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Possums (*Trichosurus vulpecula*) on Hawke's Bay farmland: spatial distribution and population structure before and after a control operation

R. E. Brockie*[1], G. D. Ward*[2], P. E. Cowan*

Over 6.5 years, 723 possums were live-trapped and marked in swamp, willow, and farmland habitats on approx. 350 ha of two adjoining sheep farms in Hawke's Bay, New Zealand. About equal numbers of males and females were trapped in each habitat, but males were recaptured more often than females. Eighty-five percent of the possums were trapped along the margins of swamp and willow habitats that comprised only 6% of the study area. The swamp habitat contained at least 8.8 possums ha^{-1}, the willow habitat 16.7 possums ha^{-1}, and the farmland habitat 0.13 possums ha^{-1}. Possums generally moved less than 200 m between successive recaptures, and there were few trap-revealed movements between habitats. Possums on part of one farm comprising 23 ha of swamp and willows were then poisoned with cyanide in bait stations. Two hundred and fifty-eight possums—including 142 previously marked animals—were found dead, an estimated 90% of the population. Fifty-nine percent of the marked possums were poisoned within 100 m of their most recent trapping point, and 85% within 200 m. Proportionately more adult possums were killed on the first night's poisoning and more juveniles on subsequent nights. After the poisoning, the surviving possums showed very varied responses to the reduced population density, ranging from no change in location or range of movements to changes in location, range of movements, or both.

Keywords: possum; *Trichosurus vulpecula*; farmland; distribution, abundance, movements; management; control; poisoning

INTRODUCTION

Brushtail possums (*Trichosurus vulpecula*) are infected with bovine tuberculosis (*Mycobacterium bovis*) over about 23% of New Zealand's land area in 21 geographically discrete areas (Animal Health Board 1995). More than 90% of cattle herds on movement control and individual Tb-reactors were associated with these defined Tuberculosis Vector Areas. Increasingly large sums of money are spent in controlling possum numbers as part of the National Tb Strategy (Tweddle & Livingstone 1994; Animal Health Board 1995). Much control for Tb management, particularly that aimed at reducing tuberculous vectors, is carried out on farmland or along forest/pasture margins (Parliamentary Commissioner for the Environment 1994). Despite the importance of possums as potential reservoirs of bovine Tb infection, little is known about their ecology and the detailed impact of local control operations in farmland habitats.

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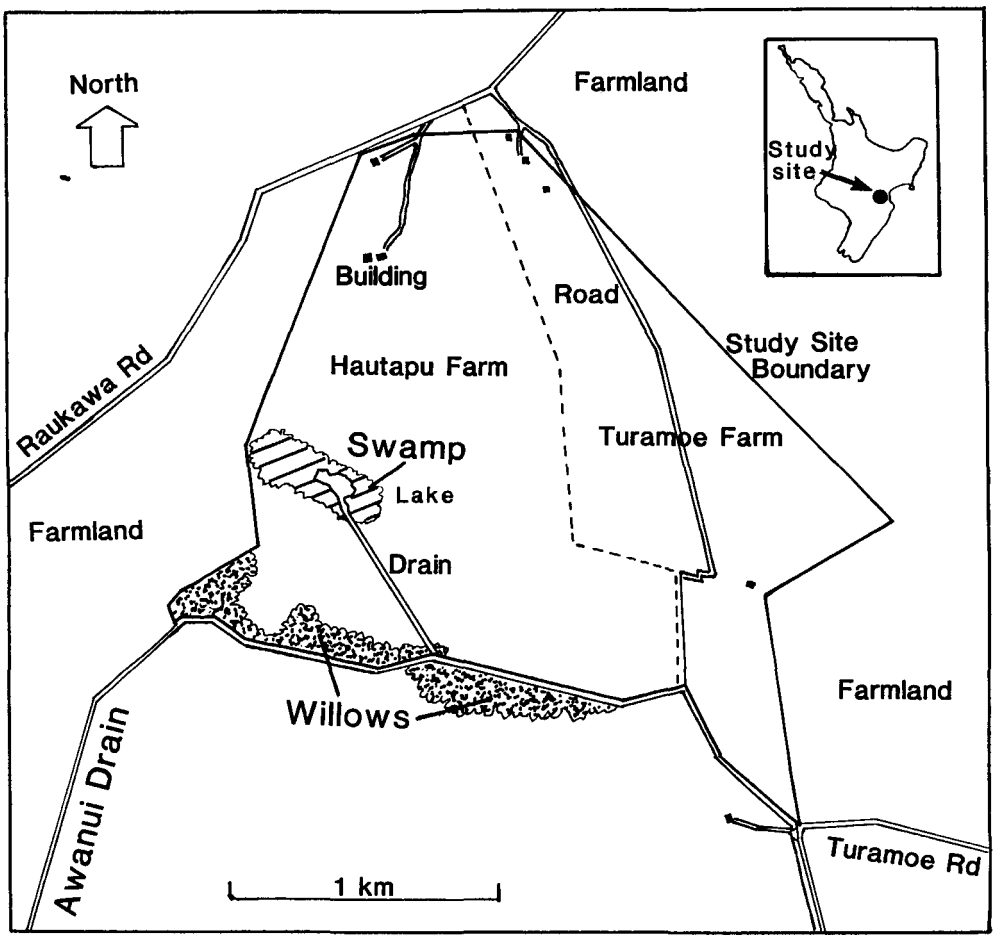

Fig. 1 Map of the Hawke's Bay study site, showing Hautapu and Turamoe Farms, swamp, willow, and farmland habitats. The boundary between the farms is marked by a dotted line.

Occasionally, astonishing claims are made for the numbers of possums killed on farmland, ranging from 25 to 70 possums ha^{-1} (Pracy 1947; Wodzicki 1950; Coleman et al. 1980). However, not all population estimates from farmland are as high (0.1 to 12 possums ha^{-1}: Jolly 1976; Triggs 1982).

This paper describes distribution, numbers, and movements between habitats of possums on farmland, how these influenced the effectiveness of a local control operation, and changes in the ranging behaviour of survivors of the control operation.

STUDY AREA

The study was centred on two adjacent farms, Hautapu and Turamoe, in Hawke's Bay, eastern North Island (39°41′ S, 176°44′ E; Fig. 1). There were three distinct habitats on the farms. The swamp habitat comprised about 12 ha of the low-lying parts of Hautapu farm. It was bounded by a single-wire electric stock fence, and was mostly covered in willows (*Salix* spp.), a dense tangle of blackberry (*Rubus fruticosus*), toitoi (*Cortaderia* spp.), flax (*Phormium tenax*), and for part of the year head-high fescue (*Festuca* spp.) and rushes (*Juncus* spp.). Tall fescue and rushes also covered about 21 ha of ground between the swamp and willow habitat

lining the Awanui Drain. After heavy rain, overflow from the swamp filled this area. The willow habitat, a dense area of standing and fallen trees, covered about 11 ha along the northern bank of the drain and 8 ha on its southern side. The farmland habitat comprised about 300 ha of flat to rolling sheep-grazing land with a few cattle and deer, occasional legume, brassica, and cereal crops, and small orchards. For most of the year the Awanui Drain had flowing water, but it dried out occasionally in the summer. Willows, poplars (*Populus* spp.), gums (*Eucalyptus* spp.), and radiata pines (*Pinus radiata*) formed windbreaks along many fence lines throughout the area.

METHODS

Possum trapping

Between October 1982 and February 1988 we attempted to mark all possums on Hautapu and Turamoe farms. Livetraps baited with apple coated with flour and aniseed were usually set for 4 nights each month. Until December 1984 traps were often moved around the farms to sites thought likely to catch possums. From January 1985 onwards we set the traps at 54 fixed sites around the swamp and willow habitats, and at 29 sites in the farmland habitat (Fig. 2). Most of the farmland sites were near shelter belts or farm buildings likely to harbour possums. The willows on the south side of the Awanui Drain were not trapped because casual trapping and radiotracking showed that possums rarely crossed the Drain. Upon first capture we anaesthetised each animal with ether, weighed it, and recorded its body measurements. Adult animals were marked with a numbered metal tag in one ear, and tattooed with a number in the other ear. We classified animals as adult or juvenile; juveniles had small (<10 mm wide) testes or shallow, unformed pouches with inverted teats, and generally weighed less than 2 kg (Brockie et al. 1987).

Possum poisoning

In April 1988 the swamp and willow habitats were poisoned by staff of the local regional council. Bait stations were laid out in two lines at 167 sites spaced 20 m apart, equivalent to a density of 15 stations ha^{-1}. They were baited with non-toxic dry flour and icing sugar mixed with a citrus oil lure for 2 nights before cyanide paste was added. Line 1 covered two-thirds of the swamp and willow habitats and was poisoned on the nights of 6 and 7 April 1988 (Fig. 3). Because bad weather intervened, the remaining third of the swamp and willows (Line 2, Fig. 3) was poisoned for 2 nights 11 days later. After each night's poisoning three people searched along the lines and in nearby undergrowth for corpses.

In the month after the poisoning we set live-traps at the usual sites in the swamp and willow habitats for 456 trap-nights to locate survivors. Live trapping was continued thereafter to study the recovery of the population (Cowan & Brockie, unpublished data). We set traps for a further 7941 trap-nights on Hautapu and Turamoe farms and for 1320 trap-nights in the surrounding district between June 1988 and February 1991.

RESULTS

Population structure and movements before control

Over the 6.5 years of the study before the poisoning, 723 individual possums were captured (Table 1). Trap success was similar in the swamp and willow habitats ($\chi^2 = 0.05$, 1 d.f., $P > 0.5$), but was significantly lower in the farmland habitat ($\chi^2 = 238.5$, 212.2, respectively, 1 d.f., $P < 0.001$, all comparisons). The numbers of males and females trapped in each habitat were roughly equal. Overall, however, males tended to be recaptured more often than females, with a higher proportion of males (44%) than females (33%) having more than 5 recaptures ($\chi^2 = 5.4$, 1 d.f., $P < 0.02$).

Possums did not generally move far between recaptures. Sixty-four percent of recaptures of males and 78% of recaptures of females were within 100 m of their previous capture site, 81% and 85% respectively were within 200 m, and 95% and 95% respectively were within

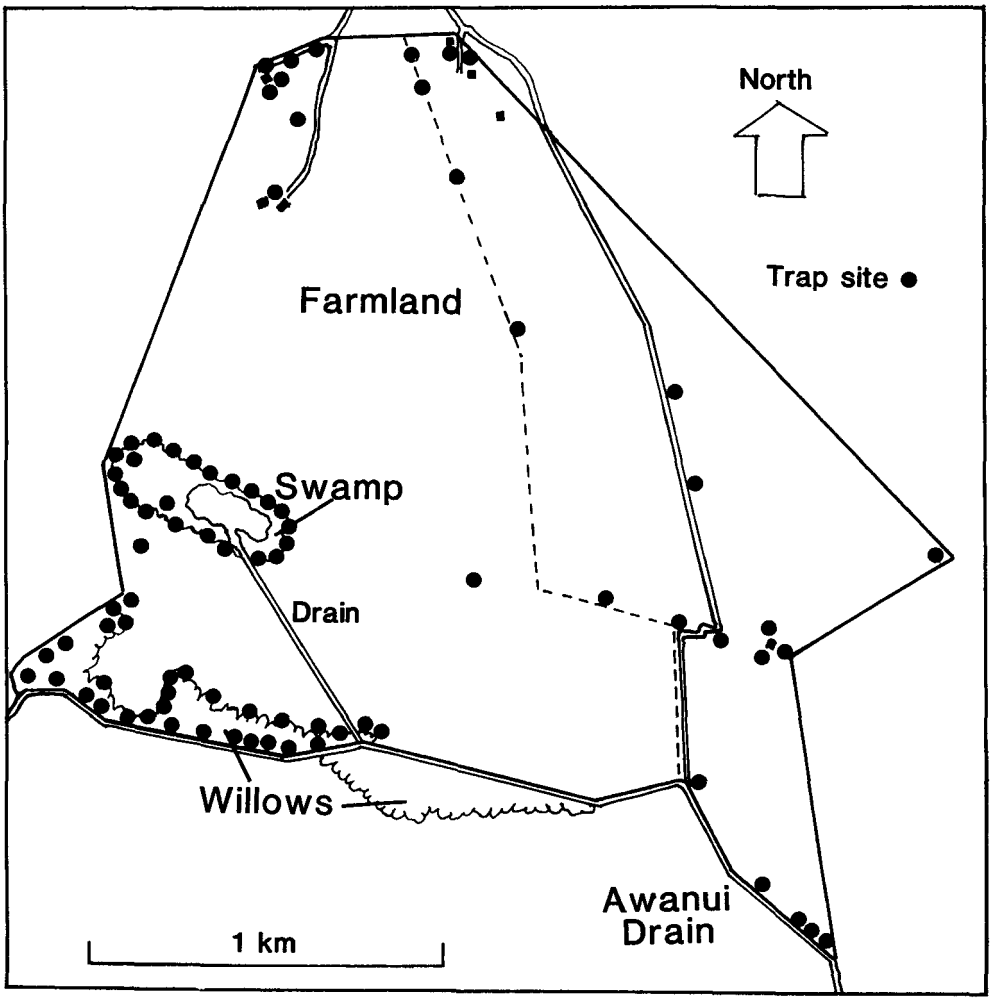

Fig. 2 Possum live-trapping sites (•) in swamp, willow, and farmland habitats, Hautapu and Turamoe farms.

Table 1 Live-trapping effort and success in three habitats on Hawke's Bay farms, based on marking and recapture of possums.

Habitat	Dates	No. of trap-nights	Sex	No. of possums	No. of recaptures	Percentage trap success
Swamp	Apr 84–Feb 88	6127	Male	134	861	16.2
			Female	147	683	13.6
Willows	Feb 85– Feb 88	4427	Male	144	603	16.9
			Female	127	454	13.1
Farmland	Oct 82–Feb 88	6280	Male	88	519	9.7
			Female	83	439	8.3
Total		16 834		723	3559	25.4

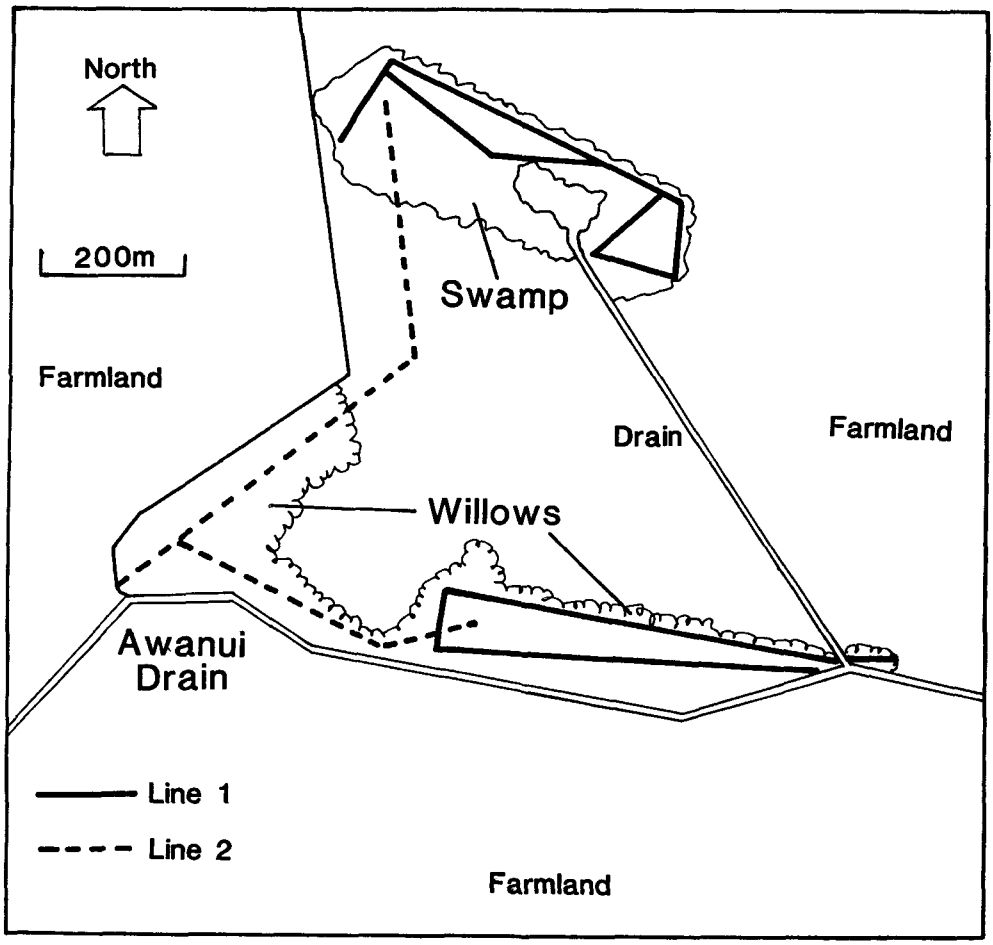

Fig. 3 Location of cyanide poison lines through swamp and willow habitats, Hautapu farm, April 1988.

700 m. The longest distances between recaptures were those of two males retrapped 1.8–1.9 km from their previous capture sites, and three females retrapped at a distance of 2.4–2.6 km.

There were also few movements between habitats. Most recaptures (97%) of possums first marked in the swamp habitat were in the same habitat, with only 1% and 2% in the willow and farmland habitats respectively. Similarly, 98% and 96% of recaptures of possums first marked in the willow and farmland habitats respectively were in the same habitat, with only 1% and 3% respectively in the swamp habitat, and 1% each in the farmland and willow habitats.

Impact of the control operation

Two hundred and fifty-eight possum corpses were found in the swamp and willow habitats after the poisoning (Table 2). No data were recorded for two animals. Most of the possums (66.4%) were killed in the willow habitat. About half of the kill (55.5%) consisted of marked possums. Proportionately more marked than unmarked adults were poisoned in the swamp habitat (85.3%) than in the willow habitat (61.3%) (Table 2; $\chi^2 = 11.1$, 1 d.f.; $P < 0.001$). The sex ratio of possums killed (44.2% males in the swamp; 47.1% males in the willows) did not

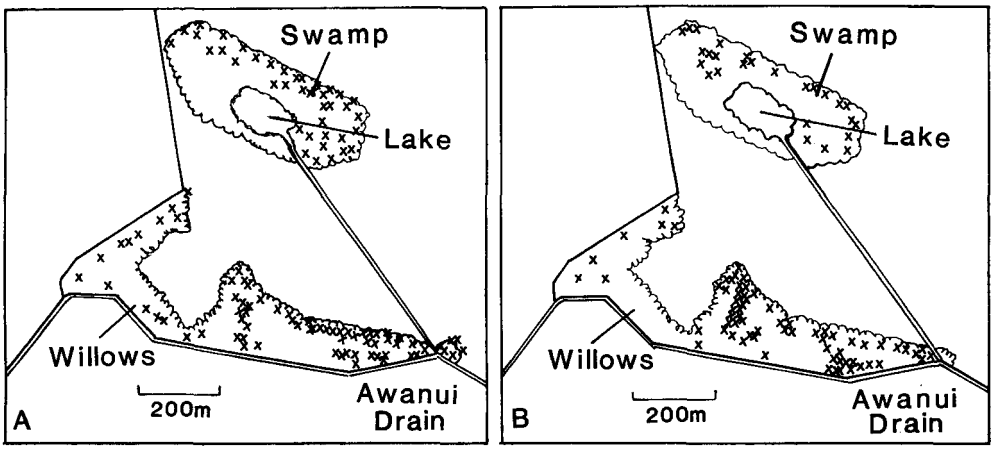

Fig. 4 Sites (x) where marked (A) and unmarked (B) possums were poisoned in swamp and willow habitats, Hautapu farm.

differ significantly (χ^2 = 1.2, 0.6, 1 d.f. respectively; Ps > 0.2) from equality in either area. Twenty percent of the animals killed were juveniles, all of which were unmarked. This was surprising, as the cohort of pouch young from the 1987 breeding season that would have contributed to the 1988 juvenile population was ear-tagged as usual in September 1987. Unmarked possums were distributed fairly evenly along the poison lines, except for a concentration of animals towards the centre of the willow habitat (Fig. 4).

Most possums were poisoned on the first night (74% on line 1, 89% on line 2; Table 3). Relatively few juveniles were killed on the first night's poisoning on lines 1 and 2: 12.4% and 8% respectively. However, juveniles constituted 39% of the second night's kill on line 1; only three possums were killed that night on line 2, including one juvenile.

Most (97.2%) of the 142 marked possums poisoned in the swamp or willow habitats had been marked originally in those habitats. Two animals first caught in the swamp habitat were subsequently poisoned in the willow habitat. None of the animals first caught on the farmland habitat were found among those poisoned.

The distance between an animal's most recent live-trapping site and the point where it was poisoned was recorded for 121 possums. Thirty-two percent were poisoned within 50 m of their last trapping sites, 59% within 100 m, 74% within 150 m, and 85% within 200 m. All females were poisoned within 500 m of their most recent trapping site, but three males were killed at bait stations 600–800 m away from their most recent point of capture.

Within a month of poisoning, 17 previously marked and 11 unmarked animals were caught in the swamp and willow habitats; all were presumed to have survived the poisoning. Despite extensive trapping over the next 2 years, no additional previously marked possums were caught in the swamp or willow habitats.

There were proportionately more juveniles among the immediate survivors

Table 2 Characteristics of possums poisoned in swamp and willow habitats, Hautapu farm, Hawke's Bay, April 1988.

	Number killed		
Possums	Swamp	Willows	Total
Marked adult males	24	38	62
Marked adult females	34	46	80
Unmarked adult males	4	21	25
Unmarked adult females	6	32	38
Unmarked juvenile males	10	21	31
Unmarked juvenile females	8	12	20

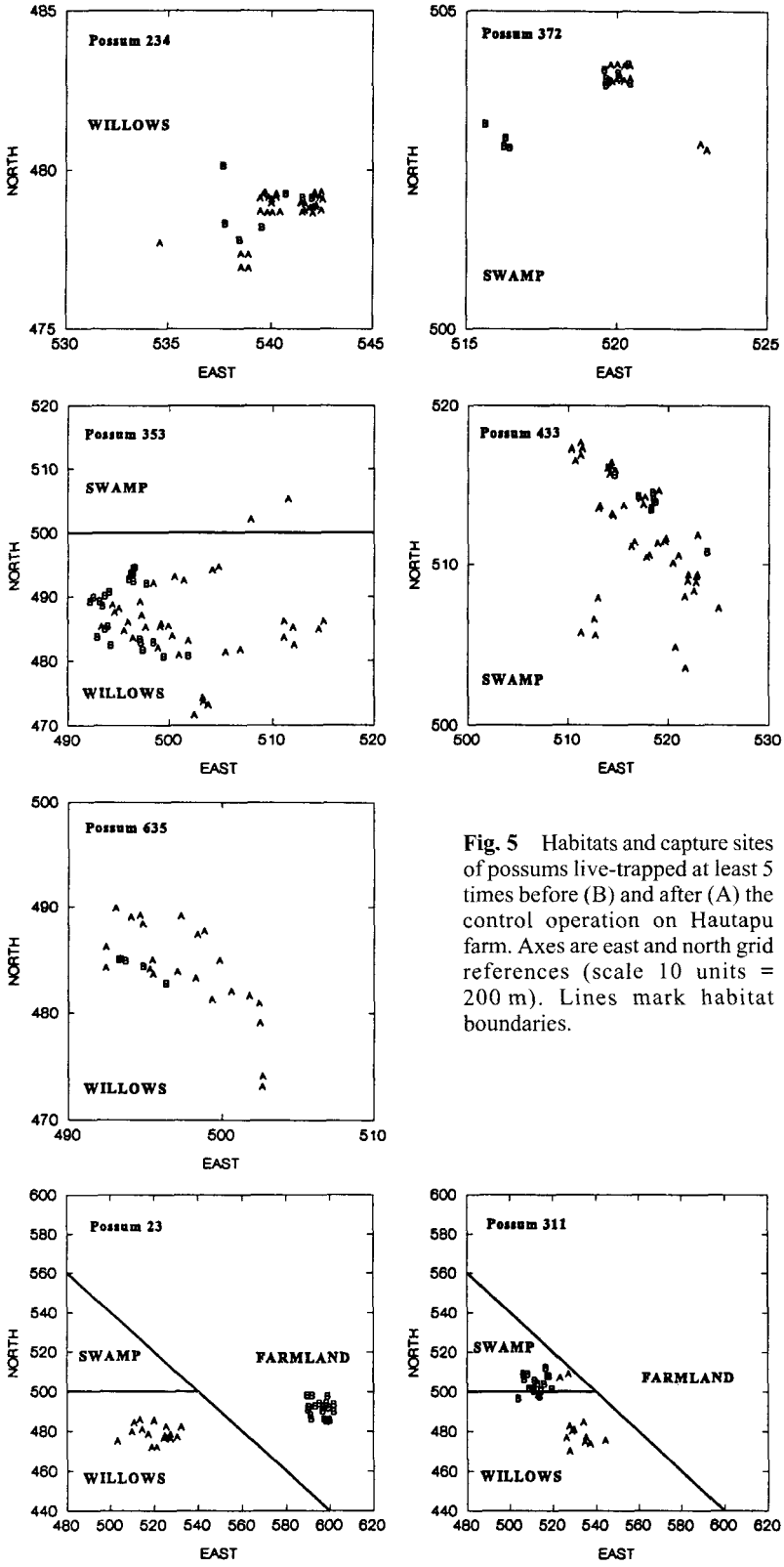

Fig. 5 Habitats and capture sites of possums live-trapped at least 5 times before (B) and after (A) the control operation on Hautapu farm. Axes are east and north grid references (scale 10 units = 200 m). Lines mark habitat boundaries.

(43%) of the poisoning than among the victims (20%) (χ^2= 6.42, 1 d.f.; $P < 0.01$). The proportion of marked animals among the survivors did not differ significantly (χ^2 = 0.2, 1 d.f.; $P > 0.05$) from that among the animals killed.

Two estimates of poisoning success are possible from these figures, assuming that there was no mortality in the month after the poisoning and that all possums present were either killed or live-trapped: (i) success = total kill/(total kill + total survivors); and (ii) success = total marked possums killed/(total marked possums killed + total marked survivors). The estimates obtained were 90.2% and 89.3% of possums killed, respectively. If not all survivors were trapped, then success will have been overestimated. Assuming only 56% trap success (the proportion of marked animals poisoned), the estimate of success decreases to 83.8%. There were a number of radio-tagged juveniles on the study site when the control operation was carried out (see Cowan et al. 1996). The 12 killed out of the 13 radio-collared juveniles that denned in the swamp and willow habitats provides another estimate of 93% reduction.

Movements of survivors after the control operation

Ten out of the 17 previously marked survivors of the poisoning had too few (<5) captures either before or after poisoning with which to examine the effects of control on movements. Responses of the seven with sufficient captures ranged from no apparent change in trap-revealed movements (possums 234, 372) to greatly increased range of movements (possums 353, 433, 635) or major shifts in range of movements (possums 23, 311) (Fig. 5).

Numbers and distribution

The poisoning and follow-up trapping allowed the minimum density of the population to be point-estimated (*minimum*, because estimates assume that all unmarked possums trapped after the poisoning were immigrants). Eighty-eight possums were poisoned in the swamp habitat, and 16 survivors were subsequently trapped there. The 11.7 ha swamp therefore held about 8.8 possums ha^{-1} in April 1988. Similarly, there were 184 animals (170 killed, 14 survivors) in 11 ha of the willow habitat, or 16.7 possums ha^{-1}.

The 298 ha of farmland habitat were not poisoned, but the prolonged mark-recapture programme provided data for calculating the minimum number alive, estimated at an average of 40 possums, or 0.13 possums ha^{-1}. Jolly-Seber estimates of population size (Cowan, Brockie, & Hearfield, unpublished data) averaged 50 animals on the farmland habitat between 1982 and 1988, or about 0.15 possums ha^{-1}.

Table 3 Numbers of possums poisoned each night on cyanide lines through swamp and willow habitats, Hautapu farm, by age class.

		Number killed				
		Line 1		Line 2		
Age class	Habitat	Night 1	Night 2	Night 1	Night 2	Total
Adult	Swamp	36	28	3	1	68
Adult	Willow	109	8	19	1	137
Juvenile	Swamp	3	14	1	0	18
Juvenile	Willow	21	9	2	1	33
Totals		169	59	25	3	256

DISCUSSION

The small patches of scrub and forest on most agricultural land in New Zealand provide refuges for possums, and are capable—as shown in the present study—of holding high numbers of animals. Eighty-five percent of the possums on the two farms were poisoned in the swamp and willow habitats that comprised only 6% of the study area. Radiotracking studies (Brockie et al. 1987; Brockie 1991; Cowan et al. 1996) confirmed that possums trapped adjacent to the swamp and willow habitats had their daytime resting sites in those habitats. Such habitats presumably support large numbers of possums because they have many den sites, and/or because dens are often shared, and they are adjacent to pasture that can provide up to 50% of the possums' diet (Cowan 1990). Whatever their cause, dense aggregations of possums would seem to provide ideal conditions for the establishment and maintenance of bovine Tb (Barlow 1991). Successful initial reduction of such populations is relatively easy, as in the present operation, but maintaining reduced densities below the predicted threshold for Tb establishment or maintenance can be difficult (Caley et al. 1995).

Figures quoted for the density of possums on farmland should be interpreted cautiously because density can be measured and interpreted in a variety of ways (see Krebs 1995). 'Density' estimates on farmland often refer to the density of animals nesting or killed per unit area (Pracy 1947; Wodzicki 1950; Coleman et al. 1980). Such estimates overlook the problem of estimating effective trapping area when animals den in one area (e.g., swamp) and forage extensively on another (e.g., farmland). Although the swamp and willow habitats held large numbers of possums, over the whole of the 350 ha study site possum density averaged only about 1 ha^{-1}. The estimates of 'density' in the various habitats are minima, because the number of survivors of the control operation may have been underestimated. However, despite regular trapping for more than 2 years after the control operation, all the marked possums known to have survived were trapped in the first month. This suggests that any underestimate of survivors was likely to be small.

Possums in each of the habitats moved only relatively short distances between live-captures, and made few movements between habitats, as in other studies (e.g., Green 1984; Cowan & Rhodes 1993). This emphasises the sedentary nature of adult possums once they have established a home range. However, trapping may underestimate local movements (Ward 1984; Brockie 1991). For example, some radio-tagged possums from the swamp and willow habitats foraged up to 1.2 km out into the farmland (Brockie 1991).

Before the poisoning only about 30% of the traps caught possums each night. But 45% of the possums killed were unmarked, and unmarked possums were concentrated towards the centre of the swamp and willow habitats. Clearly, the trapping programme was not intensive enough and/or the traps were not correctly positioned to sample the entire population. There may also have been some trap-shy animals, but unlearned trap-shyness of sufficient prevalence to explain these trap-catch data has never been observed in possums. Juvenile possums appeared to be particularly poorly sampled, partly because some of the major autumn pulse of juvenile recruitment occurred after the last live-trapping session (Brockie 1991; Cowan et al. 1996), and partly because juvenile possums appear to be less trappable than adults (M. G. Efford, unpublished data). If bait stations had been set around the periphery of the swamp and willow habitats rather than through their interiors as is usually done when possums in small habitat patches are controlled, then possums might have survived because they did not visit the periphery of the habitat.

The poisoning operation was highly successful. Possums on this farm had not been exposed to cyanide for at least 6 years and their naivety may have contributed to the success of the operation (Hickling 1995; Morgan et al. 1995). Had poisoning been limited to a single night more than half of the juveniles would have survived. Juveniles may have been inhibited or prevented from taking the baits on the first night by adults; once many of the adults had been killed, baits would then have been more accessible to juveniles and that may account for the successful kill. Juvenile possums are usually subordinate to adults (Winter 1976), and the social structure of possum populations is known to have a marked influence on the success of

poisoning with bait stations. Hickling & Sun (1997) found significantly male-biased use of bait stations, and concluded that adequate control of female possums would not be achieved unless removal of dominant individuals facilitated use of the stations by subordinates.

Most possums were killed near their last site of live capture, suggesting that they had not moved far to encounter a bait station. This confirms findings of Hickling et al. (1990), who showed that the numbers of possums that fed at marker-treated bait stations declined rapidly with distance from the station, and that few possums trapped more than 400 m from such stations had fed there. The present data suggest that high kills can be achieved with a spacing between bait stations of approx. 200 m.

The reduction in population density after poisoning had mixed effects on the trap-revealed movements of the survivors. Apparent increases in the range of movements may have resulted partly from reduced competition for traps, although some possums clearly shifted their range of movements between habitats permanently. Such shifts are occasionally observed in uncontrolled possum populations (P. E. Cowan & M. G. Efford, unpublished data). However, Cowan & Rhodes (1993) found no evidence of large or rapid shifts by radio-tagged possums with home ranges adjacent to buffer zones where possum densities had been reduced by approx. 80%. But there must be some permanent translocation of adults to account for their presence among populations recolonising areas after control (Green & Coleman 1984). Experiments with other mammals have also demonstrated that relocation or expansion of range does not invariably happen as a consequence of population thinning (Larsen & Boutin 1995). A key question remains: How do small habitat patches support such high numbers of possums?

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