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Consumption of baits containing sodium fluoroacetate (1080) by the New Zealand freshwater crayfish (*Paranephrops planifrons*)

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Abstract Native freshwater crayfish (koura: *Paranephrops planifrons*) were exposed to baits containing sodium fluoroacetate (1080) to determine whether they consumed baits in the presence of other food (detritus and invertebrates), and whether such consumption was lethal. Crayfish were collected from streams and placed individually into 50 cages in a large "stream simulator", divided into a riffle and pool habitat. A single 1080 bait (mean weight = 6.4 g) containing c. 0.15% 1080 (i.e., 9.6 mg) was added to each of 20 cages in each habitat. Non-toxic baits were added to five additional control cages within each habitat. A further five crayfish were placed in aquaria to act as double controls. Replicate crayfish exposed to 1080 baits were collected from both habitats after 1, 2, 4, and 8 days and analysed for 1080 in their viscera and tail muscle. Crayfish exposed to non-toxic bait, and double control crayfish were collected after 8 days and analysed for 1080. The highest concentration of 1080 (1.1 μg litre^{-1}) in water collected from the simulator occurred after 2 days, and no residual 1080 was detected after 8 days. Crayfish consumed baits, even in the presence of other food items, but no mortality was observed. The highest 1080 concentrations were 3.3 μg g^{-1} body tissue in the viscera, and 5 μg g^{-1} in tail muscle. 1080 concentration in the viscera was positively related to that in the tail muscle. 1080 concentrations declined in the tail muscle between days 4 and 8, suggesting that sub-lethal doses of 1080 could be successfully metabolised. The potential risk to humans consuming crayfish containing 1080 is considered virtually non-existent, as an 85 kg person would need to consume over 40 kg of contaminated crayfish tails in a single sitting to receive an LD_{50} dose.

Keywords koura; freshwater crayfish; *Paranephrops planifrons*; sodium fluoroacetate; 1080; mortality; residues; toxicity testing

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INTRODUCTION

Large-scale control of mammalian pests (especially the brushtail possum: *Trichosurus vulpecula*) in New Zealand requires use of baits containing sodium fluoroacetate (compound 1080), which are aerially applied over rough, forested terrain that is impenetrable for ground application (Green 2003). These baits are made up of cereal bait compressed into cylindrical pellets of varying size, depending on the type of bait used. There are four bait types and sizes commonly used, ranging in size from small 2 g baits to larger 12 g baits. Baits are most commonly made containing a concentration of 0.15% 1080. This means that individual baits can contain from 3 mg to 18 mg of 1080.

Aerial applications of 1080 baits have historically been contentious, with many public concerns over the fate of 1080 in the environment, its effect on non-target species, and potential contamination of surface and ground water (Livingstone 1994; Williams 1994). As a result of these concerns, regional councils throughout New Zealand often impose specific conditions on aerial 1080 operations and, in particular, impose buffer zones around waterways >3 m wide to minimise accidental contamination to freshwater ecosystems (Suren 2006). Despite buffer zones around these large streams, smaller streams often have no such protection, so bait is likely to fall into these small streams, especially in steep, highly dissected mountainous country (Suren 2006, this issue).

The ecological effects of this accidental contamination on stream ecosystems are presently

unknown. Laboratory tests have shown that 1080 is quickly metabolised by naturally occurring bacteria present in water (Ogilvie et al. 1996) suggesting that any adverse impacts of this chemical would be short-lived. Moreover, Eason et al. (1999) suggested that dilution of 1080 in streams would reduce its presence to toxicologically insignificant concentrations. This may help explain why the vast majority of water samples collected from streams flowing in operational drop zones have had non-detectable levels of 1080 in them (Eason 2002; Green 2003). Indeed, 1080 has only been detected in 58 out of 1556 water samples that have been collected from operational areas, and 51 of these had concentrations <0.1 μg litre^{-1} (Green 2003). Suren (2006), however, suggested two reasons for the lack of positive 1080 readings from monitoring studies: (1) most water sampling programmes collect samples 24 h after a drop, by which time most or all of the 1080 would have leached from baits; (2) 1080 baits do not always fall into streams flowing in operational areas. Notwithstanding this lack of positive tests for 1080 in water, and despite assertions that 1080 represents a low risk to aquatic ecosystems, no studies have looked at its effect on New Zealand aquatic invertebrate or fish communities.

Very few freshwater animals would directly consume 1080 baits. Most native fish are predators, consuming aquatic insects, snails and worms, or terrestrial invertebrates that fall into streams (Main & Lyon 1988; McDowall 1990). As such, these animals are highly unlikely to consume 1080 baits. Eels (*Anguilla* spp.) have a more opportunistic diet, consisting of both living and dead food items that they may encounter (Jellyman 1989), but recent investigations have shown that they show no inclination to consume baits (Lyver et al. 2005). Most freshwater invertebrates are far too small to consume 1080 baits, and so are very unlikely to be at risk from 1080 poisoning. Freshwater crayfish, or koura, however, are likely to consume 1080 baits; indeed commercial crayfish growers use artificial protein-based baits as crayfish food.

New Zealand has two species of freshwater crayfish, *Paranephrops planifrons* and *P. zealandicus*. *P. planifrons* is found in the North Island, and in the north and west of the South Island, and *P. zealandicus* is found in the east of the South island and on Stewart Island (McDowall 2005). These animals are very common throughout New Zealand and are an important traditional food source to Maori (Hiora 1921; Whitmore & Huryn 1999). They are found in streams draining both pasture and forested catchments (Parkyn et al. 2002), and are omnivores, consuming a wide variety of plant material, as well as aquatic insects (Parkyn et al. 2001). The stomach contents of crayfish living in streams flowing under native forest are often dominated by leaf detritus, which makes up more than 60% of food consumed (Parkyn et al. 2001). Crayfish are thus likely to consume 1080 baits in streams, which may expose them to potentially lethal doses of 1080.

There is limited information about the lethal effects of 1080 on aquatic invertebrates. For example, the United States Environmental Protection Agency has performed toxicity tests on the small freshwater invertebrate *Daphnia magna* (Fagerstone et al. 1994), but no studies have yet quantified the toxicity of 1080 to New Zealand freshwater invertebrates. The aim of the present study was to assess whether *P. planifrons* consumed 1080 baits when also in the presence of their natural food source of detritus and aquatic invertebrates, and whether such ingestion resulted in mortality. The study also assessed whether residual 1080 remained in crayfish muscle and gut viscera after exposure to 1080 baits. This has important implications from a human health perspective given the traditional use of freshwater crayfish as a food source.

MATERIALS AND METHODS

Experimental setup

An outdoors "stream simulator" consisting of a 5 m long × 1 m wide × 0.2 m deep riffle section, and a 3.5 m long × 3 m wide × 1 m deep pool was used for the experiment. Use of a riffle and pool section reflected the fact that crayfish live in both habitats, but that the fate of baits falling in each habitat may differ greatly. For example, baits landing in riffles may fragment and wash away quickly, whereas baits landing in pools may take longer to break down. Crayfish foraging behaviours may also differ between these contrasting habitats. Riffles and pools thus represented areas of different probabilities for crayfish to be exposed to bait.

Up to 5 litres s^{-1} of natural, untreated water (pH = 7.6, conductivity = 138 μS cm^{-1}) from artesian bores located on the NIWA Christchurch campus was delivered to the head of the simulator, where it flowed through the simulator before being discharged to the reticulated sewer system. Mean velocity in the riffle section was between 15 and 20 cm s^{-1}, and in the pool <3 cm s^{-1}. This system approximated a natural stream environment and prevented accumulation of

1080 leaching from baits, as it would have done if the experiment had been conducted in small aquaria. Twenty-five small replicate cages (60 cm long × 18 cm wide × 35 cm high) were constructed from wire mesh (mesh size = 15 mm) and placed into each habitat type. Gravel and small cobbles were placed in the bottom of each cage to a depth of 15 cm. Small plastic PVC pipes and cobbles were also placed in each cage to provide shelter. Cages were covered with fine mesh netting to prevent crayfish escaping.

Crayfish, stream-dwelling invertebrates and leaf litter were collected from streams on the South Island's west coast, and transported to Christchurch within 4 h in chilled bins. Only large crayfish (min. carapace length = 24 mm) were selected, as these are most likely to be consumed by humans. Individual crayfish, along with samples of invertebrates and leaf litter (c. 60 g wet weight) were placed into each cage and left for 4 days to acclimate. Additional (preconditioned) leaf material and new invertebrates (held in separate aquaria) were added on days 3 and 6 to each cage to ensure that food limitation did not occur. A further five crayfish were placed separately in aerated aquaria in a constant temperature room (18°C, 12 h day:night photoperiod) to act as double controls to ensure that crayfish were not originally contaminated with 1080, and to ensure that no mortality occurred as a result of transport and handling.

After 4 days, a single 1080 bait (Wanganui No. 7, mean weight = 6.4 g) containing c. 0.15% 1080 (i.e., 9.6 mg) was added to each of 40 randomly allocated experimental cages (20 each in the riffle and pool) at 1830 h on 24 November 2003, 2 h before sunset. This time was chosen as crayfish are nocturnal feeders and so would become more mobile after sunset, increasing the chance of coming into contact with baits. This represented a "worst-case" scenario, as most baits would have been dropped well before sunset during normal 1080 operations. As such, this experiment maximised the concentration of 1080 found within baits offered to individual crayfish, especially as 1080 is rapidly leached from baits (Suren 2006). Baits were added to each cage by sliding them down a length of PVC pipe placed under water in the middle of each cage with the end of the pipe just above the gravel substrate. This was done to minimise the chance of baits being washed away from each cage. Although most baits remained where they were initially positioned, a few in the riffle section were washed to the downstream ends of the cages where they were trapped by the mesh. Non-toxic cereal baits were added to the remaining 10 control cages (5 each in the riffle and pool) by the same method. Animals fed these baits would thus only be exposed to dissolved 1080 that had leached from other baits, and presence of 1080 in these animals could thus only have occurred through absorption of dissolved 1080. Observations were made at regular intervals (8 h, 14 h, 24 h, 38 h, 86 h and 160 h) to assess whether crayfish had consumed baits.

Crayfish were monitored daily for mortality. Five animals were collected randomly from experimental cages in both habitats after 1, 2, 4, and 8 days and humanely killed by freezing. Crayfish in the control cages in the riffle and pool, as well as the double controls placed in the aerated aquaria were collected after 8 days and killed by freezing. Duplicate water samples were collected at the outflow of the simulator at the same time as the crayfish for analysis of dissolved 1080 concentration using the gas chromatography method TLM 005 (Landcare Research; Lyver et al. 2005). The limit of detection was 0.001 μg ml^{-1} (0.1 ppb).

All animals were kept at –20°C until processed. Animals were weighed (± 0.1 g wet weight) and their carapace lengths (rostrum to the end of the carapace) measured using digital calipers (± 0.1 mm length). Their viscera (e.g., stomach, intestine, and hetatopancreas) and tail muscles were dissected and analysed for residual 1080 (AgriQuality National Chemical Residue Laboratory). In the laboratory, 1080 was extracted and quantified using a modification of the method developed by Ozawa & Tsukioka (1989), with the key modification being the use of GC-MS detection. All 1080 concentrations (μg g^{-1} wet weight) were calculated for the separate viscera and tail muscles for each crayfish. The limits of detection were 0.005 μg g^{-1} for crayfish viscera, and 0.010 μg g^{-1} for crayfish tails. The reduced detection limit for tails was only estimated, as there were high concentrations of free acids (lactic, pyruvic, and formic) in the tissue matrix, so samples had to be diluted (up to 40×) to achieve sufficient chromatographic resolution to enable easy differentiation of these products from fluoroacetate.

Statistical analysis

All data were examined for normality by normal probability plots (Zar 1984), $\log_e$ (x+0.1) transformed where necessary and analysed by general linear model (GLM) using the R statistical package (Crawley 2005; Venables & Smith 2004). The

GLM model was used with two categorical predictor factors: poison treatment (i.e., crayfish fed control baits and baits containing 1080 after 1, 2, 4, and 8 days) and habitat (i.e., pool or riffle). Crayfish weight (at the end of the experiment) was used as a continuous co-variate predictor, and we investigated all possible interaction terms between this and the categorical predictor variables, as these interactions were of potential biological interest. A significance level of $P < 0.05$ was selected for all tests, and all data reported as $\bar{x} \pm 1$ SE, unless otherwise stated. Where significant interaction effects in the GLM model were observed, linear regression analysis (Zar 1984) (SPSS 2000) was used to determine the days on which weight had a significant effect on 1080 concentrations. Linear regression analysis was also used to determine whether there was a relationship between 1080 concentration in the muscle and the viscera.

RESULTS

Of the 20 toxic baits placed in cages in the riffle habitat, 6 were not visible 8 h after placement, whereas 3 of the 20 were not visible in the pool habitat. After 14 h, an additional 8 baits were seen either in or close to the PVC pipes in the riffle habitat, whereas 5 were seen in or close to the shelters in the pool habitat. Considering that baits were originally placed away from these pipes, their location in or close to pipes most likely reflects crayfish activity. After 38 h, an additional six and five baits had been moved close to the pipes in the cages placed in the riffle and pool habitats, respectively. This meant that after 36 h, all 20 crayfish in the riffle habitat had

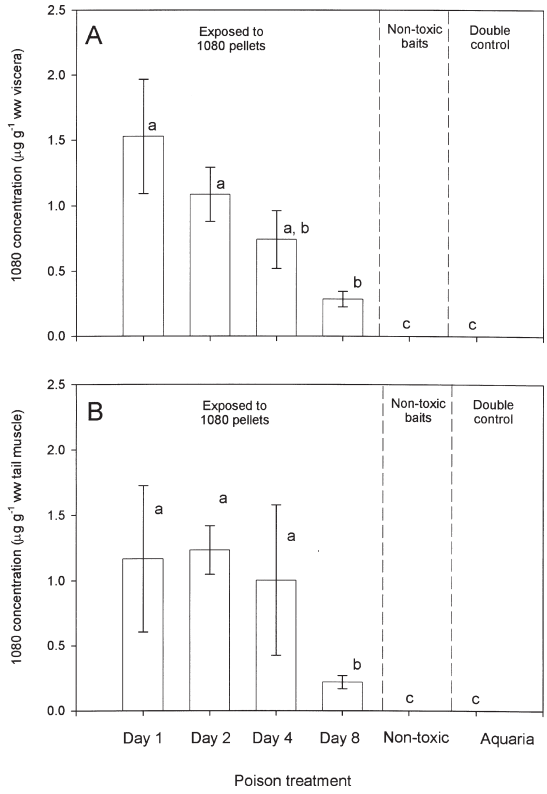

Fig. 1 Average concentration ($\bar{x} \pm 1$ SE, $n = 10$ or $n = 5$ for double control) of residual 1080 found in: **A**, viscera; and **B**, tail muscle (μg g^{-1} wet weight (ww)) of individual *Paranephrops planifrons* placed in cages in pools and riffles in a stream simulator, and which were exposed to 1080 baits for varying lengths of time. Bars with the same letter above are not significantly different from each other ($P < 0.05$).

Table 1 Results of general linear model analysis showing relationships between 1080 concentration in the viscera and poison treatment (control group—fed non-toxic baits; impact group—fed 1080 baits; and analysed after 1, 2, 4, and 8 days), habitat type (riffle or pool), weight (as covariate) and appropriate interaction terms. Values in bold are significant.

Model effect	Mean squares	d.f.	Sums of squares	*F* ratio	*P*
Weight	0.988	1	0.988	3.142	0.086
Poison treatment	9.942	4	39.767	31.615	**0.000**
Habitat	0.122	1	0.122	0.388	0.538
Weight × Treatment	1.031	4	4.123	3.278	**0.024**
Weight × Habitat	0.759	1	0.759	2.414	0.131
Habitat × Treatment	0.391	4	1.565	1.244	0.314
Weight × Habitat × Treatment	0.189	4	0.755	0.600	0.665
Residual	0.314	30	9.434		

moved their baits. After 86 h, only three more baits in the cages in the pool section had been moved next to the pipes, giving a total of 16 baits that were moved in the pool habitat.

No mortality was observed during the study, despite evidence that crayfish had consumed some of the baits. This evidence was first observed in some of the dissected viscera, which contained distinctly green fragments of the cereal baits. This observation was also supported by analysis of crayfish viscera, which revealed that 1080 was present in all crayfish exposed to the toxic baits (Fig. 1). The highest concentration of 1080 found in the viscera was 3.3 μg g^{-1}, in a medium sized individual (body weight = 25.5 g) collected 1 day after the introduction of baits. This equated to a total of 8.9 μg of 1080 in the viscera (weight = 2.7 g) of this crayfish. There was a significant effect of poison treatment (Table 1), with 1080 in crayfish viscera declining in concentration over time (Fig. 1). No 1080 was detected in animals exposed to non-toxic baits only, or to those in the aquaria. There was no difference between 1080 loadings in crayfish placed in pools or riffles (Table 1). There was no significant effect of crayfish weight on 1080 concentration in the viscera, although there was a significant interaction between crayfish weight and poison treatment and 1080 concentration in the viscera (Table 1). This interaction term suggested that over the entire data set, large animals incorporated more 1080 into their viscera than small animals. Examination of individual regressions of crayfish weight and 1080 concentration in the viscera each day showed significant relationships on day 2 and day 4 only (Fig. 2).

Crayfish tail muscle contained 1080, with the highest concentration (5 μg g^{-1}) found in a large individual (body weight = 59 g) in the pool habitat 4 days after baits were placed. This concentration equated to a total of 66 μg of 1080 in the tail muscle, which weighed 13.2 g. There was no significant difference in the concentration of 1080 in muscle tissue in animals placed in either pools or riffles (Table 2). There was a significant effect of poison treatment in the concentration of 1080 in the tail muscle (Table 2). This was highest in animals collected after 1, 2, and 4 days, and decreased in animals after 8 days (Fig. 1). Again, no 1080 was detected in animals fed either non-toxic baits, or in the aquaria. No significant effect of crayfish weight and 1080 concentration in the tail muscle was observed, although there was a significant interaction between crayfish weight and poison treatment (Table 2), suggesting that large animals incorporated more 1080 in their tail muscle than small animals. Regression analysis of 1080 concentration against weight showed a significant positive relationship only on day 4 of the experiment (Fig. 2).

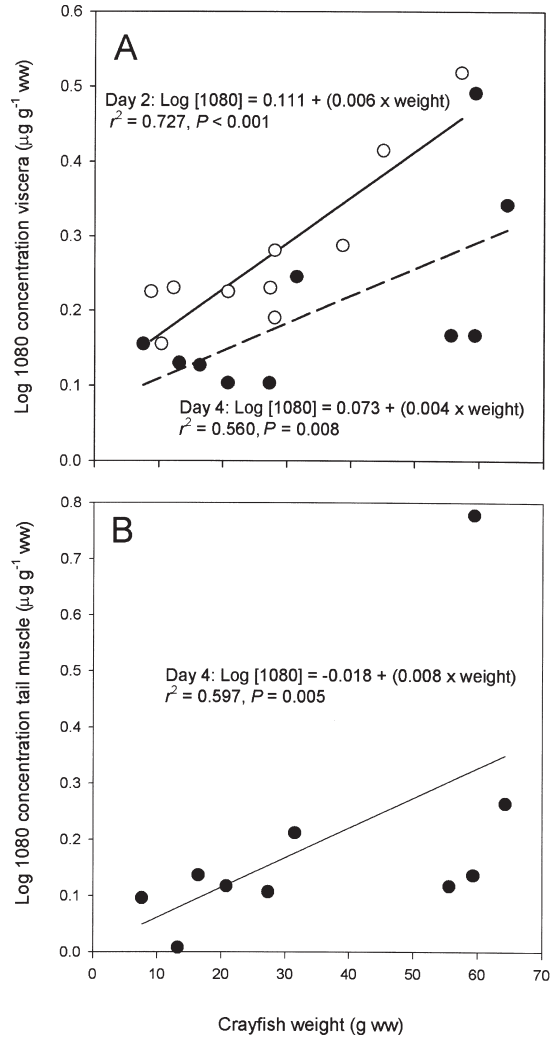

Fig. 2 Relationships between weight of crayfish (g wet weight (ww)) and: **A**, 1080 concentration in the viscera of animals in pools and riffles after 2 (open circles) and 4 (closed circles) days; and **B**, 1080 concentration in the tail muscle of animals in pools and riffles after 4 days (n = 10).

The amount of 1080 found in the muscle was significantly related to the amount found within the viscera (Fig. 3). The slope of the regression line was close to unity (0.82), suggesting that much of the ingested 1080 was absorbed into the tail muscle tissue.

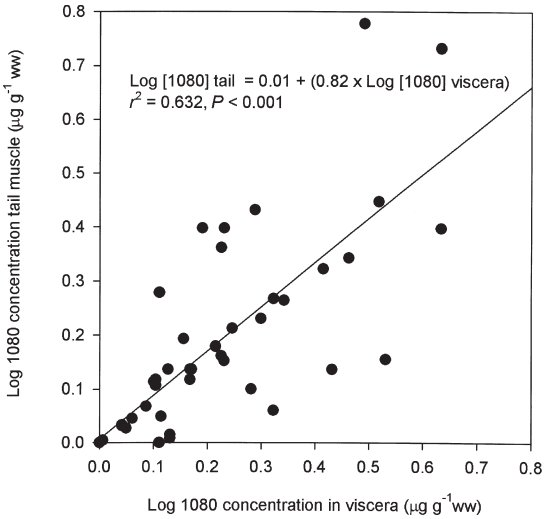

Fig. 3 Overall relationship between 1080 concentrations (μg g^{-1} wet weight (ww)) found in the viscera and tail muscle of *Paranephrops planifrons* exposed to 1080 baits.

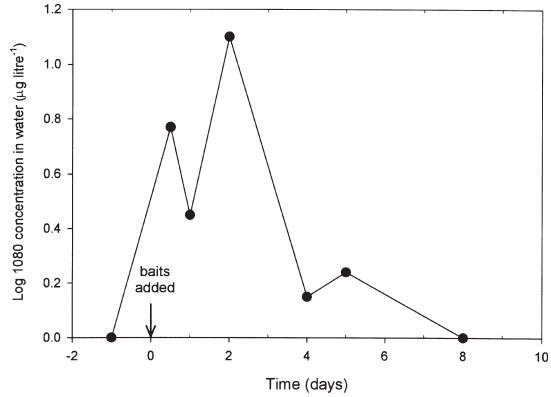

Fig. 4 Concentrations of 1080 found in water flowing from the stream simulator before, and during the experiment after 1080 baits were added.

Table 2 Results of general linear model analysis showing relationships between 1080 concentration in crayfish tails and poison treatment (control group—fed non-toxic baits; impact group—fed 1080 baits; and analysed after 1, 2, 4, and 8 days), habitat type (riffle or pool), weight (as covariate) and appropriate interaction terms. Values in bold are significant.

Model effect	Mean squares	d.f.	Sums of squares	*F* ratio	*P*
Weight	0.915	1	0.915	1.894	0.179
Treatment	7.988	4	31.951	16.539	**0.000**
Habitat	0.037	1	0.037	0.077	0.784
Weight × Treatment	2.479	4	9.917	5.133	**0.003**
Weight × Habitat	1.034	1	1.034	2.141	0.154
Habitat × Treatment	0.405	4	1.620	0.839	0.512
Weight × Habitat × Treatment	0.342	4	1.366	0.707	0.593
Residual	0.483	30	14.489		

The stream simulator was designed to run on a flow-through system, to minimise accumulation of 1080, and replicate a natural situation. Analysis of water samples collected for 1080 analysis showed that the 1080 concentration in the water was very low, and varied throughout the experiment. The highest concentration (1.1 μg litre^{-1}) was reached after 2 days, and no residual 1080 was detected after 8 days (Fig. 4).

DISCUSSION

Baits placed in each cage could have disappeared as a result of having fragmented, being consumed, or being moved into the small PVC shelters in each cage. Suren (2006) showed that Wanganui No. 7 baits lost up to 40% of their dry weight after 48 h, and 80% after 72 h in a laboratory flow tank with a water velocity of 20 cm s^{-1}. This velocity was similar to that of the riffle habitat in the stream simulator. Disappearance of nine baits after only 6 h in both habitats was thus unlikely owing to bait fragmentation, but instead most likely reflected crayfish moving baits into their shelters, or partially consuming them.

The results of this experiment showed that the native crayfish *Parenephrops planifrons* consumed 1080 baits in the stream simulator, suggesting that they could also consume baits falling into streams during aerial application operations. All animals

exposed to 1080 baits consumed at least some material, and accumulated some 1080 in their body tissue. Several baits disappeared within a relatively short time-frame (within 8 h after being added), presumably as a result of consumption and possible fragmentation, and other baits had clearly been moved. Bait consumption and/or movement occurred even in the presence of alternative food sources (detritus and invertebrates) in each cage, suggesting that 1080 baits are an acceptable food item to crayfish. The high amount of 1080 found in the tail muscle after 1 day suggests that 1080 was absorbed very quickly in crayfish and incorporated into their body tissues.

Despite bait consumption, no mortality was observed during the study. The highest total 1080 concentration (i.e., viscera + muscle tissue) in crayfish (7.7 μg g^{-1} or 134 μg in total) came from a small individual (body weight = 17.4 g) placed in the riffle habitat, and sampled 1 day after addition of baits. Another larger individual (body weight = 59.4 g) placed in the pool and sampled 4 days after addition of baits also had a very high 1080 concentration (7.1 μg g^{-1} or 422 μg in total). The mean weight of the baits used in the study was 6.4 g, which is equivalent to 9600 μg of 1080 per bait (assuming a 0.15% 1080 concentration in the baits). This means that these two crayfish had accumulated less than 5% of the total 1080 potentially available within baits, implying that they had not consumed an entire bait. It is not known whether crayfish in natural conditions would consume entire baits, but the data gleaned from this study suggests that this may be unlikely, given the low concentrations of 1080 found within individuals. Overall uptake of 1080 by crayfish will also be affected by the amount of 1080 leaching from baits. Suren (2006) found that 1080 leached rapidly from intact Wanganui No. 7 baits, with over half disappearing after 5 h. Animals consuming baits over a period longer than this would thus be consuming proportionally smaller amounts of 1080. Thus even if an entire bait were consumed over a 24-h period, the amount of 1080 present in the remaining bait would be decreasing with time. As such it is considered unlikely that crayfish would die under natural conditions from consuming baits that fall in streams.

That no lethal effects were observed may also suggest that the lethal dose for crayfish is relatively high. In a summary of 1080 research, Green (2003) lists the oral toxicity (as LD_{50} values wet weight) of 1080 to 17 different animal species. Mallard ducks (*Anas platyrhynchos*) and the New Zealand weka (*Gallirallus australis*) had laboratory derived LD_{50} values of 7.1 and 8.0 μg g^{-1} body weight respectively, similar to concentrations observed in some crayfish. These two birds were some of the least sensitive species tested, and much less sensitive to 1080 than many mammal species, which have a range of LD_{50} values from dogs (the most sensitive at 0.07 μg g^{-1} body weight) to the Norway rat (*Rattus norvegicus*), the least sensitive mammal tested to date (LD_{50} of 3.0 μg g^{-1} body weight). The susceptibility of a specific animal to 1080 is linked to its metabolic rate (McIlroy 1994), so cold-blooded crayfish are likely to have a much higher LD_{50} than so-called least-sensitive animals such as Mallard ducks or weka, as their metabolic rate is likely to be much lower.

Concentration of 1080 in the viscera and tail muscle decreased over time, and decreased by a factor of five after 8 days. When 1080 is consumed in sub-lethal amounts by animals, it is often excreted in the unchanged form, or in a range of non-toxic metabolites (Eason et al. 1993; Eason 2002). The declining quantity of 1080 in the crayfish over the 8-day period suggests that crayfish similarly metabolised or excreted 1080. This excretion may help explain some of the apparently anomalous results of the water-sampling programme. Here, the concentration of 1080 initially increased in the first 12 h, and then decreased. This first peak in concentration most likely reflected the initial rapid leaching of 1080 from baits in the water. The second peak of 1080 in the water occurred after 48 h, long after any 1080 would have dissolved from the baits (Suren 2006). However, this residual pulse of 1080 may have come from crayfish excreting it unaltered after they had consumed it.

The 1080 concentrations measured in water were fairly low (up to 1.1 μg litre^{-1}), and were under half of the Ministry of Health guideline concentrations for human health (2 μg litre^{-1}: Green 2003). These low concentrations of 1080 in the water had no detectable adverse effects on crayfish. The control crayfish that were fed the non-toxic baits also contained no detectable 1080 in their viscera or tail muscle after 8 days, despite being exposed to low concentrations of dissolved 1080. Lack of detectable 1080 in these control animals suggests that the 1080 accumulation observed in crayfish arose only from direct consumption of 1080 baits, and not by absorbing the dissolved compound. This finding has important implications, as it suggests that dissolved 1080 is unable to cross into crayfish bloodstreams from the gills, or be absorbed through

the exoskeleton. As such, crayfish living in streams that have become contaminated with 1080 will not incorporate this into their body, unless they consume baits.

Ecological implications

The results of this study confirmed that crayfish readily consume 1080 baits, even in the presence of other food sources. This consumption resulted in rapid accumulation of 1080 in their body tissue. However, crayfish appeared tolerant to 1080, with no lethal effects observed even with 1080 concentrations up to 7.7 μg g^{-1} body weight. All animals exposed to 1080 baits had consumed at least some of them; nonetheless the quantity of 1080 assimilated by the crayfish was <5% of the 1080 within the bait. Whether this reflected consumption of only a small proportion of bait, or the rapid leaching of 1080 from the baits during the first night (Suren 2006) is not known. It may be possible that under natural conditions, crayfish may consume more of an individual bait, or more than one bait. This is especially true if more than one bait is found within a crayfish's home territory. The number of baits that a crayfish could theoretically consume depends on its overall consumption rate, its home range, and the number of baits that could land in this home range. Parkyn (2000) studied crayfish populations in streams draining native forest near Hamilton over a 20-month period by repeated seasonal electric-fishing of 6–8 m long sections of stream. On each sampling occasion, all crayfish caught were marked and released at the same location. Although some crayfish were never recaptured, many did not significantly change their location over the short term (3–6 months). This finding suggests that some crayfish may have relatively small home ranges (up to 8 linear metres) and would be unlikely to move a great distance.

Surveys of aerial 1080 operations have shown that baits fall in small streams where buffer zones had not been imposed (Suren 2006). Analysis of data gleaned from these stream surveys showed that the greatest density of baits observed within a nominal crayfish home range of 8 m was seven 7 g baits (Suren unpubl. data). The average density observed in these stream surveys was around three baits per 8 m of crayfish home range. Whether crayfish are likely to consume >1 bait in their home range, and whether such consumption is enough to cause mortality, is unknown. However, given that we observed only relatively small amounts of bait consumption after 1 day, and that most or all of the 1080 would have leached from baits after 24 h, the chances of direct crayfish mortality arising from bait consumption appears negligible.

Baits were placed in the simulator at 1830 h, and sunset was at 2040 h. Baits had been in the water for c. 2 h before crayfish were likely to have become active, representing a worst-case scenario. The first observation of crayfish behaviour in the simulator was made at 1 h after sunset, when 12 animals were actively moving around their cages. Nineteen animals were observed moving at 0500 h the following day. Given that 1080 rapidly leaches from baits within the first 8–12 h (Suren 2006), it is assumed that most of the observed uptake of 1080 into the viscera and muscle tissue came from individuals that consumed the bait during the first night of the experiment. This scenario is likely to occur if accidental contamination of streams by 1080 baits occurs shortly before nightfall, meaning that any foraging crayfish may encounter baits which have not leached much of their 1080. A more likely scenario occurring during actual aerial operations would see baits lying in streams for some time before crayfish became active and found them. Considering the rapid leaching rate of 1080 from submerged baits, the risk of poisoning of crayfish would diminish with increasing time. If crayfish are common in streams within an operational area, an obvious approach to mitigate potential adverse effects of baits on crayfish would be to ensure that these streams are flown over during the early part of the day.

Another ecological implication of this study concerns the possibility that predators may kill and consume contaminated crayfish, and be susceptible to secondary poisoning. The main predators of crayfish are eels, trout and humans; predatory birds (e.g., kingfishers, shags, and hawks) and dogs are unlikely to consume these shy, generally nocturnal creatures that dwell amongst cover in streams. The LD_{50} for humans is 2.5 μg g^{-1} body weight (Eason 2002). The maximum concentrations of 1080 found in crayfish in this study (7.7 and 7.1 μg g^{-1}) came from individuals that weighed 17.4 g and 59.4 g respectively, which could be considered to be small-medium in size. These animals would have contained 134 μg and 422 μg of 1080, respectively. To receive a lethal dose of 1080, an 85 kg adult human would have to consume a total of 212 500 μg of 1080. Such an amount could theoretically be found within the bodies of 1585 of the smaller 17.4 g crayfish, or 504 of the large 59.4 g ones, if the viscera were consumed with the flesh. This scenario is not particularly relevant, as viscera is not consumed. A

more realistic scenario involves consumption of the tails only. Under such a scenario, a total of 2840 of the small crayfish, or 720 of the larger ones need to be consumed to receive a lethal dose. This equates to consuming in excess of 40 kg of crayfish at one sitting—an obvious impossibility.

There is great public concern over 1080 and its use in the environment (e.g., Livingstone 1994; Williams 1994; Hansford 2002; Laugesen & Hubbard 2002; McCurdy 2002). Given the possible (albeit very low) contamination of freshwater crayfish by 1080, and their potential as a food source for humans, it may be prudent to further minimise any risk of humans eating contaminated crayfish. Although the consequences of this are negligible, potential risks could be further minimised by placing warnings advising the public against consumption of crayfish caught within the operational area. These warnings would only need to apply for a few weeks at the most, as 1080 is unlikely to persist in crayfish tissues for more than this time.

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