Ecotoxicology and Environmental Safety 113 (2015) 1–8

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

journal homepage: www.elsevier.com/locate/ecoenv

Residue profiles of brodifacoum in coastal marine species following an island rodent eradication

Bryce M. Masuda [a,*], Penny Fisher [b], Brent Beaven [c]

[a] Department of Zoology, University of Otago, PO Box 56, Dunedin 9054, New Zealand
[b] Landcare Research, PO Box 69040, Lincoln 7640, New Zealand
[c] Department of Conservation, Stewart Island Field Centre, PO Box 3, Stewart Island, New Zealand

ARTICLE INFO

Article history:
Received 20 August 2014
Received in revised form
15 November 2014
Accepted 19 November 2014
Available online 28 November 2014

Keywords:
Anticoagulant rodenticides
Invasive species management
Marine harvest
Monitoring
Secondary exposure

ABSTRACT

The second-generation anticoagulant rodenticide brodifacoum is an effective tool for the eradication of invasive rodents from islands and fenced sanctuaries, for biodiversity restoration. However, broadcast application of brodifacoum bait on islands may expose non-target wildlife in coastal marine environments to brodifacoum, with subsequent secondary exposure risk for humans if such marine wildlife is harvested for consumption. We report a case study of monitoring selected marine species following aerial application of brodifacoum bait in August 2011 to eradicate Norway rats (*Rattus norvegicus*) from Ulva Island, New Zealand. Residual concentrations of brodifacoum were detected in 3 of 10 species of coastal fish or shellfish sampled 43–176 d after bait application commenced. Residual brodifacoum concentrations were found in liver, but not muscle tissue, of 2 of 24 samples of blue cod (0.026 and 0.092 μg/g; *Parapercis colias*) captured live then euthanized for tissue sampling. Residual brodifacoum concentrations were also found in whole-body samples of 4 of 24 mussels (range=0.001–0.022 μg/g, $n=4$; *Mytilus edulis*) and 4 of 24 limpets (range=0.001–0.016 μg/g, $n=4$; *Cellana ornata*). Measured residue concentrations in all three species were assessed as unlikely to have eventually caused mortality of the sampled individuals. We also conducted a literature review and determined that in eleven previous accounts of residue examination of coastal marine species following aerial applications of brodifacoum bait, including our results from Ulva Island, the overall rate of residue detection was 5.6% for marine invertebrates (11 of 196 samples tested) and 3.1% for fish (2 of 65 samples tested). Furthermore, our results from Ulva Island are the first known detection of brodifacoum residue in fish liver following an aerial application of brodifacoum bait. Although our findings confirm the potential for coastal marine wildlife to be exposed to brodifacoum following island rodent eradications using aerial bait application, the risk of mortality to exposed individual fish or shellfish appears very low. There is also a very low risk of adverse effects on humans that consume fish or shellfish containing residual concentrations in the ranges reported here. Furthermore, any brodifacoum residues that occur in marine wildlife decline to below detectable concentrations over a period of weeks. Thus potential human exposure to brodifacoum through consumption of marine wildlife containing residual brodifacoum could be minimized by defining 'no take' periods for harvest following bait application and regular monitoring to confirm the absence of detectable residues in relevant marine wildlife.

1. Introduction

Anticoagulant rodenticides (ARs) inhibit the formation of blood coagulation factors in the liver, resulting in uncontrolled haemorrhaging and eventually death (Silverman 1980; Suttie 1985). The second-generation anticoagulant rodenticides in common use today are more persistent in animal tissue, particularly liver, than first-generation ARs (Hadler and Buckle 1992; Fisher et al., 2003). Second-generation ARs are currently used by many countries for rodent management in agricultural production and public health settings (Albert et al., 2010; Sage et al., 2010). Increasingly, such uses are attributed to residual AR concentrations in non-target wildlife, with a monitoring focus on secondary exposure of predatory and scavenging species (Tosh et al., 2012; Jacquot et al., 2013; Langford et al., 2013; Thompson et al., in press).

Specialised, large-scale broadcast bait applications of the second-generation AR brodifacoum for eradication of invasive rodents

* Corresponding author.
E-mail address: bryce.masuda@otago.ac.nz (B.M. Masuda).

http://dx.doi.org/10.1016/j.ecoenv.2014.11.013
0147-6513/

from islands and fenced sanctuaries (Parkes et al., 2011) have been fundamental to significant successes in island biodiversity restoration (Dunlevy et al., 2011; Towns et al., 2013). Such applications also create the potential for unwanted exposure of non-target wildlife to brodifacoum through ingestion of bait (i.e. primary exposure) or ingestion of other animals containing residual concentrations of brodifacoum (i.e. secondary exposure). Brodifacoum has broad-spectrum toxicity to mammals and birds because of the common mode of action of ARs in reducing formation of blood coagulation factors in liver. Less information is available about the toxicity of brodifacoum to invertebrates but they are considered less susceptible to ARs (Pain et al., 2000; Brooke et al., 2011, 2013). Even if exposure of non-target wildlife to brodifacoum is insufficient to cause mortality, any exposure is undesirable because movement of residual brodifacoum through food webs may contaminate species that are eaten by humans, or other wildlife of high conservation status (e.g. Eason et al., 1999; Dowding et al., 2006).

Monitoring undertaken after application of brodifacoum bait for island rodent eradication has detected residues in terrestrial birds (e.g. Masuda et al., 2014), insects (e.g. Ogilvie et al., 1997), and molluscs (e.g. Morgan et al., 1996). The terrestrial focus has probably reflected perceived risk. Compared with terrestrial organisms, marine species may be at low risk of being exposed (Empson and Miskelly, 1999), due to rapid disintegration of pellet bait in water and the low quantities which are expected to reach the coastal marine environment (Howald et al., 2010; Fisher et al., 2011). However, the imperative to achieve complete and consistent bait coverage of all rodent home ranges on an island, including those at the tide line, may conflict with the technical capacity to prevent some aerially-applied baits entering the ocean (Engeman et al., 2013). For example, following aerial application of brodifacoum bait on Palmyra Atoll, bait pellets were observed up to 7 m below the high tide line at 19.1% of the target density, despite the use of a deflector intended to limit pellet distribution to only above the high tide line (Pitt et al., 2012; Engeman et al., 2013). Even if bait can be completely prevented from entering the ocean, aquatic marine wildlife might be secondarily exposed to brodifacoum through consumption of other animals that ingested bait on land but then entered the ocean (e.g. crabs, carcasses of poisoned rodents).

Here we report the results of monitoring of coastal marine wildlife undertaken following an island rodent eradication. We determined the scope and extent of brodifacoum exposure following an aerial application to eradicate Norway rats from Ulva Island, New Zealand. We assessed whether exposure was likely to have been lethal or sub-lethal, and conducted a literature review to compare the methodology and results from our case study on Ulva Island to previous studies. We also determined the risk of secondary poisoning to humans who may consume coastal marine species.

2. Methods

2.1. Case study

In December 2010, invasive Norway rats (*Rattus norvegicus*) established a population on Ulva Island (267 ha), Stewart Island, New Zealand, which was previously predator free (Masuda and Jamieson, 2013). Cereal pellet baits containing 20 mg/kg brodifacoum (Pestoff 20R, Animal Control Products, New Zealand) were aerially applied on two occasions (18 August and 20 September 2011), at a total combined rate of 11.5 kg of bait per hectare across the entire island in an attempt to eradicate the rat population. For bait application around the coastline, a deflector was attached to the bait distribution hopper in an attempt to limit bait from directly entering the ocean.

At 43, 48, 77, 176, and 274 d following the first aerial bait application on Ulva Island, we tested for residual concentrations of brodifacoum in common coastal marine fish and shellfish, including species often harvested for human consumption: blue cod (*Parapercis colias*), mussels (*Mytilus edulis*), pāua/abalone (*Haliotis iris*) (Table 1). Initially, samples were collected at 43 d following the first application, although pipi/infaunal bivalve (*Paphies australis*) were collected at 48 d. Selection of the initial sampling timepoint was based on instances where previous monitoring of shellfish had detected residual brodifacoum following aerial bait application (Vestena and Walker, 2010, Table 3). Subsequent sampling was only conducted for species in which brodifacoum was previously detected, and was conducted at approximately double the number of days from the previous interval. Sampling of a species was stopped after residual concentrations of brodifacoum were no longer detectable. Divers collected sedentary species, and fish were collected by hook and line fishing. Sedentary species were killed by freezing and fish by cervical dislocation. Samples were taken in equal proportions from three randomly chosen locations on the west, southeast and north coasts of the island, at distances ranging from 1 m to approximately 50 m from the shoreline. Samples within each site were collected randomly, to account for possible variability between depth, water movements, and substrate. Samples were frozen within 5 h of collection, and transported to the Landcare Research toxicology laboratory (Lincoln, New Zealand) where they were stored at -20 °C before being defrosted for dissection of tissues just before testing. The testing of dead animals following humane killing is not regulated and therefore does not require Animal Ethics Committee approval. A collection permit was obtained from the New Zealand Ministry of Fisheries.

The entire liver and subsamples of muscle tissue (c. 10 g) were taken from each fish, with muscle dissected to simulate a small 'fillet' cut. Intact whole-of-body soft tissues were taken from each shellfish although testing of each individual animal collected was not possible due to budgetary constraints and because some individual shellfish, particularly limpets, were too small to provide a sufficient sample quantity that would allow replicated analysis if required. Tissues (whole fish livers, cuts of fish muscle or whole bodies of shellfish) from groups of individuals of the same species and sampling date were combined and homogenised to make a composite sample to prepare for analysis (Table 1). As a result, we report the estimated residue level per individual (i.e. residue level after dividing it by the number of animals per composite sample). All samples were analysed for brodifacoum concentration using high performance liquid chromatography with fluorescence detection and a post-column pH switching technique as described by (Primus et al., 2005). Difenacoum was used as an internal standard with an analytical detection limit of 0.001 μg/g, and uncertainty (95% CI) of $\pm 6\%$.

2.2. Literature review

To compare our results with other monitoring of marine wildlife following the aerial application of brodifacoum bait to eradicate rodents, we reviewed the literature using the search terms 'brodifacoum' and 'marine' in Web of Knowledge (http://apps.webofknowledge.com), as well as 'brodifacoum in marine species' and 'brodifacoum in marine environment' in Google Scholar, April 2014. We also searched the New Zealand Department of Conservation database for additional records of monitoring in the marine environment following aerial brodifacoum applications, as well as citations in relevant articles and reports for any additional studies. We excluded monitoring results from