Factors affecting possum re-infestation—implications for management

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CONTENTS

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ABSTRACT

Re-invasion and population recovery by possums after control operations are major management problems for the New Zealand Department of Conservation. Factors influencing rates of re-infestation by possums of areas subject to control were therefore reviewed because better understanding of them will allow the development of more cost-effective management of the national problem of possum damage to conservation reserves. Minimising rates of re-infestation after control would be assisted by: collecting basic information on local possum biology in advance of control operations so that recovery rates can be better predicted; using effective boundaries to controlled areas, particularly major waterways or large expanses of pasture; considering appropriate size and shape of area to be controlled in relation to surrounding sources of potential immigrants; minimising immigration into the protected area through use of buffer zones extending out three to five kilometres; concentrating control effort to preferred habitats, particularly forest–scrub–pasture margins; maximising initial kill; timing control to target females with dependent offspring; timing control to target the main periods of possum immigration; and maintaining accurate and consistent operational monitoring. Predictive models are being developed to assist with operational planning. The site-specific nature of many aspects of operational planning require that such models operate in real terrain. Further development of such models depends on recently begun research into fundamental processes in possum population ecology.

Keywords: forest management, pest control, monitoring, habitat, population change, *Trichosurus vulpecula*, New Zealand

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1. Introduction

The Department of Conservation requested Landcare Research to review current research on possum dispersal and re-infestation because of concerns at observed rapid rates of recovery of possum numbers after control in some areas.

2. Background

Although the Department of Conservation can achieve effective initial reduction of possum numbers in its reserves, reports from various conservancies suggest that numbers recover rapidly in some areas, with, in extreme cases, return to initial levels within 12 months, particularly in the small reserves. Control to achieve conservation goals is then required annually, and is, therefore, highly expensive. A better understanding of the factors influencing rates of re-infestation and population recovery would allow the development of more cost-effective management of the national problem of possum damage to conservation reserves. The general principles governing possum re-infestation identified in this study will also apply to improving possum management in large forest tracts and along forest–pasture margins.

A recent review of possum dispersal and its implications for population recovery is that of Efford (1991). He reached the following conclusions.

- Median long-distance (>2 km) dispersal distance was 3.7 km for males and 5.5 km for females.
- Males outnumbered females among dispersers by 4.3 to 1.
- Coat colour did not influence dispersal distance.
- Possums usually disperse between weaning and the first birthday, resulting in a bimodal pattern where births occurred in both autumn and spring.
- In populations where sexual maturity is delayed, there is also dispersal of 1–2 year old possums.
- Female dispersers tended to move further, and to move repeatedly.
- In an uncontrolled population about four in five breeding males and one in three breeding females were immigrants.

These findings are reviewed in the light of a number of more recent studies (e.g. Cowan & Rhodes 1993; Cowan et al. 1996, 1997; Efford 1998).

3. Objectives

To review and report on current research and literature on possum dispersal and re-infestation after control.

To identify from the review, changes in management practices and procedures that might help minimise rates of re-infestation after control.

4. Factors influencing re-infestation

Factors influencing rates of re-infestation are of two types: those affecting immigration into an area subject to possum control; and those affecting the rate of recovery of the surviving possum population.

4.1 IMMIGRATION

4.1.1 Natural boundaries

It is generally believed that natural boundaries, such as rivers and mountain ranges, act as barriers, either impeding or preventing possum dispersal. Pracy (1975) states that rivers and streams are effective natural barriers but are often easily crossed where they narrow nearer the headwaters, or where debris has accumulated. Pracy (1975) also suggested that roads and tracks have greatly facilitated possum dispersal. Julian (1984) suggested that the spread of possums in Northland was restricted by the large drainage outfall of farmland to the north-west, and the Awapuni River. The Wairaurahiri River, which apparently blocked the spread of possums into Waitutu State Forest in Southland, was supposedly crossed by them after a footbridge was constructed (J.R. von Tunzelman pers. comm.). Analysis of the distribution and spread of possums in Westland National Park (Pekelharing & Reynolds 1983; Fraser 1988) strongly suggests that possums spread along the main waterways then up into headwaters of the valleys, invading each in turn.

Although possums venture above the snowline (Clout & Gaze 1984), Pracy (1975) suggests that permanent snow and ice also act as effective barriers to dispersal. Thick wet vegetation is also supposed to slow the spread of possums, with the clearing of the understorey by deer, pigs and goats supposedly contributing to the rapid colonisation of many forests by possums (Pracy 1975).

However, quantitative data demonstrating these effects are sparse. Brockie et al. (1989) found that only two of more than 500 possums tagged over a four year period on one side of a 2 m-wide water-filled drain on farmland were trapped later on the opposite side. Brockie et al. (1989) also observed that radio-tagged possums only crossed the water-filled drain after a wooden plank was laid across it. However, Ward (1985) and Cowan (unpubl.) both recorded radio-tagged possums crossing rivers. In the latter case, possums crossed the Manawatu River, and could only have done so by swimming. Pietsch (1994) and Cowan (unpubl.) studied the behaviour of possums trapped in one area and translocated to another area, looking for landscape features that might have guided the movements of possums after release. Both concluded that patterns of movement differed so greatly between individuals that there were no common landscape features directing their movements, with the possible exception of major waterways.

4.1.2 Habitat patch size and shape

The number of migrants arriving at a site is partly determined by site size—the larger the site the larger the number of immigrants likely to arrive there (Appendix 1). Shape is also important—for two sites of equal area, simple geometry shows that the one with the larger width at right angles to the source of dispersers would be likely to receive more migrants (Figure 1).

Patch size has a marked influence on the contribution of immigration to rate of recovery (Figure 2). For example, as patch size increases from 0.5 to 150 km^2 the time taken for numbers to increase to 50% of original density after an initial reduction of 90% increases from about one year to five years. In the absence of immigration, the population takes about eight years to recover to half its original density.

However, there are no empirical data available with which to assess the importance of these factors in observed rates of recovery after control, although such research is underway (Coleman 1997; Nugent et al. 1997).

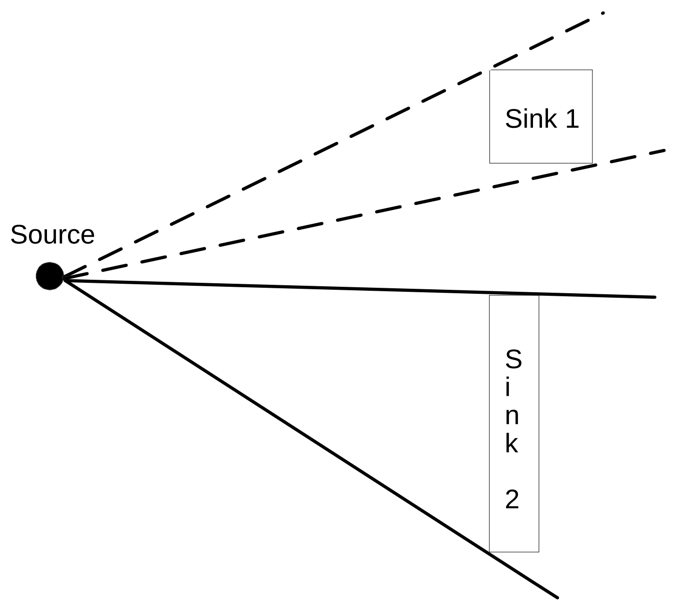
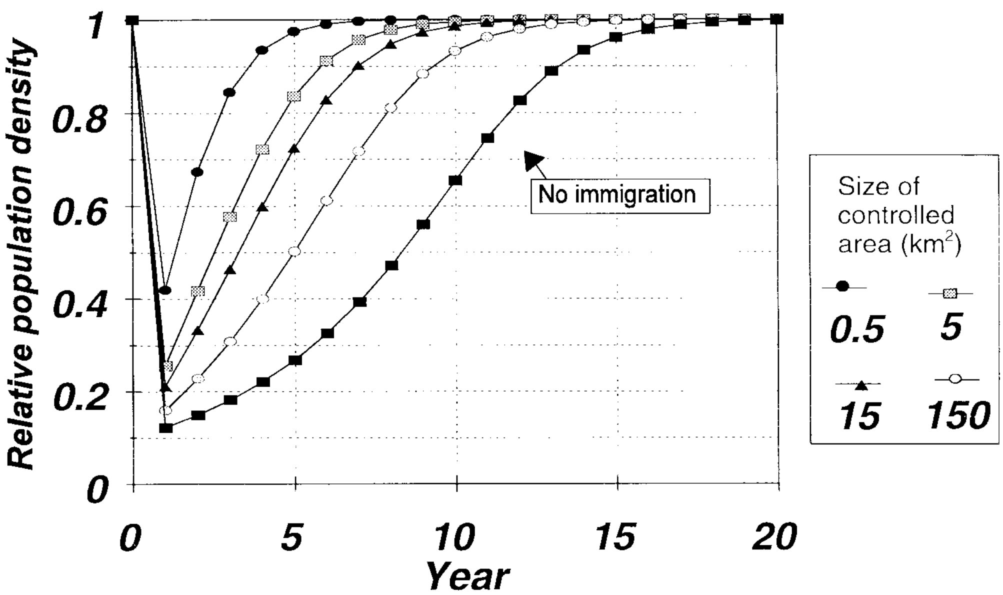


Figure 1. Effect of dispersal sink shape on the likely frequency of arrival of migrant animals. Both dispersal sinks have equal area.

Figure 2. Effects of immigration and size of controlled area (from 0.5 to 150 km²) on recovery of possum numbers in a homogeneous habitat after a single 90% control operation (Barlow model, r = 0.2; Barlow 1991).



4.1.3 Distance between habitat patches

Information on the effect of distance between habitat patches on immigration can be derived from studies of possum movements. Local movements between habitats (<2 km) appear to be rare in uncontrolled populations, and such movements would hence be expected to make little contribution to immigration. Brockie et al. (1989) live-trapped, marked, and released about 500 possums in contiguous swamp, willow and pasture habitats within a 300 ha area in Hawke's Bay over five years. Only 1–2% of animals first trapped in one habitat were ever recaptured in a different habitat. Similarly, Cowan & Rhodes (1993) found that there were few movements of possums between bush patches on adjacent farms in the central North Island and only 10% of them were of more than 500 m.

Three factors contribute to these findings:

- Adult possum home ranges generally change little in size or activity centre over the animals' lifetimes (Ward 1978; Brockie et al. 1989; M.G. Efford unpubl.).
- The nightly distances (range lengths) moved by possums are generally not large, ranging from 100–200 m in forest to about 2 km at the extreme where animals are foraging from forest out onto farmland (Green & Coleman 1986) or over extensive areas of pasture (Brockie et al. 1989).
- Long distance movements (>2 km) by possums are almost only made by juvenile animals, mostly males (Efford 1991; Cowan et al. 1996). Average dispersal distance is about 6 km, reducing to 5 km if the three extreme movements of 25, 31, and 41 km are excluded (Figure 3).

The percentage of possums dispersing over a particular distance decreases sharply as the distance increases (Figure 4).

The number of immigrants arriving at a site (dispersal sink) after control is affected by a number of factors (Figure 5).

Figure 3. Frequency distribution of dispersal distances of radio-tagged (Radio-Tx) and ear-tagged (Tag) possums (Cowan unpubl.).

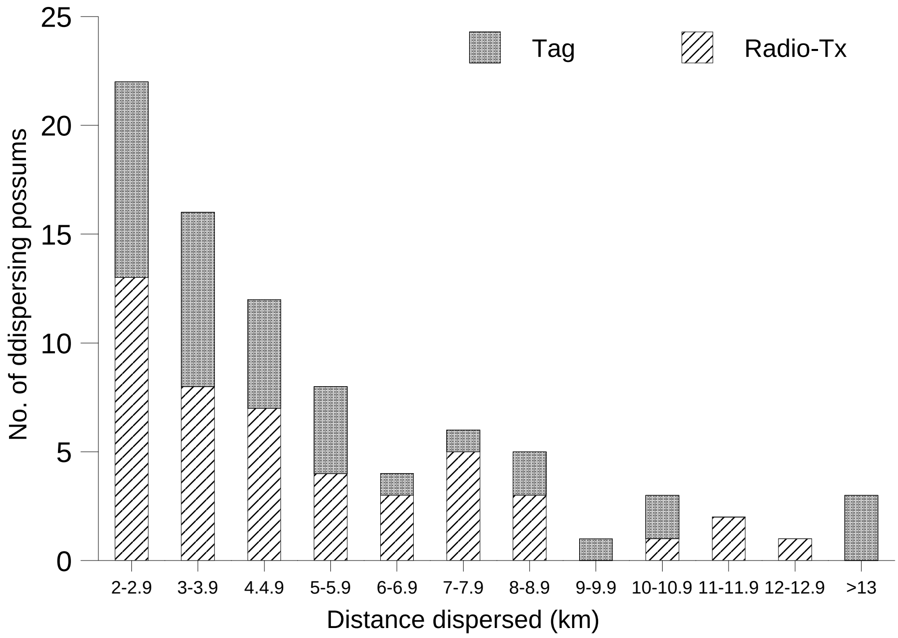


Figure 4. Percentage of possums dispersing over various distances (Cowan unpubl.). Dispersal was defined as a movement of >2 km to distinguish it from large local movements about an animal's home range (Clout & Efford 1984).

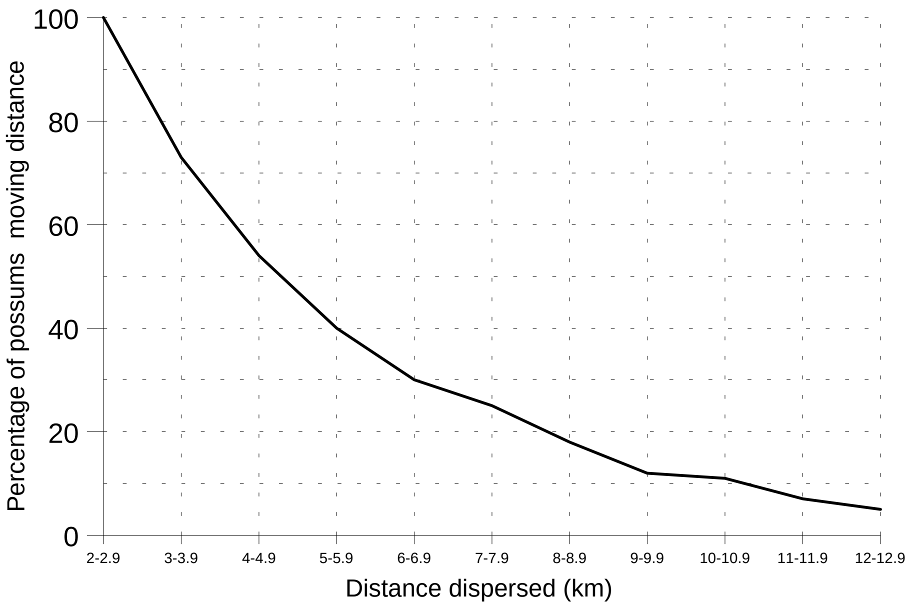
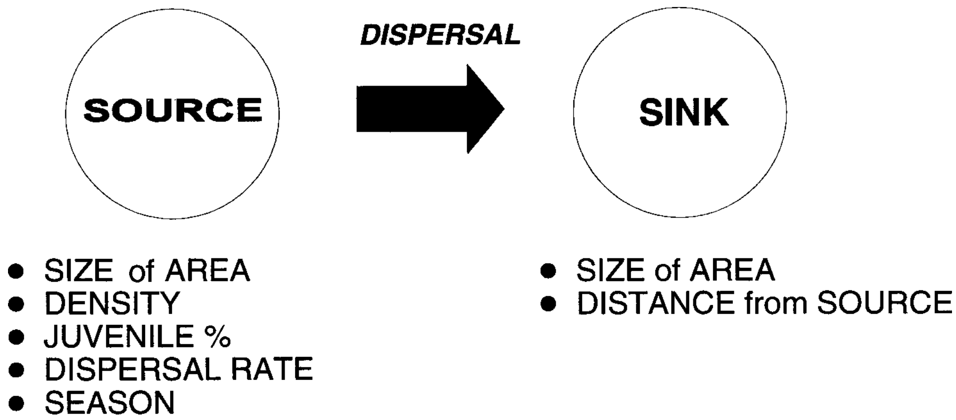


Figure 5. Factors affecting animal dispersal at source and settlement at sink.



About 20–25% of juvenile possums undertake long-distance dispersal (Cowan & Rhodes 1993; Cowan et al. 1996, 1997), and juveniles at peak numbers make up about 30% of the possum population (Efford 1996). A simple model incorporating the data on dispersal frequencies and distances (see Appendix 1) makes the following predictions.

- Increasing the percentage of juveniles in the source population from 20% to 30% increases the number of long-distance migrants by about 50%.
- Increasing the percentage of juveniles dispersing from the source population from 20% to 25% increases the number of long-distance migrants by 25%.
- Large sources generate more migrants than small ones.
- The number of migrants arriving at a dispersal sink decreases sharply as the distance from the source increases.
- From the same sized source, fewer migrants arrive at a small dispersal sink than at a large one.
- More migrants arrive at a small dispersal sink near a large source than the reverse.

4.1.4 Effects of control on immigration

One explanation for the rapid recovery of possum numbers after control is the suggestion that possums from surrounding uncontrolled areas rapidly invade the controlled area because there is reduced competition for food and den sites in the controlled area. This is often referred to as the 'vacuum' effect. There is little evidence to support this idea. Cowan & Rhodes (1993) found that only one out of 78 radio-tagged possums shifted its daytime location after a nearby aerial 1080 control operation, even although about half of the possums were within foraging range of the controlled area where density had been reduced by about 80%. Brockie (1991) tagged 141 possums at scrub patches within 3 km of two adjacent farms where about 90% of possums had been killed. Only one of these, a juvenile male on first capture, was trapped on the controlled farms over the subsequent two years. Efford et al. (2000) found effectively no new possums arriving in a 13 ha bush remnant on farmland during the 12 months after possum numbers in part of the patch had been substantially reduced. There was some local shifting of home ranges by survivors adjacent to the controlled areas during the 12 months after the control operation, however, the effect was only detectable over a distance of 200–300 m and seemed to involve animals whose ranges overlapped the control zone (Efford et al. 2000).

Where the process of population recovery after control has been studied in detail (Clout 1977; Green & Coleman 1984; Cowan unpubl.), it has been found consistently that the initial immigrants are largely young animals, mostly males, suggesting that they arrived as a result of dispersal movements rather than local range shifts.

4.1.5 Preferential re-colonisation of habitats

Possum numbers appear to build up after control more quickly in preferred than less preferred habitats. Forest/pasture margins often hold very high numbers of possums and recovery of numbers there after control is often more rapid than in other habitats. Coleman et al. (1980) estimated possum densities on Mt Bryan O'Lynn, Westland, at 25 per hectare along the forest/pasture margin, which decreased progressively with altitude to 1.9 per hectare in the high altitude forest. Three years after possums were eradicated, numbers had recovered to about 50% of pre-control in both the forest/pasture margin and higher up in the bush, so that the margin again had much higher possum numbers (Green & Coleman 1984). Cowan et al. (1996, 1997) observed a similar effect on farmland. Hickling (1993) and Caley et al. (1995) found that under annual maintenance control for Tb management, possum numbers along forest/pasture margins increased more rapidly than did those within the forest. Relative to initial numbers, there was no marked difference in rates of recovery between habitats in these studies, but in absolute terms possum numbers increased most rapidly in the initially highest density (preferred) habitats.

The large margin-to-area ratio in small patches of forest and scrub, and hence large expanse of preferred habitat, probably contributes to the rapid recovery of numbers in such patches.

4.1.6 Buffer zones

One strategy to reduce the rate of immigration into a 'target' area is to reduce possum numbers in the immediately surrounding area, to create a low-density buffer zone around the target area. Buffer zones could reduce re-infestation because they contain fewer possums and hence produce fewer dispersers. They may also reduce re-infestation by encouraging dispersing possums to settle in them rather than continue to disperse and potentially colonise the 'target' area because they offer reduced competition for food and nest sites. Barlow (1993) modelled the use of buffer zones to reduce re-infestation and concluded that they were effective more because they reduced the number of dispersing animals from the buffer zone than because they intercepted dispersers and acted as dispersal 'sinks'.

Trials are currently underway (Montague 1996; Nugent et al. 1997) to test the efficacy of buffer zones of different widths in reducing rates of re-infestation. After two years, pellet count indices of possum numbers were 120% of pre-control levels in a 1 km-wide buffer, but only 14% and 21% in 3 km and 7 km-wide buffers, respectively. In the 1 km and 7 km buffers, possum numbers appear to have recovered most quickly furthest from the forest/pasture margin, where the buffers adjoin areas not subject to possum control. Recovery in the 3 km buffer was most rapid along the forest/pasture margin, perhaps because maintenance control on adjacent farmland was less effective.

4.1.7 Settlement

A range of factors probably influence the decision of a dispersing possum to settle in one place rather than another. Such factors may include, for example, local density and sex ratio, reflected in competition for food, nest sites and mates, and other factors such as number of settlement attempts or distance already dispersed.

Currently, little is known about how such factors influence settlement. Cowan & Rhodes (1993) observed that some dispersing male and female possums moved completely across buffer zones before settling. Such possums may simply never have encountered a suitable settlement patch. By its non-uniform effects, however, control may create a greater variability of densities and sex ratios in the landscape than occurs naturally in undisturbed areas, suggesting enhanced opportunity for settlement in buffer zones. Efford (1991) noted that female dispersers tended to make more dispersal moves before settling than males. This suggests they were adopting a sampling procedure, although the decision-making rules are unknown. Cowan (unpubl.) found that some translocated possums established themselves at the release site, indicating that even in undisturbed populations there are gaps within the population that can be filled by immigrants. Experiments to elucidate factors affecting settlement have recently begun (Cowan unpubl.).

4.2 RATE OF RECOVERY OF SURVIVING POSSUM POPULATIONS

4.2.1 Habitat patch size and shape

Habitat size and shape are likely to influence the contribution of survivors to the rate of recovery only if they contribute to local variation in reproduction and survival. For example, if survival or breeding are enhanced at forest/pasture margins relative to deep forest, then populations in small patches where most possums access pasture, or in patches with a high margin to area ratio, would recover more quickly. This hypothesis has not yet been examined.

4.2.2 Population reduction

The extent to which a population is reduced by control has a marked effect on its rate of recovery in the absence of immigration. For example, reducing the initial kill from 90% to 70% reduces the time for the population to recover to half its original density from about eight years to about three years (Figure 6). With rate of increase (r) > 0.2 or with immigration these times would be greatly shortened, but the effect of the higher initial kill in slowing population recovery would remain.

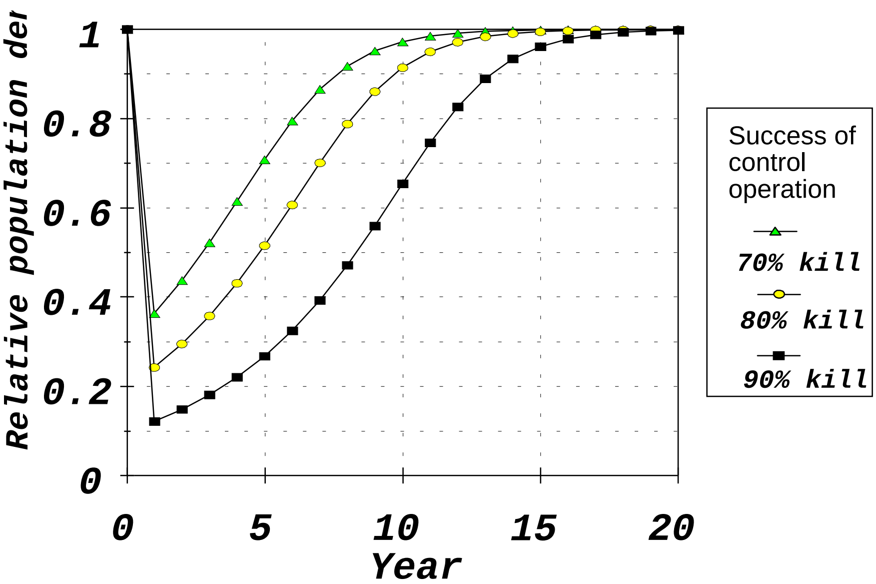


Figure 6. Recovery of possum populations after various levels of kill, from a single control operation, in a homogeneous habitat, in the absence of immigration (Barlow model, r = 0.2; Barlow 1991).

4.2.3 Density dependence

If changes in breeding, survival or emigration after control occur, they reflect density dependent processes. However, the focus of much possum research on improving management technologies has meant that knowledge of many fundamental processes, such as density dependence, remains scanty. M.G. Efford and M.E. Hearfield (unpubl.), in an analysis of 23 years of possum population data from the Orongorongo Valley, showed that annual variation in winter numbers was density dependent. The disappearance rate of both adult males and females increased with total density. Recruitment rate, however, did not appear to be significantly density-dependent, but the power of the test was low because of the large sampling error. Other data (e.g. Barlow & Clout 1983; Cowan 1993) suggest that both survival and recruitment may be related to density, but density dependent effects may be skewed and strongest near carrying capacity.

4.2.4 Reproduction

Populations could recover more quickly after control if the per capita production of young increased. This could occur if the

- Proportion of adult females breeding in autumn increased
- Proportion of females breeding in spring increased
- Females bred for the first time at a younger age

The proportion of adult females breeding in autumn generally exceeds 80% (Efford 1991; Cowan 1993) so the maximum increase in autumn breeding could only amount to about 20%. Spring breeding varies greatly from place to place (Cowan 1990), but is consistently less frequent than autumn breeding so it has potentially more opportunity to contribute to increased reproduction after control. Little is known about how the survival of spring-born young compared with that of autumn-born young, so the significance of any change in level of spring breeding is difficult to evaluate. Evidence for a short-term increase in either autumn or spring breeding after control is sparse. Cowan (1993) found little change in possum breeding on Kapiti Island during the eradication programme. Similarly, large reductions in density did not stimulate breeding in studies by Green & Coleman (1984) or Kean (1971). The changes in the age distribution of possums on Kapiti Island during the eradication programme led Cowan (1993) to conclude that control had altered survival rates, particularly of juvenile animals, in addition to any small effect on reproduction.

Both the level of spring breeding and age at first breeding are affected by the availability of food (Bell 1981; Hocking 1981). The lack of an immediate response in possum breeding after control may reflect a lag in recovery of the habitat (and hence food supply) or that the level of possum reduction has been insufficient to allow the recovery of preferred foods (Payton et al. 1997). Although improvements in body weight and condition of possums in controlled areas have been reported (Green & Coleman 1984), effects on breeding were small. Bell (1981) noted significant correlations between female body weight and breeding performance in one population. Together, these studies suggest that improvements in possum condition as a result of control are likely to result in increases in possum breeding success, but that the effects are likely to vary between habitats.

Breeding parameters in possums appear to be highly correlated (Brockie et al. 1979). Populations that breed earlier in the autumn (or in years when autumn breeding is earlier) have higher proportions of one-year-old female breeding, higher percentages of adult female breeding, higher levels of spring breeding, and higher pouch young survival. This implies that if there is a breeding response to control then it is likely to show in all aspects of breeding.

4.2.5 Survival

Populations could also recover more quickly after control if the survival of animals from birth to breeding age increased. This could occur if either (or both) the survival of young from birth to independence increased, and/or the survival of newly independent young to first breeding age increased. Any increase in the survival rate of adult females left alive after control could also speed the recovery of the population.

Bell (1981) reported a significant inverse relationship between female condition and pouch young mortality and growth in one population. Improvements in body weight and condition of possums in controlled areas (Green & Coleman 1984) are therefore likely to also improve pouch young survival. However, in most areas and most years pouch young survival to weaning is high (>80%; Cowan 1990), so the contribution of increased pouch young survival to increased population recovery cannot be great. Disappearance rates between late pouch life and first independent capture at 9–10 months of age are generally high (>50%, Efford 1998), and tend also to be high for males between independence and sexual maturity (partly because of male biased dispersal). Even allowing for juvenile dispersal, improved survival over that period has the capacity to increase the rate of population recovery more than pouch young survival. There are no data on changes in survival of adult females after control. Interestingly, though, sterilised female possums and rabbits (which make little energetic investment in breeding) have higher survival rates than normal females (D. Ramsey pers. comm.; Williams et al. 1995). By analogy, after control when there is reduced competition for resources possums might be expected to show enhanced survival.

4.2.6 Reduced emigration

If a smaller proportion of the young born to survivors of a control operation emigrated from their natal area after control than before then the population would recover more quickly. This does not seem to happen in practice. Cowan et al. (1997) found no difference in the proportion of radio-tagged juvenile possums that dispersed from their natal area before or after a control operation that reduced numbers of resident possums by about 90%.

4.2.7 Colonisation and re-colonisation

Possum populations colonising new areas generally have a higher level of spring breeding and a lower average age of first breeding than established populations (Green 1984), responses that might be expected from possum re-infesting areas after control. However, the high productivity of colonising populations is not simply a reflection of low possum densities. Productivity of possums at the same density in the increasing and decreasing phases of a population irruption is quite different. This response is presumably a result of the physiological consequences of diet change following the depletion of highly palatable species (Fraser 1979, 1988). Thus, the extent and rapidity of any change in possum population performance after control is likely to depend largely on the extent and speed of recovery of possum palatable plant species.

4.3 OBSERVED RATES OF POPULATION CHANGE

Annual fluctuations in the size of undisturbed populations provide information on natural rates of change, being the combination of immigration, recruitment of young born on the area and adult survival. Between 1966 and 1994 the extreme annual changes in the possum population in the Orongorongo Valley ranged from a decrease of 26% to an increase of 63%. There were few annual changes outside the range +20 to –20% (Figure 7).

More variation was recorded by Thomas et al. (1993) in a long-term study of an uncontrolled possum population in the Aorangi Forest Park. The use of kill-trapping, which removed some part of the local population annually, and the sensitivity of such trapping to weather conditions, probably accounts for much of the extra variation.

Such natural annual variation appears to be largely driven by interactions between climate and food supply affecting survival (Bell 1981; Efford 1991), although under extreme conditions breeding may also be affected (Efford 1997). The key point from these studies, however, is that the increases in some years are too large to be explained by observed changes in reproductive rate alone, and therefore immigration must have contributed significantly to possum numbers in those years.

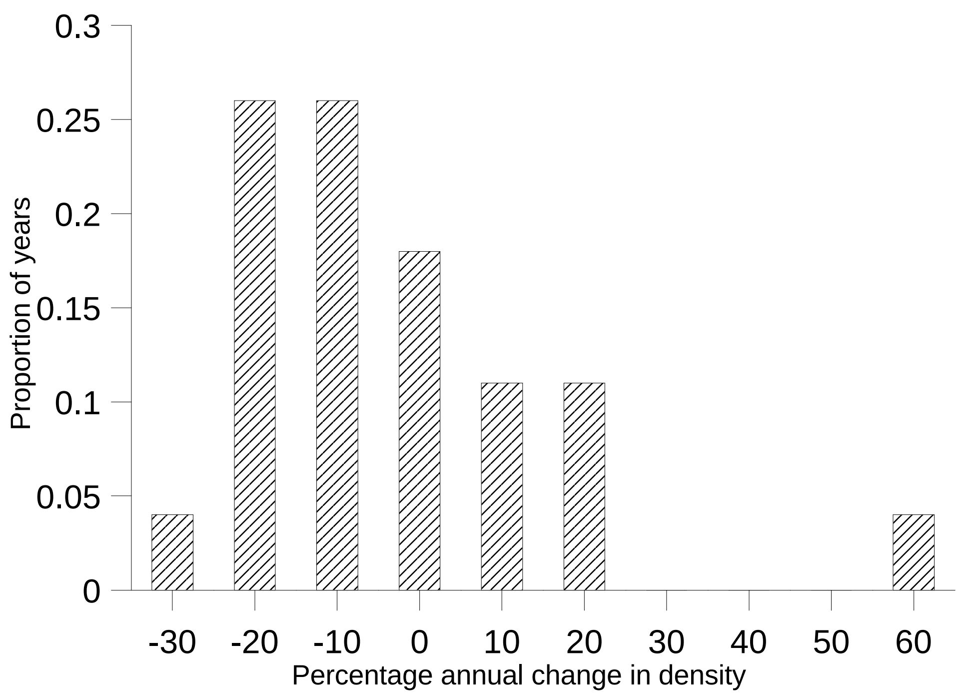


Figure 7. Frequency distribution of different levels of percentage annual change in the density of possums, Orongorongo Valley 1966–1994, based on mark-recapture estimates (M.G. Efford unpubl.).

Research is currently underway to relate observed rates of increase after control operations to possum demographic, site and vegetation parameters so that population recovery after control can be better predicted (Coleman 1997). This will enable the nature and frequency of possum control needed to maintain populations below accepted thresholds so that damage mitigation may be determined.

5. Models of re-infestation

Although several computer models of possum population dynamics can be used to estimate the recovery of possum numbers after control, only two models specifically include immigration—Barlow's (1991, 1993) possum/Tb model and Efford's (1996) Geoposs model.

Barlow's (1991, 1993) model replicates a population (with or without Tb infection) over a grid of 1 km squares. His simulation is applicable more to large areas of similar habitat (such as tracts of native forest) than to scattered bush or scrub patches on farmland. Simulation of long-distance dispersal was done by fitting a negative exponential curve to available field data on dispersal distances. Extension or alteration of home ranges of animals adjacent to controlled areas was also estimated from field data. Barlow (1993) concluded that immigration in the outer 1 km of a controlled area was likely to be high because of short-range re-colonisation by adult possums. Control was needed over large areas to reduce the impact of such immigration. Control of an 80 km^2 area was needed to limit immigration to 5% or less of the surrounding equilibrium density per year, over the whole area controlled. But if immigration in the outer 1 km strip was omitted, control of only a 15 km^2 area would result in the same level of immigration. The shape of the controlled area had little effect on immigration of juveniles, but influenced that of adults because of the high rate of adult movement into the outer 1 km strip. Barlow (1993) recognized the need for additional biological data to support the assumptions of his model, particularly on short-range movements by adults. This research is currently in progress (Efford et al. 2000), and suggests that Barlow's model may overestimate the importance of such movements.

Efford's (1996) Geoposs model represents a set of individuals , each located at a point in 2-D space and subject to certain probabilities of birth, death, and dispersal. The number of individuals in any small area is assumed to be regulated by density-dependent feedback on *in situ* demography and/or movement. Possum-carrying capacity is mapped by applying mean densities for broad vegetation types based on field data, with the carrying capacity of forest and scrub within 1 km of pasture increased to mimic the edge effect observed in field studies. The dispersal algorithm comprises for each animal a 'decision' to emigrate, an indefinite series of discrete movements, and an ultimate 'decision' to settle, the various stages being governed by sets of rules.

Efford (1996) gives a brief application of the model applied to a 45×55 km area of the central North Island to measure re-infestation rates in the 1 km forest/

pasture margin after a 90% effective control operation, and to assess the effects of varying levels of habitat selection by immigrants. In its present form, Geoposs could be used to investigate many of the factors affecting re-infestation discussed in this review, in both simulated and real terrain. However, the interpretation of the findings would need to be treated with caution until there is additional biological support for much of the Geoposs infrastructure.

Research is currently underway to validate a number of the component sub-models, e.g. factors influencing dispersal and settlement (Cowan et al. 1996, and unpubl.).

Ultimately, predictions generated by Geoposs will need to be validated by comparison with the outcome of real control operations so that its usefulness as a management tool can be assessed.

6. Monitoring

Independently of any response of possum populations, an apparent rapid recovery after control may result from problems with monitoring. These will arise particularly if initial control success is overestimated. Frampton (1994) evaluated the application, analysis and interpretation of a range of possum monitoring operations carried out for Tb control. He identified a range of problems that were contributing to inaccuracies in monitoring results. Problems may also arise if the maintenance control and monitoring techniques do not sample the same populations. For example, maintenance control around the edges of bush patches may not target possums that live within the bush, particularly if the maintenance control is of short duration. Brockie et al. (1997) found that despite several years of live-trapping using a ring of traps with never more than 50% trap success and so little competition for traps, about one third of possums within a small 12 ha patch of scrub had never been captured.

7. Conclusions

Rates of recovery of possum populations after control are influenced by changing *in situ* reproduction and survival and by immigration. Control is often conducted in the absence of any information about the biological characteristics of the local possum population. Such information will be necessary in future if management models being developed are to prove of practical benefit. To give a simple example, a population with a significant level of spring breeding will recover faster than one with only autumn breeding—and a control area surrounded by source populations with significant levels of spring breeding will suffer higher rates of immigration than those surrounded only be autumn breeding populations. Simple data on timing of the breeding season may usefully predict breeding performance of a population and its potential response to control. Such information could be collected routinely during pre-poisoning population assessment using trap-catch and used in the development of appropriate maintenance control plans.

The emphasis on research for practical improvement in possum management has meant that many of the fundamental features of possum population ecology remain poorly described, despite their obvious relevance to key management issues like rates of population recovery after control. A number of studies are now underway that will provide some of the required information over the next three to five years. The key areas where information is needed are those influencing settlement of dispersing possums and density dependent responses in recruitment and survival. Field validation of current possum population models is required, particularly as they relate to movements and dispersal.

Because a number of the factors affecting rate of recovery after control are likely to be site-specific, improving the usefulness of predictive modelling for management will require that such models operate in real landscapes (e.g. Geoposs, Efford 1996).

Doubts have been expressed about some of the reported rapid rates of recovery, because they exceed anything observed in a range of experimental studies. Improved operational monitoring should help clarify this issue.

8. Recommendations

Minimising rates of re-infestation after control would be assisted by the following actions.

- Collecting basic information on local possum biology in advance of control operations so that recovery rates can be better predicted.
- Using effective boundaries to controlled areas, particularly major waterways or large expanses of pasture.
- Considering appropriate size and shape of area to be controlled in relation to surrounding sources of potential immigrants.
- Minimising immigration into the area of conservation value through use of buffer zones extending out from 3 to 5 km.
- Stratifying control effort to preferred habitats, particularly margins.
- Maximising initial kill.
- Timing control to target females with dependent offspring.
- Timing control to target the main periods of immigration.
- Maintaining accurate and consistent operational monitoring.

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10. References

Barlow, N.D. 1991: Control of endemic bovine Tb in New Zealand possum populations: results from a simple model. *Journal of applied ecology 28*: 794–809.

Barlow, N.D. 1993: A model for the spread of bovine Tb in New Zealand. *Journal of applied ecology 30*: 156–164.

Barlow, N.D.; Clout, M.N. 1983: A comparison of 3-parameter, single species population models in relation to the management of brushtail possums in New Zealand. *Oecologia 60*: 250–258.

Bell, B.D. 1981: Breeding and condition of possums *Trichosurus vulpecula* in the Orongorongo Valley, near Wellington 1966–1975. *Zoology Publications from Victoria University of Wellington No. 74*: 87–139.

Brockie, R.E. 1991: Ecology of an uninfected farm possum population. *Veterinary Continuing Education, Massey University, Publication 132*: 53–66.

Brockie, R.E.; Cowan, P.E.; Efford, M.G.; White, A.J.; Bell, B.D. 1979: The demography of *Trichosurus vulpecula* in Australia and New Zealand. DSIR, Ecology Division report. 10p.

Brockie, R.E.; Ward, G.D.; Cowan, P.E. 1997: Possums (*Trichosurus vulpecula*) on Hawke's Bay farmland: spatial distribution and population structure before and after a control operation. *Journal of the Royal Society of New Zealand 27*: 181–191.

Brockie, R.E.; Herritty, P.J.; Ward, G.D.; Fairweather, A.A.C. 1989: A population study of Hawke's Bay farmland possums, *Trichosurus vulpecula*. Department of Scientific and Industrial Research, Ecology Division Report 26: 1–43.

Caley, P.A.; Hickling, G.J.; Cowan, P.E. 1995: Sustained control of possums to reduce bovine tuberculosis in cattle and possum populations in New Zealand. Pp. 276–281 Proceedings of the 10th Australian Vertebrate Pest Control Conference, Hobart, Tasmania, May 1995. Tasmanian Department of Primary Industry and Fisheries, Hobart.

Clout, M.N. 1977: The ecology of the possum (*Trichosurus vulpecula* Kerr) in *Pinus radiata* plantations. Unpublished Ph.D. thesis, University of Auckland.

Clout, M.N.; Efford, M.G. 1984: Sex differences in the dispersal and settlement of brushtail possums (*Trichosurus vulpecula*). *Journal of animal ecology 53*: 737–749.

Clout, M.N.; Gaze, P.D. 1984: Brushtail possums (*Trichosurus vulpecula* Kerr) in a New Zealand beech (*Nothofagus*) forest. *New Zealand journal of ecology* 7: 147–155.

Coleman, J.D. 1997: Rate of increase in possum numbers following control operations—1996/97. Landcare Research Contract Report LC9697/129 (unpublished). 7p.

Coleman, J.D.; Gillman, A.; Green, W.Q. 1980: Forest patterns and possum densities within podocarp/mixed hardwood forests on Mt Bryan O'Lynn, Westland. *New Zealand journal of ecology 3*: 69–84.

Cowan, P.E. 1990: Brushtail possum. Pp. 67–98 in King, C.M. (Ed.) The handbook of New Zealand mammals. Oxford University Press, Auckland.

Cowan, P.E. 1993: Effects of intensive trapping on breeding and age structure of brushtail possums, *Trichosurus vulpecula*, on Kapiti Island, New Zealand. *New Zealand journal of zoology 20*: 1–11.

Cowan, P.E.; Brockie, R.E.; Ward, G.D.; Efford, M.G. 1996: Long-distance movements of juvenile brushtail possums (*Trichosurus vulpecula*) on farmland, Hawke's Bay, New Zealand. *Wildlife Research 23*: 237–244.

Cowan, P.E.; Brockie, R.E.; Smith, R.N.; Hearfield, M.E. 1997: Dispersal of juvenile brushtail possums, *Trichosurus vulpecula*, after a control operation. *Wildlife research 24*: 279–288.

Cowan, P.E.; Rhodes, D.A. 1993: Electric fences and poison buffers as barriers to movements and dispersal of brushtail possums (*Trichosurus vulpecula*) on farmland. *Wildlife research 20*: 671–686.

Efford, M.G. 1991: A review of possum dispersal. Department of Scientific and Industrial Research, *Land Resources scientific report 91/73*: 1–70.

Efford, M.G. 1996: Simulating spatially distributed populations. Pp. 409–481 in Floyd, R.B.; Sheppard, A.W.; De Barro, P.J. (Eds) Frontiers of population ecology. CSIRO Publishing, Melbourne.

Efford, M.G. 1997: When possums stop breeding. *He Korero Paihama—Possum Research News No. 7*: 9–11.

Efford, M.G. 1998: Demographic consequences of sex-biassed dispersal in a population of brushtail possums. *Journal of animal ecology 67*: 503–517.

Efford, M.G.; Warburton, B.W.; Spencer, N. 2000: Home-range changes by brushtail possums in response to control. *Wildlife research* (in press).

Frampton, C.M. 1994: Application, analysis and interpretation of possum monitoring by MAF Quality Management for auditing Tb possum control. Landcare Research Contract Report LC9394/84. 17p. (unpublished).

Fraser, K.W. 1979: Dynamics and condition of opossum (*Trichosurus vulpecula* Kerr) populations in the Copland Valley, Westland, New Zealand. *Mauri ora 7*: 117–137.

Fraser, K.W. 1988: Changes in demography, physical size and reproductive performance in possums over an eruptive population cycle in Westland National Park. Forest Research Institute, unpublished contract report for the Department of Conservation, FAE 1.29. 13p.

Green, W.Q. 1984: A review of ecological studies relevant to management of the common brushtail possum. Pp 483–499 in Smith A.P.; Hume I.D. (Eds) Possums and gliders. Surrey Beatty, Chipping Norton, N.S.W.

Green, W.Q.; Coleman, J.D. 1984: Response of a brush-tailed possum population to intensive trapping. *New Zealand journal of zoology 11*: 319–328.

Green, W.Q.; Coleman, J.D. 1986: Movement of possums (*Trichosurus vulpecula*) between forest and pasture in Westland, New Zealand: implications for bovine tuberculosis transmission. *New Zealand journal of ecology 9*: 57–69.

Hickling, G.J. 1993: Sustained control of possums to reduce bovine tuberculosis infection in cattle and possum populations. Landcare Research Contract report LC9394/99. 24p. (unpublished).

Hocking, G.J. 1981: The population ecology of the brush-tailed possum, *Trichosurus vulpecula* (Kerr), in Tasmania. MSc thesis, University of Tasmania, Hobart.

Julian, A. 1984: Possum distribution and recent spread in northern Northland: with observations on the vegetation. Unpublished report to Lands and Survey Department, Wellington, and Ecology Division, DSIR, Lower Hutt.

Kean, R.I. 1971: Selection for melanism and for low reproductive rate in *Trichosurus vulpecula* (Marsupialia). *Proceedings of the New Zealand Ecological Society 18*: 18–41.

Montague, T.L. 1996: Optimal buffer widths for forest-edge maintenance control of possums (Franz Joseph). Landcare Research Contract report LC9596/154. 10p. (unpublished).

Nugent, G.; Coleman, J.D.; Fraser, K.W. 1997: Optimal buffer widths for control of possums in the Hauhungaroa Range: 1996—population recovery and Tb prevalence in possums, deer, and pigs two years after control. Landcare Research contract report LC9697/124. 25p. (unpublished).

Payton, I.J.; Forester, L.; Frampton, C.M.; Thomas, M.D. 1997: Response of selected tree species to culling of introduced Australian brushtail possums *Trichosurus vulpecula* at Waipoua Forest, Northland, New Zealand. *Biological conservation 81*: 247–255.

Pekelharing, C.J.; Reynolds, R.N. 1983: Distribution and abundance of browsing mammals in Westland National park in 1978, and some observations on their impact on the vegetation. *New Zealand journal of forestry science 13*: 247–265.

Pietsch, R.S. 1994: The fate of urban common brushtail possums translocated to sclerophyll forest. Pp. 236–246 in Serena, M. (Ed.) Reintroduction biology of Australian and New Zealand fauna. Surrey Beatty, Chipping Norton, NSW.

Pracy, L.T. 1975: Opossums (I). *New Zealand's nature heritage 3*: 873–882.

Thomas, M.D.; Hickling, G.J.; Coleman, J.D.; Pracy, L.T. 1993: Long-term trends in possum numbers at Pararaki: evidence of an irruptive fluctuation. *New Zealand journal of ecology 17*: 29–34.

Ward, G.D. 1978: Habitat use and home range of radio-tagged opossums, *Trichosurus vulpecula* (Kerr) in New Zealand lowland forest. Pp. 267–87 in Montgomery, G.G. (Ed.) The ecology of arboreal Folivores. Smithsonian Institution Press, Washington, D.C.

Ward, G.D. 1985: The fate of young radiotagged common brushtail possums, *Trichosurus vulpecula*, in New Zealand lowland forest. *Australian Wildlife Research 12*: 145–150.

Williams, K.; Davey, C.; Moore, R.; Bray, J.; Silvers, L.; Hinds, L.; Pech, R.; Kerr, P. 1995: Responses of wild rabbit populations to imposed sterility. Pp. 392–398 in Proceedings of the 10th Australian Vertebrate Pest Control Conference, Hobart, May 1995.

Appendix 1

NUMBER OF MIGRANT POSSUMS ARRIVING AT A DISPERSAL SINK

Migrant possums arriving at a dispersal sink from a source population of 10 possums per hectare. The table shows the effects of the percentage of juvenile possums in the source population, percentage of juvenile possums dispersing from the source population, source and dispersal sink areas, and distance between source and dispersal sink. The model assumes a single pulse of dispersal and a uniform distribution of dispersal directions (see text and Figures 3–5). With double breeding, more migrants would arrive.

		AREA (km^2)		NO. OF MIGRANTS ARRIVING		
				SINK-SOURCE DISTANCE (km)		
PERCENTAGE JUVENILES	PERCENTAGE DISPERSING	SOURCE	SINK	3	6	9
20	20	5	5	22	5	2
30	20	5	5	33	7	2
20	25	5	5	28	6	2
30	25	5	5	41	9	3
20	20	50	50	508	127	42
20	25	50	50	636	159	52
30	20	50	50	763	191	62
30	25	50	50	953	238	78
30	20	50	5	276	61	19
30	25	50	5	415	91	28
30	20	5	50	64	16	5
30	25	5	50	95	24	8