4-24-2020

Impacts of invasive rats and tourism on a threatened island bird: The Palau Micronesian scrubfowl

Paul M. Radley
Edith Cowan University

Robert A. Davis
Edith Cowan University

Tim S. Doherty
Edith Cowan University

10.1017/S0959270920000246

Radley, P. M., Davis, R. A., & Doherty, T. S. (2020). Impacts of invasive rats and tourism on a threatened island bird: The Palau Micronesian scrubfowl. *Bird Conservation International, 31*(2), 206-218. https://doi.org/10.1017/S0959270920000246

Impacts of Invasive Rats And Tourism On A Threatened Island Bird: the Palau Micronesian Scrubfowl.

PAUL M. RADLEY, ROBERT A. DAVIS, and TIM S. DOHERTY

Running Head: Effect of Rats and Tourism on a Threatened Island Scrubfowl

Keywords: Invasive predators, island extinction, megapode, *Rattus*, tourist pressure

Word Count: 6,894 (Summary through Literature Cited)

Summary

Invasive predators have decimated island biodiversity worldwide. Rats (*Rattus* spp.) are perhaps the greatest conservation threat to island fauna. The ground nesting Palau Micronesian Scrubfowl *Megapodius laperouse senex* (Megapodiidae, Aves) inhabits many of the islands of Palau's Rock Island Southern Lagoon Conservation Area (RISL) in the western Pacific. These islands are also heavily visited by tourists and support populations of introduced rats, both of which may act as added stressors for the scrubfowl. Using passive chew-tag and call playback surveys on five tourist visited and five tourist-free islands, we investigated if rats and tourists negatively affect scrubfowl, and if higher rat activity is associated with tourist presence. Rat detection probability and site occupancy were significantly higher on tourist visited (89% and 99%, respectively) compared to tourist-free islands (52% and 73%). Scrubfowl were detected at significantly more stations on tourist-free (93%) than tourist visited (47%) islands and their relative abundance was higher (2.66 and 1.58 birds per station, respectively), although not statistically significantly. While rat occupancy probability likewise had a non-significant negative effect on scrubfowl numbers across islands, our results show a negative relationship between tourist presence and scrubfowl in the RISL. Our findings also suggest that rat populations may be augmented by tourist visitation in the RISL. Although this situation may not seriously affect the scrubfowl, it may be highly detrimental to populations of other threatened island landbirds.

Introduction

Invasive predators are a leading cause of biodiversity loss on islands worldwide, having contributed to more than 50% of bird, mammal and reptile extinctions (Doherty *et al.* 2016). Rats (*Rattus* spp.) are perhaps the most successful invasive predator and are established on approximately 80–90% of islands globally (Towns *et al.* 2006). Occurring on 78% of islands known to support highly threatened vertebrates (Spatz *et al.* 2017), rats are well documented to be exceedingly detrimental to island avifauna (e.g., Courchamp *et al.* 2003, Towns *et al.* 2006, Tabak *et al.* 2014, Harper and Bunbury 2015). For instance, between Taukihepa and Lord Howe Islands in the South Pacific alone, the ubiquitous black rat *R. rattus* is responsible for the extinction of 10 native and endemic species of birds (Towns *et al.* 2006, Shiels *et al.* 2013).

The Micronesian Scrubfowl (*Megapodius laperouse*) is a species of ground nesting bird that occurs in the Mariana and Palau archipelagos of western Micronesia (Jones *et al.* 1995). A member of the family Megapodiidae, they do not incubate their eggs with body heat but instead use external, environmental sources of heat (Jones *et al.* 1995). The subspecies of scrubfowl in Palau (*M. l. senex*) buries its eggs in large mounds of sand filled with decomposing organic matter, which it constructs predominantly in littoral strand forest that occurs throughout portions of the archipelago (Wiles and Conry 2001, Olsen *et al.* 2016). The largest segment of this population is found in the UNESCO World Heritage listed Rock Islands Southern Lagoon Conservation Area (RISL) (Olsen *et al.* 2016).

Citing a small, fragmented distribution, comparatively small population size, and its continued decline, the IUCN (2016) classifies the Micronesian Scrubfowl as Endangered. Documented and potential threats to the species are mostly, but not wholly, deterministic in nature and include hunting, egg collecting for human consumption, and introduced predators (Pratt *et al.* 1980, USFWS 1998, IUCN 2016). Sources suggest that introduced rats are a direct threat to scrubfowl in both the Mariana and Palau archipelagos, but none cite any direct, quantitative evidence as justification (USFWS 1998, Wiles and Conry 2001, Olsen *et al.* 2013). Four species of rat have become established in Palau, two of which—the Polynesian rat *R. exulans* and black rat—occur in forested areas of the RISL (Wiles and Conry 1990) and may be detrimental to scrubfowl. Although no other species of scrubfowl is known or believed to be threatened by rats (IUCN 2016), populations of some ground and burrow nesting seabirds have been seriously affected (Jones *et al.* 2008, Ruffino *et al.* 2009).

Aside from rats, another potential stressor to wildlife populations on islands is the pressure of tourist visitation. The effect of nature-based tourism and recreation on global bird populations has drawn relatively little attention in either public or academic forums (Steven *et al.* 2011, Steven and Castley 2013). Of the 35 recognized global biodiversity hotspots (Myers *et al.* 2000), Polynesia-Micronesia supports the most bird species threatened by tourism (Steven and Castley 2013, Bellard *et al.* 2014). Steven and Castley (2013) determined that 63 birds listed as Critically Endangered and Endangered by the IUCN (2016) are directly threatened by tourism, and that species occurring in coastal areas are amongst those most at risk. Palau is one of the world's top SCUBA diving destinations (IMF 2016), and the majority of this activity occurs in and around the RISL. Many of the beaches and coastal areas on which Endangered scrubfowl breed are also highly attractive as picnic sites where dive operators bring tourists in large numbers on a daily basis. As a response, the local government has built and maintains facilities on these beaches to support and cater to these activities.

In addition to tourist activities and facilities potentially having a direct effect on scrubfowl breeding in the RISL, they may also have an indirect impact by augmenting rodent populations through supplementary food provision (Oro *et al.* 2013, Ruffino *et al.* 2013). In the absence of predators, population densities of rats on tropical islands are generally very high because of greater access to relatively rich food resources (Harper and Bunbury 2015). A consistent availability of anthropogenic food resources further enables these populations to endure environmental variability, further increasing their densities and their threat to native fauna (Russell and Ruffino 2012, Ruffino *et al.* 2013). Understanding the potential effects of tourism and rats on the Palau Micronesian Scrubfowl is essential to their conservation in Palau.

Here, we investigate whether rat and tourist presence affect Palau Micronesian Scrubfowl numbers, and whether rat numbers are affected by human presence on islands in the RISL. We undertook active and passive surveys for scrubfowl and rats on uninhabited islands in the RISL that were classified as either visited or not visited by tourists, and aimed to assess the relationships between rats, scrubfowl, and tourist presence. We specifically tested the following hypotheses: 1) rat occupancy is significantly higher on tourist visited compared to tourist-free islands (Oro *et al.* 2013), 2) scrubfowl relative abundance is significantly lower on tourist visited compared to tourist-free islands (Steven *et al.* 2011), and 3) scrubfowl relative abundance is significantly lower on islands with high rat occupancy (Harper and Bunbury 2015). We discuss our findings in the context of future research and conservation management for threatened species on the Rock Islands of Palau.

Methods

Study Area and Survey Island Selection

The Palau archipelago (7° 30' N, 134° 35' E; Fig.1) is the westernmost assemblage of islands in Micronesia. It extends 700 km northeast to southwest and is comprised of 12 inhabited islands and over 500 smaller uninhabited islands and islets (Neall and Trewick 2008, Olsen 2009). Approximately 87 percent of the archipelago is forested, 75% of which is classified as native tropical lowland rainforest (Kitalong *et al.* 2013). Our research was focused primarily on the uninhabited islands of the RISL that lie between Babeldaob to the north and Peleliu to the southwest (Figure 1), where scrubfowl are relatively abundant (Olsen *et al.* 2016). Unlike other islands in the archipelago, these “rock islands” are ancient, uplifted reefs and are thus coralline in nature (Engbring 1988). The vast majority of islands in the RISL are characterized by nearly vertical, highly fissured and eroded, densely forested karst slopes that protrude abruptly from the water, and are undercut at the water’s edge (Pratt et al., 1980; Engbring, 1988). Despite the heavy forest cover, these uplifted areas exhibit very little soil development and provide no suitable substrate for scrubfowl to construct their mounds (Pratt *et al.* 1980, Olsen *et al.* 2016). The majority of scrubfowl in the RISL breed in the fringing, sandy littoral zones that additionally characterize a relatively small number of these islands (Olsen *et al*. 2016); some of these littoral areas are also heavily visited by tourists (pers. obs., P. Radley).

(Figure 1 here)

We selected islands in the RISL for surveys based on the occurrence of sandy littoral areas that supported level, beach strand forest cover. This cover type falls under the category of “Limestone Forest” (Kitalong *et al.* 2013), an ecotype that was consistent in plant species composition and structure at all study sites and was suitable habitat for scrubfowl. Although rats are known to occur in all terrain of the islands in the RISL (pers. comm., T. Hall), areas of strand cover were solely selected for our surveys because of their exclusive use for tourist activities on visited islands, their preferred use by scrubfowl for breeding (Wiles and Conry 2001, Olsen *et al.* 2016), and the nearly inaccessible nature of the limestone areas of the islands. Tourist visited islands were additionally characterized by the presence of picnic tables and barbeque facilities, roofed shelters of varying sizes, and restrooms situated in cleared and maintained areas just off the beach. We specifically chose islands for surveys based on 1) the existence of large enough areas of littoral strand forest that were capable of accommodating full length (180 m) rat survey transects, and 2) the level or degree of human visitation they received (Figure 1). Of six islands in the RISL that are regularly visited by tourists, the five we chose for surveys both met the above size criteria and received moderate to heavy tourist visitation. Four of the five selected tourist-free islands were located in the Ngemelis Complex (Figure 1), a local government conservation area from which tourists are prohibited. The fifth, Ngeanges, was known to receive only occasional day visits by locals or kayakers. It should be noted that in this sense, none of the islands in our study were truly unvisited "controls", but represent a contrast between heavy tourism and very occasional local use.

Rat Presence / Absence Surveys

We quantified rat presence with the use of peanut butter scented WaxTags® (www.traps.co.nz). Transects of 10 waxtags spaced 20 meters apart (for a transect length of 180 m) (Ruffell *et al.* 2015a, Ruffell *et al.* 2015b) were established in the available and accessible strand forest habitat on all 10 islands selected for surveys, where tags were secured to trees approximately 10 cm above the ground. Each transect was run parallel with the shore roughly equidistant between the beach and the limestone face behind. The lengths of accessible beach habitat for transects was small and ranged from 185 to 680 m ($\bar{x}$ = 419.5), a portion of which on tourist visited islands was occupied by the facilities described above. Three beaches on tourist islands were just long enough to accommodate 180 m transects and tourist facilities were by default included in the sampling area. The facilities on the remaining two tourist islands with longer beaches were likewise included in sampling areas to avoid any possible bias in rat detections.

Rat surveys were conducted in two replicates over four nights each, from 15–18 December 2016 and 19–22 January 2017. Waxtags were deployed for two nights across each island type (i.e., tourist visited and tourist-free) during each survey. Given the size of the RISL and the relatively long travel times between some islands via small motorboat, it was necessary to alternate the days of deployment and retrieval of tags by island type. Specifically, tags were deployed and retrieved on days one and three (respectively) of each replicate on tourist visited islands, and deployed and retrieved on days two and four of each replicate on tourist-free islands.

Scrubfowl Call-playback Surveys

We established and surveyed a total of 48 scrubfowl count stations in the RISL, 19 on tourist visited islands and 29 on islands not visited by tourists. We collected data on scrubfowl presence and relative abundance on six mornings between 9 and 16 January 2017. Scrubfowl surveys consisted of a combination of stationary call playback counts and spot-mapping conducted on the same beaches and in the same habitat as rat surveys. Count stations were established during counts and were spaced 100 m apart in littoral beach strand habitat approximately 10 m inland from the mean high tide mark. We conducted surveys by walking from one end of target beaches to the other, stopping every 100 m to broadcast pre-recorded scrubfowl calls after acquiring a GPS location of each station. Recordings used for surveys were those of Palau Micronesian Scrubfowl that we collected in the Rock Islands in February and March 2016. Call playback was projected towards the limestone face behind the beach as scrubfowl have been observed to not only occur in the littoral strand forest, but also in the dense forest on the face and top of the limestone relief. Surveys at stations consisted of approximately 1 minute of call playback followed by 4 minutes of quiet listening and observation, during which time all scrubfowl seen or heard were recorded and their general locations relative to the observer mapped in field note books. After completion of each 5-minute playback survey period, we slowly walked to the next station, spot mapping all scrubfowl seen and/or heard while in transit between stations to avoid double counting birds at successive stations. Birds mapped in this manner were included in count totals at the stations they were detected closest to if it was determined that they had not already been included in station based counts.

Statistical Analysis

We assessed waxtags for evidence of rat chewing for both survey replicates across all islands, recording a ‘1’ for tags that were bitten and ‘0’ for tags that were not. We did not attempt to identify rat species. Site occupancy and detection probabilities for rats were estimated with and without the covariates “Tourist” and “Island” by fitting models in the “unmarked” package in R (Fiske and Chandler 2011). The resulting logit parameter estimates were back-transformed, and model fit and selection were assessed using Akaike’s Information Criterion (AIC). To further confirm model fit we compared our occupancy model with a null model of our data using a Likelihood Ratio Test. Occupancy and detection probabilities were then predicted for rats on tourist visited and tourist-free islands as groups and occupancy was further predicted at the island level. Many of these estimates were on the upper boundary (i.e. occupancy = 1), hence meaningful confidence intervals could not be calculated (Hutchinson et al. 2015). We provide standard errors instead. Lastly, averaging the number of waxtags bitten across replicates, we used “Tourist” as a covariate to further test for an effect of tourist presence on rat numbers across islands with a Gaussian family generalized linear model (GLM).

To account for small sample sizes and the boundary estimates, we compared our rat occupancy results to those of a Bayesian GLM that provided posterior means and credible intervals for rat occupancy probabilities for treatment and control island groups, as well as at the island level. To represent a lack of knowledge of the true values of these parameters, the prior probability distribution of both the detection and island occupancy probabilities were assumed to be uniform for this inference. Highest posterior density (HPD) 95% credible intervals were generated for the posterior means of the island level inference while 95% equal-tailed credible intervals were produced for the island group inference.

As a result of unanticipated and unavoidable logistic constraints, we were able to complete only one round of scrubfowl call playback surveys, and because of this we could neither calculate detection probability nor estimate site occupancy for the species (Knape and Korner-Nievergelt 2015). In lieu of occupancy modelling, we first used a Fisher's F-test to evaluate scrubfowl survey sample variance between tourist visited and tourist-free islands to verify homoscedasticity and then compared sample means of the two groups with a two sample t-test. We then employed both a Poisson family GLM and a logistic regression (Bates *et al.* 2015) to assess the effect of tourist presence on scrubfowl across islands, using "Tourist" as a covariate and "Island" as a random effect, with survey station used as the observational unit. We applied a Hosmer Lemeshow goodness of fit (GOF) test (Lele *et al.* 2016) to determine if there was any difference between this model and our observed data.

To test for an effect of rats on scrubfowl, we first calculated island level relative abundances of scrubfowl and compared them to the Bayesian posterior means of island level rat occupancy probability in a Pearson's product-moment correlation. We followed this with a Gaussian family GLM to model island level scrubfowl relative abundance against rat posterior means and tourist presence, using "Rat" and "Tourist" as covariates. All statistical analysis was performed in program R (R Core Team 2015).

Results

Rats were detected on all islands surveyed in the RISL, where they chewed a mean ± SD of 44.5 ± 4.9 waxtags on tourist visited islands and 25.5 ± 9.2 on islands not visited by tourists. Occupancy modelling showed that the tourist covariate had a significant positive influence on both rat detection probability ($P < 0.001$) and site occupancy ($P < 0.01$). The probability of detecting rats on the tourist visited islands as a whole (0.89; 95% CI 0.80–0.94) was significantly higher ($P = 0.031$) than on tourist-free islands (0.52; 0.42–0.62). Likewise, occupancy on tourist visited islands (0.99) was significantly ($P = 0.028$) higher than on tourist-free islands (0.73). The Bayesian posterior means for occupancy probability (0.90 and 0.69, respectively) were also significantly different ($P = 0.028$) (Table 1). At the island level, occupancy estimates for tourist visited islands ranged from 0.93 to 1.00 and from 0.52 to 1.00 for tourist-free islands while Bayesian posterior means ranged from 0.86 to 0.92 and from 0.52 to 0.92, respectively (Table 1). In all instances, the Bayesian GLM provided equal-tail and HPD credible intervals that were slightly more accurate when compared to the occupancy generated CI for each island group and each individual island (Table 1). The results of our Gaussian GLM comparing station-level averages of rat detections across tourist visited and tourist-free islands further supports the hypothesis that tourist presence has a significant positive relationship with rat detections (Table 2, model 1).

(Table 1 and Table 2 here)

We recorded 107 scrubfowl detections during surveys across all 10 islands, yielding a mean detection rate of 10.7 birds per island (range = 1 – 20) (Table 3). On tourist visited islands, 30 individual detections were recorded from nine of 19 (47%) count stations compared to 77 detections recorded from 27 of 29 (93%) stations on tourist-free islands. Sample variance between the two island groups was confirmed to be homoscedastic (P =

0.221). The relative abundance (i.e., mean birds per station or BPS) of scrubfowl on tourist islands (1.58 BPS, SD ± 2.29) was lower than on tourist-free islands (2.66 ± 1.78), although the difference was not statistically significant (*P* = 0.074; two sample t-test). However, the presence of scrubfowl at survey stations on tourist islands was significantly lower than on tourist-free islands (*P* = 0.026; logistic regression [Table 2, model 2]). The results of the Poisson GLM indicated that although the tourist covariate appears to have a slight negative influence on scrubfowl relative abundance, the coefficient was not significantly different from the intercept (Table 2, model 3). The Hosmer Lemeshow GOF test was non-significant (*P* = 0.51) when comparing the Poisson model and our observed data, thus confirming that the model was a good fit.

(Table 3 here)

A Pearson's product-moment correlation conducted at the island level showed a weak but non-significant negative relationship between rat occupancy and scrubfowl relative abundance (−0.49, 95% CI −0.85–0.20; *P* = 0.152). The results of the Gaussian GLM indicated that while both the covariates rats and tourists appeared to have a slight negative influence on scrubfowl relative abundance, the coefficients were not significantly different from the intercept (Table 2, model 4).

Discussion

We did not find a strong negative relationship between rats and scrubfowl presence on islands in the RISL. This outcome is at odds with numerous other studies that have attributed island bird extinction and extirpation to invasive rats (e.g., Tabak *et al.* 2014, Harper and Bunbury 2015) and conservation advice naming rats as a threat to the Palau Micronesian Scrubfowl

(USFWS 1998, Wiles and Conry 2001, Olsen *et al.* 2013). Rats (particularly black rats) affect island landbird populations primarily at the level of productivity by predating eggs, hatchlings or chicks in nests, but they also opportunistically take adults of some smaller species (Shiels *et al.* 2013, Harper and Bunbury 2015). Unlike other avian species, scrubfowl eggs and hatchlings are not outwardly visible and vulnerable to predation for days to weeks on end within an open nest. Instead, their eggs are buried under up to a meter of sand or soil and organic matter, through which hatchlings dig their way to the surface after hatching (Jones *et al.* 1995). A young scrubfowl would be most vulnerable for a relatively brief period just as it erupts from the incubation mound, after which it emerges as a "super-precocial" chick that cannot only run but is immediately capable of flight (pers. comm., R. Dekker). The window of opportunity for predation by rats is therefore relatively very narrow and any scrubfowl young taken by rats may likely be more so by chance. The lack of an obvious or significant effect in our study may be due to the fact that rat predation is negligible on larger sub-adult and adult birds.

Some studies show that other island birds are able to coexist with introduced rats with no apparent negative effects at the population level. Larger, ground nesting seabirds (e.g., albatrosses, frigatebirds, and gulls) tend to be far less affected by rats than smaller, burrow nesting seabirds (e.g., storm petrels and some Alcids), a result that may stem from the size of the former and their likely adeptness at defending their eggs and young from predators (Jones *et al.* 2008). Populations of larger burrow nesting shearwaters that breed almost exclusively on rat infested islands in the Mediterranean were found to be limited less by rats than the smaller, resident storm petrels, and more so by physical characteristics of the islands themselves (Ruffino *et al.* 2009). Tabak *et al.* (2014) found that the occurrence of three mostly ground-dwelling passerines, the Falkland Pipit *Anthus correndera*, Long-tailed Meadowlark *Sturnella loyca*, and Dark-faced Ground Tyrant *Muscisaxicola maclovianus*, were unaffected by the presence of Norway rats *R. norvegicus* in the Falkland Islands, regardless of island size. While the endemic pipit avoids areas of tussac grass *Parodiochloa flabellata*, a habitat preferred by Norway rats, the above-ground feeding behaviours of the latter two may reduce their exposure to rats (Hall *et al.* 2002).

There is the possibility that rats act as a competitor for food resources (Shiels *et al.* 2013), but our data are not appropriate to test this hypothesis. Although there is little in the literature pointing to rats as direct resource competitors for avian species (Shapiro 2005, Tabak *et al.* 2016), Shiels *et al.* (2013) suggest that those birds relying on either arthropods or fruit as a major component of their diet may experience direct competition with rats. The Palau Micronesian Scrubfowl is omnivorous, with a diet consisting of a variety of fruits, seeds and other plant matter, various insects and land crabs (Jones *et al.* 1995). Likewise, both species of rat that occur in the RISL are known to be highly opportunistic, exploiting virtually any available food source, but relying heavily on plant matter, with insects providing the majority of animal protein in their diets (Shiels *et al.* 2013, Harper and Bunbury 2015). The broad dietary intake of scrubfowl in the RISL may serve to minimize the chances of direct resource competition, and as primarily a scratch feeder the species may fill a functionally different foraging niche than rats (Jones *et al.* 1995).

Our results further suggest that tourists may have a negative impact on scrubfowl, as shown by lower relative abundance and detection rates at tourist compared to tourist-free islands. Aside from negative consequences to individual physiology and reproductive success, other studies (e.g., Otley 2005, Ma and Cheng 2008, Steven *et al.* 2011, Steven and Castley 2013) show that the behaviour, distribution and movement patters of some bird species in tourist visited areas are affected by human presence, while their apparent abundance or numbers are not. Otley (2005) further found that up to 80% of Gentoo *Pygoscelis papua*, King *Aptenodytes patagonicus*, and Magellanic *Spheniscus magellanicus*

Penguins at a tourist visited sites in the Falkland Islands avoided traveling between beach and colony areas during daylight hours when most human visitors were present. Indeed, scrubfowl on tourist visited islands in the RISL tended to be more skittish upon approach than on islands that experience little or no human presence (pers. obs., P. Radley). From a statistical standpoint, however, our Poisson GLM does indicate a slight negative effect of tourism on scrubfowl relative abundance. The relatively high number of birds detected on Ulong (Table 3), a tourist visited island, may have prevented this model from showing a significant result. This may leave the result of our logistic regression to be a more accurate reflection of the effect of tourists on scrubfowl.

Lastly, our results suggest that tourist presence may positively influence rat numbers. The probability of detecting rats on islands that routinely receive high levels of tourist visitation was 42% greater than on islands that were tourist-free. While occupancy on tourist-free islands was relatively high and the difference between these islands and tourist-visited islands is lower than the difference between detection probabilities, occupancy on tourist islands approached 1.00. We cannot rule out that these differences are not the result of historical visits by local people for the purpose of fishing or hunting coconut crabs (*Birgus latro*). One likely reason for this disparity, however, is that high tourist presences often equates to the greater availability of food waste that may supplement the diet of rats on islands routinely and heavily visited by tourists (e.g., Sealey and Smith 2014). Depending on the season, an island’s infrastructure, and its proximity to popular dive sites in and around the RISL, several dozens to near a hundred tourists could be fed buffet style at the picnic facilities on a single beach every day (pers. obs., P. Radley). The resulting waste was often left at these facilities in plastic bags for the local government clean-up crews to remove for disposal. In some instances, smaller portions of organic waste were simply discarded by locals, tourist and tour operators in the vegetation adjacent to picnic facilities.

There are numerous published studies illustrating the effect of tourism, particularly nature-based tourism, on wildlife populations (e.g., Steven *et al.* 2011, Steven and Castley 2013). Surprisingly, however, we could find little pertaining to the possible direct effects of tourism activities on populations of invasive rats, particularly in tropical island ecosystems. Only Sealey and Smith (2014) describe high concentrations of rats at tourist facilities as a result of the availability of solid food waste generated by tourist based operations on Great Exuma Island, Bahamas. That study, however, focused specifically on large facilities or resorts on the island, and sheds no light on its broader ecological effects on rats at the ecosystem level (Sealey and Smith 2014). Resource subsidies across numerous ecosystems, however, have been found to increase individual fitness and resilience of various opportunistic species, leading to increases in densities and decreases in temporal variability of some populations (Oro *et al.* 2013). Insular rodents with access to allochthonous resources tend to grow larger, occur at higher densities, and their populations tend to persist in the longer-term in part because they are better able to withstand local environmental stress (Stapp and Polis 2003, Ruffino *et al.* 2013). Our field observations strongly indicate that food subsidies are routinely made available to rats on islands in the RISL, and that this is likely to present a significant challenge to rat-sensitive species inhabiting these islands.

Habitat and Scrubfowl Detectability

While Palau supports the richest assemblage of native flora and the highest rate of plant endemism in Micronesia (Costion *et al.* 2009), plant diversity across islands in the RISL is relatively homogenous (Kitalong 2014). Based on this, and on the fact that the RISL supports the majority of breeding scrubfowl in the archipelago, with incubation mounds occurring on all islands surveyed, we assumed that habitat would not be a factor in our analysis of scrubfowl relative abundance.

The only comprehensive survey of scrubfowl in the Palau archipelago was conducted by Olsen *et al.* (2016), in which a combination of 15-minute passive counts and broad area searches (for birds and mounds) were used to survey 122 beach / island sites. They detected 350 individuals at 61 (50%) of the sites surveyed, for a detection rate of 2.9 scrubfowl per beach or island included in the surveys. Olsen *et al.* (2016) suggested one confounding factor that could have decreased their detections is the possibility of "commuting" by scrubfowl between their nesting and feeding grounds, a phenomena documented in other species (R.W.R.J. Dekker pers. comm., Jones *et al.* 1995). As a result, birds may have at times been detected on return visits at sites where they had not previously been encountered, or not detected at sites they previously had (Olsen *et al.* 2016).

By comparison, our surveys yielded a mean detection rate of 10.7 scrubfowl with at least one bird detected at every one of the 10 beaches or islands surveyed in the RISL. This difference may likely have been the result of our use of a targeted active survey, employing call-playback from fixed stations at survey sites. Many of our detections were of birds that responded from a distance from habitat atop the limestone relief, birds we would not have detected without call-playback. Given our relatively high detection rates, and the fact that we detected birds at every site surveyed, commuting by scrubfowl may not have been encountered on the islands we surveyed during our work.

Conservation Implications

In March 2017, Island Conservation executed an eradication of rats from the island of Ngeanges and was developing plans with the local government to do likewise for other islands in the RISL (pers. comm., T. Hall). This is inarguably the optimal approach to conservation of tropical island landbird species threatened by rats (e.g., Russell and Holmes 2015, Jones *et al.* 2016, Spatz *et al.* 2017). While our results suggest that rats do not detrimentally affect scrubfowl, other species of native and endemic landbirds that share forested habitat with scrubfowl in the RISL may be at threat (e.g., Harper and Bunbury 2015). These species include the Endangered Palau Ground Dove (*Alopecoenas canifrons*) and perhaps the Palau Fantail (*Rhipidura lepida*), and Micronesian Imperial and Nicobar Pigeons (*Ducula oceanica* and *Caloenas nicobarica*, respectively). Aside from some point-count based inventories (e.g., VanderWerf 2007), few studies have been carried out on Palau's terrestrial avifauna and little is known about population trends for most species in the RISL. Given the significantly higher level of rat detection probability and occupancy on tourist visited islands relative to tourist-free islands, a study comparing the vital rates of landbirds across the two island types would be beneficial (e.g., Saracco *et al.* 2014). The threat of rats to island landbirds suggests that quantitative studies concerning the effect of tourism on rat populations would be an asset to other insular nature-based tourism destinations globally.

To further manage rat numbers in the RISL, a good first step would be managing tourist waste by enforcing a "pack-it-out" policy that requires tourist operations to remove all their food waste from the islands they visit. Adequate signage, education and onsite enforcement of removal of all food refuse by tourist operators would go a long way to decrease supplementary food sources that may be helping to sustain or augment rat populations on tourist visited islands in the RISL.

Acknowledgements

Edith Cowan University School of Science provided financial, administrative, and logistical support, and project ethics approval (which conforms to the requirements of the "*Australian code of practice for the care and use of animals for scientific purposes*", 8th Edition, Ref. No. EA28). The Palau National and Koror State Governments provided all necessary research permits, and the latter further permitted access to restricted conservation areas. We are grateful to Clarence Kitalong for all boat transport and whose vast local knowledge of the islands made our work possible. Mike Lohr assisted with scrubfowl surveys. Greg Budney, Cornell Lab of Ornithology, provided sound recording equipment to record megapode calls. Jim Baldwin, a Statistician at the U.S. Forest Service Pacific Southwest Research Station, provided the Bayesian estimates of occupancy probability. Richard Camp and Marcos Gorresen, U.S. Geological Survey, Hawaii, provided valuable input pertaining to analytical approach and methods. Fred Amidon, U.S. Fish and Wildlife Service, Hawaii Field Office, provided technical insight with Figure 1. We thank two anonymous reviewers for their comments on an earlier version of this manuscript.

Financial Support

This work was supported by the Rufford Small Grants for Nature Conservation (grant no. G1002201), Club 300 Bird Protection (G1002235), and the World Pheasant Association (G1002935).

Literature Cited

Bates, D., Maechler, M., Bolker, B. and Walker, S. (2015) Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* 67: 1−48.

Bellard, C., Leclerc, C., Leroy, B., Bakkenes, M., Veloz, S., Thuiller, W. and Courchamp, F. (2014) Vulnerability of biodiversity hotspots to global change. *Global Ecol. Biogeogr.* 23: 1376−1386.

Costion, C., Kitalong, A. H. and Holm, T. (2009) Plant endemism, rarity, and threat in Palau, Micronesia: A geographical checklist and preliminary red list assessment. *Micronesica* 41: 131−164.

Courchamp, F., Chapuis, J. L. and Pascal, M. (2003) Mammal invaders on islands: Impact, control and control impact. *Biol. Rev. Camb. Philos.* 78: 347−383.

Doherty, T. S., Glen, A. S., Nimmo, D. G., Ritchie, E. G. and Dickman, C. R. (2016) Invasive predators and global biodiversity loss. *P. Natl. Acad. Sci. USA.* 113: 11261−11265.

Engbring, J. (1988) *Field Guide to the Birds of Palau.* Conservation Office, Koror, Palau.

Fiske, I. and Chandler, R. (2011) unmarked: An R package for fitting hierarchical models of wildlife occurrence and abundance. *J. Stat. Softw.* 43: 1−23.

Hall, J. R., Woods, R. W., de L. Brooke, M. and Hilton, G. M. (2002) Factors affecting the distribution of landbirds on the Falkland Islands. *Bird Conserv. Int.* 12: 151−167.

Harper, G. A. and Bunbury, N. (2015) Invasive rats on tropical islands: Their population biology and impacts on native species. *Global Ecol. Conserv.* 3: 607−627.

Hutchinson, R. A., Valente, J. J., Emerson, S. C., Betts, M. G., and Diettrerich, T. G. (2015) Penalized likelihood methods improve parameter estimates in occupancy models. *Methods Ecol. Evol.* 6: 949−959.

IMF (2016) *Republic of Palau: Staff report for the 2016 Article IV consultation. IMF Country Report No. 16/328*. U.S. International Monetary Fund, Washington DC, USA.

IUCN (2016) *The IUCN Red List of Threatened Species. Version 2016.3.* Available at: http://www.iucnredlist.org [accessed 20 March 2017].

Jones, D. N., Dekker, R. W. R. J. and Roselaar, C. S. (1995) *The megapodes.* Oxford University Press, Oxford, U. K.

Jones, H. P., Holmes, N. D., Butchart, S. H. M., Tershy, B. R., Kappes, P. J., Corkery, I., Aguirre-Muñoz, A., Armstrong, D. P., Bonnaud, E., Burbidge, A. A., Campbell, K., Courchamp, F., Cowan, P .E., Cuthbert, R. J., Ebbert, S., Genovesi, P., Howald, G.

R., Keitt, B. S., Kress, S. W., Miskelly, C. M., Oppel, S., Poncet, S., Rauzon, M. J., Rocamora, G., Russell, J. C., Samaniego-Herrera, A., Seddon, P. J., Spatz, D. R., Towns, D. R. and Croll, D. A. (2016) Invasive mammal eradication on islands results in substantial conservation gains. *P. Natl. Acad. Sci.* 113: 4033−4038.

Jones, H. P., Tershy, B. R., Zavaleta, E. S., Croll, D. A., Keitt, B. S., Finkelstein, M. E. and Howald, G. R. (2008) Severity of the effects of invasive rats on seabirds: a global review. *Conserv. Biol.* 22: 16−26.

Kitalong, A. H., DeMeo, R. A. and Holm, T. (2013) *A Field Guide to the Native Trees of Palau.* Kitalong, DeMeo, and Holm, Palau.

Kitalong, C. (2014) *Ethnomedical, Ecological and Phytochemical Studies of the Palauan Flora*. Ph.D. Thesis, City University of New York.

Knape, J. and Korner-Nievergelt, F. (2015) Estimates from non-replicated population surveys rely on critical assumptions. *Methods Ecol. Evol.* 6: 298−306.

Lele, S. R., Keim, J. L. and Solymos, P. (2016) ResourceSelection: Resource selection (probability) functions for use-availability data. R package version 0.2-6. Available at: http://CRAN.R-project.org/package=ResourceSelection.

Ma, J. Z. and Cheng, K. (2008) Impacts of ecotourism on wildlife in nature reserves: Monitoring and management. *Shengtai Xuebao/ Acta Ecol. Sin.* 28: 2818−2827.

Myers, N., Mittermeler, R. A., Mittermeler, C. G., Da Fonseca, G. A. B. and Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature* 403: 853−858.

Neall, V. E. and Trewick, S. A. (2008) The age and origins of the Pacific islands: a geological overview. *Philos. T. Roy. Soc. B* 363: 3293−3308.

Olsen, A., Eberdong, M., Ketebengang, H. and Chen, P.-h. (2013) *Nesting mounds and status of an endemic subspecies of the endangered Micronesian Megapode, Megapodius laperouse senex Hartlaub 1867 (Megapodiidae), in the Rock Islands*

Southern Lagoon World Heritage Site, Palau Islands, Oceania. Report: Belau National Museum, Koror.

Olsen, A. R. (2009) Palau. In R. G. Gillespie and D. A. Clague, eds., *Encyclopedia of Islands.* University of California Press, Berkeley and Los Angeles, CA, USA.

Olsen, A. R., Eberdong, M., Ketebengang, H., Blailes, P. and Chen, P.-h. (2016) Survey of megapode nesting mounds in Palau, Micronesia. *West. Birds* 47: 27−37.

Oro, D., Genovart, M., Tavecchia, G., Fowler, M. S. and Martinez-Abrain, A. (2013) Ecological and evolutionary implications of food subsidies from humans. *Ecol. Letters* 16: 1501−1514.

Otley, H. M. (2005) Nature based tourism: experiences at the volunteer point penguin colony in the Falkland Islands. *Mar. Ornithol.* 33: 181−187.

Pratt, H. D., Engbring, J., Bruner, P. L. and Berrett, D. G. (1980) Notes on the taxonomy, natural history, and status of the resident birds of Palau. *Condor* 82: 117−131.

R Core Team (2015) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria.

Ruffell, J., Innes, J., Bishop, C., Landers, T., Khin, J. and Didham, R. K. (2015a) Using pest monitoring data to inform the location and intensity of invasive-species control in New Zealand. *Biol. Conserv.* 191: 640−649.

Ruffell, J., Innes, J. and Didham, R. K. (2015b) Efficacy of chew-track-card indices of rat and possum abundance across widely varying pest densities. *New Zeal. J. Ecol.* 39: 87−92.

Ruffino, L., Bourgeois, K., Vidal, E., Duhem, C., Paracuellos, M., Escribano, F., Sposimo, P., Baccetti, N., Pascal, M. and Oro, D. (2009) Invasive rats and seabirds after 2,000 years of an unwanted coexistence on Mediterranean islands. *Biol. Invasions* 11: 1631−1651.

Ruffino, L., Russell, J. and Vidal, E. (2013) Anthropogenic subsidies mitigate environmental variability for insular rodents. *Oecologia* 172: 737−749.

Russell, J. C. and Holmes, N. D. (2015) Tropical island conservation: Rat eradication for species recovery. *Biol. Conserv.* 185: 1−7.

Russell, J. C. and Ruffino, L. (2012) The influence of spatio-temporal resource fluctuations on insular rat population dynamics. *P. Roy. Soc. B-Biol. Sci.* 279: 767−774.

Saracco, J. F., Radley, P., Pyle, P., Rowan, E. and Taylor, R. (2014) *Vital rates of landbirds on saipan and links to remote-sensed habitat data: A summary of five years (2008-2012) of the Tropical Monitoring Avian Productivity and Survivorship (TMAPS) program on Saipan, Northern Mariana Islands*. The Institute for Bird Populations, Point Reyes Station, California, USA.

Sealey, K. S. and Smith, J. (2014) Recycling for small island tourism developments: Food waste composting at Sandals Emerald Bay, Exuma, Bahamas. *Resour. Conserv. Recy.* 92: 25−37.

Shapiro, M. L. (2005) *Diet Overlap and Potential Competition between North Island Brown Kiwi Chicks (Apteryx mantelli) and Ship Rats (Rattus rattus) for Limited Resources on Ponui Island, New Zealand.* M.Sc. Thesis, Massey University.

Shiels, A. B., Pitt, W. C., Sugihara, R. T. and Witmer, G. W. (2013) Biology and Impacts of Pacific Island Invasive Species 11. The Black Rat, *Rattus rattus* (Rodentia: Muridae). *Pac. Sci.* 68: 2−94.

Spatz, D. R., Zilliacus, K. M., Holmes, N. D., Butchart, S. H. M., Genovesi, P., Ceballos, G., Tershy, B. R. and Croll, D. A. (2017) Globally threatened vertebrates on islands with invasive species. *Sci. Adv.* 3: e1603080.

Stapp, P. and Polis, G. A. (2003) Marine resources subsidize insular rodent populations in the Gulf of California, Mexico. *Oecologia* 134: 496−504.

Steven, R. and Castley, J. G. (2013) Tourism as a threat to critically endangered and endangered birds: global patterns and trends in conservation hotspots. *Biodivers. Conserv.* 22: 1063−1082.

Steven, R., Pickering, C. and Castley, J. G. (2011) A review of the impacts of nature based recreation on birds. *J. Environ. Manage.* 92: 2287−2294.

Tabak, M. A., Anderson, O .R. J., Robb, G., Poncet, S., Passfield, K., Martinez, M. G. and Martinez Del Rio, C. (2016) Comparative isotopic natural history of two native passerines (Troglodytes cobbi and Cinclodes antarcticus) and the invasive rats (Rattus norvegicus) that extirpate them. *Austral Ecol.* 41: 622−632.

Tabak, M. A., Poncet, S., Passfield, K. and Martinez Del Rio, C. (2014) Invasive species and land bird diversity on remote South Atlantic islands. *Biol. Invasions* 16: 341−352.

Towns, D. R., Atkinson, I. A. E. and Daugherty, C. H. (2006) Have the harmful effects of introduced rats on islands been exaggerated? *Biol. Invasions* 8: 863−891.

USFWS (1998) *Recovery Plan for the Micronesian Megapode (Megapodius laperouse laperouse)*. U. S. Fish and Wildlife Service, Portland, OR, USA.

VanderWerf, E. A. (2007) *2005 bird surveys in the Republic of Palau: final report*. Pacific Rim Conservation, Honolulu, Hawaii, USA.

Wiles, G. J. and Conry, P. J. (1990) Terrestrial vertebrates of the Ngerukewid Islands Wildlife Perserve, Palau islands. *Micronesica* 23: 41−66.

Wiles, G.J. and Conry, P.J. (2001) Characteristics of nest mounds of Micronesian Megapodes in Palau. *J. Field Ornithol.* 72: 267−275.

PAUL M. RADLEY*[1], ROBERT A. DAVIS[1,2], TIM S. DOHERTY[1,3]

[1] School of Science, Edith Cowan University, 270 Joondalup Drive, Joondalup WA, 6027, Australia

[2] School of Biological Science, University of Western Australia, 35 Stirling Highway, Crawley WA, 6009, Australia

[3] Deakin University, School of Life and Environmental Sciences, Centre for Integrative Ecology (Burwood campus), Geelong VIC, 3220, Australia

* Author for correspondence; e-mail: pratincola@hotmail.com

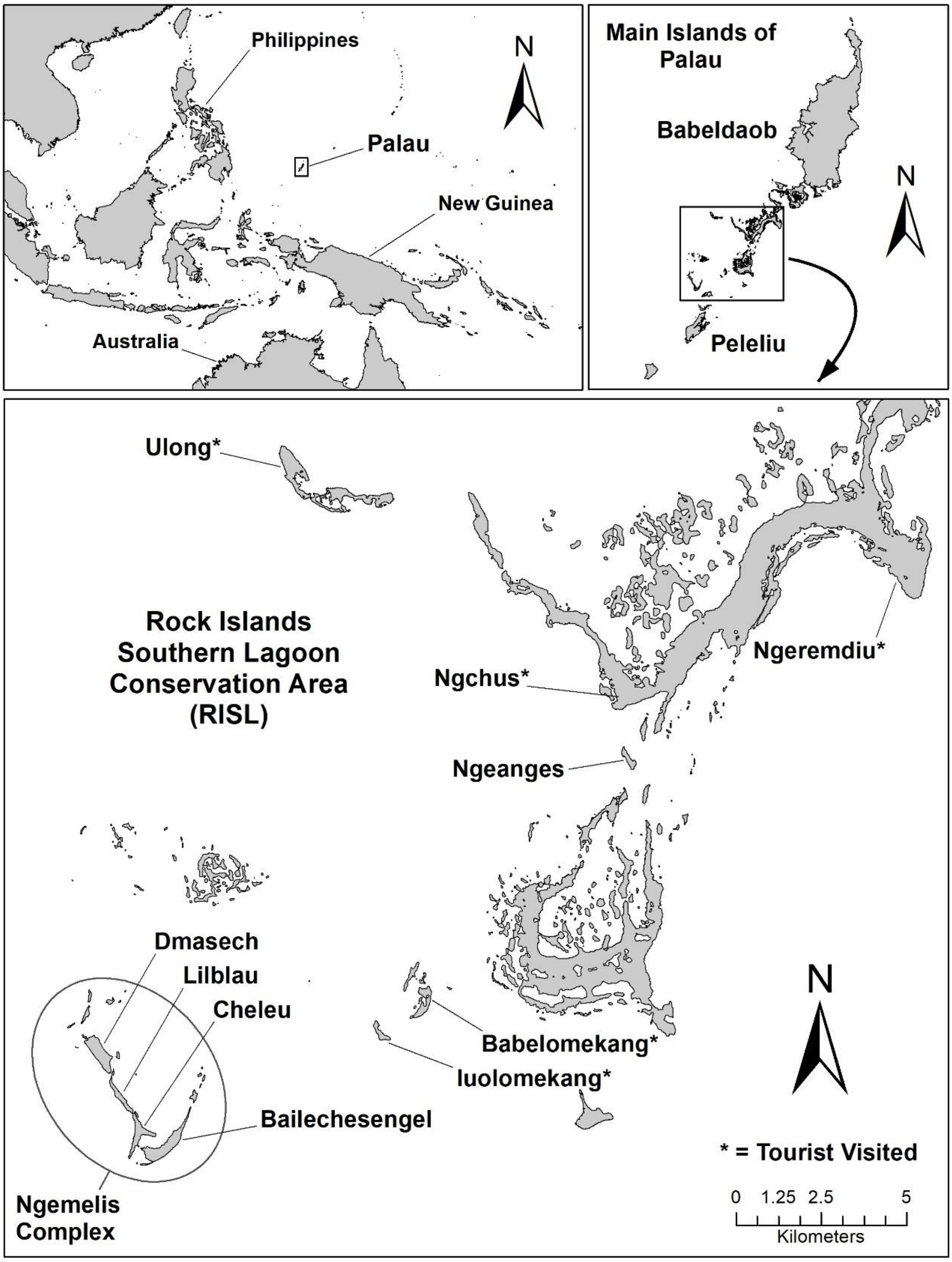

Figure 1. Map of the study area within the Rock Islands Southern Lagoon Conservation Area (RISL), Palau, and the locations of five tourist visited and five tourist-free islands surveyed for rats and scrubfowl between 15 December 2016 and 22 January 2017.

Table 1. Island level rat occupancy estimates and standard errors compared to island level occupancy probability Bayesian posterior means and 95% credible intervals for tourist visited and tourist-free islands in the Rock Islands Southern Lagoon Conservation Area (RISL) of Palau.

	Occupancy		**Posterior**		**HPD Credible Intervals**	
Island	**Estimate**	**SE**	**Mean**	**SD**	**Lower 95%**	**Upper 95%**
Tourist Visited						
Babelmokang	1.00	0.00041	0.9167	0.0767	0.7616	1.0000
Ngchus	0.93	0.09883	0.8553	0.1038	0.6548	1.0000
Ngeremdiu	1.00	0.00003	0.9167	0.0767	0.7616	1.0000
Ulong	1.00	0.00003	0.9167	0.0767	0.7616	1.0000
Ioulomokang	1.00	0.00003	0.9167	0.0767	0.7616	1.0000
Tourist-Free						
Bailechesengel	0.52	0.16378	0.5192	0.1442	0.2424	0.7961
Cheleu	0.72	0.15026	0.6921	0.1358	0.4278	0.9418
Dmasech	0.72	0.15026	0.6921	0.1358	0.4278	0.9418
Lilblau	0.62	0.16053	0.6058	0.1422	0.3299	0.8743
Ngeanges	1.00	0.00002	0.9167	0.0767	0.7616	1.0000

Table 2. Results for four models used to assess the effect of tourist presences on rats (model 1) and Palau Micronesian Scrubfowl (model 2 and 3), and the effect of rats on scrubfowl (model 4) on tourist visited and tourist-free islands in the Rock Islands Southern Lagoon Conservation Area (RISL) of Palau.

Parameter	**Estimate**	**SE**	**t/z-value**	**Pr (>t/z)**
Model 1, Gaussian GLM – Rats on tourist visited vs tourist-free islands				
Intercept	0.5100	0.0464	11.004	0.0000
Tourist Visited	0.3700	0.0655	5.645	0.0000
Model 2, Logistic Regression – Megapode presence / absence on tourist visited vs tourist-free islands				
Intercept	3.064	1.067	2.871	0.0041
Tourist Visited	−2.798	1.259	−2.223	0.0262
Model 3, Poisson GLM – Megapode relative abundance on tourist visited vs tourist-free islands				
Intercept	0.9559	0.2744	3.484	0.0005
Tourist Visited	−0.7276	0.4341	−1.676	0.0937
Model 4, Gaussian GLM – Effect of rats on Megapodes across islands				
Intercept	5.766	3.414	1.689	0.142
Rats	−4.285	4.893	−0.876	0.415
Tourist Visited	−21.777	24.093	−0.904	0.401
Rat: Tourist Visited	23.788	26.810	0.887	0.409

Table 3. Total counts and relative abundances during call playback surveys for Palau Micronesian Scrubfowl on tourist visited and tourist-free islands in the Rock Islands Southern Lagoon Conservation Area (RISL) of Palau. No. of Stations is the number of survey stations per island, and Count Total is the total number of scrubfowl counted per island.

Island	**No. Stations**	**Count Total**	**BPS**	**% Stations w/ Detections**
Tourist Visited				
Babelmokang	2	5	2.50	50%
Ngchus	3	2	0.67	33%
Ngeremdiu	6	1	0.17	17%
Ulong	5	19	3.80	100%
Ioulomokang	3	3	1.00	33%
Not Tourist Visited				
Bailechesengel	4	20	5.00	100%
Cheleu	6	14	2.33	100%
Dmasech	7	19	2.71	100%
Lilblau	7	12	1.71	86%
Ngeanges	5	12	2.40	80%