ERADICATION OF BLACK RATS FROM ANACAPA ISLAND: BIOLOGICAL AND SOCIAL CONSIDERATIONS

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Abstract—The use of rodenticides to eradicate rats (*Rattus* spp.) from islands is a powerful tool for preventing extinctions of other species. This tool has been underutilized in North America where there have been less than 10 eradications. Furthermore, rat eradications in North America have deployed rodenticides by hand rather than aerial application from a helicopter as is common elsewhere. This limits eradication attempts to small islands with relatively flat topography. Aerial broadcast of a rodenticide was the only feasible method to eradicate the introduced *Rattus rattus* from the three islets which make up the 296 hectare Anacapa Island. After two years of planning, testing and monitoring, a 25-ppm brodifacoum bait was aerially applied to East Anacapa in December 2001, and to Middle and West Anacapa Island in November 2002. No rats have been detected anywhere on Anacapa since the application. Extensive mitigation measures, including holding native deer mice in captivity, and capturing and relocating birds of prey, were adopted to minimize impacts to non-target species. Nonetheless, there were short-term impacts to non-target individuals. Preliminary ecological monitoring is showing substantial recovery of Xantus's murrelet (*Synthliboramphus hypoleucus*), Anacapa deer mouse (*Peromyscus maniculatus anacapae*), and other native species. This was the first aerial application of rodenticide to eradicate rats in North America and the first on an island with an endemic rodent. Individuals and organizations opposed to the rat eradication attempted to halt the project through a legal challenge, media coverage and political pressure. Knowledge and support of the project by mainstream environmental groups and conservation biologists was critical to maintaining support. Hopefully, the success of this project will facilitate future rat eradications in North America.

Keywords: aerial broadcast, brodifacoum, deer mouse, rat eradication, Rattus rattus, restoration

INTRODUCTION

Island ecosystems are key areas for conservation because they are critical habitat for seabirds and pinnipeds that use thousands of square kilometres of open ocean, but depend on islands for breeding, raising young, and resting. In addition, islands tend to be rich in endemic species and are home to 15–20% of all plant, reptile, and bird species (Whittaker 1998). Unfortunately, islands have been disproportionately impacted by humans. Approximately 55–67% of recorded animal extinctions have occurred on islands, with most of these extinctions, including more than half of all seabird extinctions, caused by invasive species (Island Conservation analysis of IUCN Global Red List Data and WCMC 1992).

Rats in the genus *Rattus* have been introduced onto about 82% of the world's islands and/or island chains (Atkinson 1985), where they frequently have a quantifiable negative impact on the distribution and abundance of native flora and fauna. This is most pronounced on oceanic islands where native species have evolved in the absence of mammalian predators and thus have limited behavioural, morphological, and life-history defences against rats (Brown 1997). Consequently, rats have been implicated in 40–60% of recorded bird and reptile extinctions since 1600 (Groombridge 1992). Thus, rats have been a focus of land managers as key species for removal from islands.

Anacapa Island has been subjected to introduced cats, sheep, rabbits and black rats (*Rattus rattus*). The black rat was introduced to Anacapa Island off the coast of southern California in the Channel Islands National Park, sometime prior to 1939 (Sumner and Bond 1939), probably in supplies transported onto the island for sheep ranching or lighthouse construction, or from a ship wreck (Collins 1979) such as the Winfield Scott in 1853. The black rat was the last non-native mammal on the island and was thought to have a major negative impact on seabirds, such as Xantus's murrelet (*Synthliboramphus hypoleucus;* H. Carter pers. comm.), reptiles and amphibians (Collins 1979, Towns 1991), intertidal invertebrates (Erickson and Halvorson 1990, Navarrete and Castilla 1993), terrestrial invertebrates (Erickson and Halvorson 1990) and vegetation (Erickson and Halvorson 1990, G. Howald pers. observ.).

The Channel Islands National Park (NPS) had long been aware of the presence of rats on Anacapa Island. Introduced rats were a nuisance to NPS staff living on the island and to campers due to damage to food and equipment. The ecology of the rats and impacts in the Anacapa island ecosystem and methods to control and/or eradicate rats were the subject of a few studies (Collins 1979, Erickson and Halvorson 1990, Howald et al. 1997). The NPS initiated a rat control program on East Anacapa in the late 1980s through the early 1990s using a combination of bait containing the rodenticide warfarin and trapping. The control program was stopped due to the long-term cost and time investment of perpetual control.

In 2001, we implemented a program to eradicate rats from Anacapa Island following techniques developed in New Zealand and elsewhere. Compressed grain pellets containing the second generation anticoagulant rodenticide brodifacoum (3- [3- (4'-bromobiphenyl- 4-yl)- 1, 2, 3, 4-tetrahydro-1-naphthyl]- = 4- hydroxycoumarin) were distributed by helicopter and by hand in all potential rat territories on Anacapa. The steepness and ruggedness of the island dictated the need for aerial application of the bait. This project is unique in that it was the first island rat eradication using aerial broadcast of a rodenticide in North America, and one of the world's first with a native rodent living sympatrically with introduced rats.

PLANNING AND ENVIRONMENTAL COMPLIANCE

By about 1985, conservationists refined techniques and a general approach to eradicating rats from islands. As of 2002, rats have been successfully removed from over 200 islands worldwide by delivery of bait containing an anticoagulant rodenticide into every potential rat territory on the island, a fundamental requirement for successful eradication (see Taylor and Thomas 1989, Kaiser et al. 1997, Tershy et al. 1997). In 1996, the Channel Islands National Park contracted with Island Conservation to assess the feasibility of, and to provide options for, eradicating rats from Anacapa Island. The resulting report formed the basis of the Anacapa Island Restoration Project (Tershy et al. 1997).

Formal compliance with the National Environmental Policy Act (NEPA) began in November 1999. The Park prepared an Environmental Impact Statement (EIS) due to the potential for the project to have short-term impacts on the environment and the potential controversy over those impacts. The process of public comment on the Draft EIS indicated support for the purpose of the project (i.e., the eradication of rats to restore seabirds and other native species) and concerns with the projected impacts to non-target species, particularly Anacapa deer mice (*Peromyscus maniculatus anacapae*), birds, reptiles, and amphibians. There were requests for the NPS to choose a different method to achieve eradication of rats. However, after the review of the trial data and consultation with other eradication experts, the NPS and Island Conservation felt strongly that only the chosen alternative offered a reasonable probability of eradicating rats and that any negative impacts would be short-term and not significant to native populations. The Record of Decision for the NEPA document was signed by the NPS on 17 November 2000, outlining the preferred alternative of aerial broadcast of the rodenticide brodifacoum to eradicate rats from Anacapa Island.

The planned eradication of rats from Anacapa Island required compliance with a host of additional environmental laws. One of the more significant requirements was the need to obtain a registration for an aerial broadcast bait from the Environmental Protection Agency (EPA) in compliance with the Federal Insecticide, Fungicide and Rodenticide Act. The EPA evaluated the benefits of the rat removal against the potential short- and long-term negative impact of the project and determined that the project had a high probability of eradicating rats with minimal short-term negative impacts in the ecosystem. A three-year, Quarantine Exemption registration for an aerial broadcast bait containing 25-ppm brodifacoum was granted on 12 December 2000.

METHODS

Timing and Bait Application

The major logistical obstacles to eradicating rats from Anacapa were steep and rugged topography, presence of breeding seabirds limiting access, and presence of native species, in particular landbirds and the endemic Anacapa deer mouse, a native rodent which was attracted to and competed with rats for the bait. These limitations required development of novel techniques to limit the potential environmental impact while ensuring that enough bait would be delivered into every potential rat territory.

The primary objective of the bait application was to ensure that sufficient bait was available in every potential rat territory on the island. If any areas of the island were not treated, or treated insufficiently, there was the potential that some rats may not have been exposed to the bait and the eradication could fail. Therefore, it was critical that the entire island, especially the cliff sides, was baited sufficiently. Monitoring of the aerial application was necessary to identify any areas that were either not treated, or received too little bait.

Rat eradication is more likely to be successful when the rat population is food stressed, and therefore more likely to eat the toxic bait, and when the population is declining and not breeding (D. Veitch pers. comm.). The best time to apply bait on Anacapa was during the late dry season (typically September–November), as the rat population had been shown to be declining during that period and rats were not likely to be breeding (Erickson and Halvorson 1990).

We implemented the eradication program in November 2000 with a 2.5-hectare trial in Sheep Canyon on Middle Anacapa, followed by the baiting of East Anacapa in December 2001 and Middle/West Anacapa in November 2002. At each step, we monitored for efficacy and determined that the aerial bait application was successful in killing all marked rats (see below). In addition, we monitored for environmental impact to validate that the mitigations were successful and the environmental effects were limited and within the scope predicted in the EIS.

The delivery of bait into all potential rat territories, especially on the cliff sides, was critical to the successful removal of rats from Anacapa. Rats were known to regularly use and live on the cliffs (Erickson and Halvorson 1990, Howald et al. 1997) but the friable basalt that forms the steep 50–284-m cliffs precluded baiting by hand. Thus, only an aircraft could ensure delivery of bait onto the cliffs. Bait was broadcast at 15 kg/ha from a hopper suspended under a Bell 206 helicopter fitted with an onboard differential GPS (DGPS) and computer to ensure even and complete application of bait. The cliffsides were treated with the hopper fitted with a deflector that spread bait to one side only, preventing significant bait spread into the marine ecosystem. Bait was applied by hand to the lower reaches of the cliffs, above the beaches and the intertidal zone, ensuring adequate bait application in this prime rat habitat. The remainder of the island was treated with the deflector removed, so that bait was spread in a 360 degree pattern. Bait stations were used in buffer zones around the landing cove, the buildings and the campground on East Anacapa Island to ensure that bait was always available to the rats in these areas of many alternative food resources.

We used a large (approximately 1–2 g, 9-mm diameter) green, unwaxed, compressed grain, pelleted bait containing 25-ppm brodifacoum that was highly palatable to rats (based on Bell Labs laboratory tests; field test in 2000; and field lab tests in 2001). Brodifacoum blocks the vitamin K1 oxidation-reduction cycle in the liver and impairs the ability to produce active clotting proteins; death from internal hemorrhaging occurs within 3–10 days after ingestion of the bait (Smith and Greaves 1987). The major benefit of brodifacoum is that it is potentially toxic to rats after a single feeding and the delayed onset of symptoms prevents the development of bait shyness (Smith and Greaves

1987), factors offering a high probability of killing 100% of the rat population.

Effect on Rat Population

We used radio telemetry, live trapping, and peanut-flavored wax indicator/ chew blocks to assess the efficacy of the baiting. In addition, studies on the ecological impact of rats on nesting seabirds and intertidal invertebrates are ongoing and function as additional indicators of rat presence/absence. Findings from the ecological studies will be reported elsewhere.

Eighteen rats (eight in 2001, 10 in 2002) were radio-collared prior to bait application. The rats were monitored at least every 2–3 nights prior to and after the bait application. We considered radio-collared rats to have died if the radio signal indicated no movement for three consecutive nights after the bait was applied. When possible, burrows were dug up and rats were collected for confirmation of cause of death. Live trapping (Tomahawk Live Traps) to index the rat population before and after the baiting was conducted in areas of known prime rat habitat. Traps were placed along transect lines of various lengths, with spacing of 15–25 m as dictated by island geography. Traps were baited with peanut butter. We used a peanut flavored wax chew block as an alternate indicator of rat presence/ absence. Rats or mice chewed on blocks, leaving behind an impression of their incisors. The difference in incisor widths was used to distinguish between the two species. Blocks were staked to the ground at 10–25-m spacing, along transect lines of various lengths as dictated by island geography.

Minimizing Risks to Native Wildlife

We realized that aerial broadcast of a grain-based bait containing brodifacoum would place some individuals of native birds and mice at risk of poisoning either directly through consumption of bait pellets (primary poisoning), or indirectly through scavenging poisoned animals (secondary poisoning). We therefore considered mitigation measures for those species for which baiting may have a population level or long-term impact.

Anacapa Deer Mouse

The presence of the endemic Anacapa deer mouse presented a unique challenge to rat eradication; how to deliver the bait into every rat territory without making it available to every mouse. Mice across the three islets were found to be genetically similar and functioning as a metapopulation with some movement of mice between the islets (Pergams et al. 2000). Population Viability Analysis (PVA) determined that a population of 1,000 mice across all three islets would be necessary to maintain population persistence with minimal loss of genetic diversity (Pergams et al. 2000). The mitigation plan for the Anacapa deer mouse was based on the genetic connectivity of the Anacapa islets and the PVA.

To insure that we always had two viable populations of mice, we chose a mitigation plan that included (1) staggering the eradication over two years so that a free-ranging population always existed on one or more islets and, (2) holding a representative sample of the mouse population in captivity followed by a soft release (with supplemental food) and subsequent monitoring to ensure viability. To accomplish this, we conducted a limited captive holding experiment of East Anacapa Island deer mice from October 2001–April 2002 to refine our methods and logistics for captive holding during the Middle and West Anacapa rat removal planned for 2002. We then released the mice to East Anacapa in April of 2002 at different release densities, and monitored the recovery of the mouse population.

Prior to the eradication of rats from Middle and West Anacapa Island we translocated >1000 mice from Middle and West Anacapa Island to East Anacapa Island. Furthermore, we supplementally fed free-ranging mice on East Anacapa through the winter, by hand broadcasting commercial grade rodent chow within 20 m either side of the East Anacapa ring trail. Finally, we held >700 mice from Middle and West Anacapa in captivity from September 2002 through March 2003.

The early spring was the optimum time to release mice because it was the start of the breeding season and natural food was abundant. We released the captive mice back to Middle and West Anacapa in late March 2003 and monitored the mouse population on all three of the Anacapa islets monthly through the 2003 breeding season.

Landbirds

All bird species known to use Anacapa Island were also found on the other northern Channel Islands or on the adjacent mainland. Even though the eradication of rats would not cause significant impacts to bird species, we made a large effort to reduce the likelihood of poisoning individual birds by limiting their exposure to the rodenticide by (1) timing the bait application to occur when some of the migratory birds had moved off the island for the winter, and before the initiation of breeding by gulls, pelicans and other seabirds (limiting the potential for exposure and disturbance), (2) maximizing the size of bait pellets to prevent granivorous birds from ingesting the bait, (3) coloring the pellets green to make them less visually attractive to gulls and other birds (Day and Matthews 1999, H. Gellerman unpubl. data from Anacapa Island), (4) designing the bait to break down within days of application in the moist maritime climate, (5) not applying an excessive amount of bait, but ensuring enough was available to all rats on the island, and, (6) live trapping and removing, or holding captive, resident birds of prey prior to the baiting. Captive birds were re-released onto the island after the risk period had passed.

We evaluated the impact to non-target species by conducting searches for carcasses after the broadcast. We actively searched for carcasses of native animals across all three Anacapa islets between November 3rd (24 hours after the bait application) and December 17th (45 days post-primary application). We searched 46 circular 10-m diameter plots on days 3, 7–8, 10, 14, 21, 28, and 35 post-application. (We added random transects after native bird carcasses were found opportunistically and few animals had been found in the plots.) Random transects were walked on MAI and WAI on days 19, 21, 24, 28, 35, and 82 post-application. All birds, rats and mice found (in plots) were collected, placed into a pre-labeled bag and frozen. Rats and mice found dead outside the monitoring areas were buried or tucked under dense brush. Bird carcasses were sent to the Illinois Department of Agriculture Centralia Animal Disease Laboratory for necropsy and toxicological analysis. A total of 168 person-search-hours were spent looking for non-target animals, plus the time the field crew spent opportunistically searching for carcasses.

Environmental Monitoring

To evaluate the toxicological risks and impact to non-target species, we studied the movement of brodifacoum in both the marine and terrestrial ecosystems. In the marine environment, bait was not expected to enter the marine environment in any significant quantities because of a specially-designed deflector mounted under the hopper. We assessed bait drift by sending SCUBA divers to look for and count bait pellets on the ocean floor, to assess the degradation of the bait, make observations of fish or invertebrates in the area, and to determine if any organisms were consuming the bait. The divers investigated these areas on two dives 1.5 and 5 hours post bait-drop. We collected ocean water samples (500 ml) 24 and again 48 hours post bait-drop. The samples were held in a refrigerator and shipped to the California Department of Fish and Game, Pesticide Investigation Unit, Rancho Cordova, California for brodifacoum residue analysis. In addition, we sampled marine organisms as indicators for the presence/absence of brodifacoum in the marine environment. We collected mussels (*Mytilus californianus*) and crabs (*Pachygrapsus crassipes*) at days ~15 days and 30 post-application, and tidepool sculpins (*Oligocottus maculosus*) at days ~15, 30 and 90 post-application. The samples were collected individually or pooled into pre-labeled plastic sample vials, placed on wet ice and frozen as soon as possible after collection.

In the terrestrial environment, native species were at risk of exposure to the rodenticide by consuming the bait directly, and via contaminated prey items (secondarily) if brodifacoum moved into the food chain. We qualified and quantified the movement of brodifacoum into the Anacapa ecosystem and evaluated its impact to non-target animals. The Anacapa insect and microbial communities play a critical role in the nutrient cycle through the breakdown of organic matter. Similarly, the insects and microbes ultimately removed the organic rodenticide from the environment by digesting residual bait pellets and rodent carcasses, and ultimately breaking brodifacoum down to its non-toxic base components of water and CO_2 (Shirer 1992). Invertebrates are not affected by the rodenticide because they lack a closed circulatory system and brodifacoum does not persist in invertebrate tissue (e.g., Payne et al. 2000), thus, the presence of brodifacoum in invertebrates is indicative of a recent exposure to the rodenticide.

Therefore, the residues in invertebrate tissue can be used as an index of the biologically available brodifacoum in the Anacapa environment. Similarly, brodifacoum levels in the soil, sampled over time, can be used as an index of rate of brodifacoum breakdown from the Anacapa environment. We collected samples of the invertebrate community found under rocks, shrubs, and under the grid of boards used for monitoring reptiles and amphibians. We conducted random sampling of the invertebrate community versus sampling specific groups. When a diverse sample was unavailable (especially during the dry season), we focussed on the available insects, primarily isopods and ants. We collected five samples (~5 g each) at approximately days 5, 30, 90, and 180 post-application. The samples were collected into chemically cleaned, sterile plastic sample jars and frozen. Further, we collected three soil samples each at approximately 1, 3, 6 and 12 months post-broadcast. We sampled and analyzed the top 5 cm of soil collected from under a pellet or arbitrarily within a bait uptake monitoring plot.

Legal Challenge and Public Controversy

During the summer and fall of 2001, opposition to the project was voiced by several individuals and animal rights groups. Primary issues raised were the killing of animals (rats as well as non-target mice and birds) and the use of a poison. Shortly before the planned application of bait to East Anacapa Island, the NPS was notified by the Fund for Animals, a nationwide animal rights organization, that it intended to file a lawsuit, and would request a temporary restraining order prohibiting implementation of the project in the United States District Court for the District of Columbia. The Federal Government agreed not to implement the bait application for one month, after a hearing and until a ruling was made by the judge.

The plaintiffs in the lawsuit were The Fund for Animals, Channel Islands Animal Protection Association, and two residents of Santa Barbara. The Plaintiffs alleged that "…defendants' plan to spray rodenticide-laced pellets by helicopter onto Anacapa Island in the Channel Islands National Park is arbitrary and capricious, in violation of the Migratory Bird Treaty Act,…the National Park Service Organic Act,…the Park Service's own Management Policies, and the National Environmental Policy Act…" (Memorandum Opinion, U.S. District Court for the District of Columbia, Judge Ellen Segal Huvelle, 29 November 2001).

The most substantive claim was the allegation of non-compliance with the Migratory Bird Treaty Act (MBTA). The MBTA prohibits the taking of migratory birds except under a permit issued by the U.S. Fish and Wildlife Service (FWS). The FWS regulations for management of the MBTA defined "take" of migratory birds to be pursuit, hunting, killing, or capture of covered species. FWS did not consider the unintentional mortality of a migratory bird to fall within the permitting requirements of MBTA. Nonetheless, subsequent to the lawsuit, the NPS decided to apply for an MBTA permit from the FWS. The FWS granted the NPS' application for the MBTA permit due to the benefits the Anacapa Island project would have for migratory birds. The federal government believed that all other allegations were without substance.

On 29 November 2001, the District Court issued a "Memorandum Opinion" denying the plaintiff's request for a preliminary injunction. The court concluded that "…plaintiffs' showing on the merits is not sufficient to warrant the entry of injunctive relief…" (Memorandum Opinion, U.S. District Court for the District of Columbia, Judge Ellen Segal Huvelle, 29 November 2001). Interestingly, on the question of whether the Anacapa project required an MBTA permit, the judge wrote "The only cases on this subject have concluded that unintentional or incidental take by federal agencies do not violate the MBTA." The judge's ruling cleared the way for the initiation of Phase I of the Anacapa Island restoration project. The lawsuit greatly heightened the interest of the press in the project and resulted in substantial media coverage of the project throughout all remaining phases.

Project Funding

The primary financial support for the eradication of rats from Anacapa Island and the pre- and post-eradication monitoring came from the American Trader Trustee Council (ATTC). The ATTC was formed as a result of an oil spill from the tanker *American Trader* near Huntington Beach in 1990 and consisted of representatives of the FWS, National Oceanic and Atmospheric

Administration, and the California Department of Fish and Game. The ATTC considered the eradication of rats from Anacapa to be a project that would significantly contribute to the restoration of seabird species that had been injured by the oil spill.

RESULTS AND DISCUSSION

Timing and Bait Application

The DGPS data proved to be an effective monitoring technique especially for cliff sides that could not be validated visually (Fig. 1). The use of the DGPS had two major advantages: (1) it visually showed what areas had been baited, and what areas needed to be baited, and (2) it identified gaps in the baiting that could support rats and needed to be filled in by hand application or by helicopter. The aerial application thoroughly treated the islets with minimal gaps.

Effect on Rat Population

Radio collars—All radio-collared rats stopped moving between days 3 and 14 post-application (mean 6.3 days), coinciding with the known time lag between ingestion of brodifacoum and death (Taylor 1993, Howald et al. 1999). This suggests that the majority of rats began feeding on the bait within a few days after application. In 2002, nine radio-collared rats were recovered dead. As expected, the majority (6 of 9) died below ground where they were inaccessible to avian scavengers. Two were found dead above ground, one of which had been scavenged or preyed upon. These results are consistent with other field studies evaluating the fate of anticoagulant poisoned rodents (Fenn et al. 1987, Taylor and Thomas 1989, 1993, Howald et al. 1999).

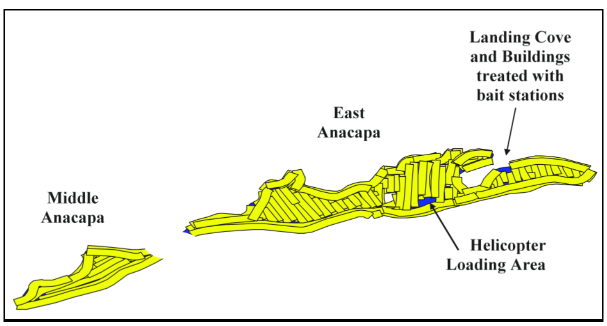

Figure 1. Final Differential GPS/computer link printout of the bait spread by helicopter on East Anacapa Island, 2001. The rectangular shapes represent the flight lines of the helicopter while broadcasting bait. The width of the flight lines represents how far and wide bait was spread onto the island. Note that the flight lines follow along the shoreline.

Trapping and wax chew blocks—Trap success fluctuated between 10–55.8% prior to the bait application. After the bait application, no rats were trapped on East Anacapa Island (>11,281 Trap Nights; Figs. 2 and 3). As of November 2004 trapping and chew block results from East, Middle and West Anacapa Island have failed to detect any rats.

Taken together, the above indicators of efficacy indicate that rats have been removed from Anacapa Island. As of November 2004, after two complete rat breeding seasons (late winter through early summer), no rats had been detected, and Anacapa Island was declared rat free.

Minimizing Risks to Other Species

Anacapa deer mouse—The mitigation strategy for the Anacapa deer mouse was successful. Not unexpectedly, it appeared that all Anacapa deer mice present on an islet during bait application were killed (Fig. 4). The staggering of the eradication over two years ensured a free-ranging population existed on Middle and West Anacapa Islands prior to the baiting of East Anacapa Island. The reintroduction of mice to East Anacapa Island in 2002 was successful in establishing a free-ranging population on the islet prior to the application of bait onto Middle and West Anacapa Island in the fall of 2002 (Fig. 4). Conditions for the release of mice and throughout the breeding season in 2003 were excellent. Above average rainfall through the spring and summer resulted in an abundance of food and protective cover. Mouse densities, on Middle Anacapa, measured on multiple trapping grids approximately 6.5 months after release, were comparable to densities measured prior to the eradication.

Monitoring is ongoing to ensure that the population has reestablished, and if necessary we will intervene to support the mouse population. The recovery of the Anacapa deer mouse has demonstrated that rats can be eradicated from islands while concurrently occupied by native mammals.

Birds of prey—The Predatory Bird Research Group removed 37 individual birds of prey

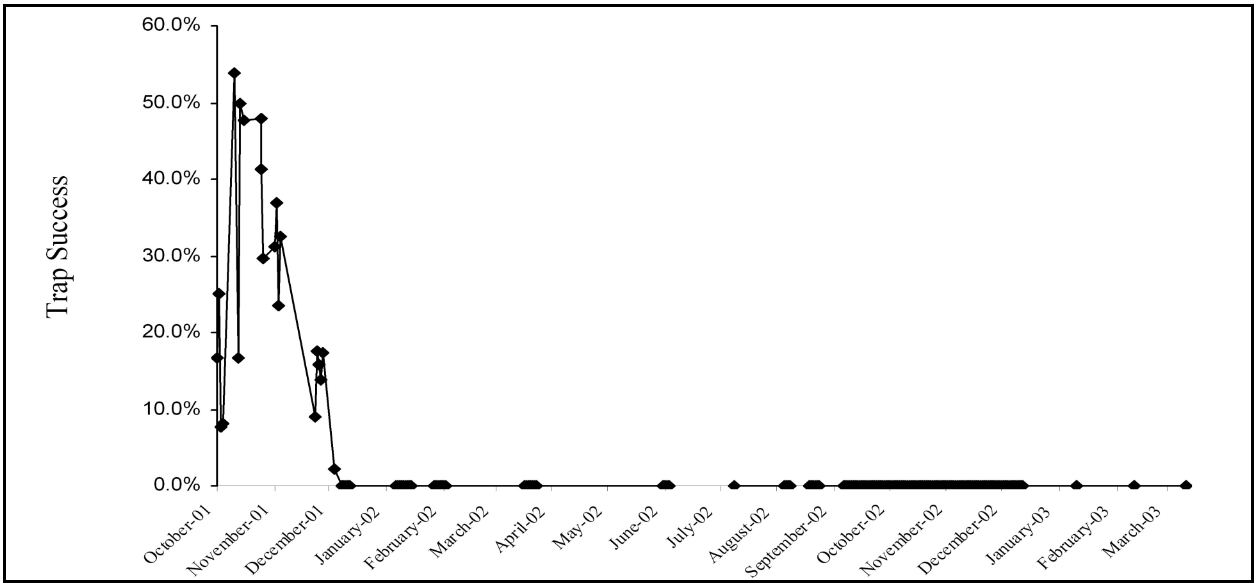

Figure 2. Index of rat abundance (percent trap success) on East Anacapa Island, October 2001 through March 2003 (*n* = 11,281 TN). Rats captured were either euthanized or fitted with radio collars and released.

including 13 of 19 from East Anacapa in 2001 and 24 of 40 raptors known to be present on Middle and West Anacapa in 2002. This represented 63% of the resident and over-wintering raptor population prior to and just after the bait application (Table 1). Most birds were released on the mainland in suitable habitat and the peregrine falcons were held and released back onto Anacapa Island after the risk period (estimated at approximately 2–3 weeks). It was decided to captively hold the peregrine falcons because of the past intensive efforts to restore their populations on the Channel Islands. Thus, in an attempt to ensure that peregrine falcons remained on Anacapa, they were captively held and released back onto the island.

The fate of the remaining birds of prey on the island is unclear. There is evidence that some birds survived the bait application. A burrowing owl was consistently observed on West Anacapa for almost two months after the bait application, long after all rodents had died. However, three barn owls, six burrowing owls and an American kestrel either died while in captivity or were found dead on the island. The American kestrel and a burrowing owl that were captured in 2001, after the bait application, likely died from brodifacoum poisoning. Our data indicate that there was an impact on individual raptors, but that the impact will not be long term. All of the species originally removed from the island have returned. One banded pair of peregrine falcons was observed to breed successfully and raised at least one chick on Middle Anacapa in the spring of 2003 (N. Todd pers. comm.), suggesting that the mitigation was successful and with no lasting impact.

The impact to the population of raptor species was negligible. The birds of prey on the Channel Islands are generally habitat limited (B. Walton pers. comm.) and any territory left open was filled by other birds (B. Latta pers. observ.). The diversity of predatory birds observed prior to the baiting was observed on Anacapa Island in the fall of 2003, suggesting that project activities had no lasting impact on populations and raptor population diversity has returned to pre-eradication levels.

Landbirds—Some incidental poisoning of non-target granivorous birds was expected. The mitigation efforts reduced the exposure of some individuals, however it was impossible to reduce the risk to all individuals. The diversity and foraging strategies of birds found dead after the treatment is consistent with primary exposure (granivorous birds) and secondary exposure of predatory birds (which prey or scavenge rodents), and is consistent with reports from other rat removal projects (Empson and Miskelly 1999, Howald et al. 1999, McClelland 2001). A total of 94 birds (49 in 2001; 45 in 2002) representing 16

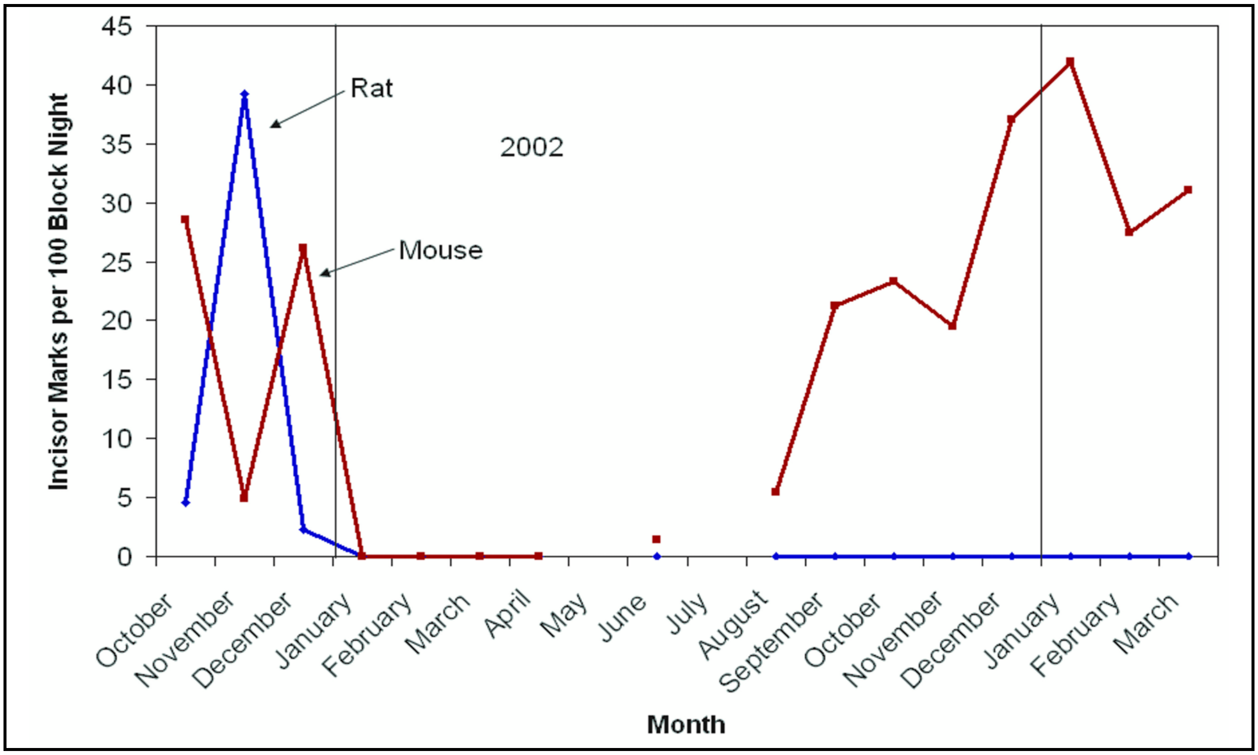

Figure 3. Index of rat and mouse abundance (incisor marks per 100 block nights) on East Anacapa Island, October 2001 through March 2003.

species were found dead in the treatment area after the application (Table 2). Six additional birds were too decomposed to be identified to species. Most of the birds were granivorous songbirds and likely picked up bait fragments soon after bait application. All birds that could be tested (i.e., enough tissue available) likely died from brodifacoum exposure.

The number of birds found dead after the bait drop, even if increased by several orders of magnitude to allow for poor recovery rates by

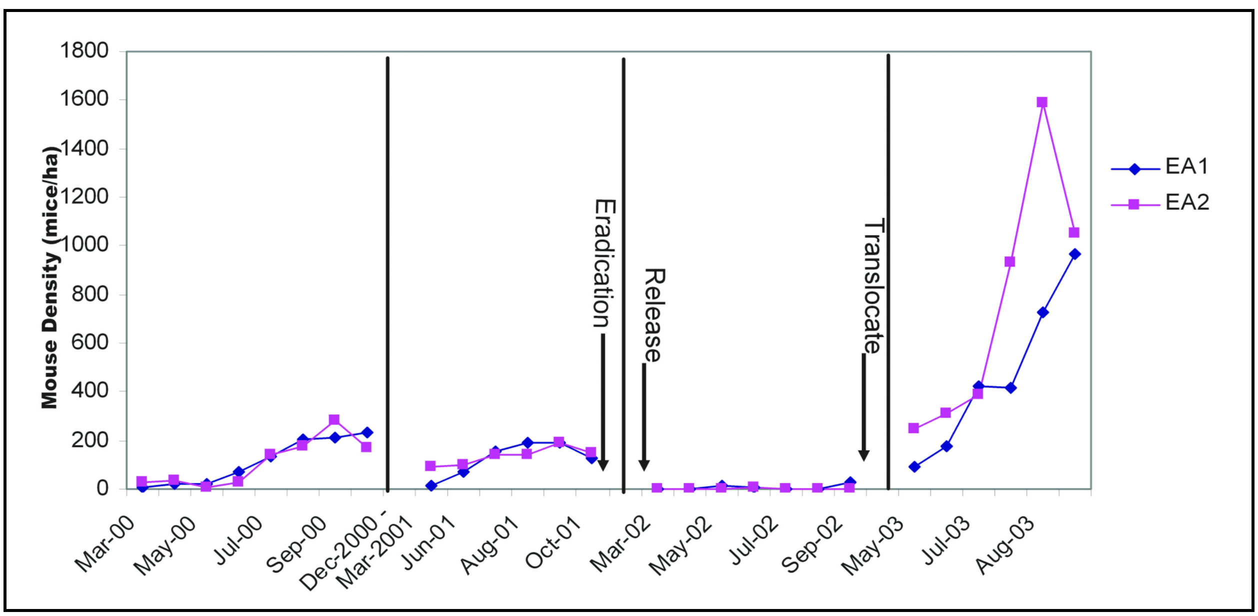

Figure 4. Anacapa deer mouse densities (# mice per/ha, calculated from a 3-night mark/recapture trap session) on two monitoring grids (10 x 10; 7-m trap spacing), before and after bait application on East Anacapa Island, 2000–2003.

Table 1. Summary of birds of prey removed from Anacapa Island prior to bait application, 2001/2002.

	East Anacapa 2001		Middle and West Anacapa 2002	
Species	Number removed/resident population	Initial population estimate	Number removed/resident population	Initial population estimate
Peregrine falcon	1 of 2	3	7 of 8	8–10
Red-tailed hawk	4 of 6	6	5 of 8	8
Barn owl	2 of 3	3	2 of 6	6
Burrowing owl	3 of 4	2	3 of 6	6
American kestrel	1 of 2	2	2 of 5	4
Northern harrier	1 of 1	0	4 of 5	0
Short-eared owl	-	-	0 of 1	1
Common raven	1 of 1	2	-	-
Merlin	-	-	1 of 1	0
TOTAL	13 of 19	18	24 of 40	33–35

searchers, was not significant at the population level for any of the recovered species. Mainland densities of white-crowned sparrow (*Zonotrichia leucophrys)*, golden-crowned sparrow (*Zonotrichia atricapilla)*, and song sparrow (*Melospize melodia*) are estimated to be 1.94–3.67 birds per hectare. House finch (*Carpodacus mexicanus)* global population estimate ranges between 250 million to 1 billion individuals. The most abundant breeding landbird species on the island are orange-crowned warblers and Bewick's wren. Both of these species as well as the house finch, song sparrow, rock wren, and peregrine falcon were breeding on Anacapa only six months after the bait drop. Based on these observations the bait application had little lasting impact on the landbird populations of Anacapa.

Removing introduced black rats from Anacapa Island will likely result in improved habitat for all birds, including birds of prey, due to decreased nest predation and harassment of nesting birds, and increased densities of breeding seabirds and deer mice. In other rodent eradications on islands, the impacts of poisoning on populations of native species have been short-term and outweighed by the long-term benefits of rat removal (Towns 1991, Empson and Miskelly 1999) with native species recovering quickly to pre-eradication levels or higher (e.g., Davidson and Armstrong 2002).

Environmental Monitoring

The helicopter had a high degree of accuracy of placing bait onto the island. The cliff sides were treated with the hopper fitted with a custom designed deflector to minimize bait being spread into the water. Boat and island-based observers reported no bait was directly spread into the ocean. These reports were consistent with observations made during calibration trials on the mainland, during the application trial in November 2000 and with the East Anacapa Island bait application in December 2001.

Island-based observers reported a small amount of bait entering the water indirectly from bounce off the cliff sides. The divers counted a mean of 72 bait pellets (range: 69–75) over 500 m, at a 1–4 m depth on the ocean floor. The pellets were starting to degrade at 1.5-hours post bait-drop, and at five hours post bait-drop, there were just a few scattered crumbs. No fish or other animals were observed feeding on the bait on either dive. Fish were not expected to consume the bait (see AIRP EIS 2000) and the observations were consistent with observations made during the East Anacapa Island bait application in 2001. No brodifacoum residues were detected in any of the water samples (n = 2 @ 24 hours and n = 1 @ 48 hours post-application). No brodifacoum residues were detected in any of the invertebrate or fish samples collected.

Terrestrial Ecosystem

Trace levels of brodifacoum were detected in three of five invertebrate samples collected five days after the bait application on East Anacapa in 2001. Trace levels of brodifacoum were detected in two of five samples on Middle Anacapa Island, five days

Table 2. Species and numbers of birds found dead after bait application, Anacapa Island, 2001/2002.

Common Name (*Scientific name*)	East Anacapa 2001	Middle and West Anacapa 2002
White-crowned sparrow (*Zonotrichia leucophrys*)	26	7
House finch (*Carpodacus mexicanus*)	2	1
Orange crowned warbler (*Vermivora celata*)	0	1
Rock wren (*Salpinctes obsoletus*)	1	0
Western gull (*Larus occidentalis*)	2	0
Spotted towhee (*Pipilo maculates*)	1	0
Song sparrow (*Melospiza melodia*)	2	4
Golden-crowned sparrow (*Zonotrichia atricapilla*)	7	3
Western meadowlark (*Sturnella neglecta*)	2	11
Barn owl (*Tyto alba*)	1	2
American kestrel (*Falco sparverius*)	1	0
Burrowing owl (*Athene cunicularia*)	4	2
Dark-eyed junco (*Junco hyemalis*)	0	1
Varied thrush (*Ixoreus naevius*)	0	2
Hermit thrush (*Catharus guttatus*)	0	1
Fox sparrow (*Passerella iliaca*)	0	4
Unidentified sparrows	NA	3
Unidentified small birds	NA	3

after the application in 2002. Brodifacoum was detected in one subsequent sample at six months after the application, suggesting that the biological availability and subsequent movement of brodifacoum into the food chain was limited to a narrow time period after application. It was likely that the invertebrates were degrading residual bait pellets that may have been on the island, however, brodifacoum concentration of caged pellets collected six months after the application had degraded by 92.2%. No brodifacoum was detected in any of the soil samples analyzed from East Anacapa Island. Trace levels were detected in one of nine samples collected at approximately six months post application on Middle Anacapa in 2003.

CONCLUSION

Rats have had a profound impact on global biodiversity, including within the Channel Islands National Park. The eradication of the black rats removes the last introduced mammal from Anacapa Island and will have ecosystem wide benefits. Seabirds and terrestrial species such as deer mice, herpetofauna, landbirds, invertebrates and plants will directly benefit from the removal. The eradication of rats from Anacapa has increased the availability of introduced predator-free seabird breeding habitat in southern California, and it is expected that seabirds will recolonize naturally and ideally local populations will increase. Some changes in the Anacapa ecosystem have already been measured, including increased numbers of breeding Xantus's murrelets and use of habitat where they were previously excluded by rats (Hamer et al. 2003, D. Whitworth pers. comm.). In the spring of 2003, within four months after the bait application, two Cassin's auklet (*Ptychoramphus aleuticus*) nests were found, a seabird that is highly susceptible to rat predation and never documented on the island. The nests were found to contain two young downy chicks (D. Whitworth pers. comm.), clearly demonstrating the benefit of eradicating rats.

The lack of detection of rats after two years and the ecological changes on the island post bait application, together provide strong evidence that rats have been successfully removed. However, the boat traffic to and around the island, and the NPS activities of hauling equipment and supplies to Anacapa, present a risk that rats may be reintroduced to the island. The National Park Service together with Island Conservation have implemented procedures to reduce the chance that rodents will reach the island. We plan to continue to refine those techniques and to build capacity to respond to any reintroduction of rodents to the island to keep the island rat-free. Components of the prevention plan include inspection of materials and supplies before loading onto boats, armed bait stations on board NPS vessels and ongoing monitoring on the island to detect any rats that may reinvade the island.

The Anacapa Island Restoration Project was successful because of the team approach and cooperative effort between the staff of the National Park Service, American Trader Trustee Council and Island Conservation at the planning and compliance phase, and during field work. This project was the first of its kind off the coast of the mainland United States. The project has demonstrated that rats can be eradicated from islands while protecting sensitive native species, including endemic rodents. The aerial broadcast approach to rat eradication is a powerful conservation tool on topographically complex or very large islands. We hope that the success of this project will facilitate future conservation efforts on other islands off the coast of North America.

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