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Badger Control Model for Wales – Trap-Test-Cull-Vaccinate

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EXECUTIVE SUMMARY

1. Here we examine the effects of badger culling, vaccination and a combined trap-test and cull or vaccinate strategy, on badger epidemiology and cattle herd breakdowns.
2. The model results are very dependent on the assumptions made about badger social perturbation, caused as a result of culling. Following recent publications, social perturbation in the model was reduced to one year after culling in line with these results.
3. In line with all previous results, culling reduces the number of infected badgers quicker than vaccination within the control area. This is because vaccination simply prevents new infections in the part of the population that has been trapped and becomes immune.
4. Since culling also perturbs the badger population and produces an increase in herd breakdowns immediately outside the control area, culling and vaccination appear to be equally effective in reducing cattle herd breakdowns across the whole simulated grid.
5. The trap and test strategy (culling animals that test positive and vaccinating and releasing the others) culls relatively few animals. Less than half the social groups had badgers culled in any one year, and very few social groups had more than badger removed in any one year.
6. If the above level of culling produced no social perturbation then the reduction in the number of infected badgers, and the reduction in herd breakdowns, was greater than either culling or vaccination.
7. If the above level of culling resulted in repeated perturbation of social groups each time a badger social group (or a nearby group) had an animal culled, then there was a dramatic increase in the number of infected badgers and the number of herd

breakdowns. This is due to the large number of susceptible badgers left during the control.

8. We do not currently have sufficient evidence to determine where reality lies between these two extremes. Given the very large uncertainty, we cannot accurately predict the outcome of a combined trap-test-cull/vaccinate strategy at present. Given the potential for adverse outcomes, further analysis of current databases would refine our uncertainty about this process, and it is quite possible that a low level of culling will not produce significant perturbation.

INTRODUCTION

Following the modelling work done by CSL for the Welsh Assembly Government (see CSL report “Badger Control Model – Comparison of Strategies for Wales”), a further piece of work was commissioned to model the inclusion of a TB-test on each captured badger, the results of each test determining whether the individual badger would be culled, or vaccinated and released. The aim of the study was to model the effects of such a trap-test-cull/vaccinate option on the disease dynamics, and in particular the Cattle Herd Breakdown (CHB) rates, compared with culling-only and vaccinating-only strategies, both in the absence of testing. The effects of social perturbation of the badger population on the outcomes of the different strategies were also investigated.

METHODS

The same, two-species spatial model was used for this supplemental study as for the previous study, with some modifications to include the testing and vaccination options. Details of the model can be found in Wilkinson *et al.* (2009) and report “Badger Control Model – Comparison of Strategies for Wales”.

In brief, the model produced by Wilkinson and colleagues comprised a farm landscape layer superimposed onto a spatial layer of badger territories, and cattle herds along with relevant management (e.g. cattle movements and TB-testing) were simulated, along with the badger population dynamics. Transmission of TB was modelled so infection could spread both ways between the two species, as well as within-species. The badger and cattle layers are both modelled on a 100 x 100 grid, each cell of which represents 200m x 200m, the total model grid thus representing a 400 km2 landscape area.

The same badger and cattle population parameters were used as for the previous study, and also the same two distinct regions (Powys and Pembrokeshire) were modelled. Pre-movement Testing of cattle was switched on in the model as a default.

Parameter Values

As a default the following parameter values and settings were used for all control strategies tested in this study:

a)	Area of control	100 km^2 (~25% of total grid)
b)	Land Access compliance	80%
c)	Control edge permeability (to badger movements)	100%
d)	Spatial strategy	Contiguous and simultaneous
e)	Control campaign duration	5 years (each June)
f)	Trapping efficacy	70%
g)	TB-Test sensitivity (infected badger positive)	34%
h)	TB-Test sensitivity (infectious badger positive)	42%
i)	TB-Test sensitivity (super-infectious badger positive)	78%
j)	TB-Test specificity (healthy badger negative)	95%
k)	Badger Vaccine conversion	60%
l)	Badger Vaccine durability	Lifetime of individual badger

All Badger TB-Test sensitivity and specificity values were obtained from Chambers et al. (2008) and refer to the use of the Brock-TB StatPak. Although in that study there was no exact equivalent category to the badger health status of “infected” used in the model, the closest equivalent was the NVL category (badgers with ‘No Visible Lesions’), so that sensitivity (34%) was used. The highest end of the range of test specificities was chosen for the model (95%), as the authors argued that the specificity was “likely to be an underestimate .. [as] it is likely that true infection was missed in some cases despite the use of an extensive post mortem protocol.”

All other parameter values used were the same as for the previous study. Where culling occurred in the model, perturbation of badger groups was also simulated (unless intentionally switched off for comparison), causing increased between-group badger-to-badger TB-transmission rates to simulate increased contact rates.

With a trap-test- cull/vaccinate procedure, it is possible that only small numbers of animals would be culled from most social groups, and that this would not cause social perturbation, as modelled. Thus, perturbation was switched off for one strategy to determine the effect of this assumption. The processes of badger perturbation were the same as the previous model except as explained below.

Control Strategies

Four different control strategies were tested in the model:

1. <u>Trap-Test-Cull/Vaccinate with perturbation</u>

   Each badger within a badger group marked for control was given the chance of being trapped. Each trapped badger was tested, and dependent on its health status in the model was probabilistically determined to be either TB-test-positive or TB-test-negative. Each TB-test-positive badger was culled. Each TB-test-negative badger was injected with vaccine, and if not previously vaccinated successfully, was given the chance of successful vaccination (conversion to full TB immunity for the rest of its life), but on the assumption that a badger which was already infected with TB (even though the test did not pick it up) would not be successfully vaccinated. Where a group was culled (partially or wholly) perturbation was activated for that group and the neighbour and neighbour-but-one groups. The perturbation lasted one year and was then switched off, but if any culling of that group occurred in a future year of the control campaign, the perturbation was reactivated for another one-year period. This may occur in real life where a patchwork of culling takes place and a group may be perturbed by culling taking place in different social groups in different years. This strategy is considered the worst-case scenario.

2. Trap-Test-Cull/Vaccinate with no perturbation

   As in Strategy 1, badgers were trapped, tested and then either culled or vaccinated depending on the test result. However, for Strategy 2 the perturbation effect was switched off (i.e. transmission rates were not increased). This strategy assumes that the level of culling in individual social groups is not sufficient to cause significant social perturbation, and gives a best-case scenario for comparison.

3. Trap-Vaccinate with no perturbation

   Each badger was given the chance of being trapped, and all trapped badgers were given a vaccine injection and a chance of immunity as appropriate. It was assumed that a badger already infected with TB would not be successfully vaccinated. As no culling occurred for this control, there was no perturbation effect simulated.

4. Trap-Cull with perturbation period

   Each badger was given the chance of being trapped, and all trapped badgers were culled, regardless of health status. Where a group was culled (partially or wholly) perturbation was activated for that group and the neighbour and neighbour-but-one groups. The perturbation lasted just one year following the initial culling in the model, and was then switched off, and not reactivated for any badger group thereafter. This perturbation period was simulated to match recent findings (Jenkins, Woodroffe &

Donnelly, 2008) as explained in the previous report, and is currently the best fitting model for social perturbation.

As a comparison, the model was first run without any control strategy, to give a “No Control” baseline, then for each of the above control strategies in turn all model values were reset to identical pre-control conditions, and the model run again with the appropriate control for that strategy.

Outputs

At least 100 simulations were run for each control strategy, a different spatial configuration for control being created for each simulation, and the output parameters were summarised by their means.

The parameters calculated at the end of each simulated year include badger population, badger TB (number of TB-infected badgers), and numbers and rates of cattle herd breakdowns – confirmed, and total (confirmed plus unconfirmed). Output metrics are calculated for (a) the whole grid area, so represent averaged values across both the non-control portion of the grid (~75% of the grid) and the controlled area (~25% of the grid), (b) the control area only – i.e. the total area being trapped at any time, and (c) the no-control area only – i.e. the area beyond the control area. Because of concern of local badger population effects, and risk of local extinctions, the graphs of badger population and disease dynamics are presented for the control area. CHB rates outside the control area may be affected by the removal of badgers from the control area (e.g. by the perturbation effect), and since it is important to consider the overall effect on cattle-TB, the graphs of CHB rates are presented for the whole grid area of the model. The area being measured and the proportion being controlled must be taken into account when interpreting the results. In addition, for each strategy the numbers of badgers culled per group, and the percentage culled out of each badger group were output for analysis.

RESULTS

Before badger control was applied in the model, the output parameters stabilised at the following approximate means:

a) 7.5 adult badgers per social group
b) 1.3 infected badgers per social group
c) 0.04 CHBs per farm per year (Pembrokeshire) and 0.05 CHBs per farm per year (Powys), after pre-movement testing

Although the outputs from both the Pembrokeshire and Powys simulations have been analysed and presented in the figures separately, many of the results are very similar and in some cases virtually indistinguishable. Therefore, unless a comparison is explicitly mentioned, the observations made in these results will refer to both the Pembrokeshire and Powys model outputs.

Any comparison between the graphs of the badger metrics and the graphs of the CHB rates must be done with caution, bearing in mind that the former are presented for the control area only and the latter for the whole grid.

1. Badger Population

As expected, the vaccine only strategy resulted in a small rise in the badger population (Fig. 1, blue line). Also as expected, the cull-only strategy with all trapped badgers being removed showed the steepest decline in badger population, seen clearly in the mean badger group size (Fig. 1, brown line). The minimum level reached over a 5-year cull campaign was to about one third of the start level, similar to that recorded in the RBCT. As soon as culling stopped, the badger population started to recover at a rate almost as steep as the fall, taking about the same time for population recovery as it took to reduce to the minimum. In contrast, with a trap-test-cull/vaccinate campaign the badger population reduced less quickly, and by only about 20% below the start level (Fig. 1, red line). As soon as control ceased, the population started to recover. When we simulated a trap-test-cull/vaccinate campaign but with perturbation switched off in the model, the population suppression was smaller, the mean badger group size reducing by only 10% (Fig.1, pink line). Population recovery after the 5-year control took about 10 years following culling with perturbation (Fig.1, red and brown lines), but only 5 years following culling without perturbation (Fig.1, pink line).

In terms of the numbers of badgers culled from each group in any one year, most groups had **no** badgers culled in the two trap-test-cull/vaccinate strategies – 61% when perturbation occurred and 71% when it was switched off. About a quarter of the groups had just one badger culled with those two strategies, leaving only around one group in ten having two or more badgers culled from the group in any year of culling. For the strategy of cull-only, around a quarter of the badger groups had none culled in any one year, and around 60% of the groups had one, two, three or four badgers culled in a year, in about equal proportions. Very few of the cull/vaccinate strategies had more than four badgers culled, in contrast to the cull-only strategy where almost one fifth of the groups had five or more badgers culled. If culling did actually take place, about 25% of groups in the cull-only strategy had more than half the badgers in the group culled in any one year, whereas that figure was less than 1% of groups for the trap-test-cull/vaccinate strategy (assuming that all test-negative badgers were released).

FIGURE 1. **Badger Group Size:** The effect of different badger-control strategies on the mean badger group size (adults) in the control area. Control started in year 120.

Fig. 1. (A)
Pembrokeshire

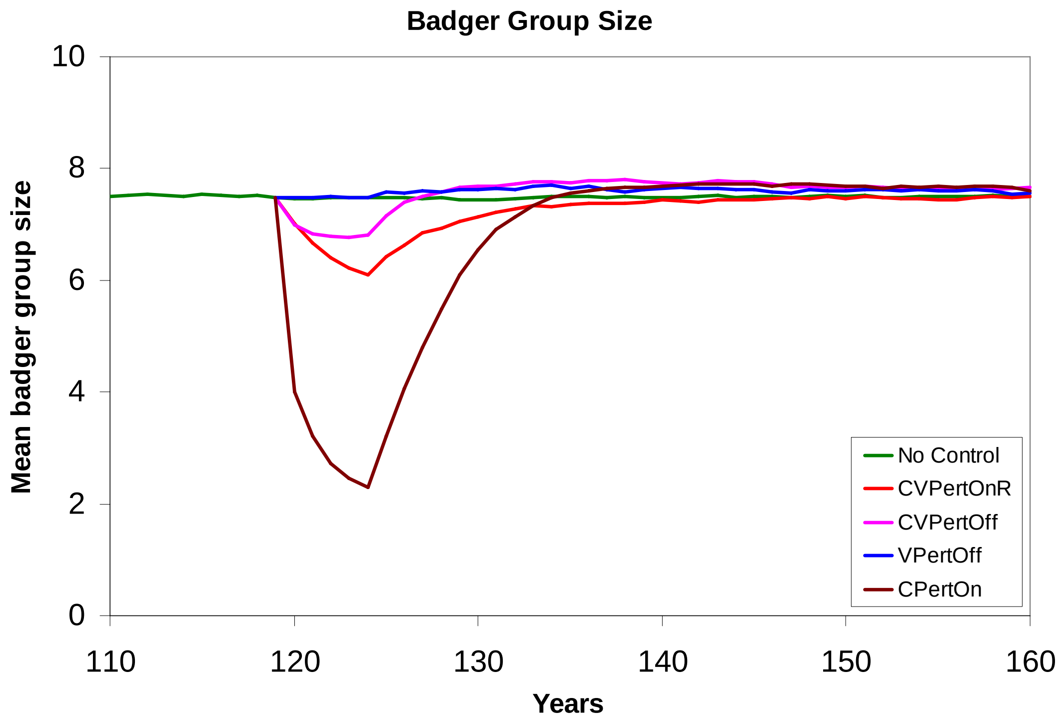
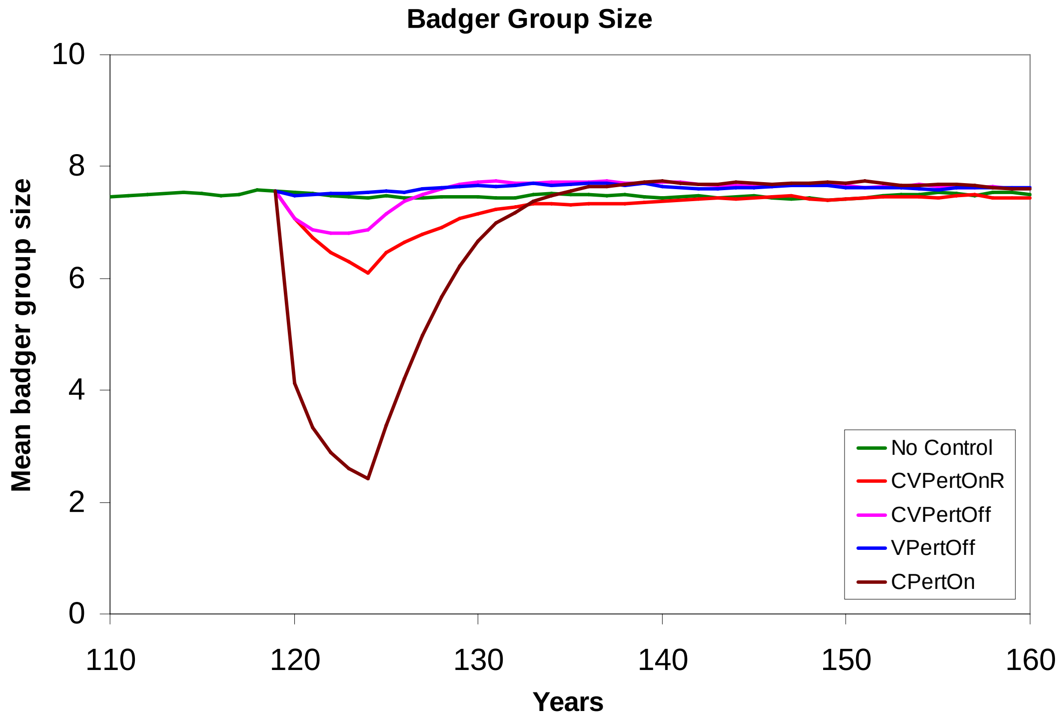


Fig. 1. (B)
Powys



2. Infected Badgers

The vaccinate-only strategy reduced the mean number of TB-infected badgers within the control area down to about 50% of the start level (Fig. 2, blue line). Following the cessation of vaccination the numbers of infected badgers rose back up much slower than it had originally declined, and was still about 25% below the start level at the end of the simulation, 35 years after vaccination stopped. In contrast, the trap-test-cull/vaccinate campaign with perturbation showed a steep rise in numbers of infected badgers within the control area, to a peak of almost twice the start level by the end of the 5-year control period (Fig. 2, red line). As soon as control and perturbation stopped, the numbers of infected badgers declined, steeply for the first 3 years, but then less so, levelling off at around 10 - 20% above the start level. Interestingly, the two strategies of cull-only with perturbation, and trap-test-cull/vaccinate but without perturbation, gave very similar trends both in terms of level of reduction of infected badgers, and return towards pre-control levels (Fig. 2, brown and pink lines). Both those strategies showed a much steeper reduction than return, so levels 35 years after control stopped were still about 40% lower than start levels.

FIGURE 2. **Infected Badgers:** The effect of different badger-control strategies on the mean number of infected badgers per group in the control area. Control started in year 120.

Fig. 2. (A)
Pembrokeshire

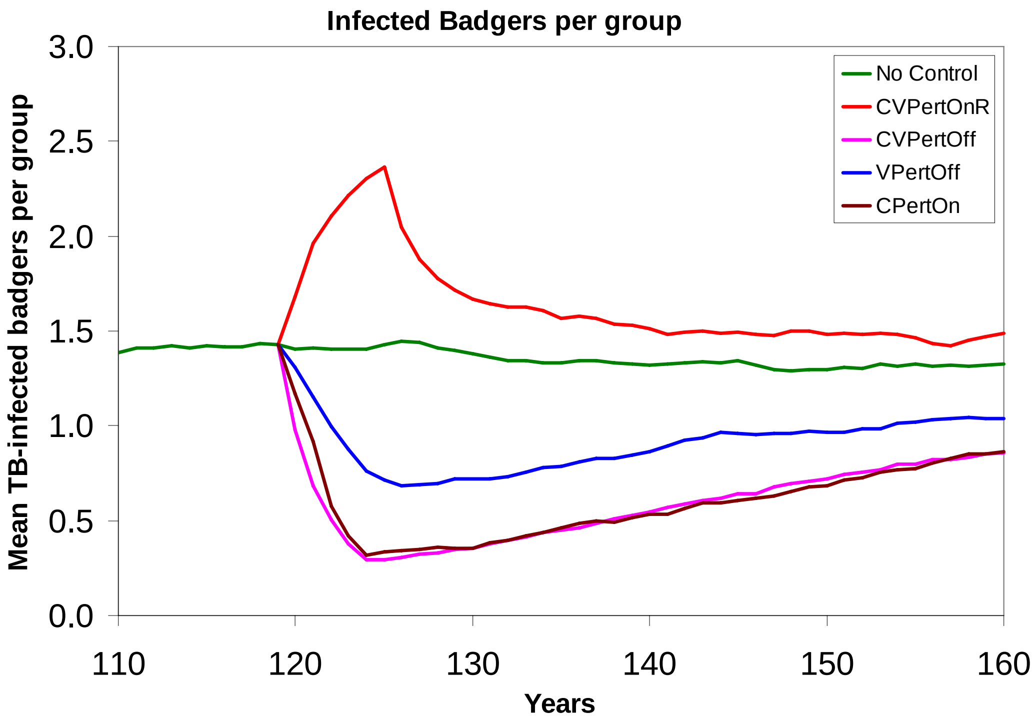
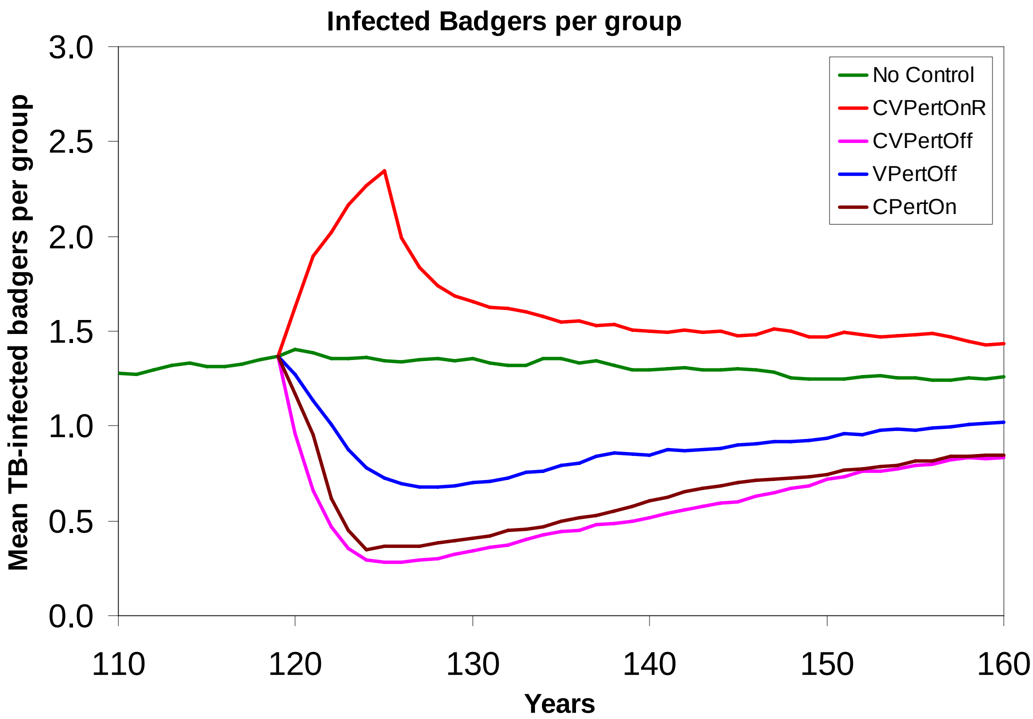


Fig. 2. (B)
Powys



3. Cattle Herd Breakdown rates

All the control strategies tested resulted in small reductions in the rate of confirmed CHBs over the whole grid area *except* the trap-test-cull/vaccinate campaign with perturbation which resulted in a significant increase in the rate of confirmed CHBs (Fig. 3). That increase was steep and sustained throughout the control period, but then declined steeply for about a further 5 years, levelling off at a value between 10% and 20% *above* the no-control base level (Fig. 3, red line above green line). There was very little difference shown between the three strategies that gave a reduction (Fig. 3: trap-test-cull/vaccinate campaign without perturbation [pink line]; vaccinate-only [blue line]; and cull-only with perturbation [brown line]). The first (pink line) gave a slightly bigger reduction during the control period than the last two, but after 10 years those three lines (pink, blue and brown) show no significant differences, all three giving a long-term reduction of between 5% and 10% below the no-control base level (green line).

The effects of the different control strategies on the rates of total CHBs (Fig. 4: confirmed + unconfirmed) showed virtually the same trends as the effects on just the confirmed CHBs (Fig. 3), the only noticeable difference being that the peaks of the trap-test-cull/vaccinate campaign with perturbation campaigns (red line peaks) are less pointed for Total CHBs (Fig. 4) than for confirmed CHBs (Fig. 3).

FIGURE 3. **Confirmed CHBs:** The effect of different badger-control strategies on the mean annual CHB rate (confirmed CHBs) for the whole grid area. Control started in year 120.

Fig. 3. (A)
Pembrokeshire

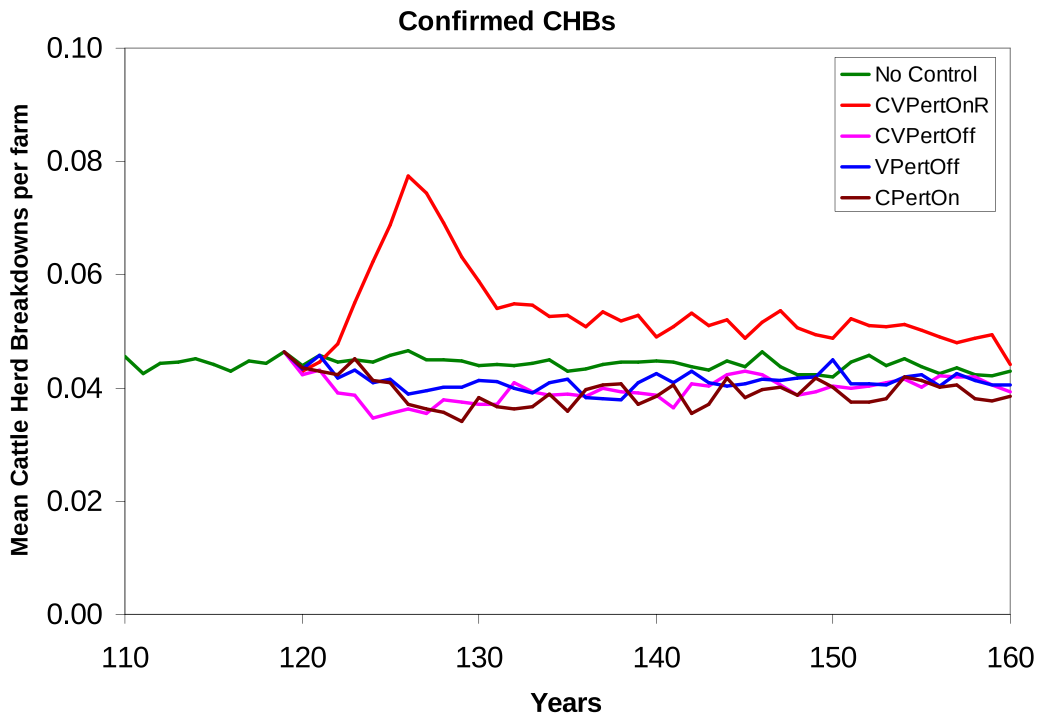


Fig. 3. (B)
Powys

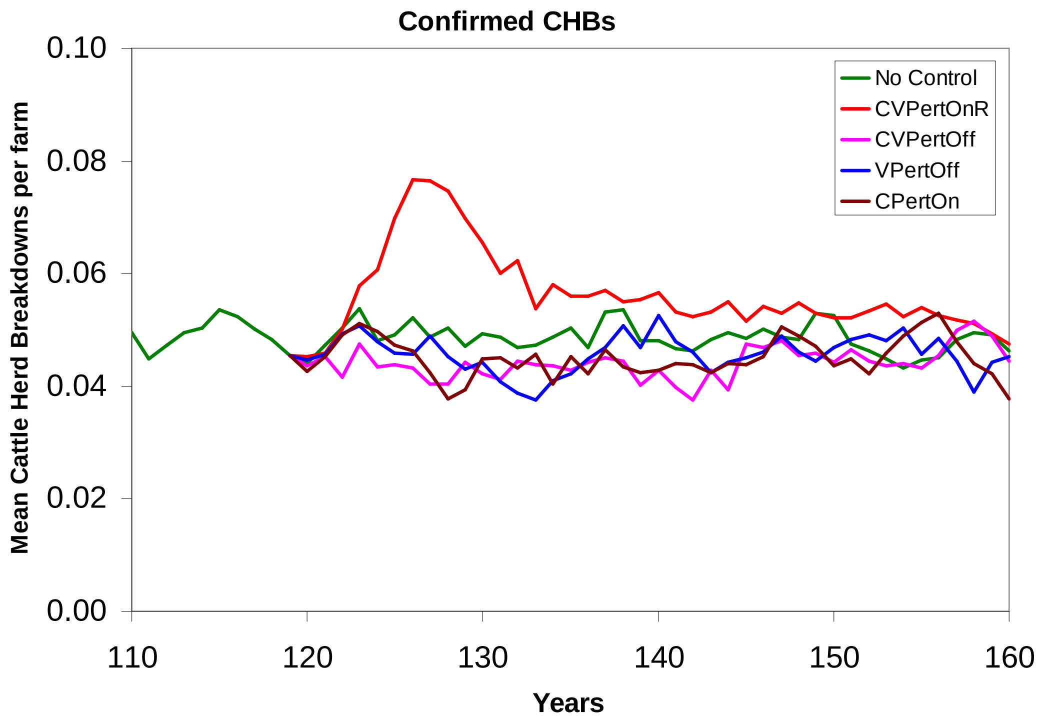


FIGURE 4. **Total CHBs:** The effect of different badger-control strategies on the mean annual CHB rate (total CHBs) for the whole grid area. Control started in year 120.

Fig. 4. (A)
Pembrokeshire

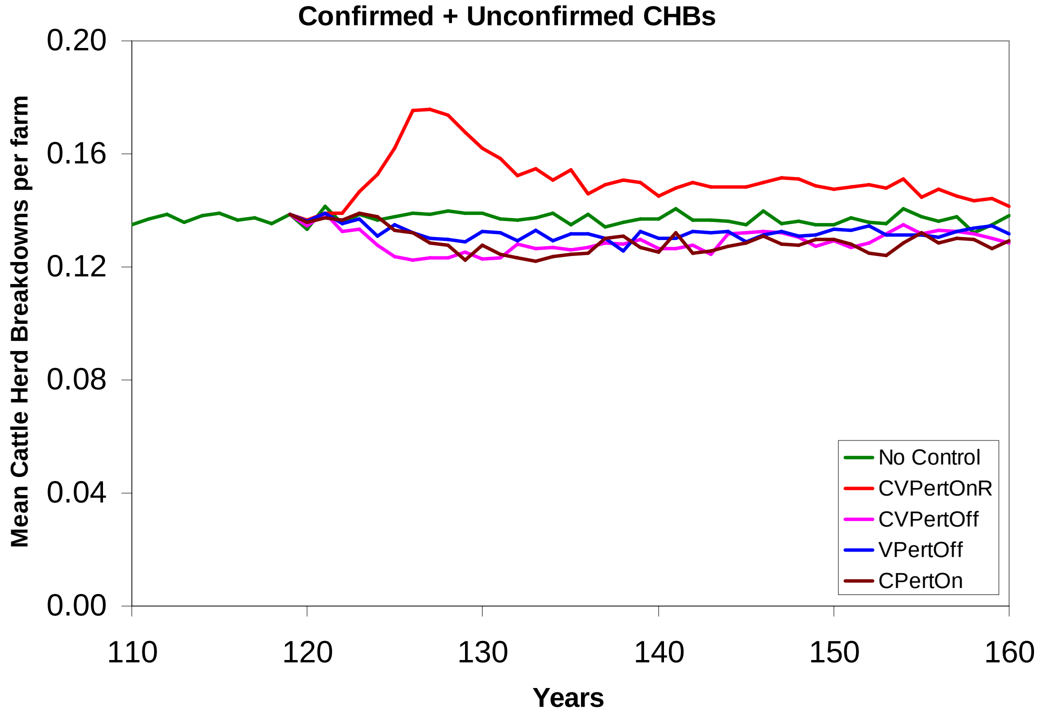
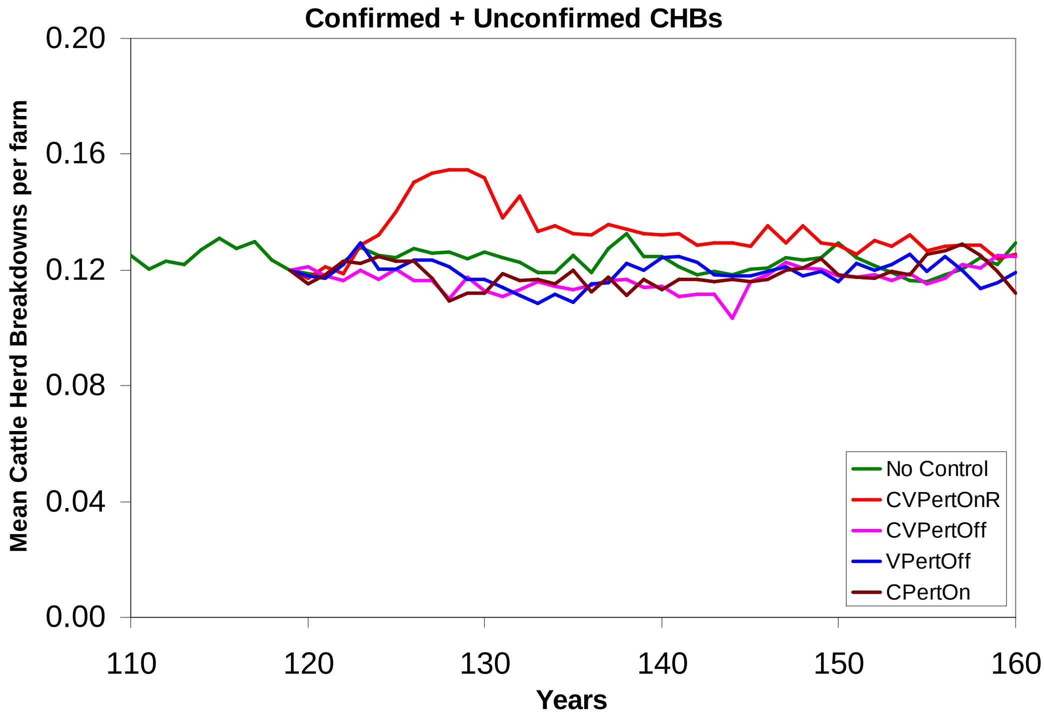


Fig. 4. (B)
Powys



DISCUSSION

The different strategies gave dramatic differences in the model. A cull-only strategy reduced the badger population within the control area to about a third, whereas using a test to determine whether a badger was to be vaccinated gave a considerably smaller population reduction. With a vaccination-only strategy, badgers were neither removed directly, nor were they perturbed, so TB levels reduced and the population actually increased, albeit slightly. The cull-only strategy result is in line with various results reported from the RBCT, and from previous modelling work, and the vaccinate-only strategy is in agreement with all previous modelling work in this area.

In the case of strategy 1 where perturbation was prolonged due to it being repeatedly reactivated, the number of infected badgers within the control area increased well above the background level, whereas in the vaccination-only strategy with the absence of perturbation the numbers of infected badgers reduced. However, the biggest reductions in infected badgers were seen when there was either some culling and no perturbation, or a high level of culling (all trapped badgers culled). The latter seemed to counteract the perturbation, at least within the control area. The former, however, was hypothetical, as it is not known if perturbation would occur in the field following low-level culling of badger groups.

With prolonged perturbation, even when both vaccination and culling were occurring, not only were the numbers of infected badgers increased, but also the CHB rates increased well above the background level. This was because, with a relatively low badger TB-test sensitivity, many badgers (infectious and healthy) were left, resulting in a large rise in the number of infected badgers due to perturbation. Although not explicitly visible in the presented graphs, it is known from previous modelling that the greatest increases in the

CHB rate occur outside the edge of the cull area, and the severity of that edge effect depends on how far the perturbation effect reaches into those areas where neither vaccination nor culling occurs. That could be particularly problematic if such an edge effect were substantial and couldn't be prevented.

At the other extreme, when perturbation did not occur, the CHB rate was reduced marginally more with a trap-test-cull/vaccinate strategy than it was with either a cull-only or a vaccinate-only strategy, but the differences between those three strategies in terms of CHB rates was minimal and it is doubtful whether any such differences would be detectable in the field.

In the model some very important assumptions were made about social perturbation. Those assumptions raise some important questions – how long perturbation would last, whether further culling could reactivate it, and what proportion of a badger group needs to be removed before perturbation is triggered? The sensitivity of the effects of the different control strategies to those model assumptions needs further investigation. The level of culling in the trap-test-cull/vaccinate strategy was quite low, and could be considered as within the background variation seen in the wild (albeit this mortality would all occur with a short time-scale). Further modelling studies could also usefully test the sensitivity of the control strategies tested here to adjustment of some parameter settings about which there is either some variability or some uncertainty – for example, the TB-test sensitivities/specificities, the vaccine conversion success, and vaccine durability. It could also be worthwhile to model the cull/vaccinate strategies with longer control durations.

The model strongly suggests that a trap-test-cull/vaccinate strategy may risk making the TB situation in cattle much worse. However, we do not currently know if the patchwork culling that results from a trap-test-cull/vaccinate strategy would lead to sustained social perturbation. If the low level of culling that results from a trap-test-cull/vaccinate strategy (about 10% of groups had more than one badger culled per year) did not lead to widespread social perturbation, then the outcome is a slight improvement in the cattle breakdown rates compared to vaccination alone. Directed analysis of the Woodchester and RBCT data would help to inform this assumption, but we cannot at this stage expect the trap-test-cull/vaccinate strategy to be better than the vaccinate strategy (as simulated in the model). It is however, quite possible that other trap-test-cull/vaccinate strategies (e.g. vaccination followed by trap-test-cull/vaccinate) could lead to substantial improvements above the vaccinate-only strategy.

LITERATURE CITED

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