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Nontarget Risk and Environmental Fate of the Broadcast Application of a Diphacinone Rodenticide at Mōkapu and Lehua Islands, Hawai'i

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ABSTRACT: Invasive commensal rodents such as *Rattus* spp. and *Mus* spp. imperil many threatened and endangered native species including plants, invertebrates and birds within Hawai'i and U.S. territories and possessions in the Pacific. In some cases, the eradication or control of invasive rodents could allow natural recovery and active restoration of native species and ecosystems negatively impacted. The broad scale application of rodenticides is a necessary management tool for this purpose, but it is highly controversial to the public and regulatory agencies. There is great perceived and actual risk of nontarget mortality and environmental contamination. One of the conservation uses of rodenticides registered in Hawai'i is the aerial broadcast of rodenticide bait over large areas of native ecosystems on the main Hawai'ian islands, repeated periodically to maintain reduced rodent population levels. Recognizing that the success of this program depends on public and regulatory support, a coalition of state and federal agencies and private landowners have carefully designed Hawai'i's rodent control program to minimize short- and long-term environmental impacts. In the early 1990s, diphacinone was selected as the primary rodenticide for conservation uses in Hawai'i because of its long track record of safe and effective use in agriculture worldwide. Hawai'i's program has 5 components: research on efficacy and environmental impacts, regulatory compliance, developing and using local technical expertise, monitoring of rodenticide impacts and native species recovery and public outreach and engagement, particularly at the community level. After many years of generating the efficacy and safety data in support of regulatory approval by the U.S. Environmental Protection Agency (EPA) and the State of Hawai'i, a diphacinone product (Diphacinone-50, Hacco, Inc., Randolph, WI) was approved in 2007 for conservation uses in the U.S. Subsequently, rodenticide pellets containing the active ingredient diphacinone at 0.005% (50 ppm) were broadcast by helicopter in February 2008 on Mōkapu and in January 2009 on Lehua. Mōkapu was the first island in the world where the aerial broadcast of this less hazardous active ingredient was used to eradicate rats. Island eradications in other parts of the world have usually used broad-spectrum active ingredients that are far more persistent and bioaccumulative, thus imparting a much higher risk to nontarget species and the environment. Monitoring of nontarget and environmental effects on Mōkapu and Lehua did not detect diphacinone residues. A number of factors, including state of Hawai'i restrictions on bait entering the ocean, led to rats surviving on Lehua. These projects demonstrate that the aerial broadcast of a rodenticide containing diphacinone can be an effective and safer tool for conservation. Hawai'i is using the results from Mōkapu and Lehua to plan future rat eradication and control projects and continue development of a long-term program.

KEY WORDS: anticoagulant, brodifacoum, diphacinone, environmental fate, hazard, nontarget, risk, rodenticide

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INTRODUCTION

Invasive rodents have been documented to have negative effects on native Hawai'ian species (Athens 2009, Atkinson 1977, Baker and Allen 1978, Hadfield et al. 1993, Scott et al. 1986, Scowcroft and Sakai 1984, Seto and Conant 1996, Stone 1985, Sugihara 1997), and most conservation and restoration plans within the Pacific islands list invasive predator control and eradication among their highest priorities. Island-wide rodent eradications (and main island control projects) have been successfully conducted worldwide using anticoagulant rodenticides, although this was once considered impossible. These compounds primarily disrupt the normal blood clotting mechanisms, although ancillary bioactivity and sublethal effects for a large proportion of organisms are mostly unknown. Many of these types of projects have used the anticoagulant brodifacoum, even though the nontarget and environmental effects are often severe (Dowding et al. 2006, Ebbert and Burek-Huntington 2010). Brodifacoum is the most toxic,

persistent, and broad-spectrum anticoagulant available and was specifically developed to combat anticoagulant resistance in areas where less toxic anticoagulants were used improperly over a long period of time. Diphacinone is less toxic and less persistent, especially where nontarget species are concerned (Eisemann and Swift 2006). For instance, brodifacoum (avian LD₅₀ = 0.26 mg/kg, rat LD₅₀ = 0.4 mg/kg) is many orders of magnitude more toxic to nontarget birds than diphacinone (avian LD₅₀ = 1,000-3,000 mg/kg, rat LD₅₀ = 2.3 mg/kg) while only about 6 times more toxic to rats (Erickson and Urban 2004). The laboratory-estimated half-life of brodifacoum residues in mammalian liver tissue is 113.5 days (Fisher et al. 2004), and brodifacoum residues have been detected in organisms more than a year after exposure under field conditions (Eason et al. 1996, 1999; Erickson and Urban 2004; Dowding et al. 2006; Ebbert and Burek-Huntington 2010). In comparison, the half-life of diphacinone in mammalian liver is 3 days (Fisher et al. 2003). This persistence makes brodifacoum far

more hazardous with regard to secondary and tertiary poisoning of nontarget species. Brodifacoum has also been shown to kill some native snails (Gerlach and Florens 2000) and is classified as very highly toxic to aquatic organisms by the EPA, while diphacinone is slightly to moderately toxic to aquatic organisms (U.S. EPA 1998) and has never been implicated in invertebrate mortality. These properties were the most important factors in Hawai'i's decision to use diphacinone for the majority of rodenticide applications.

Hawai'i has taken a comprehensive, collaborative approach to rodent control for conservation purposes. This follows the pattern of many successful conservation efforts in Hawai'i, where resources are pooled to achieve benefits greater than those that individual participants can achieve on their own. Because no single agency has the funding, expertise, and staff needed, obtaining and using state and federal registrations of rodenticides for conservation purposes was achieved since the early 1990s through the coordinated efforts of the Toxicant Working Group (TWG). The TWG is comprised of state and federal agencies and private landowners and is coordinated by Katie Swift of the FWS Pacific Islands Fish and Wildlife Office (PIFWO). After considering numerous toxicants, diphacinone was ultimately selected for conservation and agriculture registrations in Hawai'i by the TWG in the early 1990s. Diphacinone was preferred due to its long track record of safety and efficacy in the agriculture industry worldwide, and especially within the United States. No other rodenticide met the TWG's requirements for high mortality of rats, low risk to nontarget species, and rapid biodeterioration. Laboratory and field efficacy studies conducted by the USDA APHIS Wildlife Services National Wildlife Research Center (NWRC) Field Station in Hawai'i (Tobin 1992, 1994; Swift 1998; Dunlevy et al. 2000, Dunlevy and Campbell 2002) and by USGS Biological Resources Division (Spurr et al. 2003a,b) established that diphacinone could achieve 100% mortality within rat populations in Hawai'i.

Because the broad scale use of rodenticides in natural areas is highly controversial due to the potential for nontarget mortality and environmental contamination, Hawai'i's conservation rodent control program must demonstrate responsible stewardship of rodenticide use to regulators and the public. One of the most important responsibilities of the TWG is to ensure that rodenticide conservation labels are being used responsibly, effectively, and legally. The TWG has developed a set of basic principles for guidance, coordination, and to avoid potential problems that could adversely affect all conservation rodenticide use. Those involved in invasive rodent control and eradication, especially using toxicants, should eliminate all possible and unnecessary nontarget and environmental fate adverse effects and document safety and efficacy. Rodent control and eradication projects in Hawaii will be consistent with Integrated Pest Management principles and in compliance with the following laws: the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA); the State of Hawai'i's Pesticide Law; the Endangered Species Act; the Migratory Bird Treaty Act; the Clean Water Act; the State of Hawai'i's

Water Pollution Control and Water Quality Standards; the National Environmental Policy Act and Hawai'i's Environmental Review law (Hawai'i Revised Statutes 343). Also, in the case of the APHIS-WS labels, projects must follow specific Agency requirements. Projects should have clear conservation objectives, be well planned and executed, cause minimal or no negative environmental impacts and have public support.

The Hawai'i program adheres to the following 5 principles:

- 1) Rodenticides should be used only in places where clear documentation or data from a directly analogous situation exists, demonstrating that rodents are having negative population- or ecosystem-level effects on native species.
- 2) Input from communities, regulators, and other interested parties will be sought for all large scale and/ or sensitive projects.
- 3) Large scale and/ or technically complex eradication or control projects should be planned and conducted only by personnel based in Hawai'i who have extensive experience and training in rodent control using toxicants.
- 4) Diphacinone will be the default toxicant used for the majority of projects, as it has the most favorable combination of efficacy with the lowest risk of environmental and nontarget impacts; necessary exposure parameters will need to continue to be established and documented.
- 5) Environmental monitoring will be done with each broad scale application until a track record of environmental safety is established that is acceptable to regulators and the public.

The first aerial broadcast applications of diphacinone following its registration in the U.S. for conservation purposes were conducted on 2 offshore islands in Hawai'i. There are many small offshore islands within the main Hawai'ian Islands, however only a few are currently known to have invasive rodents. Mōkapu and Lehua were the only two with the documented presence of federally listed species and critical habitat. While Mōkapu and Lehua had their own conservation objectives, they also served as preliminary steps for the main island rodent control program. The projects were planned and conducted in adherence to the philosophy and principles described above. Their relatively small size, remoteness from human habitation, lack of permanent freshwater, and few nontarget species made them good systems in which to demonstrate the efficacy and safety of the aerial broadcast of diphacinone. The U.S. Fish and Wildlife Service (FWS), the Hawai'i Division of Forestry and Wildlife (DOFAW) and the U.S. Department of Agriculture – Animal and Plant Health Inspection Service – Wildlife Services (WS) were the 3 lead agencies, with additional support provided by the U.S. Army, the Kaua'i Invasive Species Committee, the Coordinating Group on Alien Pest Species, and the Partnership to Protect Hawai'i's Native Species.

STUDY SITES

Mōkapu is approximately 7 ha (16 ac) and is located roughly 1 km (0.7 mi) off the north coast of Moloka'i, just

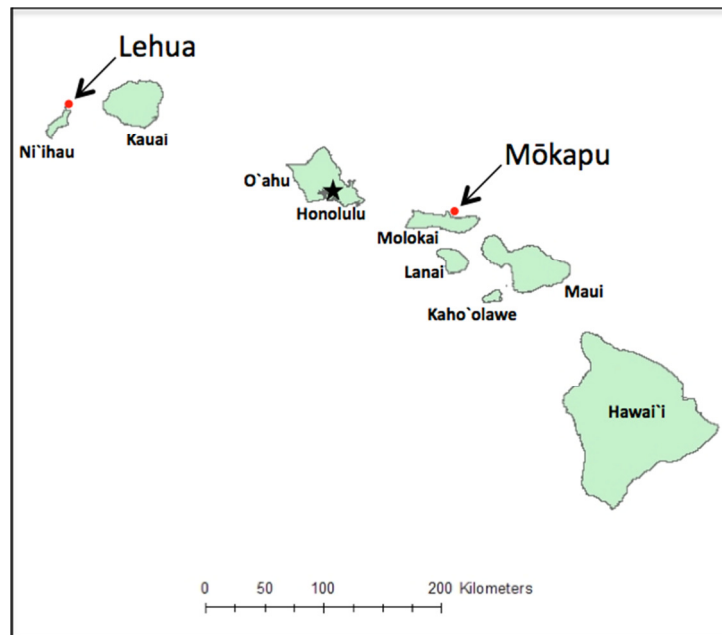


Figure 1. Locations of Mōkapu and Lehua within the main Hawai'ian Islands.

east of the Kalaupapa Peninsula. Lehua is approximately 126 ha (312 ac) and located about 1 km (0.7 mi) north of Ni'ihau and 29 km (18 mi) west of Kaua'i (Figure 1). Both islands have been designated as seabird sanctuaries by the State of Hawai'i. Lehua supports colonies of seabirds such as Laysan and black-footed albatross (*Phoebastria immutabilis*, *P. nigripes*), red-footed and brown boobies (*Sula sula*, *S. leucogaster*), black noddies (*Anous minutus*), Newell's and wedge-tailed shearwaters (*Puffinus newelli*, *P. pacificus*), red-tailed tropicbirds (*Phaethon rubricauda*), Bulwer's petrels (*Bulweria bulwerii*) and band-rumped storm petrels (*Oceanodroma castro*). Mōkapu has a less diverse assemblage of seabird species. In addition, these islands support some of the most diverse native coastal plant communities in Hawai'i. Mōkapu supports 29 native plant species, of which several are rare and vulnerable to extinction. The island is dominated by invasive shrubs but retains small groves of native lama trees (*Diospyros* spp.), some native fan palms (*Pritchardii hillebrandii*), and 11 of the last 14 individuals of *Pittosporum halophilum*, which is endemic to Moloka'i. *Peucedanum sandwicense*, a large perennial herbaceous plant, is listed as threatened, and *Lepidium bidentatum* var. *o-waihiense*, a succulent herbaceous plant, also is a species of concern on the island. In 2003, Mōkapu was designated as critical habitat for *P. sandwicense*, *Tetramolopium rockii*, and *Brighamia rockii*. During early biological surveys of these islands, Polynesian rats (*Rattus exulans*), which are not native to Hawai'i, had been documented to be present for an unknown period of time. Virtually no native plant recruitment had occurred on these islands, which was attributed to rat depredation of seeds. Reproduction for some species of seabirds, particularly Bulwer's petrels on Mōkapu and Newell's shearwaters on Lehua, was also completely suppressed. State and federal conservation agencies have developed a comprehensive 10-year restoration plan for Lehua that includes eradication of rats

and translocation of native species to the island (FWS and DOFAW 2007).

Community leaders and activists were identified and included throughout the development, implementation, and follow-up for the projects. Environmental assessments, required under federal and state law (NEPA and HRS 343), were conducted and included quantitative risk analyses for diphacinone and, for comparison, brodifacoum. Public meetings, 'talk story' sessions with members of the communities, press releases, and radio announcements were used to inform and engage the public throughout the projects. Dialogue also occurred with all of the involved regulatory agencies at both the state and federal levels. Feedback from community members and regulators was incorporated into the monitoring plan. Native Hawai'ian fishermen from Moloka'i were members of the team that collected marine samples from Mōkapu. Monitoring results were shared with regulators and the Moloka'i, Ni'ihau, and Kaua'i communities, and issues that arose were used to identify further research needs, such as quantifying the risk from diphacinone to nearshore reef fish following an unrelated fish kill on the island of Ni'ihau, adjacent to Lehua. Meetings and conversations were held on Moloka'i 2 years after the aerial broadcasts of Mōkapu, to share information about the recovery of native species as a result of the successful eradication, and to maintain communication with the community about the conservation uses of rodenticides.

METHODS

Before aerial broadcast operations began, a team of biologists conducted baseline monitoring and prepared plots and transects for operational monitoring. The islands were searched for any vertebrate carcasses, and baseline samples were collected for laboratory quality assurance / quality control (QA / QC) purposes. Populations of native species, including nesting seabirds and

protected plants, were actively monitored over several years prior to the operations in order to produce reliable population estimates, before and after treatment, to document recovery of native species.

During February 2008 on Mōkapu and January 2009 on Lehua, the WS Hawai'i state office, in cooperation with FWS PIFWO and the State of Hawai'i DOFAW, aerially broadcast Diphacinone-50 (EPA Reg. No. 56228-35) at 11.25 kg/ha (10 lb/ac) twice on each island. Each broadcast event for the respective islands was 1 week apart. On-the-ground bait pellet counts within plots confirmed the targeted application rate across the islands. The second broadcast was conducted to ensure bait was available for an exposure period known to produce 100% rat mortality, as determined by laboratory bioassays and field trials conducted on wild-caught Hawai'ian rats (Swift 1998, Dunlevy et al. 2000, Dunlevy and Campbell 2002, Spurr et al. 2003a,b). Hawai'i-based WS personnel and a local helicopter pilot, both of whom had previous experience aerially broadcasting rodenticide, conducted the aerial broadcast operations.

Extensive monitoring was conducted to assess potential adverse impacts of diphacinone on nontarget species, which was one of the foremost concerns during these rodent eradication projects. There is no way to apply adequate bait to all rat territories on steep (45-65° often with smooth/rocky surface) islands such as these without incidentally getting some bait in the water. For Lehua, during the aerial broadcast permitting process the State of Hawai'i Pesticides Branch imposed additional regulatory restrictions beyond those on the national EPA-approved label. These included prohibiting bait from entering the water directly via a 30-m (98-ft) coastal buffer where no baiting was allowed. Unfortunately, this coastal zone was an area of prime rat habitat. We accepted that the state regulators and local communities were very uncomfortable with the aerial broadcast of rodenticides and complied. Mōkapu had been conducted with no such restrictions.

To document the lack of negative impacts from diphacinone bait entering the nearshore environment, pre- and post-broadcast samples of seawater, soil, intertidal limpets (opihi, *Cellata exarata*), crabs, and finfish were collected from 3 sites on the south side of Lehua and from multiple sites around the entire island of Mōkapu. Samples were collected after each broadcast. For additional credibility and scientific rigor, samples were split and sent to 2 laboratories with experience extracting diphacinone residues from a variety of biological matrices. These were the USDA APHIS WS National Wildlife Research Center in Fort Collins, Colorado, and the USGS Columbia Environmental Research Center in Columbia, Missouri.

MŌKAPU

Six seawater and limpet samples were collected on 23 January 2008 from the nearby Kalaupapa Peninsula. Finfish were not able to be collected from the National Park at Kalaupapa; therefore, 4 ta'ape (bluestripe snapper, *Lutjanus kasmira*) were purchased at a local fish market. Each lab was sent 1 fillet from each fish, wrapped in foil, sealed in locking plastic bags, and shipped overnight on

dry ice in coolers. Post broadcast, water, limpet, and fish samples were collected at Mōkapu on 17 February 2008, 11 days after the first aerial broadcast and 5 days after the second. Water samples were taken at 6 stations evenly spaced around the island, 3 on the west side of the island and 3 on the east side of the island, for a total of 36 samples. Each lab received 12 jars of water from Mōkapu (2 jars from each of the 6 sites). The remaining 6 jars were stored in the event that additional analyses were required. Intertidal limpets (opihi) were collected at 3 locations, 1 on the east side and 2 on the west side of the island. A total of 40 opihi were collected, removed from their shells and composited into 3 samples per site, for a total of 9 composite samples. Samples were not homogenized; therefore, each lab analyzed different individuals. Each lab received 3 sets of Mōkapu opihi containing multiple individuals from each of the 3 sites sampled. The other 3 sets (1 from each site) remained in storage in the event that additional analyses were required. Fish were collected within about 15 m (50 ft) of the west side of the island. Six fish were of sufficient size to be retained as samples. These included 4 ta'ape, 1 hogfish (a'awa, *Bodianus bilunulatus*), and 1 bridled triggerfish (hagi, *Sufflamen fraenatus*). There were a total of 18 fish samples, representing 6 individuals of 3 species. Each lab received a total of 6 sets of Mōkapu fish, each containing a fillet from each of the 6 fish collected. Samples were not homogenized; each lab analyzed 1 fillet from each of the same 6 fish. The other 6 sets remained in storage in the event that additional analyses were required.

LEHUA

On Lehua, the location of sampling sites were chosen to return the most conservative monitoring results, providing the highest possible confidence that the results were indicative of actual circumstances. Lehua's largest drainages reach the ocean along the south shore, where runoff during high rainfall events enters the sea at the 3 sampling sites. Therefore, the water, soil, and organisms sampled would be most likely to reveal any potential diphacinone exposure. However, no significant rainfall events followed the bait broadcasts. Maximum rainfall of 0.7 inches (1.8 cm) was recorded by an on-island rain gauge on 11 January. Plots across Lehua were monitored to measure the disappearance of bait pellets and ensure enough remained on the ground for all rats to consume a lethal dosage. Monitoring of bait disappearance helped gauge the optimum timing of the second application; i.e., before bait density was reduced to the minimum exposure threshold density. In addition, the density of pellets initially deposited across vegetation and terrain and remaining over time were assessed. During broadcasts on Lehua, 6 people monitored the bait application and removed pellets from around albatross nests. They conducted formal detailed transect searches across 1.6 ha of transects to systematically and carefully look for any carcasses 4 times during the month.

Before aerial broadcasts on Lehua, baseline specimens were collected on 30 and 31 December 2008, and on 2 January 2009. Samples that were collected at each site included seawater, soil, opihi, a'ama crab (*Grapsus*

tenuicrustatus), ta'ape, stocky hawkfish (*Cirrhitus pinnulatus*), nenu (*Kyphosus biggibus*), to'au (*Lutjanus fulvus*), Christmas wrasse (*Thalassoma trilobatum*), and hogfish. For each site, samples were collected along 25 to 50 m (82 - 164 ft) of the shoreline. The GPS locations of the sites were recorded. Surface soils were collected 20 to 30 m (66 - 98 ft) from the water's edge at a depth of 5 to 12 cm (2 - 5 in) at the base of gulches that drain into the ocean. Opihi and a'ama crabs were collected in near-shore habitats. At each site, 3 to 5 fish were collected. A total of 18 fish samples, 9 soil composites, 9 seawater samples, 9 composites of 5 to 8 whole opihi, and 7 composites of 2 whole crabs were shipped to each laboratory. Fish fillets were analyzed as individuals; opihi were analyzed as composites of 5 to 8 individuals; and crabs were analyzed as composites of 2 individuals, except when only a single sample was available. Post-application samples were collected on 7, 12, and 19 January 2009 at 1-day and 1-week periods after each bait application.

RESULTS

Diphacinone was not detected by either laboratory in any of the Mōkapu or Lehua samples that were collected after the aerial broadcast of the diphacinone rodenticide (Orazio et al. 2009, Primus 2009). Inter-laboratory analysis of duplicate samples corroborates the finding that diphacinone was not present in the marine environment. No nontarget mortalities were documented on Mōkapu or Lehua; however, more than 28 dead rats were found on Lehua, some in advanced stages of decay.

On 2 February 2009, a month after the first broadcast on Lehua and 3 weeks after the second, inhabitants of the island of Ni'ihau reported that numerous dead fish (mostly triggerfish from the genus *Melichthyes*) had washed up on a beach more than 17 miles (27 km) away from Lehua. The next day, biologists from the state Department of Health and the Division of Aquatic Resources (DAR) investigated. They collected samples and DAR subsequently released a report with their findings (DAR 2009). They did not find any links to the diphacinone applications on Lehua. No diphacinone residues were found in any of the samples, and a necropsy of a fish found dead on Ni'ihau did not show any signs of anticoagulant poisoning. No cause of the fish kill could be unequivocally identified. However, the California Fish and Game Water Pollution Control Laboratory detected a microcystin toxin from freshwater blue-green algae in the fish, and during the site visit on 3 February, the DAR biologist noted recent freshwater runoff into the bay on Ni'ihau where most of the fish were found (DAR 2009). Nonetheless, in response to ongoing concerns from the public and regulators, laboratory studies are under way at the University of Hawai'i to determine the toxicity of diphacinone to triggerfish.

CONCLUSION

The approach to rodent control for conservation purposes that Hawai'i has developed, using the 5 principles described above, worked well during these aerial broadcasts of diphacinone bait. The numerous prior studies on nontarget impacts and efficacy, combined

with the field data from Mōkapu and Lehua, will help refine how future applications are conducted. Developing and maintaining a relationship with the community early in the project is necessary for the long-term success of a program like Hawai'i's, where the objective is not to just do a few island eradications and then move on. Maintaining a high degree of technical expertise locally provides continuity, and it creates an atmosphere of ownership and knowledge within the community.

Demonstrating safe and effective use over time will be critical to the acceptance of aerial broadcast of rodenticides for the conservation of native biodiversity. Nontarget and environmental fate monitoring on Lehua was the largest such effort to date associated with any aerial broadcast rodenticide application worldwide, and it showed that aerial application of a rodenticide can be done without contaminating the environment and causing mortality to native species. Although the 2009 eradication attempt on Lehua was not successful, the success of Mōkapu, along with numerous ground-based eradications that have used diphacinone around the world (e.g., Lujan et al. 2010, Bell et al. 2007) demonstrate that there is no intrinsic deficiency associated with using diphacinone for rat eradications. Rather, methods and regulatory restrictions need to be adjusted to accommodate an appropriate exposure profile for this compound and application method. In Hawai'i, and for Wildlife Services' projects elsewhere in the U.S., we will continue to refine the techniques that are necessary to conduct the safest and most effective rodent eradication and control operations possible.

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