A Critical Look at Aerial-Dropped, Poison-Laced Food in New Zealand's Forest Ecosystems

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SUMMARY

Each year, New Zealand aerially distributes massive quantities of acutely lethal, poison-laced foodstuffs into its wilderness ecosystems. The toxin most commonly used is sodium monofluoroacetate (compound 1080), an acutely toxic, oxygen metabolism-disrupting agent with very high toxicity to most air-breathing organisms. New Zealand ecological conservation officials claim that aerial poison operations are an essential strategy to protect vulnerable indigenous flora and fauna from exotic mammalian pests, and that the benefits of aerial poison operations outweigh their risks. This manuscript presents a critical review of the existing scientific literature on the non-target effects of aerial poison operations in New Zealand. This review reveals that in this complex, multifactorial situation, the relevant science has been selectively interpreted, selectively studied, and moreover, left grossly incomplete in its scope, possibly in favour of non-environmental, short-term economic interests. Using the existing scientific information on non-target effects of aerial poison operations, a basic cost-benefit analysis employing a numerical scoring system was performed. This cost-benefit analysis, which compared the potential costs and benefits to native species of aerial poison operations versus unchecked possum populations at their peak density, indicated that aerial poison operations have twice as many potential costs to native species as potential benefits, and that aerial poison operations were potentially twice as costly to native species as unmanaged possum populations at their peak density. The potential for widespread poisoning of New Zealand's large number of endemic and threatened/endangered omnivorous, insectivorous, and carnivorous bird species by the uncontrolled distribution of poison-laced food throughout an entire ecosystem is a serious issue worthy of international concern and immediate action.

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I. INTRODUCTION

An outstanding aim of science is to sort out the beliefs humans have about particular phenomena, distinguishing, at least to some degree, what is actually taking place from what we feel should be the case. However, with great increases in capitalistic social structure, where select groups can benefit financially at the expense of the human and non-human (i.e. ecosystem level) whole, scientific knowledge can sometimes be exploited (selectively interpreted, selectively studied, or simply ignored) to support the claims of the perspective held by the most powerful corporate group and promises to be the most economically favourable. This happened with the tobacco lobbies of the 1960's, which spread disinformation indicating no relationship existed between smoking and lung cancer.

When facing a localized phenomenon occurring over time and spatial scales that are relatively easy for humans to observe and physically manipulate (centimetres to meters; minutes to hours) it seems relatively easy to use science to appropriately develop a functional understanding of a situation. However, when considering the effects of an event occurring over slightly larger spatial scales (km), longer time scales (decades), with many entities engaging in relevant interactions and interdependencies, it is arguably much more difficult to reach a consistent, non-contentious understanding of the situation at hand. It is in these slightly larger, slightly longer-term situations where scientific information is more susceptible to selective interpretation and manipulation for political or economical reasons. Regardless, it is essential that in these situations the existing scientific evidence, or lack thereof, be brought to light, especially when the integrity of an entire ecosystem is at risk.

New Zealand currently practices aerial poisoning operations in which massive quantities (approximately 4000-100,000 kg of bait per drop) of poison-laced, palatable foodstuffs (cereal pellets and carrots) are introduced by helicopter or airplane into wide portions (10-400 km^2 per drop) of its forest ecosystems in the name of exotic mammalian pest (namely brushtail possum) population control(1). The poison most often used is sodium monofluoroacetate (compound 1080), an extremely toxic agent that, like cyanide, results in an acute disruption of oxygen metabolism in all air breathing organisms(2, 3). Other poisons, such as the anti-coagulants brodifacoum and pindone, are also used in aerial operations, however, much less commonly than 1080(4).

Compound 1080 has low lethal-doses for both avian and mammalian vertebrate organisms (LD_{50} ranging from 0.1-15 mg/kg body weight(5, 6)), no known antidote, and no discernable smell or taste(7, 8). Death from 1080 poisoning typically involves nausea, vomiting, convulsions, and foaming of the mouth, and can take anywhere from 1-72 hrs, depending on the species and the dose(7, 8). Moreover, when received in trace amounts below the lethal dose for an extended period studies have shown 1080 to behave as a male reproductive toxin and possibly an endocrine disruptor, damaging the testicles of male rats and sparrows(9), as wells as causing birth defects in foetuses of female rats(3, 9). The effects of sub-lethal 1080 exposure on humans have not been assessed(9).

Due to the hazards posed by 1080, it has been banned as a predator control agent in the United States since 1972, and as a rodenticide since 1990, except for its use in livestock protection collars[8]. Compound 1080 is used in only very limited quantities and in controlled ways (baited traps) in countries outside of New Zealand (Australia, Canada, Mexico, Israel), making New Zealand the only country to practice aerial distribution of 1080-laced food into its forest ecosystems. New Zealand purportedly uses 80-90% of all 1080 manufactured globally [1, 8, 10].

Aerial drops of 1080 were first trialled in the 1960's and 1970's [10, 11]. Since 1993, New Zealand has used approximately 2000-5000 kg of pure 1080 on its landmass per annum [8, 10], enough to kill a biomass equivalent to 14-35 million 70 kg humans per year at the human LD_{50} of 2 mg/kg [5]. To substantiate the extent of aerial poison operations currently occurring in New Zealand, **Table 1** summarizes the 49 aerial poison operations that have occurred, or are projected to occur, between Sept 2009 and Sept 2010[4]. This summary estimates that in this one-year period alone, a combined area of at least 3958 km^2 (395,828 ha) will be subjected to aerial poison operations. This also represents the total application of an estimated (at the average bait sow rate of 4 kg/ha and bait dose of 0.15 wt% 1080 [1]) total of 2112 kg of pure 1080, and 1,400,000 kg of foodstuff (mostly cereal based) in this one-year period. Poison operations of a similar magnitude are projected for different regions in the subsequent year, and to be repeated on these same areas within the next 2-7 years[1]. The summary in **Table 1** also highlights the use of brodifacoum on outlying islands (typically under 20 km^2 area), and the use of the similar anticoagulant pindone in aerial drops over vast regions (for instance 370 km^2 of Aoraki National Park from Feb-Sept 2010, see **Table 1**). The anti-coagulants brodifacoum and pindone, and other acutely toxic substances such as cyanide, are also used or are being proposed for use in similar aerial-drop operations[10], and thus, while this discussion focuses on 1080, the widespread, uncontrolled introduction of any acutely poisonous food into an ecosystem is the issue of concern.

Aerial drops of poison-laced food for possum control are advocated, funded, and instituted by two main groups [1]: (i) the governmental Department of Conservation (DoC), who aim to control possums for conservation of native flora; and (ii) the Animal Health Board (AHB), who aim to control bovine tuberculosis (Tb) in New Zealand's cattle and deer herds. Possums living near pastures have been identified as a primary disease reservoir and vector in the spread of Tb from possums to cattle[12, 13]. The DoC and the AHB, apparently supported by scientific evidence, claim that while aerial poison operations generate kill-rates of 85-95% of all rats and possums in an area [1], they pose minimal risk to non-target species such as birds [14, 15], or that the risks posed by aerial poison drops are counteracted by the benefits of the poison drop[1, 10].

However, basic common sense indicates that the widespread, uncontrolled distribution of foodstuffs such as cereal pellets (palatable to a wide number of species) laced with an acutely toxic substance targeting all oxygen breathing organisms, would pose a great risk of non-target poisoning of a number of species tending to ingest grains or seeds, and to pose a risk of secondary poisoning to those species ingesting insects or carcases that have fed upon poison-laced food if secondary poisoning is possible. Furthermore, the outstanding breeding capacity of rats means their populations can recover from over 90% kill rates to levels higher than before a poison operation within 6 months[16]. It is therefore rather inconceivable that aerial poison operations on mainland New Zealand deliver any long-term benefits to bird populations, which inherently breed and recover *much* more slowly[11] than their rodent predators.

This manuscript represents a review of the existing scientific literature concerning the non-target effects of aerial poison-laced food drops into an ecosystem, as practiced by New Zealand. This re-evaluation of the subject, which emphasizes existing peer-reviewed scientific information, reveals that in this complex, multifactor situation, the relative science seems to have been selectively interpreted, ignored, and moreover left grossly incomplete in its scope, presumably in the name of non-environmental economical interests. This paper highlights the potential for significant deaths of non-target species, particularly New Zealand's many endemic omnivorous and insectivorous birds inhabiting areas undergoing

REGION	Hectares	Km2	Posion Used	Estimated pure 1080 (Kg)	Contracting Agency	Application Date
Rangitoto Island	2311	23.11	Brodifacoum	/	DoC	June-Aug 2009
Motutapu	1509	15.09	Brodifacoum	/	DoC	June-Aug 2009
Kotuku Point*	1000	10	Brodifacoum	/		June-July 2009
Kariori Block*	1000	10	1080	8	AHB	March 2010 .
Gentle Annie*	1000	10	1080 carrot	8	DoC	Sept-Oct 2009
Whenuakite	1200	12	1080	9	DoC	Sept-Oct 2009
S Hurunui Valley	4000	40	1080	30	Doc	Sept-Oct 2009
Gouland Downs*	1000	10	1080	8		Sept-Oct 2009
Anatoki	11,000	110	1080	83		Oct-Nov 2009
Lower Waihopai	7000	70	1080	53	AHB	Sept-Oct 2009
Waihopai-spray	4200	42	1080	32	AHB	Sept-Oct 2009
N Bank Wairau	12,798	127.98	1080	96	AHB	Sept-Oct 2009
Matahura Scenic Reserve*	1000	10	1080	8	AHB	March 2010 .
Turangi Sector 2b*	1000	10	1080	8	AHB	Sept-Oct 2009
Takahiapo*	1000	10	1080	8	AHB	May-June 2010
Taupo 7b*	1000	10	1080	8		March-June 2010
Whanganui National Park	32,000	320	1080	240		Nov-Dec 2009
Egmont National Park	33,500	335	1080	251		Feb-March 2010
Isolated Hill*	1000	10	1080	8		Oct-Dec 2009
Molesworth*	1000	10	Pinidone	8		Sept-Oct 2009
Mokihinui	1400	14	1080	11		Sept-Oct 2009
Mokihinui	3000	30	1080	23	DoC	Feb-march 2009
Opara Valley	10,166	101.66	1080	76	DoC	Nov-Dec 2009
Saint Andrews	1000	10	1080	8	DoC	Sept-Oct 2009
Saint Andrews	944	9.44	1080	7	DoC	Feb-March 2010
Atarau	12,000	120	1080	90	AHB	May-Aug 2010
Cascade	27,000	270	1080	203	DoC	May-June 2010
Ianthe	9000	90	1080	68	AHB	June-Sept 2010
Karnback	8000	80	1080	60	AHB	June-Sept 2010
Mikonui North	19,400	194	1080	146	AHB	June-Sept 2010
Mikonui South	19,400	194	1080	146	AHB	June-Aug 2010
Maruia N	14,000	140	1080	105	AHB	June-Aug 2010
Mt Hercules Aerial	7,000	70	1080	53	AHB	June-Sept 2010
Maruia West	8,800	88	1080	66	AHB	May-Aug 2010
One-One	3,900	39	1080	29	AHB	June-Sept 2010
Price	4,000	40	1080	30	AHB	June-Sept 2010
Poerua	4,500	45	1080	34	AHB	June-Sept 2010
Saltwater	8,900	89	1080	67	AHB	June-Sept 2010
Lewis Pass	21,000	210	1080	158	DoC	Sept-Oct 2009
Landsborough Valley	10,000	100	1080	75		Oct-Nov 2009
Springs Junction	11,900	119	1080	89		May-Aug 2010
Public Cons Lands Canterbury*	1000	10	1080	8	DoC	June-July 2010
Hawdon Valley	4000	40	1080	30		Sept-Oct 2009
Awakino*	1000	10	1080	8		July-Aug 2010
Simons Hill Conservation Area*	1000	10	1080	8	DoC	Sept-Oct 2009
Simons Hill Conservation Area*	1000	10	Pinidone	8	DoC	Feb-March 2010
Aoraki National Park	37,000	370	Pinidone	278	DoC	Feb-Sept 2010
Silverpeaks*	1000	10	1080	8		April-June 2010
Fiordland	25,000	250	1080	188	DoC	Aug-Sept 2010

Table 1: Details of the aerial poison operations occurring between Sept 2009- Sept 2010 in New Zealand. The estimate of the amount of pure 1080 toxin used was calculated based on the average reported sow rate of 4 kg/ha, and the average reported bait dose of 0.15 wt% 1080. Where not indicated otherwise, baits are cereal pellets. For regions marked with an * , the actual land area was not available, but the drop was indicated on a map to be larger than 1000 ha. Therefore, areas marked with an * represent an area of at least 1000 ha. This information was compiled from the DoC online listing of pesticide use summaries[4].

COMMON NAME	LATIN NAME	POPULATION	REGION	IUCN Classification	DISTRIBUTION
North Island Brown Kiwi	Apteryx mantelli	25,000	Endemic	Threatened	NI
Okarito Brown Kiwi	Apteryx rowi	300	Endemic	Critically endangered	Okarito, SI
Southern Brown Kiwi	Apteryx australis	35,000	Endemic	Vulnerable	SI
Great Spotted Kiwi	Apteryx haastii	22,000	Endemic	Vulnerable	SI
Little Spotted Kiwi	Apteryx owenii	1,200	Endemic	Endangered	Islands
Pukeko	Porphyrio porphyrio		Indigenous	Least Concern	
South Island Takahe	Porphyrio hochstetteri	225	Endemic	Endangered	SI
Weka	Gallirallus australis		Endemic	Vulnerable	SI
Kahu or Swamp Harrier	Circus approximans		Indigenous	Least Concern	
New Zealand Falcon	Falco novaeseelandiae		Endemic	Near Threatened	
Ruru or Morepork	Ninox novaeseelandiae		Endemic	Least Concern	
Longtailed Cuckoo	Eudynamys taitensis		Endemic	Least Concern	
Shining Cuckoo	Chrysococcyx lucidus		Indigenous	Least Concern	
Kea or Mountain Parrot	Nestor notabilis	1000-15000	Endemic	Endangered	SI
Kākā	Nestor meridionalis	2500-10000	Endemic	Endangered	SI
Kākāpō	Strigops habroptila	123	Endemic	Critically endangered	SI
Malherbe's Parakeet	Cyanoramphus malherbi	50	Endemic	Critically endangered	SI
Antipodes Island Parakeet	Cyanoramphus unicolor		Endemic	Vulnerable	Si
Rock Wren	Xenicus gilviventris		Endemic	Vulnerable	SI
Rifleman	Acanthisitta chloris		Endemic	Least Concern	SI
New Zealand Pipit	Anthus novaeseelandiae		Endemic	Least Concern	
Fernbird	Megalurus punctatus		Endemic	Least Concern	
Tomtit	Petroica macrocephala		Endemic	Least Concern	
New Zealand Robin	Petroica australis		Endemic	Least Concern	
North Island Robin	Petroica longipes		Endemic	Least Concern	NI
Whitehead	Mohoua albicilla		Endemic	Least Concern	
Yellowhead	Mohoua ochrocephala		Endemic	Endangered	SI
Brown Creeper	Mohoua novaeseelandiae		Endemic	Least Concern	
Grey Warbler	Gerygone igata		Endemic	Least Concern	
Tui	Prosthemadera novaeseelandiae		Endemic	Least Concern	
Hihi or Stitchbird	Notiomystis cincta		Endemic	Threatened	NI
North Island Kōkako	Callaeas cinerea wilsoni		Endemic	Endangered	
North Island Saddleback	Philesturnus carunculatus rufusater		Endemic	Near threatened	NI
South Island Saddleback	Philesturnus carunculatus carunculatus		Endemic	Near threatened	SI
New Zealand Bellbird	Anthornis melanura		Endemic	Least Concern	
New Zealand Fantail	Rhipidura fuliginosa		Endemic	Least Concern	
Silvereye	Zosterops lateralis		Endemic	Least Concern	
kererū	Hemiphaga novaeseelandiae		Endemic	Near threatened	
Australian Magpie	Gymnorhina tibicen		Introduced	Least Concern	
Common Myna	Acridotheres tristis		Introduced	Least Concern	
European Starling	Sturnus vulgaris		Introduced	Least Concern	
Yellowhammer	Emberiza citrinella		Introduced	Least Concern	
Cirl Bunting	Emberiza cirlus		Introduced	Least Concern	
Chaffinch	Fringilla coelebs		Introduced	Least Concern	
European Greenfinch	Carduelis chloris		Introduced	Least Concern	
Common Redpoll	Carduelis flammea		Introduced	Least Concern	
European Goldfinch	Carduelis carduelis		Introduced	Least Concern	
House Sparrow	Passer domesticus		Introduced	Least Concern	
Song Thrush	Turdus philomelos		Introduced	Least Concern	
Common Blackbird	Turdus merula		Introduced	Least Concern	
Skylark	Alauda arvensis		Introduced	Least Concern	
Chukar	Alectoris chuka		Introduced	Least Concern	
Red-legged Partridge	Alectoris rufa		Introduced	Least Concern	
Grey Partridge	Perdix perdix		Introduced	Least Concern	
Brown Quail	Coturnix ypsilophora		Introduced	Least Concern	
Ring-necked Pheasant	Phasianus colchicus		Introduced	Least Concern	
Eastern Rosella	Platycercus eximius		Introduced	Least Concern	
Rook	Corvus frugilegus		Introduced	Least Concern	

Table 2: A listing of the common and Latin names, global region, the IUCN conservation status, and the specific distribution within New Zealand (if not widespread) of 58 species of terrestrial New Zealand birds found in areas where aerial poison operations occur. This information was compiled from Heather and Robertson 2005[17].

poison operations, and emphasizes that the study of non-target bird deaths has not been assessed to any meaningful degree. The potential for a widespread poisoning of a large number of endemic and threatened or endangered non-target species by the uncontrolled distribution of poison-laced food makes this a serious issue of international concern.

II. NEW ZEALAND's PRECIOUS, VULNERABLE FOREST ECOSYSTEMS

New Zealand is a country in the South Pacific consisting of two main islands with a combined area of 268,021 km^2 (18). On account of its isolation from other global landmasses, New Zealand flora and fauna evolved in the absence of mammals, with the exception of two species of bat (the long and short-tailed bat, respectively). However, rats were introduced to New Zealand approximately 700 years ago by the Maori(19). European settlement after 1840 introduced many mammalian species, most notoriously the brushtail possum (Trichosurus vulpecula), mustelids such as the stoat, and ruminants such as deer, goats, cattle, and sheep(19). In addition to exotic species introduction, New Zealand's indigenous species faced a massive habitat loss. Prior to human settlement, it is believed that the landmasses of the North and South Islands were 86% covered by native forest ecosystems(19). Today, after significant clearing of the forest by Maori and European settlers, only 15% of this original native forest remains(19).

The birds of New Zealand, a large number of which are found nowhere else on Earth, are a tremendously important — and vulnerable — aspect of New Zealand's forest ecosystems. Coinciding with the significant habitat loss and the introduction of mammals to New Zealand, 43 bird species were brought to extinction, with 16 of these extinction events occurring after 1840(20). Under the New Zealand threat classification system, 153 of approximately 200 (~77%) species of birds remain threatened, endangered, or critically endangered(20). This emphasizes the fragility of New Zealand bird populations, and the need to proceed with great caution to avert more losses. **Table 2** lists the common and Latin names, population (where known), global region (endemic, indigenous, or introduced), conservation status, and distribution within New Zealand (where not widespread) of terrestrial bird species living within areas currently subject to aerial poison operations(17).

The aerial distribution of large amounts of freely accessible poison-laced food is touted by New Zealand conservation officials and scientists as being the very thing that New Zealand birds and native fauna require to survive(1, 10, 21). Yet, have the outstanding risks of primary and secondary poisoning of the fragile populations of New Zealand's birds been assessed to a meaningful degree, and has it actually been shown that in a realistic cost-benefit analysis it is advantageous to the ecosystem to aerially distribute massive amounts of acutely toxic foodstuffs?

III. INFORMATION & MISINFORMATION

In the body of information freely available to the public (web pages and government or agency reports) as well as in some peer-reviewed scientific literature on the subject, there is to be found: (i) extensive misrepresentation of 1080 and its effects on living things; (ii) selective interpretation of existing information in favour of continued aerial poison operations; (iii) notable incidences of unsupported claims about the effects of 1080 and also the effects of possums; (iv) single-factor analysis where a multi-factored system science, ecosystem level view is essential; (v) potential for bias due to conflict of interest between scientists conducting research and DoC or AHB financial sponsorship; and (vi) the use of poor methodologies, such as the continued use of bird-counting methods that are known to give nonsensical results. These six issues, as they pertain to the freely available information distributed to the public and government (web pages and agency reports) as well as the existing peer-reviewed data, will be systematically addressed in this section.

Misrepresentation of 1080

New Zealand advocating agencies (DoC and AHB) have openly represented 1080 as an agent targeting mammals, when in fact it is acutely toxic to ***all*** air breathing organisms, including vertebrates such as birds, and invertebrates such as insects and spiders[5-7]. On the DoC website[22] and in publicly available information documents on 1080[1], it is clearly stated that: [21] *"New Zealand is well placed to use 1080 is because it specifically targets mammals — meaning we can target the predators and pests with limited impact on our native wildlife."* In contrast, Canadian toxicologists describe 1080 as[23]: *"sodium monofluoroacetate is highly to very highly toxic to avian species on an acute oral basis (LD_{50}=1-15 mg/kg). It may also be a cause of secondary toxicity to predator/scavenger birds and mammals."*

Similarly, in response to the question of why New Zealand is the only country to use so much 1080 in such uncontrolled manners, is the grossly misleading and incorrect statement: *"Because New Zealand has no native terrestrial mammals except for two species of bat, we are well placed to use a toxin that targets mammals. Other countries which have native mammals that they want to protect use 1080 differently to New Zealand. It is used in Australia to control foxes, as well as a rodenticide in Mexico, Japan and Israel. The United States has limited use of 1080 because of its effects on large native mammals — but it is used to reduce coyote attacks on sheep."*[21, 22] This statement is deeply problematic as it again proposes that 1080 only targets mammals, when in fact all vertebrates, including New Zealand's fragile bird species, are at risk of poisoning.

There has been extensive public representation of 1080 as a safe, naturally occurring substance by the DoC and the National Possum Control Agencies[21]. In the online webpage[22] and the document entitled "Questions and Answers on 1080"[21], as well as in similar publically-accessible government-issued material[1] compound 1080 is described: *"Sodium monofluoroacetate, or 1080, is a chemical reproduction of a naturally-occurring, biodegradable toxin that plants use to discourage browsing animals. It is found in Australian, South American and South African plants. Low concentrations are also found naturally in tea and New Zealand pūhā."*[22] In contrast, 1080 has been described by Grantz of the World Health Organization as being *"extremely hazardous to man"* and that *"precautionary measures are of utmost importance and should include the strictest control of poisoned baits and liquids and the prevention of access to the carcasses of poisoned rodents"* [7]. Cyanide is also a naturally occurring toxin found at very low concentrations in various plants; however, it is also among the world's most widely known and acutely toxic substances, with lethal doses similar to 1080.

Selective Interpretation of Scientific Information

In the publicly available information, the discussion of the effect of poison operations on non-target species such as birds is an outright misrepresentation of the existing body of scientific evidence as the available information has been selectively interpreted to support continued aerial poison operations. In a 1080 discussion document, Green writes[1]: *"Studies have shown that while some individual birds may die after 1080 operations, overall bird populations are not adversely affected in the long term because of better food supply and reduced predation. Monitoring of rare species using radio collars on birds are showing encouraging results with no loss of birds during 1080 operations."* and *"Over the past 30 years there has been extensive and increasingly sophisticated monitoring of bird populations after aerial 1080 operations. Scientists conclude on the present evidence that the ecological costs of using toxins is much less than the damage if they are not used."*

As will be examined in what follows, these statements, which supply no references, are selective interpretations of the available scientific evidence. In reality, there are very few scientific studies investigating the effects of aerial poison operations on New Zealand's bird populations. Moreover, amongst the existing body of scientific literature on the subject (which is summarized in **Table 3**), there are reports highlighting the need to study and protect a number of species which risk non-recovery if their populations are decimated[11]; reports on the significant decline of specific bird species populations (tomtit[24], robin[25, 26], saddleback[27] and morepork[28]); and a report on the capacity for invertebrates to contain lethal doses of 1080 without dying, and thus to cause secondary poisoning in insectivorous birds[6]. Moreover, while body searches are now rarely conducted and are not advocated due to their "non-scientific" nature[25], reports that have performed body searches after poison operations have documented deaths from a wide range of bird species[11, 29, 30].

From the existing scientific reports it is already possible to establish a coherent picture that poison operations (aerial 1080 and anti-coagulants) have a high capacity to be detrimental to New Zealand's omnivorous, insectivorous, and carnivorous bird populations, while having minor or even beneficial effects for nectar, fruit, and foliage-feeding bird species. An outstanding issue is that the majority of population studies have focused on the effects of aerial poison operations on these nectar, fruit, and foliage feeding bird species while the effects on the extensive number of omnivorous, insectivorous, and carnivorous birds have not been widely investigated.

The major hypothesis of this work is that birds of highest risk of poisoning from toxin-laced food can be identified by examining their primary feeding habits. Poison operations are often carried out with cereal pellets. Notably, Lloyd and McQueen in 2000 have shown that an invertebrate feeding on 1080 pellets can remain alive while accumulating enough 1080 toxin within itself to serve as a lethal dose to most insectivores receiving as little as 6.4% of their daily insect ration[6]. Therefore, in order of likelihood, the most probable transmission routes of 1080 toxin are deemed to be: (i) via direct ingestion of the poison-laced cereal pellet/carrot, (ii) via secondary poisoning of insectivorous birds consuming invertebrates that have accumulated 1080[6], (iii) via secondary poisoning from

Authors	Year	Journal	International?	DoC/AHB Funded?	Studied
Armstrong & Ewen	2001	NZ J Ecology	No	No	aerial brodifacoum: NZ robin population
Armstrong et al	2001	NZ J Ecology	No	No	aerial brodifacoum: hihi population
Davidson & Armstrong	2001	Biological Conservation	Yes	No	aerial brodifacoum: saddleback population
Dowding et al	1999	NZ J Ecology	No	DoC Scientists	aerial brodifacoum: non-target bird deaths
Eason et al	1992	NZ J Ecology	No	DoC funding	aerial 1080: water residues
Innes & Barker	1999	NZ J Ecology	No	No	Review 1080 and ecology
Lloyd & McQueen	2000	NZ J Ecology	No	DoC Scientists	aerial 1080: accumulation in invertebrates
Lloyd & McQueen	2002	NZ J Ecology	No	DoC Scientists	aerial 1080: NZ bats
Miller & Anderson	1992	NZ J Ecology	No	No	aerial 1080: 5 min bird counts
Murphy & Bradfield	1992	NZ J Ecology	No	DoC Scientists	aerial 1080: stoat prey switch to birds
Murphy et al	1998	NZ J Zoology	No	DoC Scientists	aerial 1080: stoat prey switch to birds
Murphy et al	1999	NZ J Ecology	No	DoC Scientists	aerial 1080: stoat poisoning
Notman	1989	NZ Entomologist	No	No	aerial 1080: review invertebrate effects
Nugent and Yockney	2004	NZ J Zoology	No	AHB funding	aerial 1080: deer and bird deaths
Peters	1975	Proc NZ Ecol Soc	No	No	environmental persistence of 1080
Powlesland et al	1999	NZ J Ecology	No	DoC Scientists	aerial 1080: NI robins
Powlesland et al	2000	NZ J Ecology	No	DoC Scientists	aerial 1080: tomtits
Powlesland et al	2003	NZ J Ecology	No	DoC Scientists	aerial 1080: kaka and kereru
Robertson & Colbourne	2001	J Wildlife Management	Yes	DoC Scientists	aerial brodifacoum: kiwi
Robertson et al	1999	Wildlife Research	Yes	DoC Scientists	aerial 1080: kiwi
Spurr	1979	NZ J Ecology	No	No	theoretical effects aerial 1080 various bird populations
Spurr	1993	NZ J Ecology	No	No	bird consumption 1080 baits
Spurr et al	2004	NZ J Ecology	No	No	aerial 1080: invertebrate survival
Stephenson et al	1999	NZ J Ecology	No	No	aerial brodifacoum: moreporks
Suren and Lambert	2006	NZ J Marine Freshwater	No	AHB funding	aerial 1080: freshwater organisms
Westbrooke et al	2003	NZ J Ecology	No	AHB and DoC funds	aerial 1080: tomtits
Westbrooke & Powlesland	2005	NZ J Ecology	No	AHB and DoC funds	aerial 1080: tomtits

Table 3: A summary of existing peer-reviewed scientific literature reporting on the non-target effects of aerial poison operations (1080 and brodifacoum). This table lists the journal in which these reports were published, whether this journal was an international or New Zealand specific journal, whether the scientists were funded by AHB or DoC, and gives a brief description of the subject of study.

COMMON NAME	DIET	FOUND DEAD	RECOVERY CAPACITY	PELLET FEED	Studied?
North Island Brown Kiwi	Insectivore		Low	Yes	//
Okarito Brown Kiwi	Insectivore		Low	Yes	//
Southern Brown Kiwi	Insectivore		Low	Yes	//
Great Spotted Kiwi	Insectivore		Low	Yes	//
Little Spotted Kiwi	Insectivore	Yes	Low	Yes	Yes - up to 19% mortality
Pukeko	Omnivorous	Yes	High		//
South Island Takahe	Omnivorous		Low		//
Weka	Omnivorous	Yes	Medium	Yes	//
Kahu or Swamp Harrier	Carnivorous	Yes	Low		//
New Zealand Falcon	Carnivorous		Medium		//
Ruru or Morepork	Insects, Carnivore	Yes	Medium	No	Yes - 43-55% mortality
Longtailed Cuckoo	Insectivore		….		//
Shining Cuckoo	Insectivore		….		//
Kea or Mountain Parrot	Omnivorous	Yes	Low	Yes	//
Kākā	Fruit, Insects	Yes	Low	Yes	Yes - no mortality in study
Kākāpō	herbivores		Low		//
Malherbe's Parakeet	Omnivorous		Low	Yes	//
Antipodes Island Parakeet	Omnivorous		Medium	Yes	//
Rock Wren	Insectivores		Low		//
Rifleman	Insectivore	Yes	Medium		//
New Zealand Pipit	Insectivore	Yes	High		//
Fernbird	Insectivore		Low		//
Tomtit	Insectivore	Yes	High	Yes	Yes - up to 79% reduction
New Zealand Robin	Insectivore	Yes	Medium		Yes - up to 45% mortality
North Island Robin	Insectivore	Yes	Medium		//
Whitehead	Insesctivore		Medium		//
Yellowhead	Insectivore		Low		//
Brown Creeper	Insectivore	Yes	Medium		//
Grey Warbler	Insectivore	Yes	High		//
Tui	primarily nectar		High		//
Hihi or Stitchbird	primarily nectar		Low		Yes - low 5% mortality
North Island Kōkako	primarily herbivore		Low	Yes	//
North Island Saddleback	insectivore, herbivore	Yes	Low	Yes	Yes - 34-56% mortality
South Island Saddleback	insectivore, herbivore	Yes	….		//
New Zealand Bellbird	nectar, insects		High		//
New Zealand Fantail	insectivore	Yes	Medium		//
Silvereye	Omnivorous	Yes	High		//
kererū	Frugivorous		Medium		Yes - no mortality
Australian Magpie	Omnivorous	Yes	…..		//
Common Myna	Omnivorous	Yes	….		//
European Starling	Omnivorous		….		//
Yellowhammer	Omnivorous	Yes	….		//
Cirl Bunting	Omnivorous		….		//
Chaffinch	Insectivore	Yes	….		//
European Greenfinch	herbivores		….		//
Common Redpoll	Omnivorous	Yes	….		//
European Goldfinch	Omnivorous	Yes	….		//
House Sparrow	Omnivorous	Yes	….		//
Song Thrush	Omnivorous	Yes	Low		//
Common Blackbird	Omnivorous	Yes	….		//
Skylark	Omnivorous	Yes	….		//
Chukar	Seeds and Insects	Yes	….		//
Red-legged Partridge	Seeds and Insects		….		//
Grey Partridge	Seeds and Insects		….		//
Brown Quail	Omnivorous	Yes	….		//
Ring-necked Pheasant	Omnivorous		….		//
Eastern Rosella	Herbivores		….		//
Rook	Omnivorous		….		//

Table 4: For 58 species of terrestrial New Zealand birds, a listing of the primary diet[17]; if the species has been found dead after a 1080 or brodifacoum poison operation[11, 29, 30]; if the species is listed as low, medium, or high capacity of recovery if population is decimated (according to Spurr 1979[11]); whether the bird has been observed to eat green, cinnamon lured bait pellets (according to Spurr 1993 [31]); and whether the population effects of aerial poison operations have been scientifically studied.

feeding of scavenging birds on carcasses of 1080-killed organisms, and (iv) via secondary poisoning of carnivorous birds feeding on 1080 poisoned prey. The anti-coagulants brodifacoum and pindone would transmit similarly to 1080, except with a much higher likelihood of secondary poisoning of carnivorous and scavenging birds due to the persistence of these toxins in tissue (i.e. transmission routes (iii) and (iv)) [(28)]. This places highest concern for omnivorous and insectivorous birds in aerial 1080 operations, and omnivorous, insectivorous, and carnivorous birds after aerial anti-coagulant poison operations. As none of these toxins accumulate in plant foliage, blossom, nectar, or fruit to any significantly lethal degree, the lowest risk should therefore be placed on nectar, fruit, foliage, or flower eating bird species.

Examining the species that have been found dead after 1080 or brodifacoum operations supports the above reasoning. **Figure 1** shows all terrestrial bird species inhabiting environments undergoing poison operations, classifying them in terms of their primary feeding tendencies. In **Figure 1**, exotic species are shown in simple type (legend a); native bird species are shown in bold type (legend b); bird species that have been reported dead after poison operations, but have not been studied, are shown as black boxes with white type (legend c); bird species not found dead, whose populations before and after poison operations have been studied, are shown as grey-hatched boxes (legend d); and bird species found dead, and whose populations have been studied, are shown as black boxes with grey hatching (legend e). The information detailed in **Figure 1** was compiled from peer-reviewed, published reports[(11, 24-30, 32-37)].

While reports of bird deaths[(11, 29, 30)] do not indicate the extent of damage in terms of species populations, they do indicate which species are susceptible to poisoning. From **Figure 1** it is evident that members from 73% of all omnivorous bird species were reported dead; members from 64% of all insectivorous bird species were reported dead; members from 67% of carnivorous bird species were reported dead; while members from only 15% of herbivorous bird species were reported dead. To put this in terms of total proportions, of the 31 species that have been reported dead after aerial poison operations, 48% have omnivorous feeding habits, 42% have insectivorous feeding habits, 7% have carnivorous feeding habits, and 3% have nectar-feeding or herbivorous feeding habits. This basic examination supports the common sense reasoning that poison-laced foods are most likely to affect non-target species with omnivorous and insectivorous feeding tendencies, and are least likely to affect birds feeding primarily on nectar, fruit and foliage.

However, the species most widely studied remain the nectar, fruit, and foliage eating birds (hihi[(34)], kereru[(37)], kokako[(38)], and kaka[(37, 38)]), which have been the subject of proper radio-transmitter, colour banding, and mark-recapture analysis before and after poison operations. Perhaps not surprisingly, only minor effects of poison operations (0-20% mortality) of these species were observed. These are also species whose populations would be expected to most benefit from reduction of possums[(39, 40)] due to their competition with possums for fruit, flowers, and foliage. While it is positive that poison operations are indicated to not have detrimental effects on these herbivorous bird populations, this does not establish that poison operations are safe in general or that they are beneficial to ecosystem health. The existing literature only indicates that aerial poison operations are likely safe for nectar-feeding and fruit/flower/foliage eating herbivores.

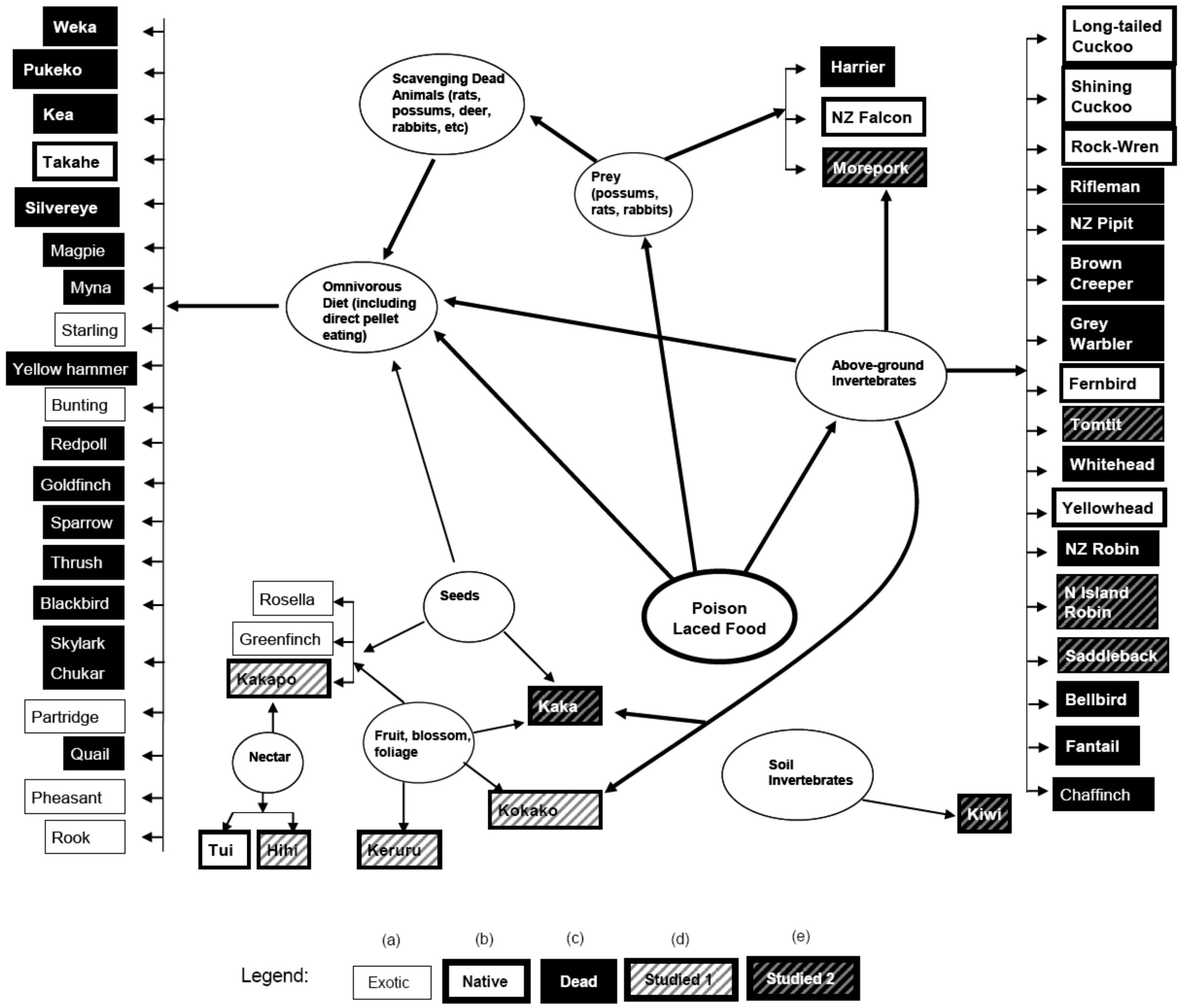

Figure 1: A schematic illustrating aerial poison impacts and the degree of scientific study of terrestrial bird species inhabiting areas undergoing aerial poison operations in New Zealand. The established trophic movement of poison laced food, as well as the trophic tendencies of the various bird species, are depicted by arrows. Exotic birds are depicted with normal type (legend a); natives by bold type (legend b); birds reported dead after poison operations are represented by black boxes (legend c); species not reported dead, but subject to population studies after poison operations are coded by grey hatching (legend d); and species reported dead and subject to poison operations are coded by black boxes with grey hatching (legend e).

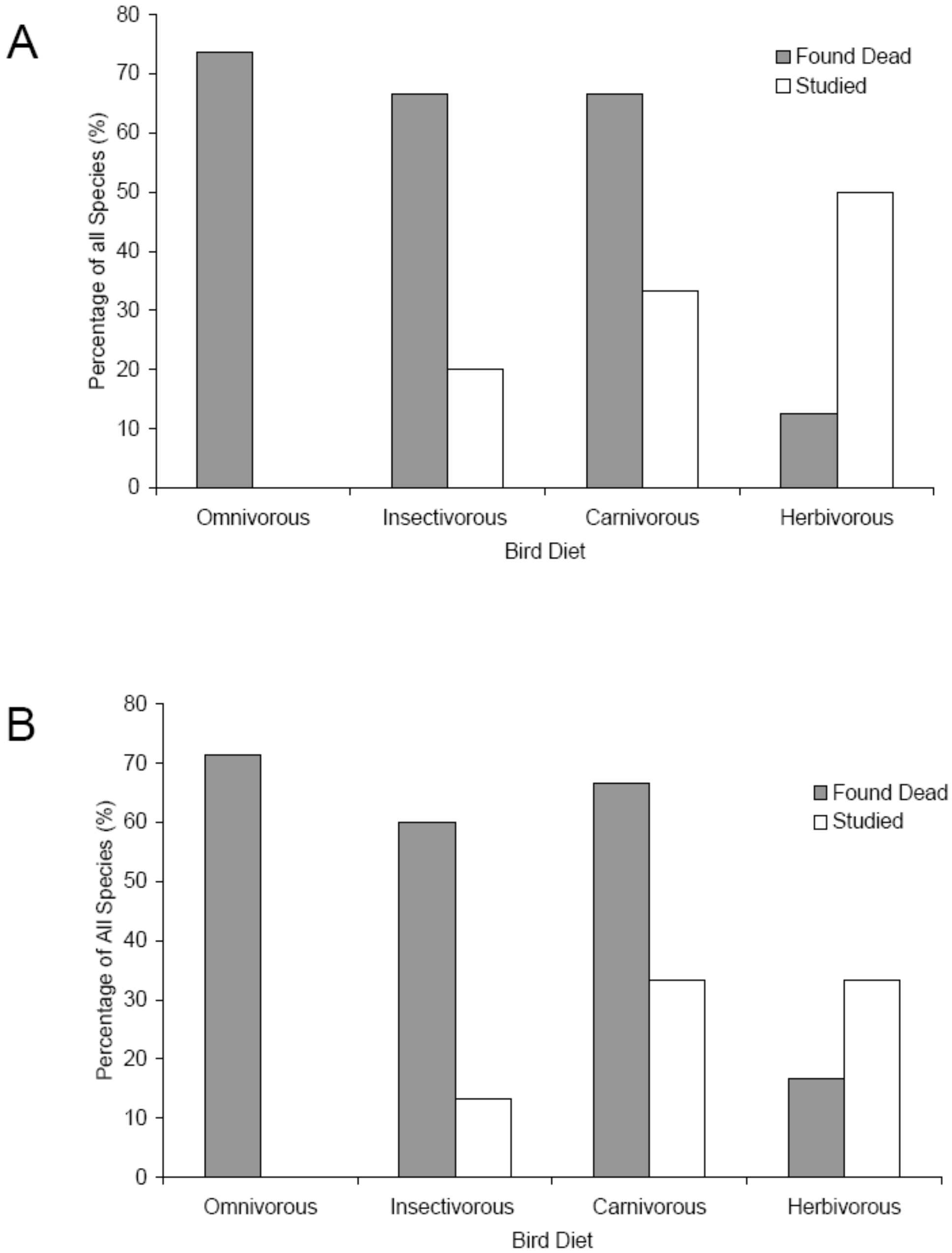

Figure 2: A comparison between the bird species reported dead after poison operations, and the number of bird species subject to population studies after poison operations, for species categorized according to their feeding tendencies. Top chart (panel A) shows North-Island specific species, while bottom chart (panel B) shows South-Island specific species.

Remarkably, in the peer-reviewed scientific literature only one report, which only partially mentions the effects of poison operations on an omnivorous bird species (the weka) could be found[38]. In this report by Empson and Miskelly 1999, 70% of weka consumed non-toxic bates in an initial trial operation, substantiating the potential for large culls of weka in aerial poison operations using cereal pellets. In media news reports, 7 out of 17 DoC radio-transmitter tagged kea were found dead after a 1080 operation at Fox Glacier in 2008[41, 42], and more recently, 7 of 9 kea in the Okarito region were poisoned in an aerial 1080 drop[43]. However, no peer-reviewed scientific report has been released regarding the effect of poison operations on kea. The kea is an endangered alpine parrot, endemic to New Zealand, with a total population as low as 1000-5000 birds[44-46]. The kea was listed by Spurr 1979 among birds with a low chance of recovery if their populations were affected by poison operations[11]. Remarkably, this information seems to have not deterred aerial 1080 operations in kea territory, with massive (greater than 10,000 ha) drops occurring/planed for Sept 2009-Sept 2010 in Fiordland, Arthur's Pass, and the West Coast Regions of New Zealand, which are prime kea habitats (please see **Table 1**). This has the potential to bring the kea to extinction.

Of the insectivorous birds, only the populations of tomtit[24, 32, 33], North Island robin[26], New Zealand robin[25, 38], and saddlebacks[27] have been officially studied before and after 1080 or brodifacoum poison operations by radio-transmitter, colour banding, or mark recapture analysis. This represents an account of only 13% (South island specific) and 20% (North island specific) of all insectivorous species present. Moreover, large drops in populations of these birds have been noted after aerial poison operations. Tomtit populations have dropped as much as 79% after 1080 poison operations[24]. North Island robin populations have dropped 55%[26], New Zealand robin populations have been observed to drop between 11%[25] to 95%[38], and the probability of a saddleback dying in a brodifacoum aerial operation was determined to be 45% (in a range between 33-56%)[27]. This peer reviewed and published scientific evidence does not forecast promising outcomes for the remaining insectivorous species, which represent a large number of species (see **Figure 1** and **Table 4**). Of the carnivorous birds (Harrier, New Zealand Falcon, and Morepork), only the response of the morepork to aerial brodifacoum has been officially studied, with results indicating that a mortality as high as 50% of the population may be expected in the weeks following poison operations[28, 38].

The picture that emerges from the above discussion is that scientists have predominantly studied the least likely group of birds to be affected by poison drops (nectar, fruit, and foliage feeders) and on the platform of the relatively favourable outcome of these investigations, have apparently ignored the detrimental evidence (or even chosen not to study) species at highest risk with omnivorous, insectivorous, and carnivorous feeding tendencies. **Figure 2 A** and **B** illustrate this tendency by showing the percentage of omnivorous, insectivorous, carnivorous, and herbivorous bird species found dead after poison operations, in comparison to the percentage of bird species studied from the same categories. The safety of aerial poison operations cannot be based on the fate of a small number of herbivorous species, while ignoring the evidence of insectivorous, omnivorous, and carnivorous bird deaths reported after poison operations; the existing studies on insectivorous birds reporting high mortality; and failing to study population effects in the majority of omnivorous and insectivorous bird species when each of these factors supports the common sense hypothesis that feeding tendencies put certain bird species at high risk of poisoning. The minimal existing literature reports[6, 24-29, 32, 33] indicate that poison operations have the potential to decimate (50% mortality or greater) populations of omnivorous, insectivorous, and carnivorous birds, which represent the majority of species in New Zealand ecosystems.

Veltman and Westbrooke's 2011 study corroborates the general problem with the existing body of research by noting that 42% of the bird species that have been the subjects of mark-recapture studies before and after aerial 1080 have never been reported dead after aerial 1080 operations[47]. According to Veltman and Westbrook, only 13 species in total, and of these only 8 out of the 19 species reported dead after aerial 1080 operations, have been the subject of proper mark-recapture studies[47]. Veltman and Westbrook also note that many of the studies suffer from very low sample numbers, short-term duration of only up to 3 weeks after the poison drop, and lack of a control making it impossible to assess background death rates for birds in untreated regions[47].

Unsupported Statements as Justification for Continued Aerial 1080 Operations

Eye-witness reports from people living in rural areas, and presumably directly able to witness the effects of 1080, describe the state of the ecosystem after an aerial poison drop as: *"There was just silence. It was as if the bush had gone into a state of shock. The dawn chorus should have been in full swing but there wasn't even a fly buzzing. We all saw 1080 pellets in the streams and dead animals on the tracks; the only noises we could hear were trees creaking in the wind. Weka disappeared from the bay that day and it was eight years before they returned."* (Steve McCellan after 1995 Marlborough Sound aerial 1080 operation[48]) and: *"It's so quiet. You normally hear the birds but there is nothing. There is very little bird life at all. It's silent in the Mamakus at the moment. You can smell the rotting carcasses before you get anywhere near them."* (Robin Fredricksen after Mamaku Forest 1080 poison aerial drop[49]).

Presumably in response to these eye-witness reports the DoC states[1]: *"The silence of our native forests is a legacy of the introductions [of pest species] and the increasing silence will continue unless we reverse the onslaught of pests on a massive scale.[1]"* This statement is completely uncorroborated by any scientific evidence, nor any scientific reasoning, and remains as unfounded and un-scientific as the eye-witness reports after poison operations.

In addition, the DoC claim that more recent aerial poison operations pose a lower risk to birds as:[1] *"carrot baits must be dyed green and the addition of cinnamon flavour deters birds".* However, a peer-reviewed and published study by Spurr 1993, showed only 1 species (the Antipodes Island Parakeet) out of the 6 studied (weka, kaka, red-crowned parakeet, Antipodes Island Parakeet, saddleback, and kokako) actually preferred unflavoured baits to cinnamon, indicating no effect of cinnamon as a bird deterrent[31]. Further evidence by Empson and Miskelly 1999 showed no preference of birds studied (weka, kiwi, robin, or saddle back) of green-dyed vs. red dyed baits[38]. DoC also claims that the reduction of chaff in carrot baits, and the use of cereal baits, leads to a decrease in tomtit mortality, as was noted in two scientific reports[32, 33]. However, Lloyd and McQueen 2000 collected various living invertebrates from baits after an aerial 1080 operation[6]. Measurements of 1080 concentrations in the invertebrates were compared with the known toxicity of 1080 on insectivorous birds, as well as their diet and food consumption rates. Results indicated that small birds such as tomtits can receive lethal doses from as little as 1.32 g of insects or 14.7% of its daily food intake[6]. Most insectivorous bird species considered could receive lethal doses by consuming less than 30% of their daily insect food ration[6]. Moreover, the risk remains high for at least 21 days after the poison drop. Whether or not the chaff in bait is reduced does not matter if secondary transmission is possible through invertebrates. Lloyd and McQueen 2000 explicitly state[6]: *"It should not be assumed that populations of insectivorous species are safe from poisoning during 1080 operations, nor should it be assumed that any mortality of insectivores observed after 1080 operations in a result of primary poisoning caused by bait fragments."*

Single Factor and Limited-Scope Investigations

An ecosystem is a complex system with hierarchical structure and many individuals from a number of different species engaging in relevant interactions and interdependencies. On account of this intricate complexity, invasive species removal from ecosystems can result in unexpected and undesirable outcomes[50]. An obvious inadvertent impact is an excessive poisoning of non-target organisms; however, other equally detrimental yet totally unexpected outcomes are possible after an invasive-species removal operation that appears 'successful'. For example, the removal of rabbits from Macquarie Island lead to major increases in cover by a native tussock grass, the preferred habitat for rats, which ultimately threatened burrow-nesting bird colonies on the island from rat predation[50].

In New Zealand, undesirable ecosystem-level effects have already been observed from possum and rat removal after 1080 operations[16, 51]. One example is stoat prey-switching from rats to birds after aerial 1080 operations, as reported by Murphy and Bradfield in 1992[51]. Before the poison operation, rats were the main component of stoat diet (rats 74%, birds 3%). The poison operation lead to a marked decrease in rats, resulting in stoats switching to birds as a major component of their diet (birds 39%)[51]. In 2007 Sweetapple and Nugent have shown that rat populations can recover from greater than 90% kill rates to increase up to 5 times their original populations for up to 6 years after an aerial 1080 operation[16]. As rats are major predators of many of New Zealand's endemic bird species a bloom in rat population is a significant drawback to bird population recovery after 1080 operations.

Other unexpected and possibly undesirable consequences may also occur. For instance, Dungan *et al* 2002 have determined that possums serve an ecologically beneficial role as seed dispersal vectors for large seed natives[52]. In some areas, possums may be the only remaining large seed dispersal vector due to decreases in populations of large-gaped birds[52]. Also, the diet of possums in specific areas consists primarily of invasive exotics such as elderberry (Sambucus nigra)[52] and therefore an eradication of possums from these areas carries the risk of further invasion and competition of these exotics with native flora[50].

Due to the complexities of ecosystem dynamics, experts recommend that the estimation of non-target effects, and of unexpected effects of eradication at an ecosystem level, can be handled using analysis and modelling methodologies such as ecosystems network analysis of food webs[50]. Ecosystem/ecological network analysis (ENA) has been recommended as an essential step to tackle the difficult assessment of the health of an ecosystem [50, 53, 54]. Ecological network analysis has not been conducted on any of New Zealand's ecosystems in the context of assessing the costs and benefits of aerial 1080 populations versus unchecked possum populations. As mentioned previously, the study of only a very few, isolated bird species has been completed (**Table 4** lists 58 relevant bird species and identifies those that have been the subject of actual population studies). With the exception of Innes and Barker's 1999 preparation of a non-species specific, non-numerical, visual food web diagram[10], no ecological modelling of any sort has been performed to examine the potential outcomes of poison operations from both species and ecosystem-wide contexts. This has apparently not been completed due to the existing gaps in knowledge and the daunting complexity of the task[10], although aerial poison operations remain widespread throughout New Zealand.

The consequences of species eradication is known to have unexpected and undesirable outcomes[50, 51]. Ecological models capable of handling at least some degree of the intricate complexities of New Zealand ecosystems are required to adequately evaluate the true risk of poison operations at both species and ecosystem scales.

Potential for Bias

A large, comprehensive literature search for peer-reviewed scientific investigations into the effects of aerial poison operations on non-target fauna was conducted by the author (March of 2010), retrieving 28 individual reports. To the best of the author's knowledge, these represent a full coverage of the scientific literature on the subject. The details of these 28 reports are summarized in **Table 3**. Remarkably, the scientific reports discussing the evidence of the relative safety of 1080 aerial drops are almost entirely (68 % or 19/28) conducted by scientists employed by DoC or AHB or by scientists receiving primary funding from the DoC or AHB (see **Table 3**). Moreover, only 10% (3/28) have been published in international journals, with the vast majority (75% or 21/28) published in the New Zealand Journal of Ecology. This reflects the high potential for bias from scientists as they are receiving funding from, or are directly employed by, the two main advocating agencies for aerial poison operations. An independent, preferably international scientific review of aerial poison operations in New Zealand is urgently required.

Continued Use of Bad Methodologies

Reports conducted by the DoC that have not been subject to an external peer-review and have not been published in academic journals[14, 15] as well as some reports in the New Zealand Journal of Ecology[38, 55], place total or heavy reliance on 5-minute bird counts or calls, or other non-marked methods of estimating bird abundance. These methods typically state no confidence intervals, and even among the bird species studied in the reports, can be seen to give highly variable data that is often selectively interpreted by the authors. These unmarked counting and calling methods have been criticized by Powlesland *et al* 1999 and Armstrong 2001 for yielding highly variable and nonsensical results[25, 26]. Armstrong 2001 notes that data derived from bird or call counts cannot be analysed to separate changes in abundance from changes in detection, due to the fact that bird behaviour is affected by the presence of a human observer[25]. Detection rates can vary depending on the weather, human observer, and unknown bird behavioural patterns[25, 26]. As a consequence of the unreliability of counting and call methods, radio-transmitter tagging, colour banding, and mark-recapture analysis have been deemed essential to determine population-scale effects of poison operations[25, 27, 34].

	Aerial poison drop:		Unchecked possum population:	
	Costs	Benefits	Costs	Benefits
Direct effects on flora	None.	None.	A Highly likely 50-72% decrease in preferred trees[51, 52, 56, 71, 72] over 20 year period. Score -81.	None.
Indirect effects on flora	B Likely loss of possums as seed dispersal vectors[48]. Score -16 .	C Highly likely slow, temporary increase in preferred trees with possum population control[54, 73, 74]. Score + 54.	D Highly likely suppression of fruit production of certain trees[55]. Score -9.	E (i) Increases in species not eaten by possums[51, 52]. Score +18. F (i) In some regions possums heavily contribute to seed-dispersal [48]. Score +16 .
Direct effects on fauna	G Highly likely massive (up to 79%) population loss of insectivorous bird species in time period of one drop (1-2 months)[6, 22, 23, 25, 68]. Score -144 (counting natives only) H Highly likely massive (may be total eradication) of populations of native omnivorous bird species in time period of one drop (1-2 months)[9, 27, 35]. Score -36 (counting natives only) I Likely impact (highly likely with anti-coagulants) of moderate population loss (50 %) to carnivorous birds in time period of one drop (1-3 months)[26]: Score -12. J Likely small non-target effects of up to 20% loss of other non-target birds: kaka[9], kiwi[32, 33]. Score -4. K Risk of sub-toxic, chronic endocrine disruption possibly affecting reproduction[8]. Score -51	L Loss of invasive mammalian pests species: decrease in possum population of 90-95% for up to 4 years; decrease in rat population by 90-100% for up to 5 months; possible decrease in mustelid population; decrease in other pests: deer, goats, rabbits. Score +50.	Essentially none. Possum's diet consists of less than 0.5 % bird or bird egg[51, 56].	Unknown.
Indirect effects on fauna	M Stoat prey switching from rats to birds after 1080 operation with approximately 30% increased predation of birds[47, 66]. Score -20.	N Likely benefits to honeyeater, herbivorous birds, and Kiwi due to decreased competition from possums and predation from other targeted mammals [37]. Score +63.	O Highly likely competition and decrease in population of honeyeater and herbivorous birds[51]. Score -54.	Unknown.
TOTAL	-283	+147	-144	+34

Table 5: A score-based, cost-benefit analysis comparing the impacts of aerial poison operations to unchecked possum populations at peak density. Scores take into account the likelihood of the event occurring, the number of species affected, and the degree of impact on native species populations. Letters (A, B, C…) index the various scored events. From this cost-benefit analysis aerial poison operations have ~2x more costs than benefits and are ~2x more costly than unchecked possum populations at peak densities.

Effect	Likelihood	Species Affected	Pop. Impact	Cost (-1) or Benefit (+1)?	Score
A	3 (well demonstrated[55-58])	9 (N rata, S rata, kamahi, fuchsia, pate, haumakaroa, tawa, mamuku, mistletoe)	3	-1	-81
B	2 (possum contribution to seed rain[52])	4 (mahoe, makomako, ngaio tree, elderberry)	2	-1	-16
C	3 (recovery not well demonstrated, but evidence highly suggests[57, 59])	9 (N rata, S rata, kamahi, fuchsia, pate, haumakaroa, tawa, mamuku, mistletoe)	2	+1	54
D	3 (1 report, and evidence highly suggests[60])	1 (hinau)	3	-1	-9
E	3 (well demonstrated[55, 56])	6 (pukatea, tree fern, silver tree fern, hinau, pigeonwood, mahoe)	1	+1	18
F	2 (possum contribution to seed rain[52])	4 (mahoe, makomako, ngaio tree, elderberry)	2	+1	16
G	3 (secondary poisoning of insects high risk[6, 61], sig pop effects to tomtits[24], saddlebacks[27], robins[26, 38])	16 (all native insectivorous birds, excluding kiwi, see Table 3)	3	-1	-144
H	3 (population effects not yet investigated, reports of extensive deaths[11, 38, 41, 42])	4 (native omnivores kea, weka, pukeko, silvereye)	3	-36	-36
I	3 (reports of morepork population effect[28], reports of deaths[11, 38])	2 (harrier, morepork)	2	-12	-12
J	2 (reports of low population effect[35, 36], reports of death[11])	2 (kaka, kiwi)	1	-4	-4
2K	1 (not yet investigated, but evidence highly suggests low dose 1080 endocrine disruption[8])	51 (affecting all bird species susceptible to primary or secondary poisoning, insectivores, omnivores, carnivores)	1	-51	-51
L	3 (1 for stoats)	5 (possums, stoats, rabbits, deer, goats)	3 (2 for stoats)	+50	50
M	2	10 (likeliest stoat prey species: kaka, tui, hihi, kakapo, keruru, kokako and kiwi, plus 3 unknowns)	1	-20	-20
N	3 (not well demonstrated, but evidence suggests[37])	7 (kaka, tui, hihi, kakapo, keruru, kokako and kiwi)	3	+63	63
O	3 (not well demonstrated, but evidence suggests)	6 (foliage, fruit and flower dependent: tui, hihi, kakapo, kaka, keruru, kokako)	3	-54	-54

Table 6: Breakdown of scoring calculations for the letter-indexed events listed in Table 5. Events are scored according to equation [1] and are negative if a cost (contribute to loss of native populations) and positive if a benefit (contribute to gains in native populations). Relevant literature contributing to a decision is directly referenced in the table. Please refer to the text for a detailed description of the scoring scheme.

IV. COST-BENEFIT ASSESSMENT

The most comprehensive (and most likely the only) peer-reviewed manuscript that proposes to assess the costs and benefits of aerial 1080 operations was completed by Innes and Barker in 1999(10). This review paper openly discusses the lack of knowledge as to the actual impacts of aerial 1080 drops on non-target populations and advocates the use of food webs in order to manage the multiple factors that must be appreciated to obtain a comprehensive understanding of the situation(10). However, in spite of its promising vision, this article suffers from many of the same serious issues of selective interpretation of the evidence and non-scientific claims as discussed previously, drawing the unfounded conclusion that:(10) *"we suggest that large-scale use of toxins continues in New Zealand despite these large knowledge gaps because research consistently suggests that the harmful effects of pest mammals are overwhelmingly greater than those of the toxins used."* This statement is powerful as it comes from a scientific manuscript that has been peer-reviewed and published in a credible journal, and its conclusions have been trusted (and referenced(1, 50)) by other scientists and presumably non-scientists such as government officials and the general public. It may be a key statement encouraging the continuity of aerial poison operations in New Zealand. It is therefore very important that the basis for this statement as it is used in Innes and Barker's 1999 manuscript(10) be carefully reviewed.

Let us first note that this statement comes without any supporting references. Furthermore, if the material presented in the Innes and Barker manuscript is examined, no substantiation for this immensely important statement is available(10). There is no discussion of Spurr's 1979 list of birds(11) (including the kea) indicated at high risk of non-recovery if their populations were decimated by poison operations, for which the effects of 1080 operations had remained (and still remain) largely undetermined at the time of the Innes and Barker 1999 paper(10). There is discussion of only 1 paper studying primary bird mortality (Powlesland and colleague's 1999 examination of North Island Robin populations), while ignoring the issue that at the time Innes and Barker wrote their paper (1999), Powlesland and colleague's 1999 study with North Island robins was one of the only population-based studies of insectivorous birds available, thus exposing the lack of studies investigating the effect of aerial poison operations on a large number of New Zealand's omnivorous, insectivorous and carnivorous bird species. The potential for secondary poisoning of insectivorous birds, as determined by Lloyd and McQueen 2001(6), was presumably not evaluated or discussed in the Innes and Barker manuscript as this important information was released only after the time of the Innes and Barker 1999 publication. The issue of nonsensical data derived from the widely used 5-minute bird counts and roll-calls was not discussed(10). Granted, the authors do admit that:(10) *"however, most attempts to quantify impacts on non-target species level are very simplistic and short term"*, which seems to reinforce the general absence of hard facts that exist with respect to the effect of poison drops on the majority of New Zealand bird species.

While failing to discuss (or being unable to discuss due to lack of information) the potential ramifications of 1080 aerial drops on non-target species in any comprehensive way, Innes and Barker also do not discuss the effects of unchecked possums on New Zealand's ecosystems. They simply imply, as do other articles on the subject(1, 22), that possums are quite simply a devastating force that is far more destructive than any possible effects of 1080 aerial drops. Yet, what does the existing literature indicate about the specific effects of possums on New Zealand's forest ecosystems? There is substantial evidence from more than thirty years of scientific research to show that brushtail possums change the composition of New Zealand's forests by eating preferred foods (primarily the native trees North and South island rata, kamahi, fuchsia, totara, pate, haumakaroa, tawa), decreasing populations of these species by 40-74% over 10-20 years(55, 56, 58). Possums also posit browsing pressure on some of New Zealand's native mistletoe species(57). High possum populations also suppress fruit production in native trees(60). There is therefore expected to be ensuing competition with some of New Zealand's native herbivorous birds (tui, hihi, kaka, kakapo, keruru, kokako) for fruit, foliage, and flowers/nectar. While preferred flora decline, other species not heavily browsed by possums increase (pukatea, hinau, pigeonwood, mahoe, tree ferns), thus leading to an overall change in the composition of forests with overall loss in biodiversity with possum occupation(55, 56). However, possum populations do not grow indefinitely, but appear to reach a peak at about twenty years, after which population decreases (to about ½ the peak population) by 30 years, where some recovery of preferred forest species is evident(55). While possums have been listed as preying upon birds and bird eggs(10), their diets have been found to consist of only trace amounts (less than 0.5%) bird or bird eggs, and to consist primarily (90%) of foliage(55, 62). Thus, population effects on birds from predation by possums may be considered negligible. Possums may also have positive roles in increasing biodiversity, as they have been shown to contribute significantly to total seed rain and to be among the only remaining seed-dispersal agents for large seeded natives in some areas where populations of large-gaped birds that previously played this role have heavily declined(52). In short, while invasive possums cause damage to certain New Zealand forest ecosystems, they do not represent an all powerful force capable of mass destruction through limitless appetites and unbounded population increases.

The most distinctly non-relevant and obvious persuasion of the reader's perception is Innes and Barker's apparent inclusion of a comparison table between the effects of 1080 aerial drops versus the effects of possums, in which they consider possums to be an applied toxin (called POS_2UM)(10). This 'comparison' between an aerial 1080 operation and the metaphorical POS_2UM 'toxin', is presumably where they base their important conclusions that possums are more detrimental than 1080 drops. One would expect that this comparison would detail some actual ecological costs and benefits of each scenario (i.e. the costs and benefits of aerial 1080 applications versus unchecked possum populations on native species populations). However, remarkably, the comparison does not indicate any species targeted by each 'toxin', the extent to which these species are affected, or the ecological impacts of the drop for these species. Instead, the comparison simply lists the "first use" of 1080 and possums; the degree of physical coverage of New Zealand; the persistence of the 'toxin'; the target selectivity of the 'toxin' (where in an unsupported statement 1080 is said to be selective for target species only, while possums are not); the hierarchical level of impact of the 'toxin' (where in a completely unsupported statement 1080 is said to be selective for individuals while possums effect the entire ecosystem); and whether or not the 'toxin' is humane (where in another completely unsupported statement, aerial 1080 is distinguished as humane, where possums are called inhumane)[10]. Innes and Baker's 1999 review clearly does not construct a comprehensive 'cost-benefit' analysis assessing the potential impacts of aerial poison operations versus unchecked possum populations.

A basic but comprehensive cost-benefit analysis that makes use of the existing scientific literature to compare the costs and benefits of aerial poison operations (1080 and brodifacoum) against the costs and benefits of entirely unmanaged possum populations at peak population densities (presumably at a 20 year occupation point) on native species populations/native biodiversity using a numerical scoring system is summarized in **Table 5**. The impacts are divided into direct and indirect impacts on flora and fauna. Direct influences are those which result in an immediate loss of population from a species. For possums, this represents feeding on members of the species. For poison, this represents a kill of members of the species. Indirect influences represent the consequences of these direct effects, and include recovery of possum-damaged forest, or prey switching of stoats to birds after poison operations. This cost-benefit analysis considers native species populations and total native species biodiversity as factors indicative of New Zealand's ecosystem health. A 'cost' is defined as a decrease in native species population/native species number, while a 'benefit' is defined as an increase in native species population/number or a decrease in exotic mammalian species population/number.

This cost-benefit analysis makes use of a numerical scoring system to assess the relative impact of the cost/benefit. The value of a cost/benefit was estimated according to the formula:

Score=(Likelihood)x(Number of Species Affected)x(Population Impact) [1]

'Likelihood' assesses the general probability that this event occurs, and is based upon the available literature reports and basic reasoning. Likelihood was graded as 3 (highly likely), 2 (likely), and 1 (somewhat likely). 'Number of Species Affected' represents the species implicated in the event. The 'Population Impact' represents the likely change in population and is graded as 3 (change exceeding 50%), 2 (change 20-50%), and 1 (change 5-20%). The scored events of the cost-benefit analysis of **Table 5** are indicated by letters, and the breakdown and justification for these individual event scores are listed in **Table 6**. This scoring system allows for a coarse estimate of potential costs and benefits to native species in New Zealand forest ecosystems. Keep in mind that this cost-benefit analysis considers impacts only to native bird species, and therefore, the large numbers of exotics which may play beneficial roles in New Zealand's ecosystems, and may be adversely affected by aerial poison drops, were not counted in the cost-benefit analysis.

The outcome of this cost-benefit analysis (**Table 5**) implies that there are approximately 2x more costs (poison cost score -283) than benefits (poison benefit score +147) associated with aerial poison operations to native species populations and diversity in New Zealand. Moreover, this cost-benefit analysis indicates that aerial poison operations are approximately 2x more costly (poison cost score -283) to New Zealand natives than unchecked possum populations at their peak density (possum cost score -144). Note that it is important to realize that the cost-benefit analysis does imply that the benefits of aerial poison operations (poison benefit score +147) are high enough to suggest that they mitigate the costs of unchecked possum populations (possum cost score -144); however in spite of this, poison operations have an enormous potential for costs (poison cost score -283) to New Zealand natives through their high potential for non-target effects to a large number of bird species. The cost-benefit analysis suggests that the costs to native species associated with unchecked possum populations (possum cost score -144) are substantially higher than any potential benefits of possums (possum benefit score +34) and therefore, measures should still be taken to control possum populations to prevent losses to native trees and herbivorous bird species. As the costs associated with aerial poison operations as a method of accomplishing possum population control greatly outweigh the benefits of this method, an immediate moratorium should be placed on aerial poison operations. Alternative methods for possum (and other mammalian pest control) such as the use of poison in baited traps specially designed to target the mammalian pest and not birds, and human hunting/trapping of mammalian predators, should see continued and possible expanded use. Notably, possums represent a resource due to their fur(63), which represents a $80-200 million NZD dollar market, annually(64).

This cost-benefit analysis considers native species populations, and total native species biodiversity, as factors indicative of the health of New Zealand ecosystems. This remains a rather coarse view of ecosystem health, as other indicators such as stability, productivity, and organization are additional properties used to discern ecosystem health(65). A more realistic assessment of the impacts of aerial poison operations and invasive pests in New Zealand ecosystems would need to include a systems model or ecosystem network analysis(53, 54). In a subsequent publication, such functional food-web models will be created and used to provide some meaningful evaluation of the effects of aerial poison drops versus unchecked possum populations in specific New Zealand ecosystems. At present, the urgency of the situation is high as New Zealand is continuing with large-scale poison operations which may be equivalent to ecocide of its remaining indigenous wilderness areas. It is immensely urgent to expose the flimsy degree of scientific evidence used to justify these aerial poison operations and bring to light the substantial evidence that aerial 1080 poison drops do appear to have significant effects on non-target species, while the effects of completely unchecked possum populations may not be the massively destructive force to New Zealand's ecosystems that they are widely reputed to be.

V. POSSUMS & BOVINE TUBERCULOSIS

Is the sustained use of aerial poison drops actually based in economical issues and reasoning?

Dairy production in New Zealand is a major industry, and the New Zealand economy relies heavily on revenue from dairy exports. New Zealand currently produces approximately 2% of the world's dairy and is the largest exporter of milk and milk products. In 2009 dairy exports brought in $11 billion (NZD) to the economy, which is roughly 6% of New Zealand's GDP(66).

Tuberculosis (Tb) in dairy cattle has been a longstanding international issue, which has been more or less eradicated in the cattle herds of many developed countries. For a country to be classified as Tb-free, their herds must have infection incidences of 0.2% or less for 3 consecutive years. The standards of many of New Zealand's key trading partners are gearing towards importation of only Tb-free dairy. Since 1990 the European Union has discussed the imposition of restrictions against the importation of dairy products from countries that are not Tb-free. Moreover, most of New Zealand's major trading partners (Australia, US, most Western European and South East Asian countries) are already classified as Tb-free. New Zealand remains unable to export live animals to Tb-free countries due to its Tb status[1].

New Zealand has long struggled with bovine Tuberculosis (Tb) infections in its cattle herds. Despite nationwide Tb eradication programs since 1970 in cattle herds, New Zealand's Tb infection rates remained at 3% in 1999 – well above the 0.2% maximum infection rate required to classify it as a Tb-free country. In the late 1980's, possums living at or near pasture margins with forest were identified as the largest population of wild animals that served as reservoirs and vectors of Tb to New Zealand's herds[12, 13, 67]. With intensified possum control operations, including aerial 1080 use, the rates of Tb infection in cattle were reduced to 0.5 % by 2006[1]. However, to be considered a Tb-free country, New Zealand's herds must test at 0.2% for 3 years. Therefore, to prevent any possible losses due to international perception of the New Zealand dairy industry, losses which have been estimated as a possible $ 500 million dollars per year over ten years[1], New Zealand proposed to increase the use of aerial 1080 operations from 2006 to 2015. This increase in aerial 1080 operations is presumably an attempt to eradicate all possum populations that risk sustaining and re-infecting cattle with Tb, in order to grant New Zealand a Tb-free status by 2015[1]. It therefore appears that New Zealand's willingness to proceed with extensive and massive aerial poison operations, in spite of a lack of scientific evidence of the effects to non-target bird populations and at an ecosystem level, is to increase profits and mitigate potential losses to its largest agricultural industry.

However, this kind of ecological risk taking is completely unnecessary as all other major countries in North America and Europe have achieved a Tb-free status without resorting to killing off all of their indigenous wildlife, which may also act as Tb-vectors. This demonstrates herd-management practices are certainly effective enough on their own to eliminate Tb infections. Furthermore, while possums have been identified as the main factor, there is evidence to indicate that sheep can also carry bovine Tb[68, 69]. Sheep are currently not included in any testing program in New Zealand.

Even from an economic perspective, aerial poison operations are not likely to be a viable strategy. New Zealand's tourism industry is larger than its dairy industry, bringing in $15 billion NZD in 2009 (9% of GDP) and boasting an 'export market' value (tourist dollars) of $9 billion in 2009. New Zealand extensively markets itself to tourists as a "clean, green" country, and is actually heavily reliant on the international perception of being an environmentally friendly nation. A government report entitled: "Our Clean, Green Image: What's it Worth" reports on a survey in which tourists from New Zealand's top five visiting nations (Australia, Korea, the US, UK, and Japan) were shown photographs of environmentally devastated regions of New Zealand and asked how a change in perception of New Zealand as a "clean, green" nation would change their visiting habits[70]. The results of the survey indicated tourist loses of 45-79% from these five nations, at an estimated annual loss of $ 530-938 million[70]. This potential loss from the affected international image of New Zealand is equal to, or as much as two times higher than, the projected losses from New Zealand's Tb status and the dairy industry[1]. In the governmental report, aspects of New Zealand that were identified as major areas of concern were poor and deteriorating air quality, erosion, degraded fresh water due to extensive agriculture, and degraded marine environments[70].

Yet how does the notion of an annual distribution of more than 1 million kg of food laced with enough poison to kill 15 million human sized-creatures into forest ecosystems, which may be killing extensive numbers of birds, some endangered and endemic, and has not been comprehensibly studied by scientists, sit with international tourists who have believed in and are attracted to New Zealand's "clean, green" image? It's possible that New Zealand will succeed in improving one of its most important industries (dairy), only to damage another of its most important industries (tourism and foreign consumers) by tarnishing its international environmentally friendly image with extensive aerial poison operations. However, there is a lot more than image and perception at stake here. Many species of bird, some rare and endemic, and therefore the status of whole ecosystems, are at risk from the extensive aerial poison operations that New Zealand is perusing.

VI. CONCLUSIONS

New Zealand is currently practicing widespread aerial distribution of large quantities of acutely toxic foodstuffs into its forest ecosystems as a possum control tactic. Annually, approximately 4000 km^2 of land is subject to aerial poison operations, primarily involving the application of ~1.4 million kg of cereal-pellets laced with over 2000 kg of pure 1080 toxin – enough to kill a biomass of 15 million 70 kg humans. Aerial poison drops are advocated, funded, and scientifically studied by two main groups: the DoC and the AHB. These agencies claim that the benefits of aerial poison operations greatly outweigh their risks.

Aerial poison operations and the toxin 1080 have been misrepresented in government documents and other information intended for the general public, cultivating an image of the safety and efficacy of aerial poison operations in dealing with mammalian pests. Compound 1080 has been openly represented as an agent specifically targeting mammals, when it is highly toxic to most avian species as well. The majority of scientific investigations are performed by scientists receiving funding, or directly employed by the two advocating agencies (DoC and AHB). Moreover, the existing scientific evidence on non-target effects of aerial poison operations has been selectively interpreted and left grossly incomplete in its scope, while poison operations remain widespread. It is indicated that the risk of non-target poisoning to nectar, fruit, and foliage eating birds is indeed minimal (0-20% mortality) and that these birds are most likely to benefit from possum reduction due to decreased competition for food. However, the safety of poison operations for this small group of 6 bird species does not indicate the overall safety of poison operations for the remaining 24 omnivorous, insectivorous, and carnivorous natives. In contrast, existing evidence indicates high mortality for omnivorous, insectivorous, and carnivorous bird species after aerial poison operations[6, 24-29, 32, 33].

In a numerically scored, cost-benefit analysis that takes into account all available scientific information, aerial poison operations are indicated to have twice as many costs to native species than benefits, and two times more costs than uncontrolled possum populations at peak density.

This further reinforces the potential for significant damage to New Zealand ecosystems from aerial poison operations and calls for their immediate stop.

A major incentive for aerial poison operations appears to be the near eradication of possums in order to acquire a Tb-free status for New Zealand's dairy herds by 2015, in order to mitigate a potential loss of $500 million per year from New Zealand's largest agricultural industry(1). This economic incentive may explain the continued widespread use of aerial poison operations, in spite of evidence indicating their capacity for harm. Evidence from existing Tb-free countries indicates Tb-free status can be achieved with herd-management strategies and without resorting to killing off all wild Tb-vectors. Moreover, New Zealand has not taken into account the potential impacts of aerial poison operations on the "clean green" image marketed to overseas tourists, which represent an industry and potential losses larger than those of dairy. However, there is a lot more than image and economy at risk as aerial poison operations threaten numerous species of endemic, threatened and endangered birds, and therefore place the status of whole ecosystems at risk.

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