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Short communication

Quantifying contamination of streams by 1080 baits, and their fate in water

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Abstract Forty-eight streams were surveyed during four aerial 1080 operations in New Zealand's South Island to quantify the number of 1080 baits falling into streams. Bait size used in each operation varied considerably: small (2 g) baits in Marlborough, medium-sized (6–7 g) baits in Canterbury and the West Coast, and large (11 g) baits in Lewis Pass. The number of baits found in streams varied widely, and was related only to bait size, with more of the small baits found in streams than the large baits. There was no relationship between stream width or canopy cover and the number of baits found within a stream. These findings suggest that the potential number of baits falling into a stream cannot be calculated from the bait application rate and the stream size. The fate of submerged 1080 baits was also examined in a laboratory flow tank. Submerged baits fragmented within 3–4 days. 1080 was rapidly leached from submerged baits: almost 50% of original 1080 had leached after 5 h, and >90% after 24 h. Such rapid leaching reflects 1080's high solubility. This finding has implications for water quality monitoring programmes used during 1080 drops, as samples should be collected within 4–8 h of potential contamination to detect presence of 1080.

Keywords sodium fluoroacetate; 1080; water quality; monitoring

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INTRODUCTION

Both the Department of Conservation (DOC) and the Animal Health Board (ABH) oversee large-scale operations aimed at controlling introduced mammalian pests (especially the Australian brushtail possum (*Trichosurus vulpecular*)) throughout New Zealand. A key component of this control strategy relies on the aerial application of cereal baits containing sodium fluoroacetate (compound 1080), usually by helicopter, over inaccessible mountainous terrain. Such aerial applications are often contentious, with public concerns over the fate of 1080 in the environment, its effect on non-target species, and potential contamination of surface and ground water (e.g., Livingstone 1994; Williams 1994; Speedy 2001; Laugesen & Hubbard 2002). Such concerns may partially reflect the lack of research addressing the effects of 1080 on freshwater ecosystems within New Zealand. Although toxicity tests have shown that fish are generally resistant to 1080 (Batcheler 1978; Fagerstone et al. 1994), no tests have examined the effects of 1080 on native New Zealand fish. Similarly, nothing is known of the toxicity of 1080 to native freshwater invertebrates, although 1080 is toxic to some terrestrial invertebrates (Eason et al. 1993).

As a result of these concerns, regional councils throughout New Zealand impose specific consent conditions on aerial 1080 operations, and in particular whether buffer zones are placed around waterways to prevent accidental contamination (Table 1). Information gleaned by the AHB from 11 regional councils regarding these conditions shows that three councils impose buffers around all waterways, six councils have buffers around all waterways >3 or 6 m in width, and two councils have no buffer zones around waterways that are not used for drinking water (Table 1). Although buffer zones are often imposed around streams >3 m wide, there are many streams smaller than this, especially in steep mountainous country where aerial 1080 application occurs most often. 1080 baits are thus likely to fall into small streams during such operations.

The Medical Officer of Health has stipulated a provisional maximum acceptable value (PMAV) for 1080 in water of 3.5 μg litre^{-1}, although a lower value of 2 μg litre^{-1} is used when water is used for human consumption (Green 2003). Extensive sampling programmes have monitored water quality for signs of 1080 contamination following aerial applications. Between 1990 and 2002, 1556 water samples were collected after large-scale possum or rabbit control operations throughout New Zealand (Eason 2002; Green 2003). Only 3.5% of these samples (i.e., 58) tested positive for 1080. Of these, the highest concentration was 4 μg litre^{-1} found in a stream in the Te Kopia Scenic Reserve (Eason 2002). Two more water samples contained $\leq$3.5 μg litre^{-1} of 1080. In the other instances where 1080 was detected, the amounts were <1 μg litre^{-1}. The other 1498 samples had no detectable 1080.

The few instances where 1080 was detected in stream water presumably reflect the presence of bait in streams (Eason et al. 1999; Parfitt et al. 1994). Laboratory tests showed that 1080 breaks down after c. 100 h in warm (21°C) water, but that the rate of breakdown is slower in cold (11°C) water, so that 1080 was still detectable after 192 h (Ogilvie et al. 1996). Given that the aerial application of 1080 is generally done during winter months, it is possible that 1080 persists in cold-water streams for some time. Eason et al. (1999) suggested that dilution of 1080 in streams would be more important in reducing it to toxicologically insignificant concentrations than its breakdown by bacteria. This may be the reason why the majority of water samples collected during aerial operations have failed to detect 1080. However, despite this assertion, no studies have specifically looked at the degree to which streams can be contaminated by 1080 baits, or the fate of baits once they fall into water. Baits are applied at rates of 2–15 kg ha^{-1} (Table 1), and so are expected by chance to fall into streams flowing in operational areas.

Lack of more positive water samples during monitoring operations may reflect absence of baits in streams, despite their occurrence within operational zones. However, the degree to which baits fall into streams has not yet been quantified.

Table 1 Summary of the size of waterway buffer, application rate, and preferred bait type used by selected regional councils throughout New Zealand for possum control operations. Data courtesy of Animal Health Board. (RMA, Resource Management Act; TLA, Territorial Local Authority; w/w, weight per weight.)

Region	Waterway buffer	Average application rate (kg ha^{-1})	Type of bait
Waikato	No buffers for RMA resource consents. Some TLAs require 50-m buffers	5, range 2–15	Wanganui No. 7 baits in 2–3 g; 5–7 g and 7–9 g bait sizes up to 0.15% w/w
Bay of Plenty	60-m buffers irrespective of width	5–8	RS 5 or Wanganui No. 7 (0.15% w/w)
Hawkes Bay	20 m irrespective of width	Initial operations: 10 Other operations: 3 and 5	Wanganui No. 7 baits (5–7 g) preferred. Toxic loadings of 0.08% and 0.15% w/w
Manawatu/ Wanganui	20 m for waterways >3 m	3 for pre-feed, 5 for toxic	Wanganui No. 7 (0.15% w/w)
Wellington	If not for drinking, no buffers. If waterways used for drinking water a 20-m buffer required	2	Wanganui No. 7 or 12 g baits (0.15% w/w)
Marlborough	20 m for waterways >3 m	2.5 for 6–8 g and 12 g baits 3–4 for 2–3 g baits	RS 5 (0.15% w/w)
Tasman	20 m for waterways >6 m but 100 m over water supplies and intakes	3	RS5 (0.15% w/w)
Canterbury	50 m for waterways >3 m	3	RS5 (0.15% w/w)
West Coast	20 m for waterways >3 m	3	Wanganui No. 7 or 12 g baits (0.15% w/w)
Otago	20 m irrespective of width[1] but 100 m over water supplies and intakes	3	RS5 or Wanganui No. 7 (0.15% w/w)
Southland	50 m for waterways >3 m	3	RS5 or Wanganui No. 7 (0.15% w/w)

[1]Buffers used only for flowing water.

An alternative explanation may be that the majority of water sampling programmes collected samples 24 h after a drop (e.g., Southland Regional Council Consent Conditions S135-079 and S135-078), by which stage 1080 could have leached from baits. This assertion is made in the knowledge that up to 99% of 1080 was leached from small baits (RS5) after only 150 mm of rain (over 7.5 h) (Bowen et al. 1995), although larger baits (Wanganui No. 7) required 250 mm of rain (over 12.5 h) to achieve a similar loss (Booth et al. 1999). Baits landing in small streams would be exposed to considerably more water than those exposed to rainfall, so 1080 may rapidly leach from submerged baits, but no studies have quantified this. This study quantified the number of 1080 baits in streams flowing through areas where 1080 had been applied aerially, and investigated the fate of submerged 1080 baits. More specifically, it investigated how long submerged baits took to fragment, and how quickly 1080 leached from them.

MATERIALS AND METHODS

Quantifying accidental contamination

Stream surveys were conducted in four areas where aerial 1080 operations occurred: the Lewis Pass and Mt Grey regions in North Canterbury, the Awatere Valley in Marlborough, and the Moana-Ruru region in the Grey Valley on the West Coast (Fig. 1). Different regulatory agencies were responsible for the operations in each of these areas, and each used different sized baits with different application rates (Table 2). Although bait sizes varied considerably, all were dyed bright green to reduce their attractiveness to birds. These green baits were particularly conspicuous on the ground or when submerged.

Surveys were made of arbitrarily selected streams in each operational area by walking up a single 100 m transect located randomly within each stream. Although longer transects could have been chosen, this was not possible in many small streams surveyed, as there was a greater chance of encountering obstacles such as large debris jams, steep waterfalls, and dense riparian vegetation that precluded an accurate, yet time-efficient survey of greater lengths. The location of baits along each transect was recorded to the nearest metre. An underwater viewing tube was used to look for baits in deep pools, or in areas of turbulent white-water where the streambed was not visible. All baits that were either submerged or in the active flood-channel were recorded. Although the overall efficiency of this sampling strategy was not assessed, it is unlikely that many of the brightly coloured baits were missed on each transect. Stream width and maximum depth were measured every 10 m, and overhead canopy cover was estimated by eye into four classes (0–25%, 25–50%, 50–75%, and >75%). Each survey was conducted on the day of the aerial operation, and care was taken to survey only areas where baits had been dropped.

Fate of 1080 baits in water

Laboratory experiments were performed to examine the fate of baits falling into moving water and to quantify the rate that 1080 leached from baits. Samples of large baits (mean weight = 11.1 g) as used by the Department of Conservation (hereafter referred to as DOC baits) and Wanganui No. 7 baits (mean weight = 6.4 g), both containing 0.15% w/w of 1080, were obtained from Animal Control Products (ACP) for this experiment. Although most regional councils use Wanganui No. 7 or RS5 baits (Table 1), the latter are not as waterproof as No. 7 baits (Bowen et al. 1995), and so were not selected for the study. DOC baits were also examined, as they represent the largest ones used in aerial operations. An oval recirculating flow-tank consisting of curved ends (inside diam. 60 cm) separated by two parallel-sided channels (40 cm wide × 30 cm high × 265 cm long) was used for these experiments.

A mixture of cobbles (mean length = 30 mm) was placed in the flume to a depth of 7 cm. Eight replicate cobble-filled containers (10 cm wide × 15 cm long × 8 cm deep) were buried in each channel so that their surfaces were flush with the cobbles. These containers were placed 15–20 cm apart along the middle of each channel. Use of cobbles as a substrate minimised the degree to which baits were washed from the plastic containers, as baits were slightly smaller than the cobbles and so lay in small depressions between them. In this way, material fragmenting from individual baits fell into interstitial spaces between cobbles, but could still be recovered. Water velocity was maintained at 20 cm s^{-1} in the flume by the use of a propeller, and velocities measured in both channels (at 0.4 × the depth for 40 s) using an Ott meter. Although higher velocities undoubtedly occur in steep headwater streams where aerial operations occur, velocities >20 cm s^{-1} typically washed baits from the containers (pers. obs). Water temperatures in the flume were maintained at an ambient temperature of 11 ± 2°C.

Three replicate pre-weighed baits were placed on top of cobbles in each of the plastic containers,

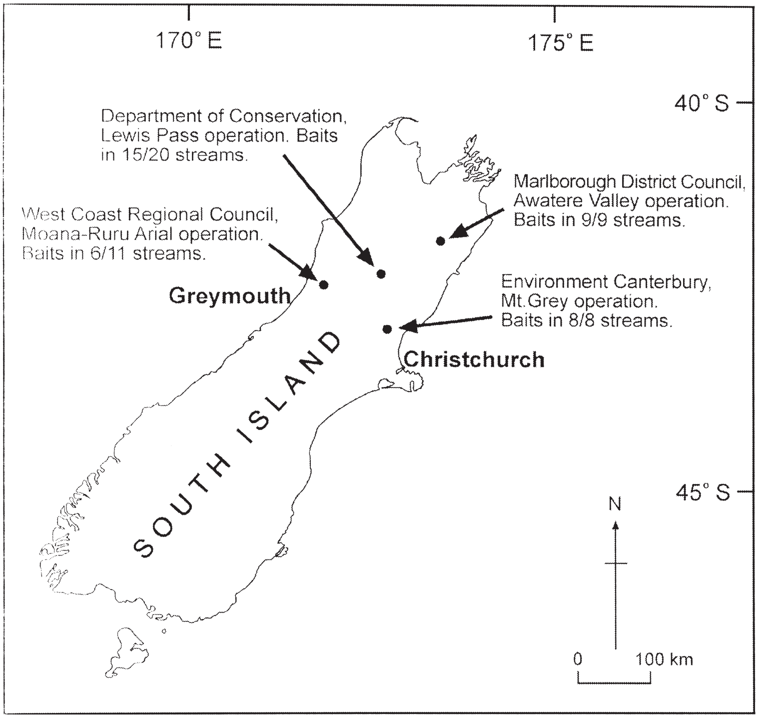

Fig. 1 Map showing the location of the four aerial 1080 operations, the authority responsible for the operation, the number of streams surveyed, and the number of streams with 1080 baits.

Table 2 Summary data of the four aerial operations where streams were surveyed to quantify the degree of accidental 1080 contamination by baits. (DOC, Department of Conservation; ECan, Environment Canterbury; w/w, weight per weight.)

Operation	Regulatory authority	Bait (all 0.15% w/w 1080)	Bait weight (g)	Application rate (kg ha^{-1})	Streams surveyed
Lewis Pass	DOC	11 g baits	12	2.5	20
Mt Grey	Target Past (ECan)	RS5	7.6	2.6	8
Awatere	Marlborough District Council	2 g baits	2	2.5	9
Moana-Ruru	West Coast Regional Council	Wanganui No. 7	6.4	3.0	11

which were removed from the flow tank at increasing lengths of time (8, 24, 48, 72, and 84 h). DOC baits were used in one channel and Wanganui No. 7 baits were used in the other. Initially only a single container (with three baits) was removed after 8 and 24 h respectively, as little fragmentation had occurred, and individual baits dried (60°C) and weighed. However, duplicate containers were removed from 48 h onwards (i.e., six baits) to more accurately quantify the amount of bait lost, as baits had swollen considerably and started to fragment. Removed baits were dried and re-weighed to calculate weight loss (expressed as a percentage of original) owing to fragmentation.

The final experiment measured the rate that 1080 leached from baits. Only Wanganui No. 7 baits were used for this trial, reflecting their widespread use throughout the country. Ten cobble-filled plastic containers as used previously were placed in each of the channels of the flume, and duplicate baits were placed in these. Water velocity was set to 20 cm s^{-1} as before. Baits were collected after 2, 4, 6, 12, 24, and 36 h, placed in individual plastic bags and frozen (–18°C) pending analysis. Six replicate baits were collected after 2 and 4 h, respectively, to better characterise short-term leaching of 1080, and four replicates were collected on each sampling occasion onwards from 6 h. Six replicate baits not used in the experiment were also used to determine 1080 concentration at the start of the experiment. All baits were sent to ACP and analysed for residual 1080 concentration by gas chromatograpy with an electron capture detector, using a modification of method 8B of the Denver Wildlife Centre (1989). The limit of detection using this method was 0.00005% of 1080.

Statistical analysis

The aerial application of 1080 baits was assumed to result in a uniform distribution of baits along the 100 m stream segments. This assumption was tested using the Kolmogorov-Smirnov test (Zar 1984). The expected number of 1080 baits in each stream was calculated based on bait weight, application rate for each operation, and stream area surveyed. A χ^2 test (Zar 1984) was used to assess whether the observed number of baits differed significantly from the expected number in each stream. Linear regression analyses (Zar 1984) assessed whether relationships existed between the number of baits in each stream, and stream width: the assumption being that the number of baits was proportional to stream area. One-way ANOVA was also used to test whether the number of baits in streams differed with the varying four classes of overhead canopy cover. For these analyses, the number of baits observed in each stream was $\log_{10}$ transformed to achieve a normal distribution, as assessed by normal probability plots (Zar 1984).

For the fragmentation experiment, a 2-way ANOVA was used to ascertain whether there were differences in weight loss over time, and whether these differences were consistent among bait types. Weight loss data was examined for normality by normal probability plots and $\log_{10}$ transformed before analysis. Finally, non-linear regression was used to describe the reduction in 1080 concentration over time in submerged baits. All statistical tests were done using SYSTAT 10 (SPSS 2000), using a significant value of $P < 0.05$.

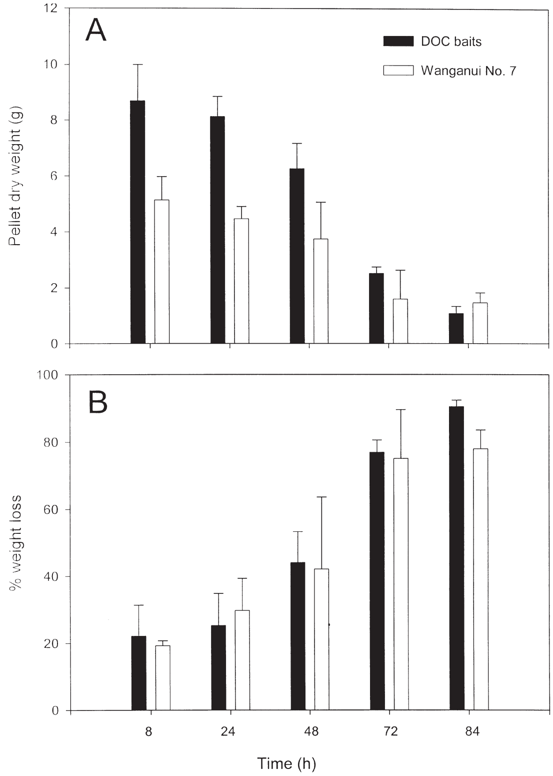

Fig. 2 **A**, Dry weight of DOC baits and Wanganui No. 7 baits. **B**, Percentage weight lost from these baits that were placed in the recirculating flume for increasing lengths of time (mean ± SD, n = 3 for 8 and 24 h; n = 6 for 48 h onwards).

Table 3 Mean (± SD), minimum, and maximum number of 1080 baits found in 100-m sections of streams exposed to four aerial 1080 operations.

	Baits per section		
Operation	Mean no.	Min. no.	Max. no.
Lewis Pass	5.2 (5.2)	0	15
Mt Grey	11.3 (4.3)	8	21
Awatere	23.3 (10.3)	7	38
Moana-Ruru	7 (7.6)	0	19

RESULTS

Quantifying the extent of accidental contamination

A total of 48 streams were surveyed in the four aerial 1080 operations (Table 2). No baits were found in 10 streams: five each in the Lewis Pass and West Coast operations. All streams surveyed in the Awatere and Mt Grey operations had baits in them (Fig. 1, Table 3). The number of baits found in streams flowing through each operational area varied widely (Table 3), most likely reflecting the different bait sizes and subsequent application rates. The highest maximum number of baits in a stream (38) occurred in the Awatere operation, which used the smallest bait size (2 g), whereas the lowest maximum number of

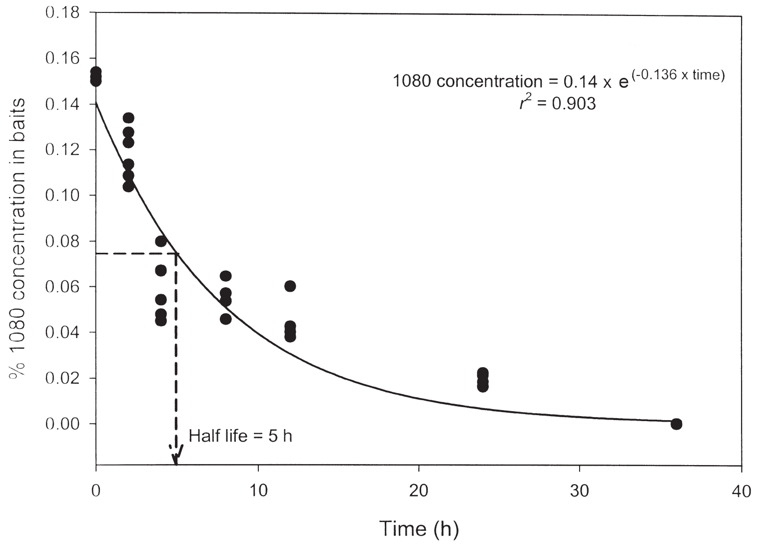

Fig. 3 Percentage of 1080 concentration remaining in Wanganui No.7 baits after increasing lengths of time under flowing water (20 cm s^{-1}). Also shown is the exponential decay relationship that displayed the best fit to the data, and the calculated half-life of 1080 under these experimental conditions. (n = 6 for control samples, and samples collected at 2 and 4 h, and n = 4 for all other samples: some symbols are obscured by others.)

baits in a stream (15) was found in the Lewis Pass operation, which used 11-g baits.

The Kolmogorov-Smirnov test showed that the distribution of baits in 38 of the 48 streams was not uniform, suggesting that the expected number of baits falling into a stream could not be calculated from the bait application rate and the stream size. χ^2 tests showed that only 19 of the 48 streams had a similar number of baits in them, as expected based on their application rate and stream size. Sixteen streams had significantly fewer baits than expected ($P < 0.05$), whereas 13 streams had significantly more ($P < 0.05$). There were no significant relationships between the number of baits in a stream and either stream width or stream canopy cover ($P < 0.05$).

Fate of 1080 baits in water

There was a significant decrease in bait weight over time for both the DOC and Wanganui No. 7 baits ($F_{(4, 37)} = 51.8$, $P < 0.001$), and the pattern of weight loss was similar in both baits ($F_{(1, 37)} = 0.66$, $P >$ 0.05). Most of the weight loss occurred over the first 72 h, with little extra after this (Fig. 2). For the first 48 h, the baits remained relatively intact, but slowly lost their vivid green colour. After 72 h, baits were swollen and started to fragment. After 84 h, most of the baits structural integrity was lost and they disintegrated.

Although baits could remain in a stream for up to 72–84 h before they disintegrated, 1080 concentration declined exponentially over time (Fig. 3). Baits had lost 50% of their 1080 after 5 h of submergence. By 24 h, baits contained only 0.019% 1080: a loss of over 90% of original 1080 (0.15%). No 1080 was detected in any baits after 36 h.

DISCUSSION

The application rates of 1080 baits are set as part of standard operational conditions, so it should have been possible to estimate the average number of baits falling into 100 m stream sections, based on total streambed area. However, no correlation existed between bait application rate and the number of baits found in streams, nor between stream size and the number of baits within a stream. These results suggest that the chance of baits falling into streams was random. Moreover, the distribution of baits in most of the streams was non-uniform. Such non-uniform distribution could occur for a number of reasons, such as baits being washed from high-energy riffle areas and accumulating in low-energy pools. These findings have implications for water sampling programmes that are used to monitor 1080 contamination in streams.

If baits fell randomly into streams, then water quality monitoring programmes may by chance sample streams without any 1080 baits in them. The large number of "zero" detection levels in sampling programmes to date may in part reflect absence of baits within streams. Absence of baits in streams is important as it suggests that not all streams within operational zones become contaminated with 1080, as observed in this study where five streams in the Lewis Pass (out of 20 streams) and Moana-Ruru (out of 11 streams) areas had no baits in them. Streams in the Moana-Ruru area often flowed through steep-sided limestone gorges, and this morphology may have reduced the likelihood of baits falling into streams as the helicopter flew over these gorges. Local geomorphology may thus play an important part in influencing contamination of streams by 1080 baits.

Absence of baits in streams may also explain the lack of detectable 1080 in water samples collected from five streams by Meenken & Eason (1995) as part of a possum control operation in the Tararua Forest near Wellington. No traces of 1080 were found in these samples, despite having been collected 2–6 h after each catchment had been treated with toxic baits, and despite the very low discharges (ranges from 0.14 to 32 litres s^{-1}) in these streams.

Baits progressively lost weight over a 4–5 day period until they had completely fragmented. Under natural conditions of higher velocity and turbulence regimes than were used in the experimental flow-tank, these fragments would likely be washed away. The length of time taken for baits to fragment is also likely to be quicker in faster flowing, highly turbulent riffles. Baits landing in slow-flowing pools, however, may maintain their structural integrity for longer. 1080 also rapidly leached from submerged baits, with a very rapid loss within the first 8–12 h. Ninety percent of 1080 had leached from the baits after 24 h, and all had leached after 36 h. Again, the rate of leaching is likely to be greater in faster flowing water, although stream-water 1080 concentrations measured below baits would reflect a combination of both leaching rate and overall stream discharge.

This rapid leaching has implications for water sampling programmes. If the intent of sampling programmes is to quantify potential contamination of 1080 in streams following an aerial drop, then sampling should occur at least within 12 h (and preferably within 4–8 h) of the stream having potentially been contaminated by 1080 baits. If a water sampling programme was started 24 h after a drop, certainly most of the 1080 present in submerged baits would have leached before the sampling programme had begun.

Many resource consent conditions stipulate that water sampling must be carried out 1 day (or more) after aerial operations. For example, consent conditions issued by Southland Regional Council (S135–079 and S135–078) require that water samples be collected within 72 h after a drop. Other sampling programmes (e.g., Taranaki Regional Council 1993, 1994) sampled streams 1–2 days following aerial operations. Not surprisingly, they found no evidence of 1080 contamination in these programmes. Fowles & Williams (1997) sampled two rivers on the boundary of Taranaki National Park using automated devices that collected subsamples every 15 min. However, these samples were pooled into four, 6 h samples, effectively diluting them 32 times. Such dilution may have masked the presence of 1080 in the water. For example, the highest concentration of 1080 found in water samples was 4 μg $litre^{-1}$ (Eason 2002; Green 2003). If a similarly high concentration had been diluted 32 fold, the resultant concentration would have just been above detection limits in their study (0.1 μg $litre^{-1}$). Given this dilution effect, it is likely that if lower concentrations of 1080 were present in the stream water collected by Fowles & Williams (1997), then pooling samples would have diluted this 1080 to below detection.

The importance of collecting samples on the same day as aerial drops occur was highlighted by recent results of a monitoring drop conducted by Environment Canterbury in the Ashley Forest near Mt Grey. Six water samples were collected for this monitoring programme on the day of the drop, and positive results were found for two samples: the Kowhai River containing 1 μg $litre^{-1}$, and a small tributary into Bushy Creek containing 0.8 μg $litre^{-1}$ (Jacqui Todd, Environment Canterbury pers. comm.) Fortuitously, the number of 1080 baits in these same streams was also counted on the same day. Twenty-one baits were found in the Kowhai River, near where the water sample was collected. Discharge of this stream was c. 30 litres s^{-1}, so the estimated 1080 concentration if all 1080 baits had occurred in a small area and the 1080 had leached from the baits within a 4-h period would have been 0.47 μg $litre^{-1}$. This is less than was found in the water sample, suggesting that either there was more bait in the river than counted, or that 1080 had leached from the baits in less than 4 h. Nineteen baits were found in a tributary into Bushy Creek, close to where the other water sample had been collected (pers. obs.). Discharge here was approximately 15 litres s^{-1}, so the estimated 1080 concentration over a 4-h period would have been 0.8 μg $litre^{-1}$, the same as the actual water sample.

Another recent study (Suren & Lambert 2004) examined the effect of 1080 baits on native fish, and illustrated the rapid leaching of 1080 from baits. A number of 1080 baits were placed in mesh bags and placed in four small west coast streams. 1080 was detected in three of the streams up to 4 h after the baits were introduced, and no 1080 was detected after 8 h. In the fourth stream, 1080 was detected in samples collected after 8 h, but not after 24 h. The longer time for 1080 to leach out of baits in this fourth stream may have been an artefact caused by the tighter "clumping" of baits within this stream's mesh bags, which held more baits. These results again highlight the importance of collecting water samples within 4–8 h of streams being potentially contaminated by 1080 baits.

Finally, although we have quantified the degree to which streams can become contaminated by 1080 baits, and the rate at which 1080 leaches from baits, there may still be concern at potential for 1080 to reach streams from run-off during rainfall events. Work by Eason et al. (1992) however, suggests that this is extremely unlikely. They collected surface and groundwater samples from the volcanic Rangitoto Island, adjacent to Auckland, following aerial application of 1080 baits at 14 kg ha^{-1}. This equated to 0.11 mg of 1080 per m^2 of island. Soil is extremely scarce at Rangitoto Island, so any 1080 leaching from baits during rain was expected to percolate through the larva into the water table (Eason et al. 1992). However, despite heavy rainfall in the month after the drop, no 1080 was detected in any water samples.

In most instances, any 1080 leaching from baits during rainfall is likely to simply soak into the soil, where micro-organisms such as *Pseudomonas* and *Fusarium* would metabolise it (Walker & Bong 1981). It is also highly unlikely that direct overland run-off would contain much 1080, as direct run-off is a relatively rare phenomena in forests that occurs only when the rainfall rate exceeds the soil's infiltration rate (Davie 2004). Such conditions would only occur after continued wet periods, by which time most of the 1080 in baits would have been leached away (Bowen et al. 1995; Booth et al. 1999). Moreover, stream discharges during such times would be also high, which would further dilute any 1080 that may have reached streams from direct run-off. As such, the risk of stream water becoming contaminated by 1080 leaching into the soil from baits landing in catchments is considered almost an impossibility.

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REFERENCES

Batcheler CL 1978. Compound 1080, its properties, effectiveness, dangers, and use. Report to Minister of Forests and Minister of Agriculture and Fisheries. Wellington, New Zealand Forest Service.

Booth LH, Ogilvie SC, Eason CT 1999. Persistence of sodium monofluoroacetate (1080), pindone, cholecalciferol and brodifacoum in possum baits under simulated rainfall. New Zealand Journal of Agricultural Research 42: 107–112.

Bowen LH, Morgan DR, Eason CT 1995. Persistence of sodium monofluoroacetate (1080) in baits under simulated rainfall. New Zealand Journal of Agricultural Research 38: 529–531.

Davie T 2004. Soil water, runoff and streamflow generation. In: Harding JS, Mosley MP, Pearson CP, Sorrell BK ed. Freshwaters of New Zealand. Christchurch, New Zealand Hydrological Society Inc., New Zealand Limnological Society Inc. 146 p.

Denver Wildlife Centre 1989. Compound 1080 grain bait assay, Method 8B. United States, Denver Wildlife Centre.

Eason CT 2002. Technical review of Sodium monofluoroacetate (1080) toxicology. Animal Health Board. 25 p.

Eason CT, Wright GR, Fitzgerald H 1992. Sodium monofluoroacetate (1080) water-residue analysis after large-scale possum control. New Zealand Journal of Ecology 16: 47–49.

Eason CT, Gooneratne R, Wright GRG, Pierce RS, Frampton CM 1993. The fate of sodium monofluoroacetate (1080) in water, mammals, and invertebrates. Proceedings of the 46th New Zealand Plant Protection Society Conference. Pp. 297–301.

Eason CT, Wickstrom M, Turck P, Wright GRG 1999. A review of recent regulatory and environmental toxicology studies on 1080: results and implications. New Zealand Journal of Ecology 23: 129–137.

Fagerstone KA, Savarie PJ, Elias DJ, Schafer EWJ 1994. Recent regulatory requirements for pesticide registration and the status of Compound 1080 studies conducted to meet EPA requirements. In: Seawright AA, Eason CT ed. Proceedings of the Science Workshop on 1080. The Royal Society of New Zealand Miscellaneous Series 28: 33–38.

Fowles CR, Williams JR 1997. Water quality monitoring in relation to a possum control operation on Mount Taranaki/Egmont. New Zealand Natural Sciences 23: 93–99.

Green W 2003. The use of 1080 to control possums and other pests. A resource document. Animal Health Board and Department of Conservation. 49 p.

Laugesen R, Hubbard A 2002. The Big Drop. In: Sunday Star Times, 19 May 2002. Auckland. Pp. C1–C2.

Livingstone PG 1994. The use of 1080 in New Zealand. In: Seawright AA, Eason CT ed. Proceedings of the science workshop on 1080. The Royal Society of New Zealand Miscellaneous Series 28: 1–9.

Meenken D, Eason CT 1995. Effects of water quality of a possum (*Trichosurus vulpecula*) poisoning operation using toxin 1080 (sodium monofluoroacetate). New Zealand Journal of Marine and Freshwater Research 29: 25–28.

Ogilvie SC, Hetzel F, Eason CT 1996. Effect of temperature on the biodegradation of sodium monofluoroacetate (1080) in water and in *Elodea canadensis*. Bulletin of Environmental Contamination and Toxicology 56: 942–947.

Parfitt RL, Eason CT, Morgan AJ, Wright GR 1994. The fate of sodium monofluoroacetate (1080) in soil and water. In: Seawright AA, Eason CT. ed. Proceedings of the Science Workshop on 1080. The Royal Society of New Zealand Miscellaneous Series 28: 59–66.

Speedy, C. 2001. 1080: fact versus emotion. Fish and Game New Zealand 34: 13–14.

SPSS Inc. 2000. SYSTAT 10 Language Reference. Chicago, Illinois, United States. 307 p.

Suren AM, Lambert P 2004. The effects of 1080 on invertebrate communities and fish in West Coast streams. National Institute of Water and Atmospheric Research Client Report CHC2004-096: 40.

Taranaki Regional Council 1993. Water quality monitoring of Stage 1 of the Department of Conservation/ Taranaki Regional Council possum control operation on Mount Taranaki/Egmont 1993. Taranaki Regional Council Technical Report 93–27. 18 p.

Taranaki Regional Council 1994. Water quality monitoring of Stages 2 & 3 of the Department of Conservation/ Taranaki Regional Council possum control operation on Mount Taranaki/Egmont 1993. Taranaki Regional Council Technical Report 94–7. 18 p.

Walker JRL, Bong CL 1981. Metabolism of fluoroacetate by a soil *Pseudomonas* and *Fusarium solani*. Soil Biology and Biochemistry 13: 231–235

Williams JM 1994. Food and fibre markets and societal trends: implications for pest management. In: Seawright AA, Eason CT ed. Proceedings of the science workshop on 1080. The Royal Society of New Zealand Miscellaneous Series 28: 20–32.

Zar JH 1984. Biostatistical Analysis. 2nd ed. London, Prentice-Hall International. 718 p.