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A 2022 Review of Sodium Fluoroacetate for Conservation and Protecting Endangered Species in New Zealand

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ABSTRACT: Sodium fluoroacetate (1080) is a vertebrate pesticide principally used to control unwanted introduced mammals in New Zealand and Australia. For 1080, over 260 publications during the last ten years supplement a body of scientific information regarding its mode of action, natural occurrence, toxicology, antidotes, metabolism, and fate in the environment. Multi-year studies have explored long-term outcomes for multiple native bird species. Numerous reviews on community attitudes stimulated by the Predator Free New Zealand (PFNZ) 2050 campaign conclude that 1080 use for conservation remains controversial. Further effort is needed to increase target specificity, avoid game species, and employ approaches with the highest public acceptance, including hunting, trapping, and species-specific toxins. Greater acceptance of the large-scale use of any pest control is likely when long-term goals and strategies for ecosystem recovery employ toxins as *one-off treatments* for eradicating pests versus continued applications.

KEY WORDS: 1080, conservation, endangered species, New Zealand, sodium fluoroacetate, vertebrate pesticide

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INTRODUCTION

There have been over 260 new publications on 1080 and pest control technology in scientific journals, book chapters, and books published since the last scientific review in 2011. Some of these publications are linked to New Zealand's (NZ) recent predator-free strategy to eradicate predators from mainland areas by 2050 (Owens 2017, DoC 2018, Ross et al.2020).

1080 bait has been used for decades in NZ to protect biodiversity and reduce the spread of bovine tuberculosis (Tb) to cattle (*Bos* spp.) and is a key tool (Hutchings et al. 2013, Byrom et al. 2016, van Vianen et al. 2018). Aerial distribution of 1080 baits is a globally-unique practice that is restricted to NZ and Australia (Doherty et al. 2022). It continues, despite sometimes fierce opposition from some sections of society (Hansford 2016), simply because aerial 1080 baiting is still considered to be the only practical and affordable approach to address the threats to conservation and agricultural production, particularly in inaccessible areas (PCE 2011, 2013; Warburton et al. 2021).

1080 – In Context

Several hundred peer-reviewed publications, including over twelve reviews, cover the period from 1940 to 2021 on all aspects of 1080. These publications span topics ranging from the experimental use of 1080 in radiology (Nishii et al. 2012) to its toxicology, environmental fate (Northcott et al. 2014, Liu et al. 2020), and the short- and long-term population responses in native species following 1080 bait applications for predator control (Byrom et al. 2016). 1080 was first applied in baits to rodents and other pests in the United States (Delfin-Alfonso et al. 2012, Ripple et al. 2013). It is the only poison registered for aerial control of possums (*Trichosurus vulpecula*) and rabbits (*Oryctolagus cuniculus*) in NZ, and the aerial application of this toxin is the most contentious (Green and Rohan 2012, Warburton et al. 2021). In Australia, aerial 1080 is used for the protection of native animals from introduced species, such as foxes (*Vulpes vulpes*) (Berry et al. 2012, Marlow et al. 2015), feral cats (*Felis catus*) (Algar et al. 2010), feral dogs (*Canis lupus familiaris*) (Allen et al. 2014), wild boar (*Sus scofra*) (Bengsen et al. 2011, 2014), and dingoes (*Canis familiaris dingo*) (Allen 2010, 2015).

Controlling pests using traps, hunting, and poisons, including 1080 baits, has enhanced and restored ecosystems and protected endangered native species on offshore islands, mainland NZ, and other islands globally (Byrom et al. 2016, Binny et al. 2020). However, any control tool will have unwanted side effects, and careful monitoring is essential to minimise non-target effects (Warburton et al. 2021). The risk to non-target bird and game species following aerial application of 1080 baits has been a continued cause of particular concern (Hansford 2009, 2016) since their early use in the 1950s and 1960s (Batcheler et al. 1967, Rammell and Fleming 1978) through to the present day.

Given the ongoing concerns around non-target species, this review focuses on two key issues. First is the risks for non-target native birds, and deer as an important game species. This section incorporates the recent research on the benefits of ongoing pest control for native bird species. Second, this review investigates the use of 1080 with the recent predator-free strategy for the NZ mainland and the Tiakina Ngā Manu (Protect the Birds) programme. This section also examines community attitudes and highlights current control tools with the highest social acceptance.

Non-target Species – Native Birds

Early non-target bird research focused on minimising the side effects of baiting strategies to what ecologists, but not necessarily the wider community, deemed acceptable collateral effects (Eason et al. 2011). In the 1990s, bait sowing application rates were significantly reduced and bait quality improved. As a direct result, pest species were still successfully targeted, and deaths have been reported in many fewer bird species since these initial changes were made (Schadewinkel et al. 2014, Morriss et al. 2016). While reassuring, considerable social concern remains about the vulnerability of native birds, particularly kea (Kemp et al. 2019) and non-target game animals (Pinney et al. 2020).

Previous research has struggled to quantify the temporal benefits of 1080 control mainly due to a lack of robust, multi-year studies (Veltman et al. 2014, Allen et al. 2023). Over the past decade, the most significant research shift has been advances in meta-analysis techniques using multi-year datasets (Table 1). Overall, these indicate significantly improved survival prospects for many endemic bird species, with benefits accumulating over time. The other key result is that these benefits are enhanced when aerial 1080 control simultaneously targets possums and rodents. While encouraging, Kemp et al.'s (2019) meta-analysis of nineteen aerial 1080 operations reported 24 kea deaths from 222 radio-tagged adult kea (~ 10% of their respective populations). This rate is higher than desired, even with 13 out of 19 aerial operations reporting no mortalities. Clearly, measures to further mitigate this must be found.

Kea Research

In direct response to concerns over kea deaths, a significant research effort has been undertaken over the past decade. This research has identified that colour (Weser and Ross 2013) (Cowan and Crowell 2017, Brunton-Martin et al. 2021) and combination of a primary (d-pulegone) with a secondary (anthraquinone) repellent are effective at repelling captive kea from baits (Orr-Walker et al. 2012, Clapperton et al. 2013). While promising, such techniques were not extended to the field due to concerns over bait stability (Crowell et al. 2016a) and potentially reduced consumption by the target species – being possums and rodents (*Rattus* sp.) (Clapperton et al. 2015, Crowell et al. 2016b).

To circumvent target species being deterred by kea repellents, thar (*Hemitragus jemlahicus*) carcasses were experimentally placed above the tree line to lure feeding kea to adjacent non-toxic possum baits containing the repellent anthraquinone. The objective was to train kea to avoid such baits before an upcoming 1080 control effort (Nichols et al. 2021). Further work is now investigating the use of kea-specific bait feeders to train kea at lower altitudes (Nichols et al. 2020). Whether these measures are effective or can be applied on a larger scale remains to be determined and is currently being investigated at several locations. Collecting long-term census data on kea numbers in areas where 1080 has been used, and in areas where there has been no predator, control, will also be critical to determining ongoing population trends, like that currently occurring at Kahurangi National Park, where kea nesting success has been monitored since 2009 (DoC 2021a).

Table 1. Key findings from multi-year bird studies.

Author	Bird Species	Number years	Key Findings
Robertson et al. 2019	North Island brown kiwi (NIBK)	22	100% survival for 142 monitored birds with improved prospects for kiwi (*Apteryx mantelli*) chick survival and NZ fantail (*Rhipidura fuliginosa*) nesting success in the first two breeding seasons following aerial application.
Robertson et al. 2016	NIBK	18	In the 1080 area - 62% chick survival compared with 20% in nearby trapped-only areas.
Veltman and Westbrooke 2011	Multiple	23	This analysis reported very low risk for kiwi, kaka, whio (*Hymenolaimus malacorhynchos*) and kokako (*Callaeas wilsoni*) with more risk for smaller birds when carrot baits were used. High kea mortality was observed in one operation at Franz Joseph.
Kemp et al. 2019 Fea et al. 2020	Multiple	41	Larger endemic species such as kaka and NZ pigeon (*Hemiphaga novaeseelandiae*) respond positively to predator management, and deeply endemic birds, especially cavity nesters, are most at risk of further decline without predator control.
Kemp et al. 2019	Kea	9	24 out of 222 individually marked kea (in 19 aerial 1080 operations) either disappeared or were found dead after aerial 1080 control.
Byrom et al. 2016	Multiple	25	Controlling both ship rats (*Rattus rattus*) and possums using 1080 increased bird populations.
Binny et al. 2020	Multiple	17	Deeply endemic bird species had the strongest population recovery responses to pest control compared with recent native or introduced biota.

Non-target Species – Deer

Possum bait containing 1080 can also kill non-target deer, with estimates ranging widely from 0 to >90% mortality (Pinney et al. 2020), but more commonly ranging from 30% to 60% (Morriss et al. 2020). Current best practice uses aerial 1080 at sowing rates of 2 kg/ha; however, rates have the potential to go even lower with cluster or strip sowing techniques. These still achieve good kills of possums and rats at sowing rates below 1 kg/ha, while halving toxin levels in the environment (Nugent et al. 2012, Nugent and Morriss 2013, Morgan et al. 2015). The continuing refinement of aerial sowing techniques could further reduce the risk for valued non-target game and native bird species.

Reducing deer by-kill is important for recreational and subsistence hunters when targeting possums. In recognition of this, the first deer repellent (Green Epro Deer Repellent; Epro Ltd, Taupo, NZ) was registered for use with 1080 bait in 2007. Early research using the Epro deer repellent indicated that repellent reduces poisoning risk for fallow deer (*Dama dama*) (Morriss and Nugent 2008), red deer (*Cervus elaphus*) (Morriss 2007) and, more recently, has been confirmed for sika deer (*Cervus nippon*) (Morriss and Nugent 2017) and white-tail deer (*Odocoileus virginianus borealis*) (Pinney et al. 2021). Two new suppliers (Orillion and Pest Control Research Ltd) have developed alternative repellent formulations over the past two years. This competition should help reduce the cost of using deer repellents and make these selective baits more readily available for routine possum control where game animals are a valued resource.

The Predator Free 2050 Goal and 1080 Use

New Zealand conservationists have eradicated all introduced mammals (predators and herbivores) from over 100 offshore islands (Towns et al. 2013). Still, in 50 years of pioneering and persistent effort, this has only increased the pest-free island area from 0.5% to just over 10% (Russell et al. 2015, Innes et al. 2019). Predator Free 2050 seeks to make NZ free of three introduced predators – possums, mustelids (ferrets, stoats, weasels) and rats, by 2050. The Government has since shown its support for this goal by investing over $300 million in Predator Free initiatives, which bolsters other funding from local governments, philanthropic organisations, and the time and effort invested by community groups (DoC 2021b).

An interim goal of PF2050 was to increase the area where pests are actively managed by one million hectares before the end of 2025. Several landscape-scale predator eradication projects have now been established across the country. At some sites, initial attempts at the local elimination of pests on a landscape scale have employed closely-timed, dual applications of aerial 1080 combined with multiple non-toxic prefeeds. Dual application of 1080 (using a similar bait type) completely removed all rats, but not all possums, in four 100-ha study blocks (Nugent et al. 2019). A dual application of 1080 (changing the bait type see: Nugent et al. 2020) combined with multiple prefeeds removed >99% of possums and rats (Nichols et al. 2021) from a 2,240-ha block in South Westland (ZIP 2017a). This study also evaluated the use of rivers as reinvasion barriers, which was successful for possums (Cook et al. 2021). Research teams are now considering aerial brodifacoum as the primary elimination tool for other large areas of the landscape. However, adopting such techniques on the NZ mainland would only have higher social acceptance if used as a *one-off treatment* at a defendable site (Cowan and Warburton 2011, Fisher et al. 2019). As such, the future use of aerial 1080 or brodifacoum as an ongoing tool for PF2050 will require the development of better barriers and detection tools to prevent pest reinvasion.

Community Attitudes

Aerial 1080 control on conservation land has increased with the Protect the Birds programme over the past decade. For example, DoC treated 174,000 ha with aerial 1080 in 2009. This compares with 694,000 ha in 2016 (Elliott and Kemp 2016), with control efforts directly related to the numbers of rats following beech and podocarp mast events (Kelly et al. 2013). Those against 1080 use have noted this increase in aerial operations, and there has been increasing resistance to pest control on public conservation land. Examples of this are a court injunction obtained in 2018 halting the proposed aerial 1080 operation in the Hunua Forest. This injunction was subsequently overturned in 2019, with the Environment Court awarding $40,000 in court costs to DoC and the Auckland Regional Council (Neilson 29 July 2019).

While some authors suggest that the acceptability of poisons may be declining in NZ, social attitudes to small herbivores, such as possums and rabbits, and predators, such as mustelids and rodents, remain mostly negative (Farnworth et al. 2014, Russell 2014). Commonly-used pest control methods, such as hunting, trapping, and poisons, are generally preferred by the public over new technologies (Kannemeyer 2017). There is also much higher social acceptance for species-specific toxins as an aerial control tool. As such, there has been significant research on norbormide for rats (Choi et al. 2016, Jay-Smith et al. 2016, Ma et al. 2018), and PAPP for predators (de Tores et al. 2011, Dilks et al. 2011) (Blackie et al. 2012, Brown et al. 2012, Eason et al. 2014, de Burgh et al. 2021).

For ground-based tools, there is a need for best-practice information for recently developed live-capture traps (ZIP 2017b) and multi-kill traps (Gillies et al. 2012, Warburton and Gormley 2015, Carter et al. 2016, Murphy et al. 2019). Ground-control approaches are likely to improve with current research that is investigating social (Garvey et al. 2016), food-based (Waters et al. 2016, ZIP 2020) and audio-lure technologies (Kavermann et al. 2013).

In general, social attitudes to biological control and genetic approaches were characterised by high levels of unpredictability, frequently due to limited knowledge or understanding of how the new technology worked (Wilkinson and Fitzgerald 2014). Rationales for preferring existing methods also include uncertainty or perceived risks associated with not knowing the future impacts of any new tool. Other arguments driving the

1080 debate and the development of new technologies are place attachment and a perceived lack of equity in the decision-making process (McSweeney 2011, Bidwell and Thompson 2015).

CONCLUSIONS

1080 Database of Science

Ten years on from the previous scientific review, our understanding of 1080 continues to improve. There is an enhanced understanding of the toxic nature of 1080, as well as up-to-date knowledge of global trends in the types of poisons available, and their properties. This information is essential to inform debate and assist with formulating future wildlife management control strategies. The approval and continued registration of 1080 also require continuous up-to-date technical, and toxicological information (ERMA 2007, Eason et al. 2011), coupled with evidence of long-term ecosystem improvements and annual audits by the NZ Environmental Protection Agency (EPA). As a result, 1080 continues to be one of the most closely monitored substances in NZ.

Desire for Change

Most researchers and pest control practitioners are empathic with the desire for change and would like to use non-lethal methods if they were available. However, this will not happen overnight, and it can be anticipated that toxins, including 1080, will continue to play a role in pest control over the next decade. Innovations, such as resetting kill traps (Ross et al. 2020), could steadily reduce the need for 1080 (Eason et al. 2017) in more accessible terrain. Other ground-control options using poison dispensers can provide more targeted delivery systems (Blackie et al. 2014, 2016) and could utilise alternative toxins (Eason et al. 2012, Hix et al. 2012, Shapiro et al. 2016). There is also research looking at drones, artificial intelligence, wireless communication (Jones et al. 2015), and biotechnology (Campbell et al. 2015, Russell and Broome 2016, Eason et al. 2017, Morley et al. 2017, Campbell et al. 2019). While promising, many believe no new *game-changers* are on the immediate horizon. For now, the focus is the sustained control of pests on the NZ mainland, with aerial 1080 remaining an essential tool (PCE 2017, Warburton et al. 2021).

SUMMARY

Up-to-date toxicological research and non-target population monitoring are necessary to refine the targeting of 1080 while its use continues. Other research also needs to consider key social concerns being human health, non-targets, and animal welfare. In addition, researchers will need to respond to any *unexpected* new questions raised by regulatory agencies, such as the EPA. There is a need to further advance close-to-market tools with the highest public acceptance, such as species-specific poisons and trapping. For aerial 1080, advances in precision targeting (i.e., low sowing rates and targeted delivery systems) and the more widespread use of bird and deer repellent could increase support.

More effective and empathic engagement with communities, iwi and hapu, is needed to discuss invasive species management goals and find common ground. This engagement needs to be open and honest, highlight risks (MacDonald et al. 2021) and benefits, and seek consensus with a long-term vision. In most cases, an agreement will likely involve an *integrated* approach to pest control (Subroy et al. 2018) using the most socially acceptable tools. Greater acceptance of any pest control tool occurs when its use is discussed within the context of long-term goals for saving endangered species and ecosystem recovery, within communities that treasure the restoration of their landscapes. However, the broader context cannot be ignored in national and global pest control trends. Values are changing, such that no (or minimal) pesticide use (Chamberlain 2016, Dayan et al. 2009, Messenger-Sikes and Quinn 2020) is an increasingly mainstream theme (MPI 2020). In this changing environment, strategies that rely on 1080 or other toxins as *one-off treatments* for eradicating pests or disease versus continued application for maintenance control are likely to be more and more important.

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