Monitoring invasive mammalian predator populations sharing habitat with the Critically Endangered Puerto Rican parrot *Amazona vittata*

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Abstract Critically Endangered Puerto Rican parrots *Amazona vittata* are one of the rarest birds in the world. Several exotic mammal species capable of preying on Puerto Rican parrots cohabit the Caribbean National Forest with the only wild population of these parrots. We used tracking plates, monitoring blocks and trapping to index black rats, small Indian mongooses and feral cats in parrot habitat and in public-use areas in the same habitat type. We had high trap success for black rats at all sites (42% of all sites combined), among the highest reported in the world. Rat response to monitoring (non-toxic bait) blocks was universally high, regardless of ground or tree placement. Mongooses were present at all sites, with a greater proportion of plates tracked within

the forest than at public-use sites. Cats were present at all forest sites and one of the public-use sites. Presence of the three species did not appear to be linked to human disturbance. Because only 30–40 Puerto Rican parrots survive in the wild, with as few as three pairs nesting in 2002, we concluded that the abundance and pervasiveness of exotic mammalian predators poses a greater threat to the parrots than has been generally acknowledged. This is evidenced by mammalian predation during recent parrot breeding seasons, including six fledglings taken by mongooses and one nest failure from rats during 2000–2003.

Keywords *Amazona vittata*, black rat, endangered species, exotic species, feral cat, invasive species, mongoose.

Introduction

The Puerto Rican parrot *Amazona vittata* is one of the 10 most threatened birds, categorized on the IUCN Red List as Critically Endangered (US Fish and Wildlife Service, 1999; IUCN, 2004). The only wild population comprises 30–40 individuals in the Caribbean National Forest, Puerto Rico. Predation critically threatens many rare species (Hecht & Nickerson, 1999; Wanless *et al.*, 2002), and is one factor limiting Puerto Rican parrot productivity (Snyder *et al.*, 1987; Lindsey *et al.*, 1994; USFWS, 1999). The deleterious impacts of predation can be

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compounded by habitat loss, human disturbance, and altered predator communities (Reynolds & Tapper, 1996), all of which apply to Puerto Rico. Even a few predators can have substantial impacts on prey demography (Nogales *et al.*, 2004) and increase the risk of catastrophic extinction (Schoener *et al.*, 2001), a concern on a hurricane-prone island. Because smaller populations often face a greater likelihood of extinction (Shaffer & Sampson, 1985), even the loss of a few birds can severely affect a species as rare as the Puerto Rican parrot.

Most attention has been given to red-tailed hawks *Buteo jamaicensis* as predators of adult parrots (Snyder *et al.*, 1987; Lindsey *et al.*, 1994; USFWS, 1999), but several invasive mammalian species also potentially threaten Puerto Rican parrots. Black rats *Rattus rattus* have long been recognized as actual or potential parrot nest predators (Snyder *et al.*, 1987). Based on rat signs in failed parrot nests, Rodrigues-Vidal (1959) considered black rats the greatest threat to Puerto Rican parrot population viability. Such observations cannot distinguish post-failure scavenging from rat-induced failure because of harassment or predation, and Snyder *et al.* (1987) discounted threats from rats by attributing much of the evidence of rat predation in nests to secondary scavenging. Zwank & Layton (1989) found high rat abundances in the forest, but felt their threat was minimal because their densities were greatest after fledging. Small Indian mongooses *Herpestes javanicus* and feral cats *Felis catus*

were also cited as potential predators (Snyder *et al.*, 1987). Despite documentation of the predatory abilities and impacts of cats and mongooses on islands throughout the world (Seaman & Randall, 1962; Moors & Atkinson, 1984; Wanless *et al.*, 2002; Nogales *et al.*, 2004), these species have not recently been considered a major threat to parrot recovery (Snyder *et al.*, 1987).

To better understand current threats to Puerto Rican parrots from invasive mammalian predators we (1) evaluated the relative abundance of black rats, mongooses and cats in parrot habitat, (2) gauged the impact of human disturbance on predator populations by also monitoring in public-use sites, (3) assessed index methods for efficiency in operational predator management applications, and (4) evaluated predation threats based on recent parrot reproductive data and predation observations.

Study area

The Caribbean National Forest is managed by the US Forest Service and encompasses 11,500 ha in the Sierra de Luquillo Mountains, approximately 40 km north-east of San Juan (Fig. 1). We conducted our study in the Palo Colorado (*Cyrilla racemiflora* dominant) forest type that provides critical nesting habitat for the Puerto Rican parrot (Arendt, 2000). The Palo Colorado forest covers 3,300 ha and is associated with the lower montane wet zone over 600–900 m. Temperatures are mild (average 27ºC, range 21–36ºC) with high humidity. Rainfall averages 400 cm annually. The rainy season is June-October, and the dry season October-May, although rain falls year-round. Human use is low in most of this forest type, but the Palo Colorado Recreation Area is heavily used by visitors, with a system of cabanas, cook pits and cobbled trails. Despite daily cleaning, anthropog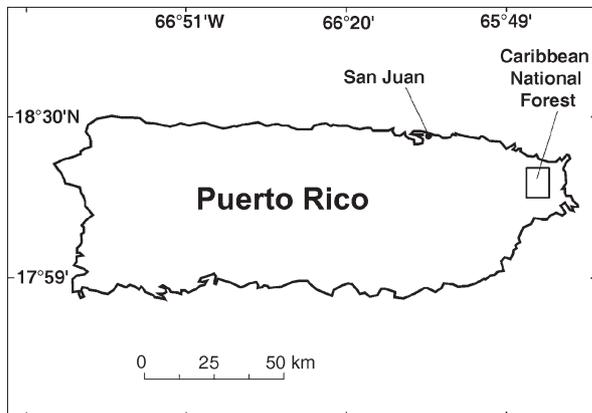enic food sources are common. Timber cutting, hunting and fishing are not allowed in the Forest. Access to parrot habitat is restricted.

Methods

Sampling sites for mammalian predators

We selected five 0.5 ha sites in the Palo Colorado forest type, three in habitat critical to Puerto Rican parrots, either close to nest trees (Site 1) or in nearby forest areas used for roosting and foraging (Sites 2 and 3). Two sites (4 and 5) were at public-use areas in the same forest type. All sites were ≥100 m apart. Forest sites and public-use sites were observed to determine whether exotic species associated more closely with human disturbance than forested areas. Sites were sampled in late June and early July 2002 to avoid disturbing parrot nesting and fledging activities.

Small mammal population indexing

We assessed the relative abundance of rats, mongooses and cats at each site using tracking plates. We also used live traps and paraffin monitoring blocks to index rat abundance. Remote cameras verified tracks and identified mammals consuming monitoring blocks. A Trail Master unit was set at a monitoring block at sites 2, 3 and 4, a tracking plate at site 1, and a location baited with tuna fish at site 5.

Tracking plates were 25 * 25 cm white linoleum squares baited with canned tuna. We placed an 8-cm strip of India ink across the center of each plate. Visitors to the plate step in the ink and leave tracks on clean sections of the plate (Plate 1). Four tracking plates, ≥55 m apart, were placed at each site for two nights. We identified tracks each morning and re-baited and re-inked the tracking plates for the second night.

We made 50 g monitoring blocks from equal proportions of molten paraffin and oats. This formulation had demonstrated high acceptance by rodents, including black rats, in laboratory and field tests (Salmon *et al.*, 2002; Whisson & Engeman, 2003; Whisson *et al.*, 2005). We staked 9 blocks on the ground and attached 9 blocks up to 2 m high in trees at each site. Blocks were placed at intervals ≥5 m along four 40 m lines radiating from the center of each site. We inspected each block for 4 consecutive days and recorded the amount consumed by rats.

After completing tracking plate and monitoring block observations, we removed rats from each site with five Sherman live-traps ≥5 m apart on the ground in the center of each site. Traps were baited with an oat and peanut butter mixture and checked daily for 4 days. Trap success was calculated as the number of animals trapped

Fig. 1 Location of the Caribbean National Forest in Puerto Rico, where the only wild population of Puerto Rican parrots survive.

Plate 1 Application of a tracking plate to monitor invasive mammal species in the Caribbean National Forest, Puerto Rico (photo by D. Whisson).

per number of traps available, corrected for sprung traps. Rats were euthanized by cervical dislocation.

Data analyses

We examined the influence of human disturbance on invasive mammal populations by comparing response rates at tracking plates and monitoring blocks between the three parrot habitat sites and the two public-use sites. Because of small cell frequencies, Fisher's exact test was applied as a conservative test for detecting differences in response rates (e.g. D'Agostino *et al.*, 1988). A two-factor repeated measures design, analysed as a mixed model (McLean *et al.*, 1991; Wolfinger *et al.*, 1991) using SAS PROC MIXED (Littell *et al.*, 1996), compared the percentage of monitoring blocks visited between tree and ground positions, between parrot habitat and public-use sites, and their interaction. Total amount consumed from monitoring blocks was analysed in the same way. Rat trapping success rates based on trap-nights with captures were compared among all sites using Pearson's χ^2 statistic.

The daily percentage of available monitoring block consumed by rats provided an appropriate data structure for calculating abundance indices (AI) at each site according to the analytical methods outlined in Engeman (2005) and Engeman *et al.* (1998), and as extensively applied for passive tracking indices (Engeman *et al.*, 2003a). The AI and associated variance were calculated according to Engeman *et al.* (2005). A linear model incorporating random effects (McLean *et al.*, 1991; Wolfinger

et al., 1991) described measurements at each station each day, with no assumptions of independence among stations or days. The mean measurement across stations was calculated for each day. The index values were the means of the daily means:

$$AI = \tfrac{1}{d}\sum_{j=1}^{d}\tfrac{1}{s_j}\sum_{i=1}^{s_j}x_{ij}$$

where x_{ij} represents the proportion of monitoring block removed at the ith station on the jth day, d is the number of days of observation, and s_j is the number of stations contributing data on the jth day. SAS PROC VARCOMP, using restricted maximum likelihood estimation (REML; SAS Institute, 1996) was used to calculate the variance components (Searle *et al.*, 1992) needed in the variance estimation formula (Engeman *et al.*, 1998):

$$\mathrm{var}(AI) = \tfrac{\sigma_s^2}{d}\sum_{j=1}^{d}\tfrac{1}{s_j} + \tfrac{\sigma_d^2}{d} + \tfrac{\sigma_e^2}{d^2}\sum_{j=1}^{d}\tfrac{1}{s_j}$$

where the σ_s^2, σ_d^2, and σ_e^2 are, respectively, the components for station-to-station variability, daily variability, and random observational variability associated with each station each day.

Data from recent years on parrot reproduction in the wild were summarized, as were mammalian predation events (US Fish and Wildlife Service, unpubl. data). These events were assessed according to their impacts as predatory threats to the parrots, particularly during nesting and fledging.

Results

There was little difference in mammalian species composition among the five sites (Table 1). Photographs recorded mongooses at sites 1 and 5, black rats at all sites, and a cat at site 1. Mongooses were not photographed at monitoring blocks, and no tooth-mark or other sign indicated that monitoring block consumption was by any species other than black rats.

Rat response to monitoring blocks was universally high, regardless of site or placement. The lowest response rate was for tree placements at site 3, where 56% were gnawed. All other site and placement combinations showed $\geq 67\%$ response, with four site-by-placement categories having 100% response (Table 1). Although rat responses to ground placement was greater than tree placement at four of five sites, the difference in visitation rates between tree and ground placement was not statistically significant ($F_{1,3} = 0.95$, P = 0.40). Similarly, differences in visitation rates were not detectable between the forest habitat and the picnic areas ($F_{1,3} = 3.04$, P = 0.18), nor for the interaction between placement and habitat ($F_{1,3} = 0.02$, P = 0.90). However, the consumption results

Table 1 Small mammal species recorded on tracking plates, black rat visitation rates, mean consumption and abundance index (AI) from monitoring blocks on trees and on the ground, and relative abundance trap index of black rats at 5 sites in 2002 in the Caribbean National Forest, Puerto Rico. Habitat for each sampling site is designated as being in parrot habitat (PH) or in public-use areas (PU).

| Site | No. (out of 4) tracking plates where species recorded | | | Monitoring block visitation | | | | | | Rat captures per 100 trap-nights* |
| | | | | Tree | | | Ground | | | |
	Rat	Cat	Mongoose	% visited	Mean consumption	AI	% visited	Mean consumption	AI	
1 (PH)	4	1	3	78	22.6	14	100	36.5	29	33
2 (PH)	3	2	3	89	32.0	24	78	41.2	40	40
3 (PH)	2	1	2	56	27.6	20	67	29.0	20	33
4 (PU)	3	0	1	78	38.5	34	100	47.1	39	44
5 (PU)	4	3	0	100	53.9	66	100	55.0	64	64
Total	16	7	9	80	34.9	32	89	41.8	38	42

*Rats / (number of traps set - sprung traps) * 100

showed average consumption per monitoring block to be higher at public-use areas than at parrot habitat sites ($F_{1,3} = 9.80$, P = 0.05), primarily because Site 5 had greater consumption than the other four sites (Table 1). A potential difference was indicated between ground and tree placement ($F_{1,3} = 5.66$, P = 0.10). No interaction between placement and habitat was indicated for consumption ($F_{1,3} = 0.37$, P = 0.59). Site 5 had the greatest AI among sites but there was no difference between ground and tree placement of monitoring blocks (Table 1).

Rat trapping success was consistently high among all sites. Although trap success ranged from 33 to 64% (42% overall), the sites were not statistically distinguishable on this basis ($\chi^2_4 = 3.1$, P > 0.54). Likewise, the prevalence of rat tracks was similar between tracking plates at forested and public-use sites (Fisher's exact test, P = 0.36). Rats were recorded on tracking plates at all sites, with nine of 12 plates in the forest and seven of eight in public-use areas showing tracks. Mongoose tracks were found at all three forested sites, with eight of 12 plates tracked. Only one of eight plates was tracked in the public-use areas, resulting in a higher tracking rate within parrot habitat than public-use areas (Fisher's exact test, P = 0.02). This was unexpected because the Forest Service considers mongooses to be a human health hazard through attacks by rabid animals (Caribbean National Forest, unpubl. data).

Cats were recorded at all forested sites, but only one public-use site. The overall rate of four of 12 plates tracked in the forest was similar to the rate of three of eight plates tracked at the picnic grounds (Fisher's exact test, P = 0.75).

Since 2000 there have been 3–5 active nests, with fledgling production ranging from two to eight (Table 2). Rats and mongooses have each been implicated in losses of young, with annual losses to mongooses of up to 50% of wild-produced fledglings, and an undetermined number of rat-induced nest, egg or chick failures (Table 2).

Table 2 Reproductive parameters for all active wild Puerto Rican parrot nests and observations of predation by invasive mammals from 2000 to 2003 (US Fish and Wildlife Service, unpubl. data).

| Nest ID | 2000 | | 2001 | | 2002 | | 2003 | |
	Eggs	Fledge	Eggs	Fledge	Eggs	Fledge	Eggs	Fledge
SF2A	3	2	1	0	3	0	3	3
SF2B	3	2	3	3	2	2	2	2
SF1T	3	3	0	0	0	0	3	1
SF1A	2	1	2	0	3	0	0	0
QG	1	0	3	2	0	0	3	2
L					0	0	2	0
Total	12	8	9	5	8	2	13	8
Predation events	Fledgling remains (4) & radio transmitters found in mongoose burrows		Fledgling remains (1) & radio transmitter found in mongoose burrow		Rat nest in nest cavity prior to parrot nesting, rat sign in failed nest (SF1A) afterwards		Fledgling remains (1) & radio transmitter found in mongoose burrow	

Discussion

Our capture success for black rats is among the highest reported in the literature using live or snap traps. Goodman (1995) reported 65.2% trap success of *R. rattus* on Madagascar, whereas most studies report <10% trap success (Tamarin & Malecha, 1972; Robinet *et al.*, 1998; Dunlevy *et al.*, 2000). Even those low rat densities are well-documented as causing insular avian extinctions or declines (Atkinson, 1985). Black rats appear exceptionally abundant in the Caribbean National Forest, irrespective of proximity to public-use areas where high densities may be expected. Our rat capture rates were orders of magnitude above the 2.8–8.5 captures per 100 trap-nights reported by Zwank & Layton (1989) in the Forest. Our high capture and visitation rates to monitoring blocks on the ground and in trees at all study sites suggest rats are a pervasive presence that pose a constant threat of predation or harassment to parrot nests.

Rat predation was indicated in 2002 at one nesting cavity where successful reproduction could have occurred (Table 2). This observation, plus our data on rat abundance and distribution across five sites led to intensified rat control near nesting cavities. Prior to 2002 rat control involved a few bait stations containing 0.005% diphacinone bait. Population reductions beyond the annual surplus of animals would be unlikely for population levels indicated by our data. More intensive baiting for the 2003 breeding season was tested for efficacy by monitoring radio-collared rats. Eighteen bait stations, each holding four blocks of Ditrac® (0.005% diphacinone), were spaced 20 m apart along four rows around a nesting tree (Whisson, 2003). After 1 week bait consumption decreased and all monitored rats were dead (Whisson, 2003).

Wild parrot breeding success fluctuates considerably (Table 2). A rat-induced nest failure (including harassment that deters nesting) was particularly unacceptable in a year (2002) with only three active nests. Nest success improved substantially in 2003 when rat control was intensified (Table 2), with four of five active nests successful. Various factors may have influenced that nesting success including weather conditions, natural fluctuations in breeding success, and enhanced rat control. Rat control is the only one of these factors that could be managed, and is highly cost-effective to apply (Engeman *et al.*, 2003b).

Cat and mongoose predation on rats appears to provide little net benefit towards population reduction, as indicated by the observed high rat populations. Mongooses have been introduced to tropical islands worldwide to control rat populations (Hoagland *et al.*, 1989), with only temporary or insufficient population suppression (Baldwin *et al.*, 1952; Pimentel, 1955; Seaman & Randall, 1962; Hoagland *et al.*, 1989). More likely, abundant rats supplement cat and mongoose diets.

The perception that cats and mongooses are not serious predatory threats undoubtedly stemmed from the belief that little contact would occur between parrots and terrestrial animals. Snyder *et al.* (1987) stated: 'We have never seen them [Puerto Rican parrots] feed from the forest floor.' This referred to wild parrots. Since 2000, captive-reared parrots have been regularly released to augment the wild population. While deploying our monitoring devices on 19 June 2002 we observed two radio-tagged adult (released) parrots alight on the forest floor and forage. Moreover, fledgling parrots may land on the forest floor before their flight abilities are fully developed. Contact is also possible above the forest floor. Cats are well-known for their climbing abilities, but mongooses are not perceived as climbers. Nevertheless, we twice observed mongooses above 2 m in trees, suggesting their predation threat may extend to the first strata above the forest floor. Mongooses are common in parrot habitat, and are active animals that cover relatively large home ranges quickly (Quinn, 2004). Whether captive-bred or wild, fledgling or adult, any parrot on or near the forest floor appears vulnerable to cat or mongoose predation.

We twice observed cats in the parrot nesting area, with another photographed on a tracking plate <75 m from a nest tree (Plate 1). Their presence is an obvious hazard for parrots coming into positions of contact. Cats have not been removed from parrot areas in recent years, although they were in the past. A reassessment of the predation risk from cats is warranted, because of their abundance and their well-known negative impacts on insular avifauna world-wide, including extinctions (Karl & Best, 1982; Tideman *et al.*, 1984; Smucker *et al.*, 2000; Wanless *et al.*, 2002; Nogales *et al.*, 2004). The last population of the Stephan Island wren *Traversia lyalli* was extirpated by a single cat (Fuller, 2000), as probably was the Angel de la Guarda deer mouse *Peromyscus guardia* on Estanque Island, Gulf of California (Vàzquez–Domínguez *et al.*, 2004). The successful reintroduction of Aldabra rails *Dryolimnas aldabranus* was partly attributed to releasing the birds on a cat-free island (Wanless *et al.*, 2002). Birds reached their highest proportion in feral cat diets in the montane wet forest of Hawaii (Smucker *et al.*, 2000). Similar dietary studies are not available for feral cats in Puerto Rico but the Hawaiian data, given our findings, reinforces the need to increase attention on cats as predatory threats to Puerto Rican parrots.

Parrots regularly disappear without identification of a cause (Lindsey *et al.*, 1994) and cats and mongooses are capable of inflicting unidentifiable losses. Moreover, there is recent evidence of mongoose predation, with

at least six wild fledglings having apparently fallen prey to mongooses since 2000 (Table 2). Lindsey *et al.* (1994) reported recovering remains of two parrots from under a root mass in the forest, but they felt that scavenging precluded determination of the cause of death, rather than implicating mongoose predation as the cause. With released parrots occasionally spending time on the ground, the predation threat may be more significant than previously considered. If parrot numbers were sufficiently high that a single predatory event would have no practical impact, then mongoose and cat predation may merit minimal concern. In reality, loss of a single wild parrot represents 2.5–3.5% of the entire wild population. Losing a member of a breeding pair would represent a much larger segment of the reproductive portion of the population (33% in 2002).

A major component for Puerto Rican parrot recovery is to establish a second wild population (USFWS, 1982, 1999). Similar surveys for predators and their control, if necessary, should be conducted prior to releases, followed by a focus around parrot nests as they become established. This conservation approach has proven successful for captive-bred and released species such as malleefowl *Leipoa ocellata* (Priddel & Wheeler, 1997) and Guam rails *Gallirallus owstoni* (Brock & Beauprez, 2000; Vice *et al.*, 2001).

Assuming exotic mammalian predators pose unacceptable threats to parrots, management actions to alleviate the situation must be considered. Management of non-native rats has proven highly cost-effective for conservation of endemic birds in Hawaiian rainforests (Nelson *et al.*, 2002). Costs were approximately USD 7,000 km^{-2} in the first year, and USD 2,000 km^{-2} in subsequent years for a 4-month baiting and trapping programme during nesting. Costs in the Caribbean National Forest would probably be less because predator management would focus around few parrot nests. An economic analysis found predator management highly cost-effective for conserving Puerto Rican parrots (Engeman *et al.*, 2003b). All predator removal combined was found cost-effective at the median valuation of parrots if one parrot is saved from predation every 2.6 years. Cost-effectiveness was achieved at the maximal empirical valuation for parrots with one parrot saved every 11.8 years.

Integrating predator monitoring into predator management programmes in the Forest could lead to similarly efficient and effective strategies and results as occurred for protecting marine turtle nests from predators on Jupiter Island, Florida (Engeman *et al.*, 2003a). Bait blocks offer a low-cost, low-effort means to index rat populations. Great efficiency can be achieved by simultaneously monitoring and controlling rat populations using consumption of multi-feeding toxic bait blocks to reduce rat populations while indexing their initial populations and their subsequent declines (Taylor & Thomas, 1993). Cats and mongooses could be monitored at low cost using tracking plates, whereas removal would be accomplished through trapping or specially registered toxicants. Indexing methods would provide a metric for evaluating the need and subsequent efficacy of predator management strategies.

Puerto Rican parrots face a host of natural enemies besides invasive mammals (Snyder *et al.*, 1987). Regardless, a highly threatened species in the midst of high mammalian predator populations, documented predation, and with the availability of highly cost-effective predator management methods leads us to conclude that control of these exotic mammals should be implemented or intensified, as appropriate.

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