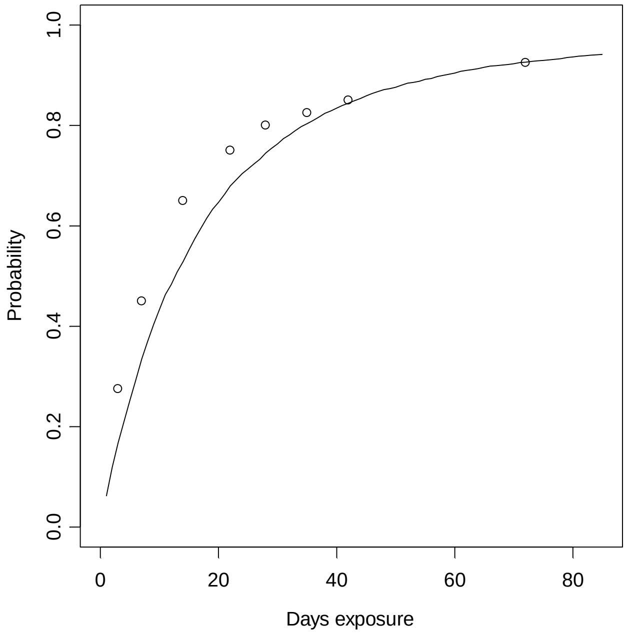

Fig. 2 Observed probability of a possum carcass being scavenged (open circles) and simulated probability of a possum being scavenged (line) as a function of the number of days the carcass was exposed. Observed data were the scavenging probabilities estimated from a trial at Mt White (Barber 2004).

We simulated the release of between 1 and 20 Tb-free sentinel pigs on to game estates of either 400, 900 or 1600 ha in size, covering the range of actual areas of game estates we investigated. We simulated scavenging of possum carcasses (two carcasses per year, subject to decay) for each sample size of sentinel pigs left in situ over 5 years, for each of 1000 replicates. For each sample size of sentinel pigs we determined:

1. The probability that at least one pig acquires Tb infection if sampled at the end of 5 years, averaged over the 1000 replicate simulations.
2. The minimum time for at least one pig to acquire Tb infection, averaged over the 1000 replicates.
3. The proportion of the initial number of released pigs that would need to be retrieved and tested at various intervals following release.

4.3 Likely costs and utility of sentinels

The likely costs and utility of using complementary sentinel species were assessed from past experience with sentinel pig releases (Nugent et al. 2002; Nugent et al. 2003a,b; Yockney & Nugent 2002 unpubl. data) as well as current sentinel pig work (AHB contract R-10558). The idea of deliberately released sentinel ferrets was not pursued further primarily because of the legal complexities of deliberately releasing ferrets following a recent law change prohibiting this, coupled with the practicality of release and subsequent radio-tracking of ferrets in some of the estates and the difficulty of ensuring that ferrets remained within the estate, especially those in the North Island where ferrets are not normally present.

5. Results

5.1 Game estate characterisation

Game estates in the NZAGE focus primarily on hunting of trophy deer species (red and fallow deer being the most common, followed by wapiti (elk), sika, rusa, and sambar deer, depending on the region of the country; Table 1). Most estates also have small numbers of other more ‘unusual’ game species (e.g. Arapawa sheep and water buffalo; Table 1).

Table 1 Range of species, average (and range) of herd size, and annual average and total turnover (number of animals culled annually) on the 12 estates surveyed. These data are approximations only as accurate figures could not always be provided, and on some estates only pooled total turnover across species was provided, from which we made best guesses.

Species	Estates (*N*)	Herd size Mean (range)	Annual turnover (Mean)	Annual turnover (Total)
Red	12	227 (30–400)	70	955
Fallow	11	139 (11–500)	30	327
Sika	4	50 (2–150)	11	44
Arapawa rams	1	40 (-)	40	40
Rusa	2	20 (15–25)	17	35
Elk/Wapiti	6	6 (2–12)	6	34
Wild cattle	1	40 (-)	15	15
Sambar	3	19 (15–25)	3	10
Water buffalo	2	9 (3–18)	3	5
Wild boar	1	5 (-)	5	5

The detailed (and confidential) responses to our survey are summarised in a separate Appendix. The size of hunting estates varied from 162 ha to 1800 ha, and averaged 756 ha. Of the 12 estates surveyed, five were located within vector risk areas.. Eight were amenable to the use of released pigs as a Tb surveillance tool. The remaining four were unsure, but none completely ruled out the idea.

5.2 Current levels of surveillance on game estates

Trophy stags

Most trophy stags on the estates surveyed were brought in on a seasonal basis just for the hunting season. Stags are generally brought in from known Tb-free herds, or from the operators’ own farm herd bred for this purpose. There are obvious problems with Tb-testing trophy stags prior to release in the estate, because the large shaved neck is not acceptable to clients. One option might be to blood-test these animals prior to release, but trophy stags released on the estate provide generally only short-term surveillance due to the limited time that they typically spend on the estate (usually less than 4 months). However, the key lymph nodes contained in these stags’ heads would be available for inspection. Only two of the 12 estate operators interviewed left trophy carcasses in situ and were reluctant to make the heads available for assessment.

Cull animals

All of the estates interviewed routinely cull deer herds with some operations turning over a large proportion of their herd annually. With the fluctuating venison schedule and difficulties selling cull animals (especially in the South Island), the potential for Tb surveillance through meat inspection at works is diminishing. However, estate managers were generally proactive in testing cull animals and, if this was not already part of their surveillance practice, most of those surveyed were amenable to having at least the heads inspected. One estate in particular has approximately 10 years' data on every carcass (necropsied by a professional) that has been shot on the property. Two further estates currently cull a large number of animals (120–150) annually.

Other species

Eight of the twelve game estates had wild pigs present within the estate. Many of those pigs are either harvested or have the potential to be harvested. Typically 4–12 pigs are shot on each estate per year, with 25–30 pigs per year being the highest number shot on one of the estates. Several of the estates with wild pigs present commented on the pigs 'cleaning up' the gut piles left when deer species are killed and butchered. Wild pigs are also easily harvested on those estates that use grain feeders (typically maize) for either supplementary deer feed or for game birds present on the estate.

Half of the estates (6 of 12) also grazed cattle within the deer blocks. All cattle grazed in such a regime are Tb-tested prior to going into the deer-fenced blocks and again after being in the block, thereby providing additional surveillance. Two estates had Asian water buffalo (which were Tb-tested annually) and one estate had wild cattle (a proportion of which were shot).

Ferret, cat, and possum control was often undertaken, but with no great consistency (depending on species present, recency of control, and planned control operations by regional councils). However, most estates undertook some form of vector control, either through local initiatives or as part of the routine pest control on the property. Typically more ferrets were obtained on South Island estates and more possums on North Island estates; generally these animals are not inspected as part of the estates' current surveillance programmes. Numbers of wildlife vectors obtained on most estates were generally low. Of the 12 estates, three removed a reasonably large number of possums annually (more than 200). None removed more than a few ferrets. A further two estates culled a moderate number of possums (20–30). Another two normally undertook intensive vector control, but had put this on hold because of large-scale poison operations planned for their areas.

5.3 Response to sentinel species

The response of estate owners/operators to pigs as sentinel species was generally positive. The idea of ferrets as sentinels was not favoured in any context other than through routine control of resident animals already present (in some cases, particularly the North Island estates, it was not appropriate to discuss the issue of using sentinel ferrets and we used our discretion here). One-third of operators (4 of 12) were unsure about using released pigs as sentinels on their properties. This uncertainty was due either to wild pigs not being present in the area, the perceived 'wandering nature' of pigs, or perceived problems the release of sentinel pigs might cause with neighbouring properties, particularly if pigs were not already present. Generally, operators were agreeable to the use of pigs as sentinels and could see the merit of such a system as a surveillance tool, especially when combined with sampling of resident pigs. Most preferred to have 'wild type' sentinel pigs released with minimal or no identifying features (e.g. ear tags or radio-collars) so as not to detract from the estate's wild situation. One operator had no problem with visible radio-tags on pigs' ears.

5.4 Modelling – the sensitivity of sentinel pigs

The probabilities of at least one pig acquiring Tb infection over a period of five years as the number of released sentinel pigs increased are given in Fig. 3 for game estates of three different sizes. Assuming that all the released pigs remain present and are recovered, a 95% probability of one pig detecting Tb within 5 years was reached for sample sizes of 5, 10 and 16 sentinel pigs on estates of 400, 900 and 1600 ha respectively. Over 5 years, there was near certainty of at least one pig (from an initial 10 released) becoming infected in 400 ha, one of 15 released pigs in 900 ha, and one of 20 released pigs in 1600 ha. Expressing this another way, estates of 400, 900 and 1600 ha would need to maintain an average of 10, 15, and 20 pigs present as sentinels for 5 years to be certain that at the minimum possible level of Tb presence in possums, infection would be passed to at least one pig.

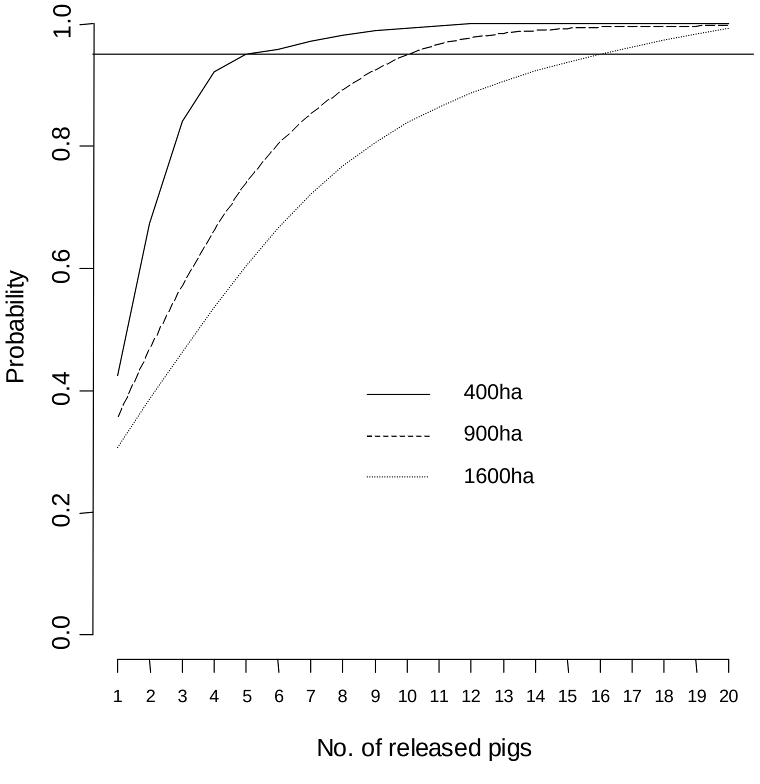

Fig. 3 Probability of at least one released sentinel pig acquiring Tb infection over 5 years for varying numbers of released pigs for game estates of either 400, 900 or 1600 ha. Horizontal line represents a probability of 0.95 for detecting Tb presence.

The predicted median time to first infection in the released pigs, assuming disease is present in possums (across 1000 iterations of the model), is shown in Fig. 4a. Times to first infection increased as property size increased, and declined as the number of released pigs increased. The median figures effectively represent 50% probabilities of infection. For example, in 50% of simulations at least one pig had become infected after one year when five pigs were released into a 400-ha estate (left arrow, Fig. 4a). Likewise, Fig. 4b shows 78.5% detection probabilities. For 400-ha estates, for example, there is a 78.5% chance of Tb being detected within 2 years if six pigs were present in that time period.

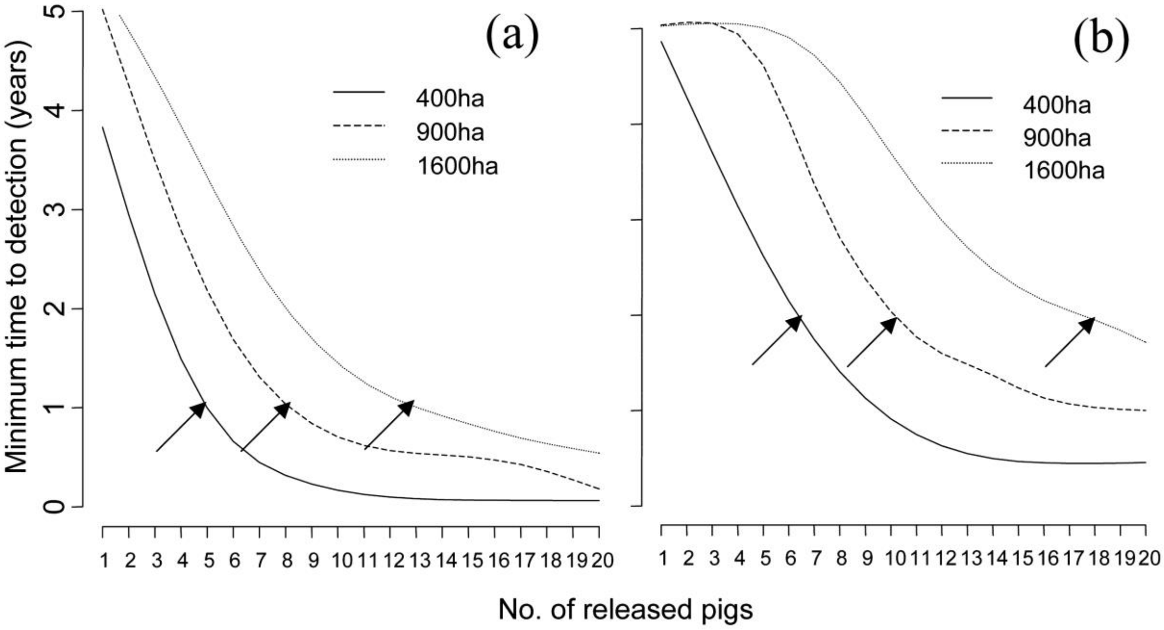

Fig. 4 (a) Median (50% percentile) and (b) 78.5% percentile times to first infection (= minimum time to detection of Tb) in 1000 iterations of the model for each of 1–20 pigs released into each of three simulated game estate sizes (400, 900 or 1600 ha). Arrows show the number of pigs required to be released on each estate size for Tb to be detected (a) after 1 year with 50% probability and (b) after 2 years with 78.5% probability.

With 20 pigs released into a 400-ha estate, at least one pig became infected within 1 year in 97.5% of iterations; i.e. there was a 97.5% annual detection probability under this scenario. For 1600-ha estates, release of 12 or 13 pigs would provide a 50% annual detection probability (right arrow, Fig. 4a). However, if those same pigs were left in situ (i.e. not replaced annually with new releases), pigs failed to detect Tb in about 2% of iterations of the model after 5 years even with 20 pigs released. This failure to detect Tb stems largely from the artificial stability of both the home range centre of the pigs (i.e. the 20 pigs simulated had no change in the location of their home range centre over the 5 years) and in the location of the Tb focus. Basically, where the model failed to detect Tb, there was, by chance, no overlap between pig home ranges and the location of Tb in possums. This stability is extremely unlikely in nature, and in practical terms can be overcome simply by ‘resetting the detector array’; i.e. by removing released pigs (and necropsying them) and then replacing them with the same number of new releases on an ongoing annual basis. Doing so would increase the probability of detection of Tb on a 1600-ha estate with 20 released pigs to close to 90% in 3 years. This prediction is based on total recovery of all pigs at the end of the first year. In reality, however, some pigs are likely to die or escape and not be recovered. The number of pigs needed to detect Tb within the space of a year would need to be increased so that the number of years of exposure actually sampled by those recovered matches the predicted sample sizes above (i.e., 20 pig-years of exposure annually).

5.5 Likely costs of using released pigs as sentinels

Young wild pigs can be bought for a basic cost of $100. The costs of using these as sentinel pigs for surveillance depends on whether locally caught pigs are readily available, whether castration of the pigs is required, and whether the pigs are radio-tagged to facilitate recovery. If castration is required, a veterinarian should be able to complete the surgery for about $100.

The need to radio-track released pigs to facilitate their later recovery is a key cost question. In an estate with pig-proof fences, the pigs are likely to remain within the estate, and could be recovered as part of normal hunting activities – although there is less likelihood of recovery of the released pigs at specified times, it is likely that, in smaller estates in particular, most pigs could be recovered more or less on demand. Radio transmitters cost around $350 and can be made up as eartags (which sometimes break off; Nugent et al. 2004) or as implants (which are more costly because implantation requires surgical procedures and incurs the veterinary costs related to that). Eartag transmitters may not be acceptable on some estates because their visibility could detract from the image of 'wildness' that estates often try to evoke. However, this might be minimised by using dull 'pig-coloured' tags. Overall, use of radio transmitters is likely to add about $400–$450 to the cost of a sentinel (including the labour costs of fitting transmitters), plus the capital cost of a receiver ($1500).

To summarise: key costs to be taken into account in determining the cost of a released sentinel pig are:
- Obtaining wild pigs locally (minimum $100 per pig).
- Radio transmitter ($350 per pig, exclusive of labour).
- Castration if required ($100 per pig).

In total, a group of 10 released sentinel pigs would therefore cost a minimum of $1000, and possibly up to $5000, plus the costs of recovery and necropsy. The latter is typically about $30–$50 per pig, and we assume recovery would be by estate staff. Costs of mycobacterial culture of key lymph nodes would be about $150 per pig.

6. Conclusions

The New Zealand Association of Game Estates proved to be a group of highly organised and professional individuals who pride themselves in delivering high-quality behind-wire hunting experiences. The Industry Agreed Standards developed by the NZAGE epitomise their proactive stance on animal disease management, and many of the members interviewed were already proactive with Tb surveillance. Certainly most were amenable to developing a 'working system' of surveillance, and most were pleased that the AHB is willing to formally develop a surveillance protocol specifically tailored to each individual operation. Some operators commented that they saw a formalised Tb surveillance system as a potential benefit of belonging to the NZAGE. Given this proactive stance, and willingness to interact with researchers and the AHB, we think that the AHB will meet little resistance developing such surveillance regimes in consultation with each estate manager/owner.

6.1 Validity and accuracy of the 'PigDetect' model

We made several assumptions in developing the model for released sentinel pigs:

1. Infectivity of possum carcasses was based on carcass detection data from Barber (2004) collected in mountain beech forest in winter. Based on this, simulated carcasses in the model were assumed to remain infectious for up to about 42 days. In reality, however,

possum carcasses would decay far more rapidly in summer, reducing the likelihood that a pig would encounter a possum carcass before the carcass was no longer infectious. Because we assume two infected possum carcasses were 'produced' each year, at least one of those would have been in winter. Any bias will therefore be substantially less than 50%.

2. We assumed the probability that an individual pig scavenged a carcass declined as a half-normal function of the distance between the carcass and the centre of the pig's home range. However, other scavenging functions are possible. A stepped function, for example, would assume the scavenging probability was constant across the entire home range of a pig and only fell to zero at the edge of the area actually used by an individual pig. A stepped function fits with our limited unpublished data from Taupo in 2002. We used a half-normal scavenging function in the model because it was more conservative than our current knowledge of pig home range utilisation.
3. Likewise, the home range sizes of model pigs in our study were based on data collected at a site near Lake Taupo as part of project R-10558 (Nugent et al. 2004). Home range sizes of pigs in the Taupo study (which included some domestic pigs) were likely to be somewhat smaller than those of wild pigs in open country (e.g., Knowles 1994). Larger home range sizes would shorten times to first detection of Tb, so our model was conservative in this respect.
4. Scavenging of a carcass by an individual pig resulted in that carcass being unavailable to other pigs. In reality, it is possible that several pigs in a group could feed on, and become infected by, a single possum carcass, especially groups of young littermates. While this will not change time to first infection in the model, in the real world where not all pigs will be recovered, it would shorten the effective times to first detection.
5. Each focus of infection in a possum population produced two infected possum carcasses annually, based on survival times of Tb-infected possums (Ramsey & Cowan 2003). This part of the model has to be extremely conservative as it makes the assumption that for much of the time there would only be a single infected possum present. As transmission is likely to be a highly stochastic event, a substantially larger number of infected animals would need to be present (on average) for the number of infected possums not to occasionally fall below one and for Tb to disappear from the population.

All but the first of these assumptions are likely to be conservative, some of them substantially so. It is therefore likely that the predictions from this model tend to overestimate the numbers of sentinels needed to detect Tb on game estates with reasonable levels of accuracy.

6.2 Defining adequate levels of surveillance on game estates

The key question in defining the type of surveillance required on game estates is how much surveillance is needed to detect the presence of Tb in local wildlife. Because possums are the primary wildlife host, ideally the AHB should specify a desired annual probability of detection of Tb in possums, and from that, the proportion of the possum population or the number of spillover 'sentinels' (both livestock and wild animals) that need to be tested annually to attain that detection probability. However, there is currently insufficient data and surveillance theory on the relative sensitivity of different species as sentinels to express the level of annual surveillance required in terms of some standard measure such as the equivalent number of cattle skin tests.

A pragmatic answer to the question is therefore to accept that on similarly enclosed deer farms managed for venison production, the AHB by default accepts the level of surveillance provided by whatever density of deer the farmer chooses to hold. There is no obvious reason why game estates should be required to provide a different level of surveillance, so we propose that the default level of surveillance is the annual number of deer skin tests that would be required if the estate was run as a conventional deer farm. If, for example, an estate with an average herd size of 200 deer would be required to have one annual whole-herd test, then the level of surveillance required is 200 deer tests per annum. The next question is: how should that be achieved?

One important issue that emerged from our interviews was that on most estates culled and sometimes trophy animals could be made available for inspection (either fresh or frozen). Given that 20–40% of the deer available on a given estate are killed annually on average, necropsy (and culture of key nodes, e.g. pooled retropharyngeal and tonsils) from these animals would provide 20–40% of the desired surveillance. Concentrating on trophy and cull animals therefore provides the ‘first tier’ of surveillance on a game estate, and would also provide the AHB with some assurance that Tb has not become established in the deer population. On conventional deer farms with annual whole-herd testing, each deer test represents a single year of exposure to the risk of infection on that farm. However, assuming that a cull animal was bred on the estate, necropsy of an aged cull would represent far longer exposure than one ‘deer-year’, as there are indications that, once infected, deer mostly survive (in an infected state) for many years (Nugent & Whitford 2003). This greater exposure increases the value of the necropsy of a cull relative to a single annual test, and a simple system for accounting for that would be to add up the years of exposure represented by each cull (i.e. their ages), and subtract 1 year for each cull (because wild fawns seldom become infected from possums during their first year of life; Nugent & Whiford 2003). A more sophisticated system would perhaps discount each successive year of age after 2 years by (say) 25% so that exposure many years previously does not contribute excessively to current surveillance. In addition, if cull animals had not been bred on the estate, some unique system of identification (such as PIT tags) may be desirable.

It is clear from our survey that deer-based surveillance alone will seldom be adequate on most estates. Other complementary surveillance information is needed to make up the shortfall. This concept of complementarity centres on the idea of equivalence. If we assume that there is some form of equivalence in the surveillance information from each species, the practical question becomes which other sentinels can be used to make up the shortfall, with the aim being to create a ‘total surveillance effort’ on each estate. Possible sources of information are cattle, possums, resident ferrets, resident pigs, and released pigs.

If cattle are run on the estate as a normal part of operations, then the AHB would expect them to be tested in their own right anyway, so the desired level of surveillance would increase by the number of cattle present (i.e. the cattle could not be used to make up for the shortfall in the deer-based surveillance). Arguably, however, if cattle were not usually kept on the estate, they could be used to provide the extra tests, which would provide an improved overall level of surveillance. Assuming that one cattle test is equivalent to a deer test, this would require the number of sentinel cattle tests to match the shortfall in deer tests. However, the high feed demands of cattle are unlikely to make that feasible, let alone the aesthetic effects of domestic cattle detracting from the ‘wild’ image game estates usually attempt to foster.

The next option available for an estate operator would be to trap and necropsy possums, because necropsy (with mycobacterial culture) would provide the most direct measure of Tb presence in a possum population. Possum recovery, necropsy, and culture should be a particularly high priority on game estates located within VRAs. The level of confidence that Tb is absent is closely related to the proportion of possums necropsied from a given population, assuming the sensitivity of necropsy (with culture of nodes pooled across animals) as a diagnostic tool is very high. Necropsy of 30–40% of available possums annually (i.e. removal of most possums produced annually through reproduction and immigration) would provide 35% confidence of Tb absence after one year, 58% after 2 years, 73% after 3 years, 83% after 4 years and so on. Because maintaining a possum population at low density actually requires an annual harvest of 30–40% of the population, use of these animals for surveillance would, by itself, provide quite a high level of confidence of Tb freedom, particularly after several years of possum control. This scenario would require game estates to do all of their possum control by methods that enabled recovery of the carcasses, and necropsy and culture costs might be prohibitively high with high numbers of possums (e.g., on estates outside VRAs). However, where the density of possums is low, the number of necropsies required might be few enough to make this a viable option. On estates located within VRAs, maintenance control will likely be keeping possums at low enough densities to make carcass recovery and necropsy a feasible option.

Use of resident ferrets and resident pigs to make up for a possible shortfall in deer tests on some estates obviously depends on the availability of those species. Conservatively assuming that both species are only ten times more sensitive as sentinels of Tb in possums than are deer (Nugent 2001; Ramsey et al. 2001; Nugent et al. 2003a), the requirement would be to obtain as many ferret- and pig-years of exposure as needed. For example, if the shortfall is 200 deer tests representing 200 years of deer exposure, then 20 pig and/or ferret years of exposure would be required annually. This could be made up of 40 6-month-old pigs or 10 2-year-old pigs, etc. The difficulty with this scenario is that the size of some game estates is smaller than the home range size of ferrets and pigs, so the years of exposure represented by the age of the animal at death would not reflect actual exposure on the estate. Although that could be compensated for by making a conservative assumption about the relative sensitivity of these species as sentinels, the assumption that surveillance ‘effort’ actually relates to a particular estate will always be questionable. In addition, the utility of resident ferrets as sentinels is closely related to the proportion of the total population of ferrets taken. Depending on the time of year that ferrets are controlled, less than half of the available ferrets may be removed (Norbury & Efford 2004), providing a lower level of confidence that Tb is absent.

The final option is use of released sentinel pigs.

6.3 Costs and utility of using sentinel pigs on game estates

As with the use of resident pigs, we make the assumption that 1 year of pig exposure is equivalent to 10 years of deer exposure. Under this assumption, an estate with a shortfall of 200 deer tests representing 200 years of deer exposure will require 20 years of pig exposure annually. Our model suggests that even on 1600-ha estates, this level of surveillance alone would have a >50% likelihood of detecting Tb within 1 year (Fig. 4a), without the data provided by first-tier surveillance. Therefore, for a relatively small cost, released sentinel pigs could provide a high level of surveillance on at least half the game estates surveyed.

The utility of the approach hinges on two factors. First and most importantly, retrieval of a high percentage of initially released sentinels is critical to increasing the probability of detecting Tb if the disease is present. It may therefore be better to simply release a greater number of pigs to compensate for a potentially lower recovery rate. The disadvantage of this approach is that it increases the chance that the pigs that become infected may not be recovered, which would lengthen detection times. The use of radio-transmitters was not acceptable to all estate operators, but clearly their use would substantially increase the chances of retrieval of most of the initially released pigs, at the 'right' times. Radio transmitters could either be surgically implanted (Nugent et al. 2002) or used as an eartag that is easily attached to the pig.

Second, release of sentinel pigs is most useful when either semi-wild bred pigs or fully wild-caught pigs are used, because wild pigs survive better than, and behave differently from, domestic pigs (Nugent & Yockney 2002 unpubl. data). This raises the possibility that a 'hybrid' approach, using a combination of resident and released pigs, could work on game estates. For example, initial release of one or two radio-collared sows, in addition to the trophy boars present on some estates, would provide ample litters of pigs that could be culled annually, achieving the required 'pig-years' and/or 'deer-years' of exposure for the operator. Recovery and replacement of breeding sows is also a possibility, to check whether they have detected Tb. The use of grain feeders (where pigs tend to congregate) by some estates would greatly facilitate this approach.

6.4 A decision support tree for Tb surveillance on game estates

In Fig. 5 we present a decision tree to help the AHB define an adequate surveillance protocol and framework for individual estates. Although developed here in the context of 12 members of the NZAGE, the model is also applicable to game estate operators outside the NZAGE, and could also apply to 'conventional' deer farms. However, the focus of this decision tree is entirely on detection of Tb presence in wildlife. As such it ignores the other key aim of Tb testing of livestock, namely to confirm the disease is absent from a herd itself when that herd is at densities high enough for Tb to be self-sustaining. The latter aim requires testing (or necropsy) of a high proportion of the deer present.

6.5 Tb surveillance on estates that are not members of the NZAGE

Many game estates do not run such highly organised and professional operations as members of the NZAGE. 'Fly by night' operators arguably pose a greater risk to the spread and persistence of Tb, because they work with untested animals and because they are likely to be less proactive in regular surveillance of wildlife vectors on their properties. Our discussions with several estate operators indicated that there may be more than 50 such operations in New Zealand. The next step for the AHB will be to focus on these game operations and decide on an acceptable level of surveillance that they should be expected to comply with. At the very least, these operators should be routinely controlling, necropsying, and culturing pooled nodes from possums, particularly if they are located inside VRAs.

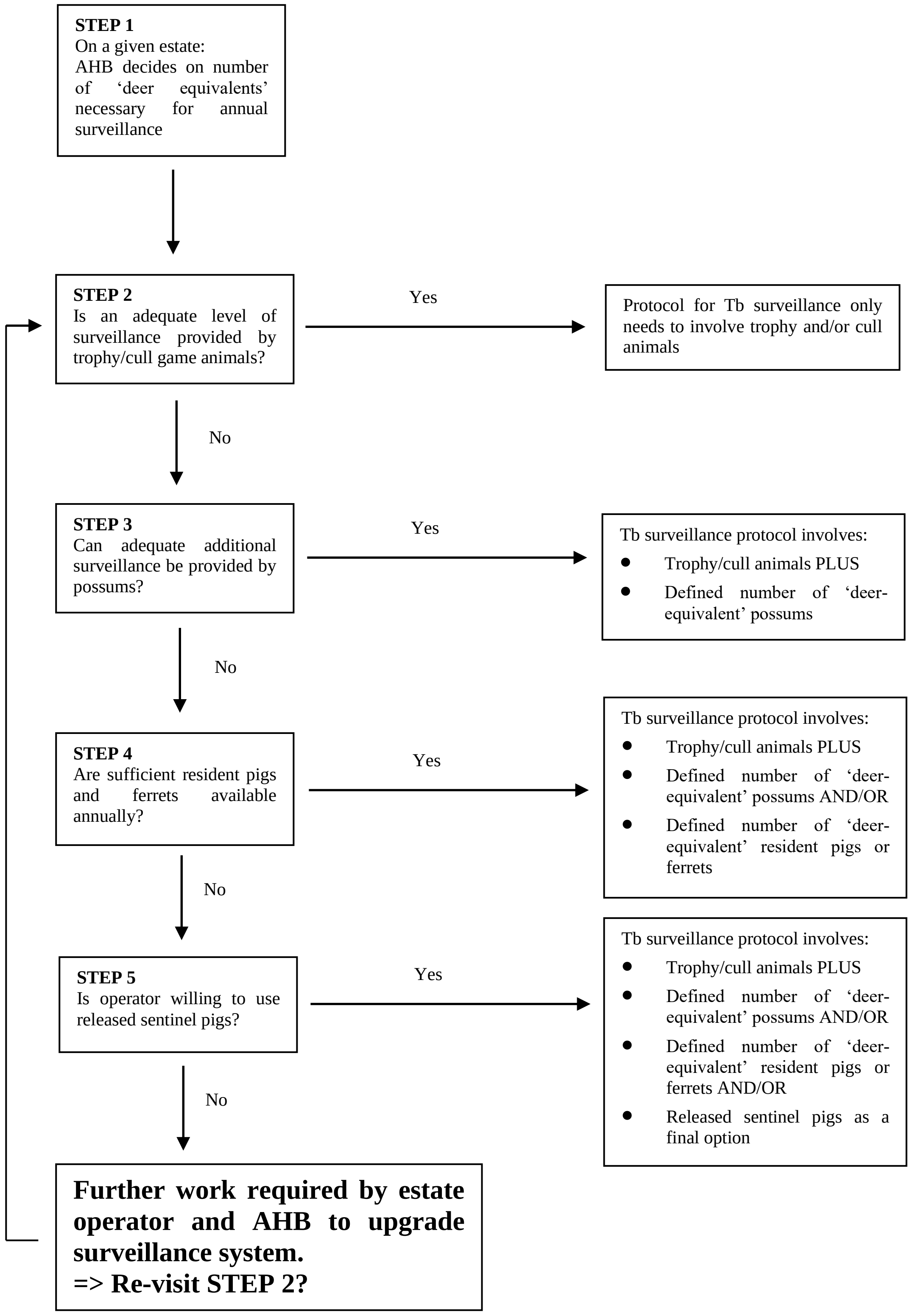

Fig. 5 Decision tree to help the AHB develop a Tb surveillance framework on individual game estates.

7. Recommendations

- The AHB should formally decide what level of surveillance is required on game estates. We recommend that the ‘default’ level of surveillance required be set as a number of ‘annual deer test equivalents’ (based on the size of the herd and the testing frequency that would apply to that herd if it were managed as a conventional deer farm). Where the desired level of surveillance cannot practicably be attained by ‘first tier’ surveillance (direct testing or necropsy of the deer herd), we further recommend implementation of a new paradigm of complementarity, based on ‘equivalency’ between sources of surveillance information.
- ‘First tier’ surveillance should be based on skin testing wherever practicable, backed up by necropsy and culture of trophy and cull animals. A system for taking into account the age (and therefore the length of exposure) of cull animals should be developed. Necropsy of a deer that has been present for several years provides more surveillance than does a skin test of an animal that was skin tested the previous year.
- To make up the expected shortfall in total surveillance effort on game estates, the priorities should be as follows:
    1. Surveys of possums, at least where possum numbers are being maintained at low density through annual culls of 30–40% of the population. This applies particularly to estates located within VRAs;
    2. Surveys of a high proportion of resident pigs and ferrets, coupled with some assessment of the proportion of each population surveyed;
    3. Use of released sentinels.
- Because estates differ in the nature of their operations, and in the availability of alternative sentinels, it seems inevitable that estate-specific surveillance plans will need to be developed. This will require that the relative sensitivity of different species as sentinels is better quantified and explained to estate owners, because it is central to the concept of surveillance equivalency.

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