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FATE OF MOREPORKS (*NINOX NOVAESEELANDIAE*) DURING A PEST CONTROL OPERATION ON MOKOIA ISLAND, LAKE ROTORUA, NORTH ISLAND, NEW ZEALAND

Summary: We monitored 16 radio-tagged moreporks (*Ninox novaeseelandiae*) on Mokoia Island after a brodifacoum poison drop to eradicate mice (*Mus musculus*), normally included in the owls' diet. All 16 moreporks were alive after 13 days. One bird was found dead on day 22, and corpses of two radio-tagged birds were located on day 51. The bird found on day 22 contained 0.97 mg kg^{-1} of brodifacoum in its liver. The other two carcasses were not analysed, but they probably died as a result of brodifacoum poisoning. Thus, three out of 14 birds died (21% mortality). A further eight banded and six non-banded birds were also monitored. Of these, 50% were not seen following the drop. Secondary poisoning is implicated in the disappearance of these birds. Sublethal effects such as lowered breeding success and stress may have affected morepork over a prolonged period following the poisoning operation. Further studies are needed to investigate the exact pathway of this poison, especially the potential for invertebrates to carry poison.

Keywords: Brodifacoum; Talon®; *Ninox novaeseelandiae*; rodenticide; secondary poisoning; island restoration.

Introduction

The aerial broadcast of brodifacoum is being used to eradicate rodent pests from islands surrounding New Zealand to create offshore refuges for endangered fauna. Anticoagulants have proven to be extremely effective in eradicating rodents from such islands. The Department of Conservation (DoC) is developing a strategy to eradicate rodents from a series of islands up to 3,000 ha (Clout and Saunders, 1995). With this widespread use, the impacts of these eradications on non-target species need to be fully understood.

Brodifacoum (active component of Talon®) is one of the second-generation compounds designed in the 1970s. Current island restoration programmes are breaking new ground with the use of brodifacoum. It is not being used in the way in which it was originally intended (as a control rodenticide placed in bait stations) (Holloway, Taylor and Warburton, 1992). However, the environmental impacts of these "new" toxins, such as brodifacoum, are less understood than alternative poisons, such as compound 1080, and careful consideration of potential impacts must be made before the toxin is used (Holloway, *et al*., 1992).

Brodifacoum is toxic to non-target vertebrates in New Zealand (Eason and Spurr, 1995a). Species such as North Island robin (*Petroica australis longipes* Sparrman) and North Island saddleback (*Philesturnus carunculatus rufusater* Gmelin) peck at poison baits and can die of primary poisoning (Towns, McFadden and Lovegrove, 1993; Eason and Spurr, 1995a; Brown, 1997). Anticoagulants also kill bird and mammal predators that feed on poisoned prey ('secondary poisoning'; Mendenhall and Pank, 1980; Townsend *et al*., 1981; Alterio, 1996; Alterio, Brown and Moller, 1997).

Though secondary poisoning can be advantageous in multi-species pest control (e.g., Alterio, 1996; Alterio *et al*., 1997), the impact of secondary poisoning on New Zealand's native avian predators, morepork (*Ninox novaeseelandiae* Gmelin), Australasian harrier (*Circus approximans* Peale) and New Zealand falcon (*Falco novaeseelandiae* Gmelin) has not been widely studied.

Morepork are at risk from secondary poisoning because they eat house mice (*Mus musculus* L.) (Lindsay and Ordish, 1964) and rats (Saint Girons, Newman and McFadden, 1986). If invertebrates, such as weta and beetles, have ingested or are carrying brodifacoum, this can pose an additional risk for morepork. Eason and Spurr (1995b) included morepork in the list of species that "probably would not eat cereal-based baits if encountered but might be at risk from secondary poisoning".

Morepork have been found dead following pest control operations using Talon® 20P or Talon® 50WB (Eason and Spurr, 1995b) and there is some evidence of decline in morepork populations on some islands.

A morepork was found dead following a brodifacoum poisoning operation on Stanley Island, but was not tested for brodifacoum presence. One dead morepork was also found on Inner Chetwode Island following a Talon® 20P drop (Eason and Spurr, 1995a). Following a Talon® 20P poison drop to eradicate kiore (*Rattus exulans* Peale) from Lady Alice Island in 1994, two dead morepork were found. One was assayed and its liver contained 3.4 mg kg^{-1} of brodifacoum; the other was too decayed to determine the cause of death (Ogilvie *et al*., 1997). On Tiritiri Matangi Island morepork numbers also appeared to decrease after aerial distribution of Talon® 20P (Eason and Spurr, 1995a). There was no evidence that morepork were killed by the use of Talon® 50WB in bait stations for eradication of Norway rats (*Rattus norvegicus* Berkenhout) on Breaksea Island (Taylor and Thomas, 1993). Morepork were also considered to be numerous five months after poisoning on Red Mercury Island (Robertson, Colbourne and Nieuwland, 1993). Morepork call counts conducted before and after a brodifacoum poison drop on Nukuwaiata Island were inconclusive due to large variations in calling activity between nights (Walker and Elliott, 1997). However, a dead morepork with a lethal level of brodifacoum residue in its liver was found (Walker and Elliott, 1997).

The house mouse eradication attempt on Mokoia Island provided us with an opportunity to study the effects of brodifacoum on the survival of morepork. Information gathered from this study and presented in this paper can assist with future island restoration attempts.

Methods

Study site

Mokoia Island is a 135-ha island in Lake Rotorua, North Island, New Zealand (38° 05' S; 176° 17' E). It is the largest inland island in New Zealand. Mokoia Island is Maori-owned, administered by the Mokoia Island Trust and is managed in association with DoC. The shortest distance from the island to the mainland is 2.1 km and thus Mokoia Island has the potential to remain free of introduced mammalian predators. Goats (*Capra hircus* L.) and Norway rats were exterminated in 1990, leaving house mice as the only resident mammalian pest.

Mokoia Island is a steep-sided rhyolitic volcanic plug which rises to 156 m above the lake level (Andrews, 1992). The island is covered with regenerating secondary forest, dominated by mahoe (*Melicytus ramiflorus*), kohuhu (*Pittosporum tenufolium*), five-finger (*Pseudopanax arboreus*) and mamaku tree ferns (*Cyathea medullaris*) (Beadel, 1990). Large areas of blackberry (*Rubus fruticosus*) cover the northeastern flats and some grassy areas are maintained around the hut, hot pool and wharf area.

Since 1990, the island has received translocations of North Island robins, North Island saddlebacks (Armstrong and Craig, 1995), and stitchbirds (*Notiomystis cincta* Du Bus) (Rasch, Boyd and Clegg, 1996). The eradication of mice, the last introduced rodent species on the island, would constitute a major step towards the restoration of this island.

Pre-poisoning study of morepork

From November 1995 to July 1996 adult morepork were attracted with taped calls and captured using mistnets. We used single-stage SirTrack Ltd. (Havelock North, New Zealand) transmitters (6.5–7 g) with an expected life of 10–12.5 months, attached using back-pack style harnesses (Stephenson, Minot and Olsen, 1998).

The poison drop

Talon® 7–20 cereal baits (3–4 grams) containing 20 ppm brodifacoum were air-dropped on 18 September 1996 at a rate of 10 kg ha^{-1}. Extra baits were applied by hand around buildings and the hot pool area. When referring to dates following the poison drop, the day of the drop, 18 September 1996, is designated as day 0. Thus, monitoring began on day 1 (19 September 1996).

Post- poison monitoring of morepork

Following the poison drop, an initial intensive monitoring period was conducted (days 1–13). During this intensive period, an attempt to visually locate all 17 radio-tagged birds was made each day. The appearance and general behaviour of individual birds was noted. Searches for banded, but un-tagged birds (n=8), were also conducted. This type of search was unreliable and we were unable to locate several of the birds for some time. Owls were not observed or tracked at night between days 1–13 in order to reduce disturbance, that may have affected their behaviour and potentially their survival. For the same reasons, disturbance during daily visual location of each bird was kept to a minimum.

Because the poison drop occurred later than planned, we were unable to monitor the morepork from day 13 to day 50. During this period DoC staff collected dead morepork if found. Following the intensive monitoring period all radio-tagged birds were located in early November and then monthly until the end of monitoring in February 1997.

After the poison drop, Bay of Plenty DoC staff did routine ground searches for dead birds and assessed bait distribution. All dead birds, including morepork, collected during these searches were necropsied by DoC staff at a later date to determine whether poisoning was the cause of death. Livers of morepork were removed and sent to the National Chemical Residue Laboratory (New Zealand Ministry of Agriculture and Fisheries) for brodifacoum assays using the Anticoag. v2 with detection levels of 0.01 mg kg^{-1}. Liver tissue has been shown to be the main site of toxin accumulation (Gray *et al*., 1994).

Results

Effect of the poison drop

Observations by Bay of Plenty DoC staff during pre-poisoning ground work suggested there was a drop-off in the mouse population just before the poison drop. Mouse populations usually peak in autumn and decline through winter (Murphy and Pickard, 1990). Thus, the operation occurred when food was expected to be a limiting factor to mice. Dead mice were first discovered on day 4, and were frequently found on the forest floor throughout the intensive monitoring phase (days 1–13). Many of the mice showed external bleeding from the mouth, ears and anus.

No mice were recorded using tracking tunnels during the October 1996 mouse monitoring. However, on 16 December, 90 days after the drop, a live mouse was seen in the vicinity of the hut. Anecdotal observations suggest that by November 1997, mice had re-established themselves over the entire island to pre-poisoning levels.

Several species of birds were found dead during the fortnight following the poison drop. The most common were chaffinch (*Fringilla coelebs* Kleinschmidt), but species such as North Island robin, North Island weka (*Gallirallus australis greyi* Sparrman) and North Island saddleback were also found dead. One stitchbird was also witnessed in a very distressed condition feeding from a feeder provided on the island as part of their management. This bird was not seen again and possibly died as a result of poisoning.

Morepork survival after poisoning

Radio-tagged birds

The radio-tagged moreporks (11 males, 6 females) were monitored following the poison drop. Two of these birds (1 male, 1 female) were juveniles fledged from the 1995/96 breeding season. One bird could not be located after day 2 because its transmitter battery failed, but was seen alive on day 137. The remaining 16 birds were alive at the end of the intensive monitoring stage (day 1–13) and had functioning transmitters. During a ground search on day 13, DoC staff found an untagged dead morepork. On day 22, one of the radio-tagged birds was found freshly dead.

In early November (day 51) an attempt was made to relocate the remaining 15 radio-tagged birds. Signals were received from 13 radio transmitters. Two moreporks with functioning transmitters were found dead. One of the dead birds had been scavenged, possibly by weka, and so brodifacoum analysis was not possible. The other dead bird was found about 4 m from its nest and could not be assayed either because of its advanced state of decomposition. The two moreporks whose radio transmitters did not respond, were not seen during the rest of the study.

The remaining 11 birds (8 males, 3 females) were located alive and apparently well on day 51. Transmitters on all of these birds functioned until at least day 89. Seven of these birds were later captured and their transmitters removed. Five birds were located on days 136–139, and three were seen alive on days 197–198. One bird was also captured and its transmitter removed on day 281.

The poison drop therefore caused the deaths of at least one and probably three out of the 14 radio-tagged birds (21%) (1 male, 2 females) within 51 days after the operation. The unmonitored bird was also killed by brodifacoum poisoning. Eleven out of 14 radio-tagged birds (79%) survived for at least 89 days after the poisoning operation.

Two further radio-tagged males were found dead on days 138 and 389, respectively. The cause of mortality could not be established.

The fates of banded and unbanded birds

A further eight banded, but not radio-tagged adult moreporks (4 males, 4 females) were monitored following the poison drop. Four of these birds (2 males, 2 females) were seen at least 89 days after the poison drop, and three were seen on days 137–138. Four birds were not seen after the intensive monitoring period following the poison drop. Therefore, the maximum mortality of these banded birds was 50%.

A further six unbanded adult birds (1 male, 5 females) were associated with moreporks that were radio-tagged following the drop. Three of these birds were seen only within the intensive monitoring period and were not seen later during the study. The three remaining birds were seen on days 198–199. Again, maximum mortality of unbanded birds was 50%.

Morepork behaviour

Fifteen of the 16 radio-tagged morepork were observed to behave normally during the intensive monitoring period. They roosted at sites that were typical, or on roosts they had used before. Their feathers appeared preened and they showed no signs of external bleeding nor blood in their faeces.

Eight of the radio-tagged birds were found roosting with mates during days 1–13. Several of the pairs were also roosting together within several m of nest sites they used later. This was normal pair behaviour at this stage of the breeding season. On days 11–13 a normally wary radio-tagged bird allowed a closer and closer approach. On day 13, the last day it was checked, the bird allowed a very close approach to within 6 m and did not fly. Its feathers were fluffed up and unpreened. This bird was found dead on day 51.

Necropsy and brodifacoum analysis

Two birds found dead and necropsied (1 radio-tagged and 1unmonitored bird) showed extensive internal haemorrhaging consistent with anticoagulant poisoning. The stomachs fluoresced under UV light, showing signs of the biotracer Pyranine. The livers of these birds contained 1.10 mg kg^{-1} and 0.97 mg kg^{-1} brodifacoum, respectively. The male bird found dead on day 389, 12 October 1997, showed signs of subacute hepatitis of unknown aetiology. This was unlikely to be related to brodifacoum toxicity. No brodifacoum analysis was conducted on this bird.

Possible sub-lethal and indirect effects

Breeding success during the season before the poison drop (1995/96) and the season following the drop (1996/97) gives an indication of possible sub-lethal effects.

In the pre-poisoning season six nests were located. Four of these nests were found during the egg stage, two were found at the chick stage, and a further one was assumed when two newly fledged chicks were found. A total of eight chicks fledged from these seven nests. This may be an overestimate of breeding success, because nests that had failed would not have been found. Of these eight chicks, three are known to have died within several weeks of fledging. However, three of these fledglings are known to have survived at least until September 1996 following the poison drop.

During the breeding season following the poison drop, only one chick fledged from six nests. One nest was not completed because the radio-tagged female died following the poison drop. Two nests were deserted during the egg stage, and the eggs disappeared from a further two nests.

A first year female bird who was presumed to have attempted breeding with an older male was also apparently unsuccessful. A nest was not found and the distinctive call of chicks was not heard in their territory. Another banded pair was seen on 3 February 1997. Both birds were moulting heavily, a sign of the end of their breeding attempt. No fledglings were with them although fledglings should still have been roosting with their parents.

Discussion

The discovery of several dead non-target bird species following the poison drop is consistent with most poison drops conducted in New Zealand (Towns *et al*., 1993; Towns *et al*., 1994; Brown, 1997; Ogilvie *et al*., 1997). The chaffinch, North Island robin and North Island saddleback found dead are likely to have directly consumed the poison baits. This is evidence of primary poisoning and proves the risk of aerial sowing of cereal based brodifacoum baits. Wekas probably ate poison baits although they may also have scavenged dead and dying mice and thus could have died from a combination of primary and secondary poisoning. Morepork are unlikely to eat poison baits and were most likely the victims of secondary poisoning.

Mortality rates

Of 14 radio-tagged birds whose transmitters worked for at least 51 days after the drop, three (21%) died during that period. The banded and unbanded birds suffered a maximum mortality of 50%. This is probably an overestimate due to the difficulty of locating un-tagged birds. True mortality was probably closer to the 21% mortality experienced by the radio-tagged birds. In comparison with the mortality found in screech owls (*Otus asio* L.) (Hegdal and Colvin, 1988), the mortality found in this study is low. It is also low considering the near 100% mortality of stoats (*Mustela erminea* L.), ferrets (*Mustela furo* L.), cats (*Felis catus* L.), and weasels (*Mustela nivalis* Erxleben), during similar operations (Alterio, 1996; Alterio, Brown and Moller 1997). The low mortality of morepork in this study could be a consequence of their primarily insectivorous habits. Nevertheless, mice made up 40% of morepork pellets (by volume) during September 1996 when the poison drop occurred. By February 1997 mice had reappeared in morepork pellets, averaging 13% by volume.

Liver analysis and lethal residue levels

Analysis of the livers of two dead morepork on Mokoia Island revealed brodifacoum residue levels (1–1.1 mg kg^{-1}) comparable with levels found in other poisoned owls overseas. Necropsy also revealed signs consistent with anticoagulant haemorrhaging. Analysis of livers from screech owls that died during Hegdal and Blaskiewicz's (1984) study found levels of brodifacoum between 0.4–0.8 mg kg^{-1} (detection level was 0.3 mg kg^{-1}; Hegdal and Colvin, 1988). The one barn owl (*Tyto alba* Scop.) that died during experiments conducted by Gray *et al*. (1994) had a residue of 1.67 mg kg^{-1} brodifacoum in its liver. Ogilvie *et al*. (1997) present the only published record of brodifacoum residues in moreporks found following poison drops, with 3.4 mg kg^{-1} in the liver of a dead bird from Lady Alice Island, New Zealand. Thus, levels of brodifacoum found in livers of dead morepork during this study are comparable with levels found in dead owls in previous studies. The levels of brodifacoum found in livers may represent more than a lethal dose. Because of the slow action of this poison, birds may have continued to consume poisoned prey after a lethal dose had already been ingested. Different levels of brodifacoum may also reflect dietary differences between island populations of morepork.

Mortality and population effect

The loss of three out of 14 birds within 51 days extrapolates to an annual mortality of around 82%. This is greatly in excess of the normal rate of mortality (B. Stephenson, *unpubl. data*) and further supports the assumption that these birds were killed by brodifacoum. Our tracking data support this point. Transmitters were fitted to morepork for 3839 bird days prior to the poison drop. During this time one bird died because of injury from a band and two juveniles less than a year old died, possibly killed by a harrier. Thus, there was one morepork death per 1279 bird days. In the first 51 days following the poison drop transmitters were fitted to live birds for no more than 762 bird days. During that time contact was lost with two birds and three are known to have died. This extrapolates to one morepork death per 254 days; a five-fold increase in the death rate over the pre-poison drop period.

The deaths are attributed to secondary poisoning. Diet analysis of morepork on Mokoia Island has shown that mice are important prey at certain times of the year and were present in their diet at the time of the drop (Stephenson, 1998). At that time invertebrates and birds were also eaten. Morepork hunt by watching and listening for movement and thus could have preyed on mice that were still active despite having ingested a lethal dose of brodifacoum. At this stage the mice may have behaved normally as ship rats (*Rattus rattus* L.) do (Hooker and Innes, 1995). However, if mice changed behaviour, such as light-dark reversal activity pattern or sluggishness seen in Norway rats (Cox and Smith, 1992), then morepork faced an even greater risk. Morepork are unlikely to eat dead mice from the forest floor, but will hunt during the day.

Brodifacoum levels in mice poisoned on Mokoia Island were not tested. However, ship rats analysed by Alterio *et al*. (1997) contained residues averaging 16 mg kg^{-1} in their livers. It could be assumed that mice contain similar concentrations of poison, or even more since mice are more tolerant to anticoagulants than rats (Kaukeinen and Rampaud, 1986; Jackson and Ashton, 1992). Recently perished mice were still found on day 11 and because poisoned rodents appear to feed until near to death (Cox and Smith, 1992), they would have been able to consume a large amount of poison by this time. In this case, a few mice may be sufficient for a lethal dose to be ingested by the owls. Invertebrates have also been suggested as "vectors" of brodifacoum (Godfrey, 1985; Eason and Spurr, 1995a; Ogilvie *et al*., 1997); the invertebrates in the owls' diet may have contributed to the death of morepork on Mokoia Island.

Those birds that survived the initial 51 days following the poison drop may still have been affected. Most birds on Mokoia Island would have been exposed to sub-lethal levels of brodifacoum. The effects of these doses on birds have not been investigated. Experiments on sheep, however, show that brodifacoum can cause abortions and death of newborn lambs (Godfrey, 1985). Possible sublethal effects of other pollutants and other chemicals on adult birds and embryos include reduced fertility, suppression of egg formation, eggshell thinning, impaired incubation and chick rearing behaviours (Fry, 1995). These may have played a role in the decreased breeding success of morepork on Mokoia Island following the poison drop. This could also be the cause of the two morepork deaths some time after the poison drop. Sublethal effects on chicks may have increased embryo and chick mortality. Another possible cause for the decline may have been the lack of prey. Only intensive monitoring of wild populations will allow us to assess the role of such sub-lethal effects.

The long-term effects of these compounds should be investigated. Substantial brodifacoum residues can remain in animal tissue for more than eight months (Towns *et al*., 1994; Eason, Wright and Batcheler, 1996). This suggests that long-term

effects may last at least as long. Moreover, if other non-target species carry sub-lethal doses of brodifacoum following an eradication operation (e.g., blackbirds (*Turdus merula* L.) on Red Mercury Island; Towns *et al*., 1994), then morepork could accumulate a lethal dose well after the poison drop.

Transmitter attachment

The backpack transmitters used in this study provided valuable data on the movements and survival of morepork. Hegdal and Colvin (1988) suggest that harnesses may cause bruising which could lead to haemorrhaging or irritation and thus increased mortality. We did not record any damage caused by harnesses, except for one bird that died because its transmitter caught on a tree fern.

Conclusions

Based on our analysis of marked birds, about one in five moreporks died within 50 days of the poison drop. Assuming a population of 50–55 on Mokoia Island, the total mortality could have been 10–12 birds. It is therefore likely that at least 9–11 dead morepork were not found in ground searches which provides some indication of the number of birds that are missed in a ground search. Other poison operations in New Zealand have also reported dead morepork (Towns *et al*., 1993; Ogilvie *et al*., 1997; Walker and Elliott, 1997), suggesting higher mortalities than numbers indicate (Wobeser and Wobeser, 1992; Philibert, Wobeser and Clark, 1993). Although the time and area searched has not been quantified, the results from Mokoia Island suggest that these recoveries may underestimate true mortality by up to a factor of ten.

Mortality levels caused by poisoning operations should not endanger the survival of non-target populations. With passerines that can produce several clutches per breeding season and fledge several young per clutch, the population will probably recover within one or two breeding seasons from a loss of 30% during a poison drop (Powlesland, Knegtmans and Marshall, 1999). However, long-lived species, such as morepork, may fledge fewer than one offspring per year, and will be slower to recover from mortality induced by secondary poisoning. On the basis of immediate mortality alone, morepork on Mokoia Island could have been expected to recover from the poison drop within two to three breeding seasons. However, in the breeding season following the poison drop very few chicks were fledged and probably even fewer survived to breeding age. Their recovery may be further hindered by sub-lethal or dietary factors following the poison drop.

This study provides an indication of the short-term mortality we can expect in a morepork population following an eradication attempt. The findings of this study should only be extrapolated to other islands on which mice are the only introduced mammal. The impacts of a poison drop may be totally different if the island has kiore or Norway rats present.

The use of brodifacoum and other second-generation anticoagulants in New Zealand should be re-evaluated as these toxins have not been adequately tested. Little is known about their effects on non-target species, their sub-lethal effects, persistence and breakdown in animal tissue and the environment. At the same time alternative toxins should be evaluated. For example, cholecalciferol appears to present less of a secondary poisoning risk, especially to birds (Eason *et al*., 1994; Haydock and Eason, 1997). Cholecalciferol is currently marketed as a rodenticide in many countries (Jolly *et al*., 1995) and with further research in New Zealand it might prove acceptable and cost-effective for use with baits. A new toxin, however, should not be introduced simply because there are problems with the ones currently used. The effectiveness of each toxin as well as its likely environmental effects should be evaluated prior to approving its use.

Our results demonstrated that brodifacoum was not a risk-free rodenticide. Its use for eradication of rodents from New Zealand islands needs to be closely monitored. Nevertheless, use of this poison has created rodent-free refugia on many New Zealand islands and these are important to endangered species.

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