# Possums and possum control; effects on lowland forest ecosystems

## A Literature Review with specific reference to the use of 1080

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by I.A.E. Atkinson, D.J. Campbell, B.M. Fitzgerald,
J.E.C. Flux, M.J. Meads

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CONTENTS

# Introduction

Possums were first brought to New Zealand in 1837; the first successful introduction was in 1858 (Pracy 1974). An active policy of liberation by the Acclimatization Societies, with Government approval and protection for the possums until 1921, guaranteed that they became widespread (Wodzicki 1950). The possum proved to be easily acclimatized and their numbers increased rapidly (Kean and Pracy 1953). Early concerns that they had become a nuisance led to an assessment of their impact by Kirk (1920) who concluded that they were not causing serious damage to native forests, but were causing problems in orchards. The advantages of establishing a fur industry were deemed to outweigh any minor problems that possums might be causing: "At any rate, if it is proved eventually, which is unlikely, that possums are a menace to the forests, their skins are so valuable that at any time the animals can be reduced in numbers to the extent desired without any cost" (Cockayne 1928). From 1922 to 1946 it was convenient to assume that the rates of commercial harvesting would be capable of limiting numbers adequately (Green 1984). Kirk undertook his survey before possum numbers had peaked in most areas, but even by 1922 there were signs of possums having a detrimental effect on forests (Cowan 1990a). Since the 1940s, overwhelming evidence has accumulated to show that possums have adverse effects on both native forest and forest animals, especially birds, (Esler 1978, Batcheler 1983, Leathwick et al. 1983, Green 1984, Cowan 1991 b). By 1953 it was realised that trapping would not be sufficient to keep possum numbers low (Kean and Pracy 1953).

In 1967 possums on the West Coast were found to be carrying bovine Tb (Seitzer 1992). By 1971 it was realised that possums could be a significant vector in the transmission of Tb to cattle (Livingstone 1994). Because of the threat presented to New Zealand's meat industry from a widespread and abundant wild animal that carries the disease, control of possums has been active in farmland and in forest bordering farmland in areas of the country where Tb is endemic. Although there is usually a low incidence of Tb-infected possums in a population, the risk of cross-infection to cattle and domestic deer has to be minimised by maintaining possum numbers at low levels within or bordering Tb endemic areas. This can now be done by an initial 1080 poison operation followed by maintenance operations using a variety of different techniques and toxins (Livingstone 1994). His Fig. 2 shows the reduction in numbers of Tb reactors associated with annual maintenance operations over an eight year period.

In the North Island the canopy of 2/3 of the indigenous forests is vulnerable to possum browsing; in the South Island where there is more beech, 1/4 of the indigenous forest canopy is vulnerable (Cowan 1991b). Only c. 10% of mid-altitude southern rata-kamahi forest in Westland remains unmodified by possums (Cowan 1991b). In unstable montane sites where terrestrial rata and kamahi predominate, the extent of possum-induced dieback is often related to stand age and thus the disturbance history (Payton 1983, 1987). However Allen and Rose (1983) showed that dieback affected stands of mixed ages. These forests were often replaced by forest of lower stature and a dense understorey of shrubs and tree ferns (Allen and Rose 1983). In the North Island the loss of northern rata and kamahi can sometimes bring about rapid loss of the forest, and its replacement with pepper tree, ferns, grasses, or other unpalatable species (Esler 1978, Batcheler 1983, Campbell 1984). When possums browse lowland forest they change both its composition and structure. The loss of browsed trees (and others from windthrow) results in forest with a lower canopy, less palatable species, faster turnover rates, and a less diverse range of microsites (Campbell 1990).

Since the report on 1080 (sodium monofluoroacetate) to the Minister of Forests and the Minister of Agriculture and Fisheries by Batcheler (1978), several reviews have dealt with the management of possums and 1080: the review of the status of the possum in New Zealand commissioned by the Technical Advisory Committee of the Ministry of Agriculture and Fisheries, (Batcheler and Cowan 1988); the report on the management of possums from the Parliamentary Commissioner for the Environment (Peterson et al. 1994); the proceedings of the science workshop on 1080 convened by the Royal Society of New Zealand (Seawright and Eason 1994); and the 10-year possum control strategy produced by the Department of Conservation (1994).

The terms of reference of this report are:

"The contractor shall write a review of the literature pertaining to the effects of control operations on possums in altering the conservation values of forests. This review will cover the impacts of possums on such values in order to elucidate how the perturbation of reduced numbers, primarily and secondarily, change forest biota. It will not report on the efficiency of control techniques themselves but will cover any effects of control (i.e. use of biotoxins) on the biota.

The review will emphasise what is known about effects inside larger tracts of non-coastal forest. It will not cover forest boundary situations where possums have alternative food on pasture. However any information from studies in coastal or forest boundary areas that is relevant to forest interior populations will be considered.

The review will specifically distinguish between short-term (within 12 months of control) and longer-term effects and point out any deficiencies in the latter component of current knowledge.

The review will be organised under, and cover, the following headings:

1. Direct impacts of possums on plants and vegetation

2. Direct impacts of possums on vertebrates and invertebrates

(these two sections are to specifically cover what is known about rare and endangered species)

3. Indirect (secondary and "run-on" effects) of possums on vegetation and animals

4. Effects of possum control operations, including those both positive and negative on conservation values, on non-target species and ecological systems. Non-target species is to include non-target pest species and "run-on" effects of changes in their populations.

5. Assessment and listing of gaps in current knowledge related to section 4 above. Recommendations of broad research topics which would produce information to fill such gaps.

*It is required that the review places primary emphasis on section 4 above and covers sections 1 to 3 only insofar as they are required to interpret the changes described in section 4."*

Beech forests have not been a focus of this review for the reason that most possum control is carried out in non-beech forest.

It will be seen from the above that this report is not concerned with the obvious desirability of reducing possum numbers. We should emphasise that in preparing the review we have not provided a complete bibliography on the subject. Rather we have given emphasis to publications that relate most closely to the effects of controlling possums in forest.

# 1. Direct effects of possums on plants and vegetation

The impact of possums depends on the type of forest they inhabit. Usually the structure of beech forest is less affected because suitable foods are sparse, but possums remove mistletoe (Wilson 1984), kamahi from the understorey (Campbell 1984), or seral species such as tree fuchsia or wineberry that are found along stream banks or on landslides (James 1974). In lowland forest possums browse a greater range of species and have a far-reaching effect on the forest composition but often this is less obvious because structurally the forest canopy remains largely intact (Kean and Pracy 1953, Campbell 1990).

Possums browse selectively, and concentrate on individual plants of their preferred species; their continued defoliation over several years kills the tree (Meads 1976, Payton 1983). Tawa, kohekohe, titoki, tree fuchsia, southern rata, northern rata, kamahi, pohutukawa, rewarewa (on Kapiti), swamp maire, toro, lowland ribbonwood, hinau, taupata, Hall's totara, fivefinger, tree tutu and white maire are all known by the writers to be killed by possums. Although individual possums may be conservative feeders, as a population possums eat an extremely wide range of food plants from all layers of the forest (Green 1984). A possum population usually feeds on about 70 species of plant (Kean and Pracy 1953, Mason 1958, Coleman et al. 1985, Cowan 1990a), but only about 10 of them comprise 1% or more of the diet, and only 3-4 make up 50% or more of the diet (Fitzgerald 1976, Coleman et al. 1985). As well as eating a wide range of leaves from mature trees (Mason 1958, Fitzgerald 1976, Coleman et al. 1985, Cowan 1990a), possums eat many different parts of plants. Seasonally these include buds and flowers (Mason 1958, Fitzgerald 1978, Coleman et al. 1985, Cowan 1990a, 1991b, Cowan and Waddington 1990), fruits (Fitzgerald 1976, Coleman et al. 1985, Cowan 1990b, 1991 a, 1992b, Cowan and Waddington 1990), and seedlings (Campbell 1984, Atkinson 1992). They also eat bark, fungi and ferns (Cowan 1990a). In any one night an individual possum usually eats 2-8 plant foods, (Mason 1958, Fitzgerald 1976). Monthly changes in the proportion of major food species in the Orongorongo Valley, Wellington, are given by Fitzgerald (1976). Monthly changes in percentage browse of leaves of major food species are given by Coleman et al. (1980) for podocarp/hardwood forest in central Westland. The long-term impact on their food trees depends, to some extent, on the abundance of the species in the forest; those foods that are uncommon often receive comparatively more attention from possums, and are removed more rapidly.

This selective feeding on forest trees by possums is usually in addition to browsing by hoofed herbivores which remove the ground vegetation, seedlings and shrubs. With this combined impact, palatable plants gradually disappear from the forest and are replaced by less palatable species.

## 1.1 DIRECT EFFECTS ON ENDANGERED PLANTS

Some plants are particularly susceptible to browsing: because they have been made rare through habitat loss, because they have specialized life cycles, because other parts of the cycle are disrupted by browsing, or because birds that disperse their seed or pollinate them have become less common. Mistletoes are now rare or endangered over most of their natural range, especially in areas where possums have been present for some time (Ogle and Wilson 1985). Although mistletoes often withstand possum browsing for several years (Ogle and Wilson 1985), a single visit by a possum can kill a mistletoe (Campbell 1984). *Trilepidea adamsii is* now presumed extinct (Given 1981), and possums are thought to have been part of the reason for its disappearance (Wilson and Given 1989).

Other endangered plants include the seven adult trees of Bartlett's rata (Dawson 1985) growing at Te Paki in Northland, and the kaka beak (Wilson and Given 1989). The parasitic *Dactylanthus taylori, is* vulnerable (Wilson and Given 1989, Ecroyd 1993a), and is listed as a highest priority species for conservation action (Molloy and Davis 1992). *Pittosporum turneri is* in the second priority list of species for conservation action (Molloy and Davis 1992) and is listed as at risk from possums in the Tongariro/Taupo Conservancy (DoC 1994). Locally, possums have made some plants rare, vulnerable or extinct, such as the loss of northern rata from the Aorangi Range (Druce 1971), or the loss of tree fuchsia from almost all of Kapiti Island, (Atkinson 1992). Peterson et al. (1994) list the major flora/fauna at risk from possums as identified for priority funding for possum control (Department of Conservation 1994 Appendix 3 pp. 59-68). These species at risk include many that are not yet threatened, but are important within the conservancy, either as habitat or for landscape values (such as pohutukawa in Northland, Auckland and Waikato).

# 2. Direct effects of possums on vertebrates and invertebrates

## 2.1 DIRECT EFFECTS ON RARE AND ENDANGERED VERTEBRATES

Little evidence of predation by possums on vertebrates is obtained from analysis of gut contents of possums. No remains of vertebrates were found in almost 1900 possum stomachs from five studies (Morgan 1981), but M. Coleman (in Brown et al. 1993) recently found remains of a greenfinch in one of 43 possums. Although birds and their eggs and nestlings are evidently rare items in the diet of most possums, detailed studies of the nesting of particular species show that predation by possums can be an appreciable source of mortality. The significance of this mortality will increase when the numbers of the endangered vertebrate decrease. Casual predation by an animal as numerous as the possum (10 per ha) may be just as important as full-time predation by relatively scarce cats, stoats or ferrets. Brown et al. (1993) review records of predation by possums on birds (and eggs) and mammals. Incubating kokako and their eggs and nestlings, and eggs of saddleback and kereru are included. Using video cameras at nests of kokako, Brown et al. (1993) recorded possums eating eggs from a recently-deserted nest and from one where the sitting bird flew when the possum approached to 1.5 m. They also suggest that some of the signs of predation at nests that were attributed to rats in earlier studies, may in fact have been caused by possums. Possums were responsible for some losses of eggs from falcon nests (N.C. Fox, in Marchant and Higgins 1993 p. 282).

Possums have been recorded destroying eggs of brown kiwi (McLennan 1988) and invading burrows of the Okarito brown kiwi and harassing the breeding birds (Anon 1994a). However, Jolly (1989) did not find evidence of possums preying on little spotted kiwi eggs on Kapiti Island.

## 2.2 DIRECT EFFECTS ON RARE AND ENDANGERED INVERTEBRATES

There is little information available on the impact of possums on endangered invertebrates. We understand that K.J. Walker and G.P. Elliot have unpublished observations showing that possums prey on large native landsnails of the genus *Powelliphanta* (Rhytidae). Possums are certainly significant predators of the more common rhytid landsnail *Wainuia urnula.* Efford and Bokeloh (1991) state that between 44% and 58% of the shells that they found had been damaged by predators. Possums were the most important predator in the Wainuiomata water catchment accounting for 44% of the predation, but in the Orongorongo Valley rats were more important.

That other species of endangered invertebrates are likely to be affected is shown by the range of invertebrate groups known to be eaten by possums. During a four-year study in the Orongorongo Valley, Wellington, Cowan and Moeed (1987) analyzed monthly samples of possum faeces. Nearly half the pellets contained invertebrates, mostly insects, although usually these animals comprised only a small part of the diet. Landsnails, millipedes and 14 orders of insects were represented including (in descending order of frequency) stick insects, cicadas (adults and emerging final instars), orobatid mites, wetas, beetles (larvae and adults), flies (larvae and adults), ants, spiders, and lepidopteran larvae. Similar monthly samples collected from Kapiti Island over one year all contained some invertebrate remains.

Much of the evidence for possums eating invertebrates is direct observation that has largely gone unreported. During November 1976, when light-traps were set between 2000 and 2300 hrs near the DSIR field station in the Orongorongo Valley, more than 500 puriri moths *(Aenetus virescens)* were attracted to the light trap. The "rain" of moths flapping on the ground attracted nine tagged possums, most of which had left their normal trap-revealed home ranges (M j. Meads unpubl. obs.). It is possible that other Hepialid moths *(Aoraia spp., Dumbletonius spp.)* less common than puriri moths, are preyed on by possums. Stick insect numbers increased markedly after metal bands were attached to browsed northern rata to exclude possums from these trees (M.J. Meads in Cowan and Moeed 1987).

Seasonal and year-to-year changes of invertebrates in possum faeces parallel the patterns of invertebrate abundance, which in turn reflect life history characteristics of the various invertebrate groups (Cowan and Moeed 1987). Some of the feeding by possums on small invertebrates is certainly accidental but larger invertebrates appear to be actively hunted, as with the puriri moths mentioned above.

Possums should be considered a potential threat to some rarer native invertebrates. The risk to any one species will again be related to the animal's characteristics, particularly life history, as well as to population size. Cowan and Moeed (1987) suggest that invertebrates most at risk are likely to be small localized populations of large-bodied relatively sluggish nocturnal species that can be detected easily.

# 3. Indirect effects of possums on vegetation and animals

## 3.1 INDIRECT EFFECTS ON VEGETATION AND RARE PLANTS

In at least some forests possums now comprise a greater biomass than all other forest vertebrates combined (Brockie and Moeed 1986); thus the pathways and rates of nutrient cycling are changed. Possums compete for food with birds that pollinate flowers and disperse seed, reducing the numbers of these birds, and disrupting the links between plants and their co-evolved birds. Selective browsing by possums, and the gradual loss of possum food plants, change the proportions and amount of foliage, flowers and fruit available for the invertebrates associated with these items, and those that break down the litter. Changes in the numbers of very long-lived forest trees seriously affect the long-term structure of the forest and the turn-over of nutrients. As vulnerable populations of plants and animals are further reduced in numbers the genetic variability of the population is lessened, and chance mortality factors assume greater importance.

## 3.2 INDIRECT EFFECTS ON VERTEBRATES

Possums may compete with birds for food. They have been shown to reduce the crops of some fruit; either by feeding on flower buds and flowers, and so reducing the potential crop of fruit, or by eating the fruit itself, e.g. hinau and nikau, and kohekohe (Cowan and Waddington 1990, Cowan 1991 a, Atkinson 1992). They may also reduce the food supply for nectar-feeding birds by eating buds and flowers. Leaves and fruit of many of the plants eaten by kokako are also eaten by possums (Leathwick et al. 1983, Fitzgerald 1984). As possums are at far higher densities than kokako, their feeding could seriously reduce the food supply for kokako and have contributed to the decline in abundance and distribution of kokako. On Rangitoto Island possums destroyed the flowers of rewarewa; after possums were poisoned, rewarewa flowered well, the vegetation as a whole improved markedly, and numbers of tui and silvereye increased (Miller and Anderson 1992). Possums may also compete with short-tailed bats for flowers of *Dactylantbus;* bats feed on the nectar but possums eat and destroy the flowers (Ecroyd 1993a). A temporary gap in the annual sequence of foods available could be sufficient to reduce numbers of bats or some birds. Geckos take considerable amounts of nectar (especially pohutukawa) and fruit is important in the diet of geckos and skinks (Whitaker 1987). Possums may reduce the available food of both skinks and geckos.

Possums compete with native animals for nest-sites and roosts. On Kapiti Island they were found in 10% of burrows of little spotted kiwi that were checked repeatedly (Jolly 1989), and have been recorded taking over the burrows of brown kiwi on Stewart Island (Morrin 1989). They frequently take over starling nest boxes if the hole is more than 70 mm wide. (J.E.C. Flux unpubl. obs.). Whether bat roosts are disturbed by possums is unknown but seems likely. Because possums are so abundant in forests, even incidental disturbance to incubating birds at night might cause significant nest desertion.

## 3.3 INDIRECT EFFECTS ON INVERTEBRATES

The current literature does not specifically include research or findings on the indirect, secondary, or "run-on" effects to invertebrates. Meads et al. (1984) found that browsing animals, especially goats, browsed and suppressed seedlings and other ground-cover plants, which opened up and dried the floor of the forest, exposing the surface-moving invertebrates, such as *Powelliphanta,* to avian and mammalian predators, including possums.

Following the possum control campaign on Rangitoto Island there was a very marked increase in flowering of pohutukawa. The apiarist running hives on the island reported a commercially viable honey crop in the year after the campaign following a considerable period of declining yields (Country Saturday 1995 *).*

If possums eliminate a species of plant, any associated monophagous insects will also be lost. New Zealand insects that feed on plants have a high degree of host-plant specificity (Dugdale 1975 *).* The three or four genera restricted to mistletoes are as much under threat as are their hosts.

# 4. Effects of possum control operations

## 4.1 DIRECT EFFECTS OF POSSUM CONTROL ON PLANTS

Despite the numerous control operations against possums, benefits from the reduction in numbers of possums have seldom been documented. This may reflect the difficulty of recording quantitative data on canopy recovery. Furthermore, when possums are controlled the numbers of rats, deer, goats and pigs are also reduced, which makes it difficult to quantify all the benefits of possum control. The effects of reductions in possum numbers on the flowering and fruiting of forest trees were followed by Cowan (1991 a) who removed possums from an 8 ha area of the Orongorongo Valley. Possum numbers were first reduced from seven possums per ha to about half that density, and the following year the remainder were removed. Before possums were controlled, all nikau flowers were damaged and only 11% of the fruit ripened. When the possums were removed all the nikau flowered and fruited. During the six years when possums were being removed from Kapiti Island (Cowan 1992a), the response of the main species of tree previously eaten by possums was followed by Atkinson (1992). He found that several species - kohekohe, fuchsia, northern rata, taws, toro, titoki, white maire, swamp maire, and supplejack - were all severely affected by possums before control and most species recovered following the removal of possums. With possum numbers high, kohekohe produced almost no flowers or fruit, but when possums were controlled kohekohe flowers were found on more than half of the trees. As the control operation progressed, more seedlings were seen of several of the trees that possums had been browsing (Atkinson 1992).

In beech forest, even where possum numbers were low (0.46 per ha) they severely damaged mistletoe, and threatened these plants with local extinction (Wilson 1984). When possums were poisoned the damage to mistletoe was reduced (Clout and Gaze 1984).

## 4.2 DIRECT EFFECTS OF 1080 ON PLANTS

There appear to be no New Zealand-based studies that deal with the possible uptake of 1080 by higher plants, or the consequences of any such uptake. Bong et al. (1979), state that "it is possible that sodium fluoroacetate leached by baits may either enter higher plants or be toxic to them", and that the "available evidence suggests that plants vary widely in their tolerance of sodium fluoroacetate and in most cases they are susceptible to inorganic fluoride". David and Gardiner (1951) found that plants will tolerate relatively high concentrations of 1080, and that it acts as a systemic insecticide. Bean and tomato plants were injured much more severely by sodium fluoride than by sodium fluoroacetate (Preuss and Weinstein 1969). In laboratory conditions, fluoroacetate from 1080 was translocated to the shoot, whereas fluoride accumulated mainly in the roots (Cooke 1976). Growth of seedlings of *Helianthus annus, Lolium perenne* and *Achillea millefolium* was inhibited more by 1080 than sodium fluoride. In these plants "1080 caused leaf necrosis but the exact cause of the lesions was not known" (Cooke 1976).

## 4.3 DIRECT EFFECTS OF CONTROL BY TRAPPING ON VERTEBRATES

### a. Losses

Birds are caught in gin traps set for possums. Results from replies by 60 trappers to a 1946 questionnaire showed that in catching 32,292 possums, 979 birds were caught. These were mainly blackbirds but also included thrushes, moreporks, hawks, magpies, quail, weka, pigeon, robin, tomtit and little owl (Wodzicki 1950). Reid (1986) surveyed possum trappers throughout New Zealand; 46% reported catching kiwi, but many also reported catching rats, cats and mustelids. McLennan (1987) replied, expressing concern at the impact of trapping deaths on kiwi populations. In Hawke's Bay as many as 38% of kiwi have lost parts of feet and toes and others will have died of injuries (McLennan and Potter 1992). They considered that possum trapping "is probably the most significant cause of death in adult kiwi, and the reason why the birds are declining in many areas." In some lowland South Island forests up to half of the great spotted kiwi have fractured or amputated toes, from previous capture in gin traps (Marchant and Higgins 1990, p. 87).

In trials comparing gin traps with more humane leg-hold and kill traps, the newer leg-hold and kill traps, designed to be more humane than gin traps seem to be just as hazardous to birds (Warburton 1982).

On Kapiti Island bird mortality during the eradication of possums was carefully monitored over the seven-year period. In about 1.4 million trap-nights no kiwi were caught because traps were set on sloping wooden boards 80 cm. above the ground (Sherley 1992), but 181 other birds of 16 species, especially pigeons, moreporks, weka and kaka were caught. These four species comprised almost 90% of the birds caught. Bellbirds and robins were the smallest birds trapped (Cowan 1992a). Although this represents only one bird for every 8000 trap nights, if that bird happens to be of a threatened species, even this mortality would be serious.

### b. Gains

Deaths of rats, cats and mustelids in traps set for possums are generally considered a benefit (Wodzicki 1950, Reid 1986), but may have unexpected repercussions. During intensive possum trapping in the Orongorongo Valley in the late 70's-early 80's most of the cats were caught in gin traps and killed. The rat population (the main item in the cats' diet) then increased dramatically. Any benefit to the bird populations from the substantial reduction in the number of cats may have been more than outweighed by the increase in the number of rats (Fitzgerald 1988).

## 4.4 DIRECT EFFECTS OF CONTROL BY POISONING ON VERTEBRATES

### a. Losses

Deaths of non-target species, mainly birds, have been measured by searches for dead birds, by five-minute bird counts, by call counts of some species, and from survival or death of known individuals. All except the last of these methods have serious limitations.

Searches for dead birds are usually made only in part of the poisoned area and the unpoisoned area is not searched, so there is no measure of how many dead birds might be found under normal circumstances. Warren (1984) found only piles of feathers, indicating that predators may be removing dead birds. If birds die on their nests or in roosting sites they are not likely to be found. In California, yellow-billed magpies died during a 1080 poisoning programme against ground squirrels; bodies of eight birds were found, three in nests, one after falling from a tree and four on the ground (Koenig and Reynolds, 1987). Searches for dead birds are probably only useful in detecting high mortality, as at Karioi State Forest and at Turangi in 1976 (Harrison 1978a, b). Screening carrot baits to remove "fines" and using pellet grain baits is reported to have eliminated the problem of killing large numbers of bird during poisoning operations, but careful trials to measure the improvement appear to be lacking. It appears that different species of birds may be vulnerable to poisoning, compared with trapping. In the poison operations studied by Harrison (1978a), mainly in exotic forest, blackbirds and robins were the largest birds found dead, whereas in the trapping on Kapiti Island, bellbirds and robins were the smallest birds caught and most were much larger.

Five-minute bird counts have been used extensively (reviewed by Spurr, 1994b) but show as many increases as decreases in the numbers of a species after poisoning. Because poisoning is done when the birds are not breeding, statistically valid increases in the counts cannot reflect recruitment from breeding but must result from either changes in conspicuousness or seasonal movements. Five-minute bird counts of forest birds by Dawson et al. (1978) and Clout and Gaze (1984) showed seasonal changes in numbers that they thought probably reflected movements. Summer and winter counts of grey warblers in the Victoria Range showed that they favoured lower altitudes in the winter (Dawson 1981). Clout et al. (1986) radio-tagged pigeons that subsequently moved long distances and to higher altitude. Thus, even where 5-minute bird counts reveal statistically significant decreases in bird populations, there is no means of determining whether this results from seasonal movements, seasonal changes in conspicuousness (especially singing) or from deaths by poisoning or other cause. Therefore 5-minute bird counts are not a reliable method of assessing the effects of poisoning operations except where there is very substantial mortality.

Call counts have been used for birds that cannot be monitored effectively with 5-minute bird counts e.g., nocturnal species such as kiwi and morepork (Pierce and Montgomery 1992) and rare species that are not recorded often enough to show differences before and after poisoning. The same problem of seasonal changes in conspicuousness or movements apply to call counts as to five-minute counts.

The fate of known individuals has been determined by mapping territories, banding, or radio-tagging birds (Innes and Williams 1990, review by Spurr 1994b). This method has been applied chiefly to kokako, (Innes and Williams 1990, Pierce and

Montgomery 1992), but also to falcons (Calder and Deuss 1985), brown kiwi and fernbirds (Pierce and Montgomery 1992) during 1080 poisonings, and for little spotted kiwi during brodifacoum poisoning of kiore on Red Mercury Island (Robertson et al. 1993). Few birds have disappeared during these studies, and no loss could be attributed definitely to 1080 poisoning. This method of assessing the effect of 1080 operations on birds is the only one that provides definite information about the survival of birds through a 1080 operation. The method has been applied mainly to large birds, but small birds can be vulnerable in 1080 poisoning operations, and more attention needs to be given to them.

Bats have not been monitored or found dead after 1080 operations (Spurr 1994). A short-tailed bat was killed by a fruit-lured cyanide bait laid for possums in Karamea (Daniel and Williams, 1984). Short-tailed bats in captivity and in the wild "did not eat carrot baits in bait acceptance tests" (Ecroyd, 1993b, quoted by Spurr, 1994b, p. 128).

### b. Gains

Deaths of individuals of non-target pest species, especially rodents and ungulates, from eating baits is a bonus in poisoning operations against possums. In Taranaki, more than 90% of the rats present were killed in an aerial 1080 poisoning operation for possum control; mice were also reduced in number (from eleven in 941 trap nights before, to two in 962 after poisoning compared with controls of 11 in 939 trap-nights to 15 in 944 trap-nights in the non-treatment area) (Warburton, 1989). In a Northland forest after aerial 1080 poisoning in September 1990, rat numbers declined to very low numbers, and remained low for the following summer (Pierce and Montgomery 1992). Aerial 1080 poisoning of possums, using pollard baits, at Mapara in September 1990 and at Kaharoa in October 1990 drastically reduced rat numbers. At Mapara, 4.5 months later, rats were at only 11% of pre-poisoning numbers, but by April 1991 were back to their original numbers. At Kaharoa, 3.5 months after the poisoning, rats were at 8% of pre-poisoning numbers but then quickly recovered (Innes and Williams 1991, Murphy and Bradfield 1992). These results suggest that rat populations (and probably mouse populations) are substantially reduced by 1080 poisoning operations against possums, but that the effect is short-lived and the population recovers by the end of the rats' breeding season. After an aerial poisoning at Pureora in 1983, three dead deer were found and 1080 residues confirmed from two of them (Warren 1984).

## 4.5 DIRECT EFFECTS OF 1080 POISONING ON INVERTEBRATES

Sodium monofluoroacetate was patented as an insecticide in 1927 (Twigg and King 1991), and can act as a systemic and contact insecticide (David 1950). David showed that 1080 had a marked contact action, killing aphids in two days when applied at a concentration of 0.001 per cent. In tests against other insects, it was shown that a 0.0005 per cent solution of 1080 was effective systemically against aphids. 1080 was found to be an extremely effective systemic insecticide whether applied to the leaves or roots (David and Gardiner 1951), and too dangerous to use as an insecticide (David and Gardiner 1958). The compound has been tested on and used in the field for aphid control in several countries (Atzert 1971, Dunning and Winder 1960). Lowe (1960) used 1081 (similar properties to 1080) on cabbage aphids in New Zealand. Spurr (1991) reduced the numbers of common wasps *(Vespula vulgaris)* and German wasps (V. *germanica)* with 1% 1080 in canned sardine baits.

Few studies have dealt with the impact of 1080 on native insects and other invertebrates. Notman (1989) in a review of the literature, found that invertebrate species from ten different orders were affected by 1080. Tree wetas were susceptible to 1080 poison, becoming dis-oriented in laboratory trials (Hutcheson 1989). McIntyre (1987) found some native cockroaches were killed and the behaviour of others affected by a 1080 aerial drop. Honeybees (*Apis mellifera)* readily take and are poisoned by 1080-jam baits (Goodwin and Ten Houten 1991). Amphipods eat dead plant material and some achieve the highest biomass values ever recorded for New Zealand animals (Duncan 1994). He comments that 1080 is likely to be toxic to amphipods if eaten in sufficient quantities, but Meads (1994) and Spurr (1994a) found that amphipods were not affected.

The two major field studies of the effects of aerial 1080 poisoning operations on invertebrates in forests are by Meads (1994) and Spurr (I 994a). In both studies the treated and untreated areas have to be compared with caution; Meads' sites were close together and the untreated area was thought to have been contaminated with bait fragments. Spurr's untreated areas were 4 km and 7 km distant from the treated areas and at least one was on a different soil from the treated area. In Meads' study the baits fell unevenly and very few fell anywhere near the traps. This could have meant that he was unable to measure the effect of 1080 on the invertebrate populations. He therefore added baits to the vicinity of traps and this complicates interpretation of results. Meads reported declines in the numbers of ants, beetles, cave wetas, collembola, earthworms, flies, harvestmen, wasps and spiders on the treated area, relative to the untreated area. In contrast, Spurr (1994a) did not find declines in these groups or any others. However, several points need to be made. Too few earthworms and harvestmen were present in Spurr's samples to tell whether or not they were affected. At his Northland site collembola increased significantly more on his untreated area than on his treated area in the month after poisoning, but he did not accept this as a poison effect because trends on the two areas also differed significantly in the month before poisoning. We consider that he cannot exclude the possibility that the difference in collembola between his treated and untreated areas in the month after poisoning is a result of the poisoning. Differences in the time of year of poisoning may also affect the results; Spurr's were done in March and June, when the populations of many groups of invertebrates were declining naturally, while Meads' was done in July, shortly before populations began to increase. Some of the groups listed above include species with very different habits and it is important in future to list the species composition of any affected groups, wherever taxonomic knowledge allows this.

## 4.6 SECONDARY POISONING OF VERTEBRATES

### a. Losses

Native predatory birds (especially morepork, harrier, falcon) might die from eating poisoned carcasses, and insectivorous birds possibly from eating poisoned invertebrates, although there is no definite evidence of this at present. Pierce and Maloney (1989) found no evidence of secondary poisoning of harriers in the Mackenzie Basin after rabbit poisoning with 1080. Godfrey (1985) states: "birds in a zoo were killed after eating cockroaches and ants that had been feeding on brodifacoum baits" and Hegdal et al. (1986) that "ants killed by 1080 baits have been implicated in the secondary poisoning of insectivorous birds" (quoted by Eason et al. 1994 p.84).

**b. Gains**

Deaths of mustelids, cats and rats from eating poisoned carcasses are possible. Marshall (1963) estimated, from feeding trials, that ferrets could eat enough poisoned rabbit to be killed by secondary poisoning. After a 1080 aerial poisoning for possums, Murphy and Bradfield (1992) could not detect secondary poisoning of stoats, but they did not begin monitoring the numbers of stoats until a month after the poisoning operation.

## 4.7 SECONDARY POISONING OF INVERTEBRATES

Hegdal et al. (1986) suggest that birds may have died after eating ants that were poisoned after 1080 baiting for ground squirrels. During an outbreak of bubonic plague in Peru, 1080 was reported to act as a secondary poison that killed the fleas on the poisoned rats (Macciavello 1946). Small, apparently insignificant amounts of 1080 may be sufficient to kill carrion-feeding insects. Such amounts may persist in the carcasses of poisoned animals for a considerable period of time. Gooneratne et al. (1994) found that traces of 1080 were still present in tissues, especially muscle, of dead rabbits in the laboratory three weeks after death. Presumably traces of 1080 will persist even longer in the tissue of dead possums in cold, damp forest.

## 4.8 EFFECTS ON ECOLOGICAL SYSTEMS

The complexity of ecological systems and the diversity of interactions between the multitude of species within them makes it extremely difficult to determine accurately the effects of any one species, even when it is as abundant and influential as the possum. The responses in the system when possums are removed can often show the impact they were having, but may not reveal sufficient detail about the interactions for planning effective management. Also, the research carried out to date has not been of sufficient duration to reveal more than the short-term effects of control methods (including 1080) on populations or communities. The duration of the changes varies greatly from species to species; e.g. possums can take more than a decade to recover their numbers after poisoning (Pekelharing and Batcheler 1990) whereas rats bounce back in one season (Sect. 4.4b).

Increases in vertebrate populations, especially birds, are to be expected after possums are controlled, because of improvements in the vegetation and so in food supply and shelter. Kapiti is probably the best example of bird populations increasing after possums are removed. On the mainland, poisoning and trapping programmes against possums also reduce rat and predator populations but it is almost impossible to separate the contribution of habitat improvement from that of reduction in predator numbers. Trappers killed 15631 possums on Kapiti Island in 1980-82, another 3933 from February 1983 to January 1985 and only 48 more in 1985-86 Cowan (1992a). From 1980 on the vegetation showed measurable improvement (Atkinson 1992). On Kapiti, bird counts made each year between 1982 and 1988 showed a rapid increase in the numbers of birds between 1982 and 1985, especially tui, bellbirds, whiteheads, and robins. Insectivorous as well as nectar and fruit-feeding birds are included. Numbers of birds increased little, if at all, in the three years after 1985 (Lovegrove 1986, 1988). This suggests that much of the increase may be a response to the immediate improvement in the supply of fruit and flowers, and/or the reduction in predation by possums, rather than longer-term increase and changes in the vegetation and its insect populations. Bird counts made by members of the Ornithological Society in 1975-78, 1983-85 and 1991-94 also show substantial increases in the numbers of many species (H.A. Robertson, pers. comm.). It is not possible to identify how much of the increase in bird populations resulted from the reduction in predation on nests by possums and how much resulted from the improvement in food supplies. Also, because most of the possums were removed over several years, by trapping rather than poisoning, rat numbers over this period are unlikely to have been lowered much and so predation by rats on the bird populations would not have been reduced.

The numbers of kokako and other birds at Mapara increased substantially over five years of intensive control of introduced mammals. This included aerial 1080 poisoning of possums and rats in 1990, 1991 and 1992, and ground trapping of predators. Of 52 banded kokako only nine have died and none of these deaths were associated with poisoning operations. Nesting is much more successful than in other areas without mammal control and the number of pairs has increased. Other birds, especially falcons, fernbirds and kereru have also benefitted (Flux 1994). At Pureora in contrast, few pairs of kokako produce young and the population has declined by more than half over the 10 years 1981-1991 (Meenken et al 1994). At Mapara, as on Kapiti, it is probably not possible to determine how much of the increase in bird populations is from improved food supply, from reduced predation, or from improvement to the habitat.

Substantial, though short-term, reduction in the numbers of rats as a by-product of possum control with 1080 is usually considered as an added bonus. One study has examined the effect of this on predators; at Mapara, stoats whose numbers compared with the previous season, were not reduced by secondary poisoning during the poisoning operations, then turned to prey much more on birds (Murphy and Bradfield 1992). Their possible repercussions on bird populations are difficult to unravel. The number of birds that are taken in place of rats by stoats, in the six months or so until the rat population has recovered, might (or might not) be greater than the number that would have been taken by rats during that time if poisoning had not been done.

Many more cats and stoats are reported killed by gin trapping than by 1080 poisoning (Sect.4.3 and 4.6). The mortality of these predators in gin traps is usually viewed as a bonus to the possum trapping, but it may have undesirable effects elsewhere in the system. In the early 1980's possums were trapped intensively in the Orongorongo Valley in areas adjacent to the research area and most of the cats were caught in gin traps and killed. The rat population increased from about 2/100 trap nights in 1971-78 when cats were common, to 9/100 trap nights by 1986 when cats were scarce. The bird populations may have been no better off with few cats and abundant rats than they were with more cats but fewer rats (Fitzgerald 1988).

The numbers of predators are usually determined by the availability of their food. Where possums are abundant, predators such as stoats, which scavenge carcasses of dead possums (King 1990) are likely to be more common. Harriers scavenging road kills also may be affected similarly. Higher numbers of predators may in turn mean higher rates of predation on native species than in the past when possums were rare or absent. For example the predation by harriers on kokako (J. Innes, pers. comm.) may be much greater now than when possums were not available and harriers were less common. Another example may be the extinction of the Macquarie Island parakeet. The parakeet co-existed with a sparse population of cats for 70 years until 1879 when rabbits were introduced. Rabbits soon became abundant and cats also multiplied. Taylor (1979) suggested that the resulting intensified predation on the parakeets led to their extinction.

So little is known of the ecological processes among populations and communities of invertebrates that the effects of possums on them are almost unknown and the effects of control operations likewise. Almost all studies of invertebrate communities in forest have been conducted for no more than 12 months; so the natural variations in populations from year to year are not known. In addition, many groups of invertebrates are identified only to order or family. With identification only to that level all manner of important ecological events may be overlooked.

Amphipods provide one of the main routes for the mineralisation of plant wastes, so are very important in the long-term health of the forest. Numbers of amphipods will be affected by the changes in floristic composition brought about by possums, and perhaps by 1080 poison operations (Duncan 1994), and this in turn will have an impact on their predators, such as the carnivorous snails and ground-feeding birds.

Overseas research (Atzert 1971, David and Gardiner 1951) has shown that 1080 is taken up by plants and that it is an effective systemic poison on hemipteran bugs. If 1080 is taken up by native plants during a possum poisoning operation, then invertebrates such as native scales, pseudococcids and aphids could be poisoned and indirectly impact on bird species feeding on them. For example the sixpenny scale *(Ctenocbiton viridis) is* an important food of kokako in some seasons (Leathwick et al. 1983).

# 5. Persistence of 1080

1080 is readily detoxified in the environment. The main means of biodegradation appears to be adsorption to litter and soil, and subsequent breakdown by soil micro-organisms. It has been adequately demonstrated that 1080 is quickly broken down in soil or water by microorganisms at laboratory temperatures. We have yet to be convinced that these laboratory-derived rates of breakdown apply at winter field temperatures. More work is urgently required to determine realistic field breakdown rates, and thus the persistence of 1080 in the field.

## 5.1 IN WATER

In pure sterile water 1080 is stable. In biologically active water it is defluorinated by micro-organisms. In laboratory aquaria containing higher plants and bacteria, kept at 21 °C, 1080 was eliminated after 48 hours when the water contained *Pseudomonas spp*., and after 141 hours when *Pseudomonas* was absent (Parfitt et al. 1994). No 1080 residues were detected in water collected from streams and/or ground water after the 1080 aerial poisoning of Waipoua forest and Rangitoto Island. Water samples taken from a stream in Cental Otago showed traces of 1080. The stream water was 0°C during this poisoning operation and unlikely to have been biologically active (Parfitt et al. 1994). The dilution of 1080 during normal poisoning operations would keep concentrations of 1080 in streams or ground water at trace levels (parts per trillion), but the breakdown rates at normal winter temperatures have yet to be determined.

## 5.2 IN SOILS

Microflora capable of breaking down 1080 are present in a wide range of New Zealand soils, (Bong et al. 1979). They found that at 25°C sodium fluoroacetate is readily broken down by soil microflora, but these breakdown rates do not realistically represent field conditions because a small amount of soil was added to a nutrient solution which was then rotated at 300 rev. per min. for from 3 to 11 days. Parfitt et al. (1994, Fig. 2) found that when 1080 was added to sieved Kaitoke silt loam soil in the laboratory it was completely degraded after 24 days at 23°C. At 10°C 93% was degraded after 115 days, whereas at 5°C only 58% of the 1080 was degraded after 115 days. They used a plug of cellulose when determining the rates of leaching through soils, and this may have affected the results (see Griffiths 1959, Section 5.3).Further experiments are required to simulate field conditions, by following the disintegration of baits on the litter layer of the soil.

Peterson et al. (1994) conclude that "soil micro-organisms that can detoxify 1080 appear to be ubiquitous in the environment, and 1080 is unlikely to be persistent in the environment over the long-term, but the biodegradation process may not be "rapid"".

## 5.3 IN PLANT MATERIAL

Twigg and King (1991) state that detoxification of fluoroacetate by defluorination is known to occur in plants (Preuss and Weinstein 1969, Ward and Huskisson 1972), and bacteria (Bong et al. 1979). Defluorination of fluoroacetate takes place in higher plants, but the rate is slow and varies among different plant species (Preuss and Weinstein 1969).

In tests for leaching of 1080 from baits, Corr and Martire (1970) found that poison was leached at similar rates, whether the poison was sprayed on the outside or incorporated throughout the bait, and the rate of leaching was similar whether pellets were manufactured under low extrusion pressure in a small pellet-making machine or commercially under much greater extrusion pressure. They also found that rainfall, not time of exposure, was the dominant factor in the rate of loss of poison; that leaching was higher from baits initially containing more poison, and that there was a trend towards constant poison content irrespective of original poison content.

In experiments with sunflower *Helianthus annuus,* uptake of 1080 was substantial, with very high concentrations of fluoride in the leaves and cotyledons, and greatest accumulation in the roots when exposed to inorganic fluoride (Cooke 1976). In research of uptake of 1080 in sugar cane, Hilton et al. (1969) state: "The high degree of adsorption of monofluoroacetate to leaf and root tissue, as well as to other cellulosics such as filter paper, was entirely unexpected in view of its water solubility and volatility. It can be assumed that monofluoroacetate would remain adsorbed to fibrous bait components, probably would not be washed off the bait formulations by moderate rainfall, and would not readily leach into soils, especially into those with considerable organic content."

Several authors have shown surprise and curiosity in the way 1080 has "attached" to materials that are cellulosic, has lost about half its potency after two to three cm of rain, and retained half potency for long periods, in spite of continued rain. In a field experiment to test the effect of weathering on baits treated with 1080, Griffiths (1959) found that "after a fall of 1% in. of rain, oats retained about half of the initial potency and showed no change up to the seventh week, in spite of two more falls, each of 0.9 in. of rain. The static level of 1080 in the oats suggested that the poison was not on the surface but was actually imbibed by the grain". After eight weeks of exposure a sample was husked and tested; "Curiously, all the 1080 appeared to be in the husks and none was detectable in the grain. Somehow a substantial amount of the 1080 becomes adsorbed on, or absorbed into, the husk so that it is impervious to the leaching action of rain."

## 5.4 UNDER FIELD CONDITIONS

It is essential to do analyses within the natural range of environmental temperatures and humidities, rather than those that are comfortable in the laboratory. Eason et al. (1993) report the rate of breakdown of 1080 in two aquaria at 20°C and later Parfitt et al. (1994) report further experiments with two aquaria at 21 °C. These temperatures are considerably higher than those expected in natural aquatic regimes in winter. The mean annual temperatures 1 m below the surface of seven lakes at Rotorua was 15.1-16.2°C and the minima ranged from 8.4 to 11.0°C. (McColl 1972).

1080 poisoning is usually carried out in the winter; July mean air temperatures vary, depending on locality, from 10°C at Waipoua Forest, 7°C at Rotorua, 4°C at Karioi Forest, 3°C at Hanmer Forest to <2°C at Naseby State Forest (Gerlach 1970-72). Winter mean air temperatures are usually higher than soil temperatures by 1-2°C, and higher than temperatures taken in litter in the forest (Moeed and Meads 1986). Moeed and Meads (1986) buried a standard Max-Min thermometer under litter and recorded the temperature at monthly intervals. Their figures for minimum monthly temperatures show much less variation than the recorded maximum for each month which suggests that the maximum temperature for the month may have been elevated by the brief passage of sunflecks during sunny weather. These maximum temperatures may affect the breakdown rates of 1080 in the forest, but may represent a much shorter period of time at that temperature than the total time when the temperature is nearer the minimum.

In corpses, 1080 may persist for a considerable time. Gooneratne et al. (1994) analysed rabbits killed with 1080 for residues in the tissues at death and one, two, and three weeks later. Some 1080 was still present after three weeks. The carcasses had been kept at room temperature in the animal house, considerably warmer than the forest in winter. They suggest that in "extreme cold or drought complete breakdown of 1080 residues might take several months". (Note: although their Fig. 4 gives the impression of sequential sampling of three rabbits it is actually of three different rabbits each time).

# 6. Gaps in current knowledge and recommendations for further research

This review suggests that gaps in current understanding of the subject can be grouped under possum effects, 1080 effects, and flow-on effects resulting from both possum removal and the method of killing (trapping or poisoning) that is used. Several new lines of research relating to 1080 effects were suggested by Clark (1993:34). These ideas are covered in more detail in section 6.2.

## 6.1 POSSUM EFFECTS

### Plants

There is little quantitative information relating to the reproductive response of forest plants, particularly the major trees, following a possum removal operation. These responses include flower and nectar production, the size of the seed crop, and seedling recruitment. With respect to seeds and seedlings, the role of possums in seed destruction during consumption, as opposed to seed dispersal in the droppings, is unclear. Information on the extent to which seedlings of forest trees are killed by browsing is altogether lacking for many species.

### Birds

There is increasing evidence of predation by possums at bird nests but the magnitude of this effect is unknown. Also the degree to which competition for some kinds of nest site by possums, and disturbance at nests that does not result in predation, may reduce reproductive output by forest birds is not known. No evidence of these two effects can be gleaned from identifying bird remains in possum stomachs or faeces. Some birds will be more vulnerable to predation and disturbance by reason of their nest position. These effects are additional to any effects of possums on the food available to birds.

### Vertebrates excepting birds

Whether native frogs, particularly Hochstetter's frog, would increase following possum removal is unknown; the vulnerability of native frogs to possum predation has not been established. Similar questions are associated with possible effects of possums on bats through predation, disturbance at roosting sites and, with short-tailed bats, competition for fruit.

### Invertebrates

Recovery of some invertebrate populations such as stick insects and weta may follow possum removal but again there is no quantitative information.

### General

Some studies have monitored events adequately after a poisoning operation, but few if any have established a baseline of sufficient length before poisoning. Too often insufficient time is available to monitor populations more than once before poisoning so that clear-cut answers are not possible. With invertebrates it is particularly important to identify seasonal trends.

Although it appears desirable to identify the minimum possum densities to sustain particular conservation values, this may not be a realistic goal. Such minima are likely to differ for each conservation value and vary significantly from place to place.

The biomass of possums in native forests can now be greater than for all other vertebrates. Following reductions in possum numbers, rates of nutrient cycling and litter breakdown will be significantly altered. With a general lack of such data from forests without possums, there are few opportunities for comparisons before and after control.

## 6.2 1080 EFFECTS

Although 1080 is the best method of controlling possums at the moment, this review indicates that there are gaps in our understanding of its effects and persistence. These should be filled before we can have complete confidence in all aspects of the method.

Clark (1993) suggested several lines for further research:

1. Impact of 1080 on a wide range of native animals and plants, especially threatened ones.
2. Persistence of 1080.
3. Impact of 1080 poisoning on existing predator/prey relationships.
4. Effects of sub-lethal doses (single and repeated).
5. Impact of repeated 1080 poisonings on ecological communities.
6. Alternative methods of controlling or exterminating pest species.

Ideas 1-5 are covered below in more detail.

### Plants

Nothing is known about the possible uptake or breakdown of 1080 on native plants, seedlings, and soil fungi including mycorrhizal fungi.

### Vertebrates

The limitations of 5-minute bird counts mean that more reliable methods will be required to check that small species of birds are not vulnerable in current poisoning operations (Sect. 4.4).

To date there is little evidence that secondary poisoning is of any significance. Birds and predators would need to be radio-tagged before poisoning operations, the gut contents of any that die checked, and their carcasses analyzed for poison residues. Nothing is known about the impact of 1080 on lizards and on native frogs in forest; this may be of special importance for species that are already rare.

### Invertebrates

The contradictory results obtained by Meads (1994) and Spurr (1994a) mean that it is important that further studies of the effects of 1080 on invertebrates are conducted. The effects of 1080 on litter fauna, soil fauna, and subterranean populations of scarab beetles, cicadas and other subterranean macro-fauna that feed on roots or litter are very poorly known. In particular, the response of New Zealand forest earthworms to 1080 is unclear, and is of particular concern because of their importance to kiwi.

The effects of 1080 on large vegetarian native invertebrates such as *Schizoglossa* and *Pseudaneitea* slugs, and *Placostylus* landsnails are not known.

The toxicity of 1080 to aquatic animals, particularly invertebrates, has yet to be established. Nothing is known of 1080 effects on freshwater detritus feeders, especially freshwater crayfish (koura).

### Persistence of 1080

It is not known how long baits remain toxic and accessible to animals, (especially invertebrates) - 1080 appears to adsorb to litter and remain toxic for long periods in cold conditions.

More information is needed of the rate at which 1080 pellets detoxify at winter temperatures in forest, and the persistence of 1080 in carcasses in winter. Nor is it clear how long the toxicity persists when 1080 is associated with litter.

### Effects of sub-lethal doses (single and repeated)

Little seems to be known about the effects of sub-lethal doses of 1080 (either single or repeated) on wild animals. Warburton (1989), referring to the work of Sullivan et al. (1979) on the effect of 1080 on laboratory rats, stated that sub-lethal doses reduced sperm production and the testes failed to regenerate. Eason et al. (1994), also citing the work of Sullivan et al. (1979), stated that seminiferous tubules in the testes were completely regenerated one week after the treatment ceased. However, the rats recovered only on a dosage of 2.2 ppm of 1080 in their drinking water. At higher concentrations (6.6 and 20 ppm.) regeneration was not complete after three weeks, when the study ceased. Innes and Williams (1991) noted at Mapara a delay of five months before trapping young rats and suggested that "it took 2-3 months for rats to find mates after the poisoning." Or were these animals affected by sub-lethal doses sufficient to inhibit breeding?

Some insects are also affected by sub-lethal doses; a single meal of 1080 reduced the egg production for the life of the beetle *Bracon bebetor* (Smith and Grosch 1976). The effect of sub-lethal doses on native vertebrates or invertebrates is not known.

Although poisoning is usually done in winter it is sometimes done at other seasons e.g. Waipoua Forest in September 1990 (Pierce and Montgomery 1992), Kaharoa in October 1990 (Innes and Williams 1991), and Rangitoto in November 1990 (Miller and Anderson 1992). These times overlap with the breeding seasons of many forest birds, and raise the possibility of nestlings of some species receiving sub-lethal doses by being given invertebrates containing 1080. Rapidly growing nestlings may be more vulnerable than adults but nothing is known in either case.

### Impact of repeated 1080 poisonings on ecological communities

Where Tb is present in cattle herds, possum numbers are reduced initially with 1080 and then kept low by annual maintenance control using a variety of techniques (Livingstone 1994). If the maintenance control includes the further use of 1080, the effects of sub-lethal doses can be compounded and may affect the reproduction of non-target species with a danger of further flow-on effects.

Although the impact of a 1080 poisoning operation on a few major groups of organisms in the forest (eg. possums, rats and birds) has been documented, the impact on other forest organisms is unknown. This applies to an even greater extent if 1080 is applied repeatedly. Some native species that are affected might not be able to recover to their previous numbers before the next poisoning, and so gradually decline in numbers, much as yellowheads appear to do under predation during the intermittent stoat plagues in beech forest.

Long life-cycle invertebrates such as cicadas could be affected by repeat poisonings, reducing the population in a series of steps.

The timing of a 1080 drop in relation to animal life-cycles may be significant. Parfitt et al. (1994) refer to poisoning operations in different areas in June and July, as well as May, September, and November. What difference does the timing of a poison operation have on the persistence of 1080 in the environment and the vulnerability of non-target species? For example, if food is scarce, and vertebrate body weights are low, non-target species could be more vulnerable.

### General

Although there is evidence of an effect on invertebrates of fine bait fragments generated during loading and dispersal of 1080 pellets (sect 4.5), the extent and significance of this effect needs to be further studied.

## 6.3 FLOW-ON EFFECTS

Few studies have measured the repercussions that flow on beyond the immediate effects possums have on plants and animals. Nor do they examine the flow-on effects of controlling possums by trapping versus those by poisoning. 1080 poisoning operations against possums also reduce rat populations and stoats then switch to preying more on birds; but the rat population recovers within a few months. Do the stoats return then to the previous level of predation on rats, or persist in preying on birds? And is the predation of stoats on birds more severe than that by rats? Whereas controlling possums by poisoning reduces rat populations (Sect.4.4b), gin trapping to control possums reduces cat populations; this can lead to substantial increase in the rat population (Sect.4.3b). What birds, or other native animals, are better off with fewer cats/stoats and more rats? And if the higher rat population seriously depletes the supplies of some fruit, does this affect the overall food supply for birds and the seed supply for regeneration?

The complexity of the web of relationships and interactions in a forest ecosystem is generally acknowledged but little understood. In New Zealand this is based on incomplete listings of the organisms that are present and knowledge of a few of the interactions between them. The known interactions are biased very strongly in favour of vertebrates i.e. interactions of a vertebrate, usually a mammal or bird, with another vertebrate or plant, and rarely with invertebrates. The flow-on effects of these interactions are often surmised, but rarely studied. For example, possums destroy the flowers and fruit of nikau and this "is one more threat to pigeon survival" (Cowan 1991 a). We do not know how the loss of this fruit compares with the loss of other fruit to possums or to other animals, and with any increase in availability of other foods that are unpalatable to possums but sought by pigeons. Reduction in the numbers of pigeons might also affect the dispersal and rate of germination of nikau.

Relationships and interactions within forests may have been disrupted by possums many decades ago and new ones established; removal of possums will not necessarily mean that the system returns to its previous state. Chance events of time of year, weather or the kinds of modifications that have taken place in the ecosystem may mean that when possums are removed species other than the original ones may gain the ascendancy and the system re-establishes itself with different pathways. The very complexity and unpredictability of these systems makes them difficult to study and discussion of these kinds of relationships can only remain speculative until proper studies are made.

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