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Short communication

Recovery of the Galápagos rail (*Laterallus spilonotus*) following the removal of invasive mammals

C. Josh Donlan[a,b,*], *Karl Campbell*[c,d,e], *Wilson Cabrera*[c], *Christian Lavoie*[f], *Victor Carrion*[c], *Felipe Cruz*[c,d]

[a]*Department of Ecology and Evolutionary Biology, Corson Hall, Cornell University, Ithaca, NY 14853-2701, USA*
[b]*Advanced Conservation Strategies, P.O. Box 8254, Santa Cruz, CA 95061-8254, USA*
[c]*Galápagos National Park Service, Puerto Ayora, Isla Santa Cruz, Galápagos, Ecuador*
[d]*Charles Darwin Foundation, Casilla 17-01-3891, Quito, Ecuador*
[e]*School of Natural and Rural Systems Management, University of Queensland Gatton, Gatton Queensland 4343, Australia*
[f]*United Nations Development Program, Av. Amazonas 2889, Quito, Ecuador*

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ABSTRACT

Rails (family Rallidae) are vulnerable to the impacts of invasive mammals, and this is particularly true for species on oceanic islands. The endemic Galápagos rail (*Laterallus spilonotus*) is no exception; previous studies suggested that Galápagos rail populations were heavily impacted due to predation by pigs (*Sus scrofa*) and habitat degradation by goats (*Capra hircus*). Following recent conservation actions that have eradicated pigs and goats from Santiago Island, changes in rail abundance were observed. Estimated densities have increased by over an order of magnitude between 1986/1987 and 2004/2005. Limited data on rail densities from two additional islands over the same time period provide further support to the notion that the eradications spurred recovery. On Fernandina Island, where there is no history of invasive mammals, rail density increased slightly between 1986/1987 and 2004/2005. In contrast, on Isabela Island where invasive mammals were present both in 1986/1987 and 2004/2005, rail densities declined at one site between those two time periods. While the Galápagos rail is vulnerable to invasive mammals, the observed changes following goat and pig removal are encouraging for Rallidae conservation.

"Rails are the most intriguing and tragic family of birds in Oceania if not the world... If not for human impact, more species of rails would be alive today than of any other family of birds." – David Steadman, 2006

1. Introduction

Insular endemic birds in general and rails (Rallidae) in particular are vulnerable to non-native mammals and other anthro-

* *Corresponding author:* Address: Department of Ecology and Evolutionary Biology, Corson Hall, Cornell University, Ithaca, NY 14853-2701, USA. Tel.: +1 607 254 4269; fax: +1 607 255 8088.
E-mail address: cjd34@cornell.edu (C.J. Donlan).

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pogenic impacts (Harding et al., 2001; Innes et al., 1999; Miller and Mullette, 1985; Owens and Bennett, 2000; Steadman, 2006). The late Quaternary fossil record documents an unprecedented avian extinction event in Oceania: roughly 1000–2000 species, most of them rails, were lost on tropical Pacific Islands after the arrival of humans (Steadman, 2006). Those extinctions were presumably the result of predation and habitat degradation by humans and their commensals, such as rats (*Rattus* spp.) and pigs (*Sus scrofa*). More recently, 17 species of insular rails have gone extinct in the Pacific since 1600 (Greenway, 1958), and one third of the 142 extant rail species are threatened (Bennett and Owens, 1997).

The Galápagos Islands were uninhabited by humans prior to European discovery in the mid-sixteenth century, and consequently the fauna suffered little extinction until recently. However since European arrival, extinction and extirpation have become increasingly common trends (Cruz and Cruz, 1987; Dowler et al., 2000; Steadman, 1986; Steadman and Ray, 1982). Invasive mammals, including pigs, rats, goats (*Capra hircus*), and cats (*Felis catus*) are the primary agents driving those biodiversity impacts (Cruz and Cruz, 1987; Hamann, 1979; Loope et al., 1988; Steadman, 1986). The endemic Galápagos rail (*Laterallus spilonotus*) is no exception, with populations suffering from the adverse effects of invasive mammals.

The Galápagos rail originally occurred on seven islands; nest predation by pigs, habitat destruction by goats, and the indirect impacts of invasive plants have caused rail populations to decline throughout the archipelago (Coblentz and Baber, 1987; Franklin et al., 1979; Gibbs et al., 2003; Rosenberg, 1990). During 1986/1987 surveys, only 25 rails were detected on Santiago Island (Rosenberg, 1990), where both goats and pigs were abundant. Considering the impacts by goats and pigs (Hamann, 1993b; Schofield, 1989), Rosenberg (1990) speculated that the eradication of those invasive species would benefit rail populations.

Here, we report on recent Galápagos rail surveys. Between 1998–2006, pigs, goats, and donkeys were eradicated from Santiago Island: over 17,000 pigs and 70,000 goats were removed (unpublished data, Carrion et al., 2007; Cruz et al., 2005; Donlan et al., 2005). In an effort to quantify the consequences of invasive mammal eradications, we repeated surveys conducted in 1986/1987 by Rosenberg (1990) on three islands: Santiago, Fernandina, and Isabela. Fernandina Island has remained free of invasive mammals since the initial surveys (Table 1). Goats, pigs, and donkeys remain on many parts of Isabela Island (as was the case in 1986/1987). Thus, distinct differences exist among the three islands with respect to the presence of invasive mammals in 1986/1987 and in 2004/2005 (Table 1). While we lack data on other environmental aspects that may have changed during the 20-year period including natural variation of rail numbers through time, the three islands provide an opportunity to compare rail abundance between two time frames, enabling us to draw some inference with respect to potential causes of rail population changes.

2. Methods and results

We conducted rail surveys on Isabela (December 2004, February 2005), Santiago (December 2004, February 2005), and Fernandina (December 2004) Islands. Our field methods and statistical analyses are identical to the survey of Galápagos rails taken in 1986/1987 (Rosenberg, 1990), which enables us to make direct temporal and spatial comparisons. We sampled sites during the same time of the year as the original surveys (within 8 weeks) to remove seasonal bias in response of rails to playbacks (Conway et al., 1993). Sites were located approximately in the same location, based on survey site descriptions (see Table 2 and Rosenberg, 1990). Surveys were replicated at each site and consisted of 25 m radius circular plots (0.20 ha), with approximately 100 m spacing between plots. We used a playback system (recording obtained from Cornell Lab of Ornithology), playing rail calls for 1 min (15 s in 90° rotations); we scored responding rail calls for a total of 3 min (1 min of playback + 2 min following). We scored only those rails within the 25 m radius, and we attempted to count individual rails only once. We characterized plot vegetation structure using two categories: high (>25% cover of forbs and grass >30 cm tall) or low (<25% cover of forbs and grass >30 cm in height and >25% cover in forbs and grass <30 cm in height; sensu Rosenberg, 1990). We also recorded the presence or absence of standing water within the survey plot. We surveyed seven additional sites on Isabela Island for the first time to provide baselines for future surveys (Table 2).

We detected a total of 303 rails ($n = 370$ surveys at 12 different sites; Table 2). Rail density varied from 0–17.9 rails per hectare (Table 2). Overall, rails showed a significant affinity for high vegetation compared to low ($\chi^2 = 19.05$, $d.f. = 3$, $p < 0.001$, $n = 326$, four categories: 0, 1, 2, >2 rails at each plot compared across vegetation score). Rails also showed a significant affinity for the presence of water in the survey plot

Table 1 – Non-native mammals and dominant invasive woody plants present on three Galápagos Islands where rails were surveyed (X = Present, E = Eradicated)

		Mice[a]	Rats	Cats	Goats	Pigs	Donkeys/horses	Cattle	Plants
Isabela	Ecuador, Wolf, Darwin Volcanoes	X	X	X	E[b]				
	Alcedo Volcano	X	X	X	E[b]		E[b]		
	Sierra Negra Volcano	X	X	X	X	X	X	X	X[c]
Fernandina									
Santiago		X	X		E	E	E		

On Isabela Island, the distribution of non-native species differs depending on the location.
a *Mus musculus*, *Rattus rattus*, *Felis catus*, *Capra hircus*, *Sus scrofa*, *Equus* spp. *Bos* sp.
b Eradicated after rail surveys.
c Guava (*Psidium guava*) dominant over large areas.

Table 2 – Galápagos rail surveys conducted in 1986/1987 and 2004/2005

Island (site)[a]	# of rails: 1986/2004	Mean density: 1986/2004	# of survey plots: 1986/2004	Chi sq.	p-Value
Fernandina					
Highlands	0/11	0/3.4	29/16	10.2	0.017
Mangrove	n.a./0	n.a./0.0	n.a./15		
Isabela					
Highlands – Ecuador	n.a./0	n.a./0.0	n.a./16		
Highlands – Wolf	n.a./10	n.a./1.4	n.a./37		
Highlands – Darwin	n.a./0	n.a./0.0	n.a./18		
Mangroves – Puerto Chino	n.a./0	n.a./0.0	n.a./20		
Highlands – Alcedo	n.a./0	n.a./0.0	n.a./85		
Mangroves – Punta Alfaro	n.a./0	n.a./0.0	n.a./14		
Highlands – NE Sierra Negra	1/0	0.3/0.0	15/29	1.9	0.16 (0.341[b])
Highlands – SE Sierra Negra	23/3	2.6/0.5	45/28	10.7	0.005
Santiago					
Highlands – Central	18/233	1.4/17.9	70/65	77.2	<0.001
Woodlands – La Chosa	0/46	0/8.5	43/27	44.6	<0.001

Number of rails detected and density (per hectare) at 12 sites on three islands in the archipelago. Chi square and p-value columns show temporal comparisons following Rosenberg (1990); Sierra Negra Southeast declined and the Santiago sites and Fernandina increased. Data from 1986/1987 are from Rosenberg (1990).

a Site locations: Fernandina-highlands S 00.4075 W 91.5493; Fernandina-mangrove S 00.2646 W 91.4487; Isabela-Ecuador S 00.0278 W 91.5553; Isabela-Wolf S 00.0216 W 91.3716; Isabela-Darwin S 00.1977 W 91.3168; Isabela-Puerto Chino S 00.4258 W 90.9588; Isabela-Alcedo S 00.4492 W 91.1063; Isabela-Punta Alfaro S 00.3535 W 91.2800; Isabela-NE Sierra Negra S 00.7967 W 91.0910; Isabela-SE Sierra Negra S 00.8458 W 91.1052; Santiago-highlands S 00.2375 W 90.7581; Santiago woodlands S 0.2768 W 90.7604.

b p-Value for Fisher's exact test.

($\chi^2 = 38.48$, $d.f. = 3$, $p < 0.001$, $n = 326$, four categories: 0, 1, 2, >2 rails at each plot compared across presence of water). We did not detect rails at the three mangrove sites surveyed.

On Santiago Island, we identified 279 rails in 92 survey plots (Table 2). Density increased significantly at both survey sites compared to 1986/1987 (four categories: 0, 1, 2, >2 rails at each plot compared across year; categories used for comparison with Rosenberg, 1990 Table 2). In the highlands of Santiago Island, only 18 rails were located in 1986/1987 in 70 survey plots compared to 233 rails in 2004/2005 in 65 survey plots (Table 2). In the lower elevation woodland habitat (La Chosa), rails were not detected during 1986/1987; 46 rails were detected in December 2004 (Table 2).

In the highlands of Fernandina Island, which has remained free of invasive mammals, we observed eleven rails on the south-southwestern slope which was an increase from 1986/1987. Rosenberg (1990) failed to detect rails on the southeastern rim of Fernandina with surveys ($n = 29$ plots); however, he did detect a small number of free-calling rails on the south-southwestern slope during the same time period. We detected only three rails at the two sites on Sierra Negra Volcano, Isabela Island, a significant decline from the surveys in 1986/1987 (1986/1987: 23 rails in 45 survey plots; Table 2, Rosenberg, 1990). We detected rails on Wolf Volcano, but not at the remainder of sites surveyed on Isabela Island (Table 2). However, they have been observed on Alcedo Volcano (V. Carrion and K. Campbell, personal observations).

3. Discussion

The changes in rail densities on Santiago Island between 1986/1987 and 2004/2005 are impressive, and a comparison of rail abundance among the three islands surveyed in this study provides inference that these changes are likely attributed to eradication of invasive mammals on Santiago. A total of eighteen rails were detected in 1986/1987 on the island compared to 279 rails in 2004/2005 with similar effort (113 vs. 92 survey plots, respectively). On Fernandina Island (free of invasive mammals), survey results were similar, with rails increasing in 2004/2005 but relatively rare during both periods. On Sierra Negra, Isabela Island, where invasive mammals have been present since the original survey, survey results were similar between the two periods with some evidence of decline at one site (Table 2). In a separate Galápagos study, rail surveys on Santa Cruz Island in 2000, where goats and pigs are present, detected a minor decline compared to surveys in 1986/1987 (Gibbs et al., 2003). The cause of the declines on Santa Cruz are unknown; however, habitat changes via invasive plants are suspected (Gibbs et al., 2003). The plant communities on Santiago Island are recovering following pig and goat removal campaigns (Fig. 1; Cruz et al., 2005), following a pattern similar to what has been documented on other Galápagos Islands where goats have been removed (e.g., Pinta Island; Campbell et al., 2004; Hamann, 1979, 1993a). While it remains to be seen how the Santiago rail population will respond as plant communities continue to recover, the initial changes in rail density are encouraging.

While many insular rail species have suffered extinction due to invasive mammal impacts, populations of this and other insular species have recovered following eradication campaigns. On Pinta Island, Galápagos, rails were not observed in 1970 when goats were present in high densities (Franklin et al., 1979). In contrast, rails were common three years later after the initiation of a goat control program and the vegetation began to recover (Franklin et al., 1979; Kramer and Black, 1970). In New Zealand, a massive conservation

Fig. 1 – Habitat recovery on Santiago Island. (A) An exclosure and surrounding area in the highlands of Santiago Island before (March 1999) and (B) after non-native pig and goat removal (March 2005).

intervention spanning over fifty years, including the control of non-native red deer (*Cervus elaphus*), has prevented the extinction of the takahe (*Poryphyrio hochstetteri*); over 200 birds are now in the wild (Lee and Jamieson, 2001). On Lowe Howe Island, Australia, an endemic woodhen (*Tricholimnas sylvestris*) was on the brink of extinction; however, pig eradication and a captive-breeding program have now restored this species (Miller and Mullette, 1985; NSW National Parks and Wildlife Service, 2002).

While pig and goat removal appear to have facilitated the Santiago Galapagos rail recovery, additional abiotic and/or biotic factors may also play important roles in the species distribution and demography. For example, it is unclear why rail densities are low on Fernandina where there is no history of non-native predators and herbivores, invasive woody plants are not present, and the appropriate highland vegetation is present. Due to large areas of bare lava on Fernandina, rail populations may be low as a consequence of fragmentation effects. There are also historical records of rails from coastal mangrove sites on Fernandina (Franklin et al., 1979; Salvin, 1876), but there have been no observations among mangrove sites in this study or the three others over the past 20 years (Franklin et al., 1979; Gibbs et al., 2003; Rosenberg, 1990). In 2004 rails were detected in mangrove habitat on Genovesa Island (T. Grant and G. Estes, personal communication).

Previous evidence suggests that egg predation by pigs and habitat degradation via invasive woody plants and goats threaten the persistence of Galápagos rail populations (Coblentz and Baber, 1987; Franklin et al., 1979; Gibbs et al., 2003; Rosenberg, 1990). As has been documented elsewhere (Wanless et al., 2002), predation by cats and rats likely also threaten Galápagos rails where they are sympatric. However, this study and others suggest that insular rail populations can respond positively to restoration actions (Lee and Jamieson, 2001; Miller and Mullette, 1985; NSW National Parks and Wildlife Service, 2002; Wanless et al., 2002; Witteman et al., 1990). However, as demonstrated for the Lord Howe Woodhen, recovering rail populations should be managed with close attention to other potential demographic threats, such as catastrophes and disease, as well as invasive species (Brook et al., 1997). In general, insular rails may be useful as a focal species (Landres et al., 1988) on islands where direct and indirect impacts of invasive mammals are apparent, and they may be useful as a restoration and recovery gauge once invasives are removed.

Globally, thousands of species or populations of insular rails have gone extinct due to anthropogenic impacts, including those of invasive mammals, and many remained threatened today (Bennett and Owens, 1997; Steadman, 1986). Twenty-two of the 33 threatened rail species currently listed by the World Conservation Union occur on islands, and 86% of those insular species are threatened by invasive mammals (data compiled from BirdLife International's World Bird Database, and includes IUCN categories *VU*, *EN*, *CR*, and *EW*). Invasive mammal eradications from islands are now commonplace (Campbell and Donlan, 2005; Howald et al., 2007; Nogales et al., 2004). Targeted eradications, along with proposed reintroductions and translocations (Steadman, 2006), would likely benefit endangered rail populations. Before the turn of the century, Darwin commented on the great number of rails on Santiago Island (Darwin, 1896). Their recovery a century later is encouraging for Rallidae conservation.

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