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ABSTRACT: Introduced roof rats (*Rattus rattus*) pose a substantial threat to the fauna and flora of many tropical islands. In the Caribbean, there is concern about rat impacts to several endangered species, including the Atlantic hawksbill sea turtle (*Eretmochelys imbricata*) and the least tern (*Sterna antillarum*). The authors surveyed the rat population on Buck Island, Buck Island Reef National Monument, U.S. Virgin Islands in February 1998. Based on three nights of trapping, rats were of low to moderate abundance during the sampling period when compared to results from other Caribbean islands. The impact of rats on native vegetation was evident over the entire island. A rat management program was proposed using anticoagulant rodenticide baits in bait boxes in and around the two picnic areas on the island. Once an appropriate rodenticide registration is obtained, the baiting program can be extended to include the rest of the island. The eventual eradication of rats from Buck Island will not only provide relief for several endangered species nesting on the island, but will set the stage for the reintroduction of the endangered St. Croix ground lizard (*Ameiva polops*).

KEY WORDS: endangered species, least tern, *Rattus rattus*, rodent damage, rodenticide, roof rat, sea turtle, wildlife management

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INTRODUCTION

At the request of the National Park Service (NPS), Wildlife Services (WS) conducted a site visit to the U.S. Virgin Islands to assess damage by rats to resources at Buck Island Reef National Monument and to assist the NPS in designing a rat management program. WS' biologists visited the U.S. Virgin Islands National Park and Buck Island on February 15 to 21, 1998. The visit included meetings in St. Croix and fieldwork on Buck Island. Personnel of several agencies participated in the meetings. In this report the authors provide an overview of the situation, some results of the rat population assessment, and a proposal for rat management on Buck Island.

OVERVIEW OF SITUATION

The overview of the situation on Buck Island is based on: 1) a review of literature on rats on islands and reports provided by the NPS; 2) a brief site visit to the island in February; and 3) the authors' experience in other similar situations. Buck Island is about 1.5 miles offshore of the northeast coast of St. Croix in the Caribbean Sea and comprises about 180 acres, rising from sea level to about 340 feet in elevation. The island has no permanent sources of freshwater and is covered with a dry, tropical deciduous forest. Although the island is uninhabited and managed as part of the NPS system, it has a history of human habitation that involved various land uses and activities: settlement with structures, farming, tree harvest, human-caused fires, and deliberate, as well as, accidental introductions of plants and animals. Roof rats (*Rattus rattus*) were accidently introduced to Buck Island via ships and cargo, probably in the early years of European exploration and settlement of North America. Roof rats, along with two other European rodent species, Norway rat (*Rattus norvegicus*) and house mouse (*Mus musculus*), have achieved worldwide distribution in this manner. The close association of these prolific, adaptable species with humans and their ready ability to use various human-provided sources of food has resulted in the use of the term "commensal rodents." The numerous and serious problems caused by commensal rodents (loss and contamination of food stuffs, damage to property, and human health hazards) has been well documented and control has been aggressively pursued worldwide (Witmer et al. 1995). Additionally, in tropical areas, commensal rodents have caused major disruption of ecosystems, often reducing biodiversity and putting native species at risk of extirpation (Buckle et al. 1992; Key et al. 1996; Wace 1986). The fauna of many islands has evolved with only a minor (or no) mammalian component and relatively few—if any—predatory species. As such, rats—with their diversified and voracious feeding habits and ability to reproduce rapidly and achieve high densities—can put many species (both plants and animals) at risk. Indeed, high extinction rates on islands have often been attributed to introduced mammalian species, especially rats (Burger and Gochfeld 1994; Whitaker 1978).

A number of species, both floral and faunal, are at risk on Buck Island. Rats may affect island faunas by preying on eggs, young, or adults, and by competing with them for resources such as food or nest sites (Campbell

1989). The NPS has documented impacts to several threatened or endangered species: sea turtles (and in particular, the Atlantic hawksbill turtle [*Eretmochelys imbricata*]) and least tern [*Sterna antillarum*]. Although the authors were not on the island during the nesting season of these species, NPS biologists have documented predation on eggs and hatchlings of these species (e.g., Small 1982). This is consistent with published scientific literature. For example, Atkinson (1985) presented many cases of roof rat predation on oceanic island birds. Roof rats may have been responsible for the 100% mortality reported for two separate roseate tern (*Sterna dougallii*) colonies on Little Saint James Island in the Caribbean (Dewey and Nellis 1980). Endangered brown pelicans (*Pelecanus occidentalis*) also nest on Buck Island, but rats are generally not considered a threat to them (Anderson et al. 1989).

Because rats are omnivores, a number of plant species may also be at risk. The native flora of Buck Island has already been affected by various human activities such as grazing by goats, and especially the introduction of non-native plant species that aggressively compete with native species for light, moisture, nutrients, and space (Woodbury and Little 1976). Drought and periodic hurricanes make the perpetuation of some native plant species even more difficult. Botanical surveys have documented extensive damage to native (and non-native) plants by rats (Gibney 1996; Key et al. 1996). This was observed, as well, on the site visit. Rat damage was commonly observed on cactus, trees, and shrubs all along the trail system, including these plant species: *Adelia ricinella*, *Bourreria succulenta*, *Cephalocerus royenii*, *Cordia rickseckerii*, *Guaiacum officinale*, *Melocactus intortus*, and *Tournefortia volubilis*. The level of damage may be indicative of a moderate density of rodents using plants to obtain moisture on an island with no permanent freshwater.

The NPS and the U.S. Fish and Wildlife Service (FWS) plan to reintroduce the endangered St. Croix ground lizard (*Ameiva polops*) to Buck Island as part of the FWS recovery plan for that species (USFWS 1984). The island provides a primary recovery area for this species which currently only occurs on two much smaller Cays (Protestant Cay, about 7 acres, and Green Cay, about 14 acres). Both of these Cays also have rats, and Protestant Cay is privately owned and developed for tourism; this situation puts the St. Croix ground lizard at great risk of extinction. Both NPS and FWS personnel realize that the value of Buck Island as a reintroduction site is severely reduced by the presence of rats on the island. The impacts of commensal rodents on reptiles and other members of island faunas have been well documented (Campbell 1989; Rivero 1978; Whitaker 1978). In addition to direct predation, rats can reduce habitat quality for lizards by removing substantial amounts of ground cover (e.g., litter, vegetation).

As has occurred on many tropical islands, mongoose (*Herpestes auropunctatus*) were introduced to Buck Island in the late 1800s for the purpose of rat population reduction. It is now known that this is rarely successful, in part because mongoose are primarily diurnal while rats are primarily nocturnal. Mongoose do prey upon rats, but have rarely, if ever, been shown to cause a significant reduction in rat density. Conversely, mongoose are generalist predators, feeding on a variety of vertebrate and invertebrate species (Coblentz and Coblentz 1985). As such, they have caused significant impacts to the native fauna of islands to which they have been introduced. Mongooses have been strongly implicated in the extirpation of the St. Croix ground lizard from St. Croix and Buck Island (Philobosin and Ruibal 1971). The NPS began an aggressive mongoose eradication program on Buck Island in the mid-1980s, using live traps. This resulted in a large reduction in the mongoose population on the island, but the NPS has suspected that a few mongoose remain, based on occasional observation of tracks or, in one case, the recovery of a carcass. The authors observed what appeared to be a fresh set of mongoose tracks along the west beach during their site visit. Protection of the native fauna and the re-establishment of a population of the St. Croix ground lizard on Buck Island will require the prevention of mongoose population expansion (Meier et al. 1990).

Rats have not been controlled on Buck Island in recent history, short of some minor trapping and removal activities by NPS personnel during turtle nesting season. It appears that this effort was very limited and occurred because of the incessant harassment not only of sea turtles, but also of nesting survey personnel. Rats not only feed upon turtle eggs and hatchlings, but also harass female turtles attempting to select a nest site. NPS personnel observed that some females abandoned their nesting attempt and returned to the sea. Losses (of eggs or hatchlings) to as many as one-third of the hawksbill turtle nests being monitored has been documented by NPS personnel in recent years. Rat predation on sea turtle eggs at Buck Island is not a new problem; Small (1982) reported the destruction of about 23% of hawksbill turtle eggs and hatchlings in 1981.

Least tern eggs and hatchlings are also consumed by rats. Predation has been documented by NPS personnel in recent years and the nesting attempt by about 20 adult terns in 1997 was abandoned before eggs were laid. Predation by introduced rats has been implicated in the decline in many populations of island-nesting birds in the Caribbean and elsewhere (Burger and Gochfeld 1994).

There is also a human health risk from the rats on Buck Island. There have been cases of tick-borne relapsing fever (caused by a *Borrelia* spirochete bacteria) in humans living in the Virgin Islands (Flanigan et al. 1991) and the tick species responsible (*Ornithodoros puertoricensis*) for transmitting the spirochetes to humans have been found on rats collected on Buck Island. In theory, the risk of tick bites to humans on the island is low because of the nocturnal activity patterns of both rats and these ticks, and because there is no overnight lodging by humans on Buck Island. However, day visitors to the island have been harassed by rats, and sea turtle research personnel, working nights on Buck Island, have been even bitten by rats.

RAT POPULATION ASSESSMENT

On the authors' preliminary survey of Buck Island, some rats were observed during daylight hours, especially in the west beach picnic area. Some ground burrow entrances and many cases of damaged plants of various species were also observed. Rat tracks were common along beach-rocky slope interfaces. Field personnel were instructed in the identification of poisonous plants (in particular, manchineel trees [*Hippomane mancinella*] and Christmas-bush [*Comocladia dodonaea*]); this would be especially important for personnel safety during subsequent night work.

It was decided to use a rat trapping protocol that had been used on other Caribbean islands (Campbell 1989). This allowed the authors to work efficiently and to make a relative comparison of the Buck Island results with those from other islands. The existing trail system was used, and 11 to 19 rat snap traps were placed along each of three trap lines. Traps were secured to the side of a tree about 10 to 20 inches above the ground surface with a trap placed every 15 feet along the trail. The three trap lines covered a variety of habitats, slopes, and elevations on the island: 1) the low-lying west beach area; 2) the island ridge line west from the Coast Guard; and 3) a line ascending the south-central trail from the Diedrichs picnic area.

Traps were baited with a mixture of rolled oats and peanut butter and set just before sunset on each of three consecutive nights. The traps were checked at one-hour intervals from 7 p.m. to 10 p.m. Trapped rats were labelled and bagged for later examination and the trap reset. At the last check (10 p.m.) of each night, the traps were sprung and left in place for the next night. Reflector tape on traps and pink plastic flagging on a nearby tree or bush facilitated the locating of traps at night. All traps were removed at the end after the last check on the third night. NPS personnel assisted in establishing and running the trap lines; this provided them with the knowledge and experience needed to monitor the rat population in the future.

Rats were very commonly encountered during the night work, especially at the picnic areas where they were very unwary. Eighty rats were captured over the three-night period (Table 1). More rats were captured from the west beach area (52) than either the ridgeline area (12) or the ascending south-central trail area (16). The capture rate did not decline by the third night, and because trapping was only done for three nights, it is not known how many more nights of trapping would have been needed to see a substantial decline in captures. When the capture data were adjusted for sprung traps, as recommended by Nelson and Clark (1973) and Innes (1990), trap success indices (on a scale of 0 to 100) ranging from 11.0 to 29.3 were obtained. When compared to the results of previous trapping efforts on other Caribbean islands where indices ranged from 0 to 90 (Campbell 1989), the Buck Island results suggest a low to moderate rat population abundance. Because the rat population was sampled at one brief point in time, direct comparisons with other study results may not be appropriate. Additionally, it is noted that rat densities on islands would be greatly effected by amounts of vegetation and precipitation (Atkinson 1985; Jackson et al. 1987). As such, the Buck Island rat population could potentially irrupt to a much higher density with the onset of the rainy season. In any case, this rat population data provide a baseline that could be used to monitor changes in rat abundance. Both sexes and age classes (juvenile and adult) were represented in the rat sample from Buck Island. There was a nearly equal ratio of male-to-female captures with slightly more females captured. Most females (>90%) were sexually mature, as were most (>90%) males. The low total proportion of juveniles in the population (8.8%) suggests low reproductive activity; it is also possible that a high rate of juvenile mortality is occurring. Reproductive activity could be quickly initiated with rainfall and greater food availability. The lengths of male and female rats were similar to those reported for other roof rat populations (Campbell 1989; Jackson 1982); however, the average weights of Buck Island rats were somewhat lower for both males and females, suggesting that the population may be nutritionally stressed. There was some evidence of fighting among the rats, based on lacerations and scars.

RAT MANAGEMENT

A wildlife damage management program should be based on a thorough understanding of: 1) the biology and ecology of the problem species; 2) the type, amount, and timing of damage; 3) management options and methods available; and 4) the relevant laws and regulations. Most rodent damage management programs use a combination of methods, including: 1) exclusion or rodent-proofing; 2) habitat modification and sanitation; and 3) toxicants and/or traps. Other methods (increasing predation, shooting, fumigants) are less often used or are ineffective (frightening devices, repellents). The basic biology and ecology of roof rats and management methods are presented in Buckle and Smith (1994), Jackson (1982), Marsh (1994), Meehan (1984), and Storer (1962).

Even with the brief, one-point-in-time assessment of the Buck Island situation, it would appear that the sizeable rat population is impacting numerous floral and faunal resources. It would also appear that the proposed reintroduction of the St. Croix ground lizard to the island would be jeopardized by the rat population. The authors were initially contacted by the NPS because they wanted assistance in designing a rat eradication program. Rat eradication is a worthy goal and would provide a permanent solution to the problem. Rats have been successfully eradicated from a number of islands around the world (Moors 1984; Morgan et al. 1996; Taylor and Thomas 1993). In the Caribbean, rat eradication efforts have been completed on several islands and efforts on additional islands are underway (D. Nellis, U.S. Virgin Islands Bureau of Wildlife, pers. comm.). Once eradicated, a relatively low-keyed monitoring effort would be used to determine if reinvasion has occurred. A prompt response with appropriate measures if reinvasion occurs, while rodent numbers are very low, may preclude the development of another serious situation as now exists on Buck Island.

While rat eradication from islands can be achieved, it requires a concerted, sustained effort with adequate resources. In general, rodenticides are used because they are more efficient, less costly, and more effective in removing large numbers of rats than are live or kill traps. Additionally, a portion of any rat population is usually "trap shy." It should be noted, however, that a rodent population may become "bait shy" (this usually occurs with acute toxicants) or resistant to the toxicant (although

Table 1. Assessment of Buck Island rat population, based on three nights of trapping, February 18-20, 1998.

Transect (No. of Traps)	Rats Captured by Date 2/18	2/19	2/20	Total	Mean Corrected Trap Success[a] (SE)
West Beach (19)	16	13	23	52	29.26 (4.07)
Diedrichs (15)	3	10	3	16	11.97 (4.61)
Tower (11)	0	9	3	12	10.97 (4.67)
Totals	19	32	29	80	

[a]An index of abundance; values can vary from 0 (no captures) to 100 (very high capture success). This is a measure of captures per trap-effort (CE), adjusted for sprung or nonfunctional traps, according to the formula: CE=Ax100/(TU-IS/2), described in Innes (1990) and Nelson and Clark (1973).

Sex Ratio of Population	Proportion of Juveniles in Population
Males: n = 37	Juvenile Males: 3/37 = 8.1%
Females: n = 43	Juvenile Females: 4/43 = 9.3%
M:F Ratio = 1:1.16	Total Juveniles: 7/80 = 8.8%

Morphological Data on Population

Attribute	Males (n = 37) Mean	Males SE	Females (n = 42) Mean	Females SE
Body Weight (g)	147.6	6.3	139.9	5.7
Total Length (mm)	396.6	5.2	387.2	5.6
Body Length (mm)	182.4	2.7	176.8	3.1
Tail Length (mm)	214.2	2.9	210.4	3.0

rare, this has occurred with some anticoagulants); in either case, an alternate rodenticide should then be used. Numerous types of rodenticides are available and have been used for the management or eradication of commensal rodents. Both acute and chronic (anticoagulant) types are available. In general, anticoagulants are preferred because: 1) they can be used effectively in very low concentrations; 2) there is an antidote (vitamin K) available; and 3) secondary hazards are usually lower than for acute toxicants. The two anticoagulants most commonly used in the United States are chlorophacinone and diphacinone.

In general, the use of registered rodenticides is allowed in or within 150 feet of man-made structures. To use rodenticides in other areas would require a: 1) federal [Section 3]; 2) state or local needs [Section 24c]; or 3) emergency use [Section 18] registration as per the Federal Insecticide, Fungicide, and Rodenticide Act and as administered by the U.S. Environmental Protection Agency (EPA). Because emergency use registrations are usually issued for a one-time use, it would be better to obtain a Section 3 or 24c registration. The authors were not able to ascertain, during their brief visit, what rodenticide registrations—if any—are available for the Virgin Islands. NPS personnel will need to contact the NPS Integrated Pest Management (IPM) specialist, the EPA Region 2 Office, or the Virgin Islands Department of Planning and Natural Resources.

Rat eradication would be most efficiently achieved with the aerial application of bait blocks. Obtaining a registration for such an operation may be difficult, however, because of environmental concerns and potential hazards to nontarget species. The use of bait boxes would reduce the potential hazards, but results in additional expense and labor. To be effective, baits should be distributed over the entire island in a grid-like pattern with bait blocks/boxes about every 100 to 150 feet. Bait boxes could be placed in trees or on the ground. A pattern of trails would need to be established for bait placement and maintenance, similar to what was done for the mongoose trapping program of the 1980s. Once initiated, the baiting operation would probably require several months to complete. After placement, baits would need to be checked and replaced as needed. Initially, this would probably be every few days, but would drop to about once per week after the rat population was greatly reduced. Typically, baits are maintained for weeks after all consumption has virtually stopped to help assure that all rats have been eliminated. Because of limited personnel to dedicate to this effort, it is recommended that the NPS consider subcontracting out this work to an appropriate agency or party. To accomplish this goal an EPA registration for the use of rodenticides for conservation purposes on wild lands would be required.

Before the funding, materials, personnel, and permits are secured for a rat eradication program—and in the event that this level of effort is never achieved—it is recommended that the NPS begin a rat management program as part of a tiered approach. The authors envision these three tiers:

1. Use of bait boxes within 150 feet of the two picnic areas. The existing structures make this readily possible with a minimum of permit requirements. This approach would focus on the high rat density areas and would most specifically address rat-human encounters.
2. Expansion of Tier 1 to include bait boxes distributed over an area not to exceed 10 acres that includes as much of the west beach turtle nesting area as possible. An experimental use permit (Section 5) is more easily obtained if the area treated is <10 acres. This approach should provide relief to nesting turtles and would allow the NPS to monitor the rat population in the area *and* turtle nesting success, as well as to address and correct any problems with the baiting program before an island-wide eradication attempt is undertaken. This area could perhaps include the least tern nesting beach as well.
3. An island-wide eradication effort as described above. If, and when, the appropriate registration is obtained and logistical arrangements are in place, this effort could proceed. Only this Tier 3 action has the potential to resolve the rat problem on Buck Island on a permanent basis; the other two tiers would require annual effort and expense for an indefinite time period.

It is difficult to accurately estimate the implementation cost for each tier. Expenses could be kept lower through the cooperation and interaction of several agencies or parties and the use of volunteers. Taylor and Thomas (1993) estimated that it cost about $120 per acre to eliminate rats from a 425 acre island off the shore of New Zealand in 1988-89; they relied on volunteers for much of the labor. This would correspond to a cost of about $22,000 (1990 prices) for the same intensity effort on the 180 acre Buck Island. It is recommended, however, that the NPS not rely on volunteer effort for this important project. Salaries, and the need for a project vehicle on St. Croix, increase the project cost substantially over the New Zealand project even with the conversion of their costs to 1998 dollars. Information on the suppliers of materials that would be needed for any level of rat management were provided by Hygnstrom and Hafer (1994).

The NPS has already initiated a public education program regarding the rats and their impacts on Buck Island. This effort should be continued and even expanded. The goals of the program should not only be to educate the public, but to gain public support for a vigorous, sustained rat management or eradication program. Other elements of an integrated pest management strategy need to be implemented as well, especially with the Tier 1 and 2 approaches which involve a protracted management program. Trash must be contained and regularly removed from the island. Consideration should be given to not allowing concessionaires to feed visitors to Buck Island. Buildings and structures should be inspected and modified, as needed, to minimize or prevent rat access and damage. A routine rat monitoring program should be established. The current monitoring and documentation of rat damage to other resources should continue and, preferably, be expanded to more fully quantify the problems and provide additional insight into the timing and location of damage and into the association of damage with other factors (e.g., storms, drought, human activities). Monitoring also provides a feedback mechanism so that the rat management program can be revised (expanded, down-graded, or eliminated) periodically, as needed.

This assessment of the rat situation on Buck Island derives from one brief visit during one week in February. As such, statements and recommendations are of a preliminary nature. A more thorough assessment would allow better definition of the situation and more confidence in those statements and recommendations.

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