

AVIAN POPULATION RESPONSES TO ANTHROPOGENIC LANDSCAPE
CHANGES IN POHNPEI, FEDERATED STATES OF MICRONESIA

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by
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CHANGES IN POHNPEI, FEDERATED STATES OF MICRONESIA

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AVIAN POPULATION RESPONSES TO HABITAT CHANGES IN THE LAST
THREE DECADES, AND USE OF OCCUPANCY AND DENSITY ANALYSIS TO
IDENTIFY POPULATION DRIVERS IN POHNPEI AVIFAUNA

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ABSTRACT

Islands exhibit the planet's most unique flora and fauna, but the diversity on islands is also vulnerable to impending forces of global change. Scattered across the Pacific Ocean >20,000 islands range from sandspits to large islands and support some of the most unique biotic assemblages. Shaped by island size, topography and degree of isolation from other landmasses, including continents and other islands, insular systems support the largest number of endemic flora and avifauna. Because of the mobility associated with flight, birds have colonized the most remote islands, and are one of the most important taxa in insular systems.

The unique characteristics of islands provide habitat and resources for of avian species, including resident, migrants and seabirds. For many species, islands and archipelagos extremely important, they represent full habitat ranges, and for others may provide key resources, including migration stopover sites and suitable habitat for

reproduction and nesting. Insular organisms are often naïve to foreign forces, and island species are susceptible to introduced competitors and predators from continental origins and the effect of anthropogenic processes. Almost without exception, island habitats and species have been impacted by invasive species and anthropogenic processes – islands systems exhibit the highest rate of avian extinctions. Habitat alteration and introduced species often have detrimental effects in insular biota. The effects range from native habitat disturbance to the annihilation of native species, including endemics (e.g., Tern island and Guam).

Micronesia is a subregion of Oceania in the western Pacific Ocean. It encompasses >2,200 islands spread in four main archipelagos, including the Caroline Islands, Gilbert Islands, Mariana Islands and Marshall Islands. Composed of small islands, low atolls and high volcanic islands (e.g., Majuro and Pohnpei), the region has been exposed to anthropogenic processes for several thousand years. However, anthropogenic forces and introduced species had different effects on each island.

Located in the Caroline archipelago, which includes >550 islands, Pohnpei Island, Federated States of Micronesia, is considered an emerald of the Pacific. The island maintains large tracks of native forest. Its flora includes more than 110 endemic species of plants, and it support the largest mangrove forest in the region. Pohnpei is characterized by large gallery forest, and the lowest montane cloud forest in the world. Pohnpei's forest provide habitat for more than 40 avian species, including 6 Pohnpei endemics. However, changes in culture and forest use have originated substantial landscape changes on the island landscape in the last three decades.

The Pohnpei avian community has not been studied thoroughly. Knowledge of life history traits is limited for several species, including birds common throughout Micronesia and Pohnpei. Prior to this study only two systematic surveys had been conducted. Pohnpei's first avian survey was executed in 1983 by J. Engbring and colleagues (Engbring et al. 1990), and the second survey was conducted in 1994 by D. Buden (Buden 2000). Buden (2000) reported a large decline in the number of birds detected on Pohnpei between the 1983 and 1994 surveys. The total number of birds detected in six elevation zones (sea level [Mangrove], 0-100m, 100-200m, 200-400m, 400-600m, 600-800m) declined between 67-80%, and for 14 of 29 species studied, detections declined more than 50% in lowlands and highlands (< 200 amsl <). During the same period of time large tracks of native forest were transformed to anthropogenic habitats, mainly through new cultivation of local staple crops and "sakau" (*Piper methysticum*). Unlike other islands in the region, Pohnpei does not have introduced snakes (e.g., Guam) and introduced species (e.g., rats, lizards, and birds) are present in low densities; suggesting that habitat alterations are the major drivers of Pohnpei avifauna populations.

This thesis presents two analyses. In the first, we incorporated historic and current surveys (Engbring et al. 1990, Buden 2000, and Oleiro and Kesler 2012) and vegetation information in three different ways to identify avian population responses to landscape changes that occurred across three decades. We compared detection rates for 21 species that were recorded in 2012 with those reported by Buden (2000). We assessed whether the declining trend reported between 1984 and 1994 continued in the following decade. Overall, detection rates for the endemic *Rukia longirostra* increased the most

(359%) and declined the most for *Anous* spp. (-58%). However, when detection rates were analyzed by elevation zone different patterns were observed. Six species showed reduced detection rates in all elevation zones, 3 species elucidated increasing detection rates in all elevation zones, and 12 species showed a mixture of increasing and declining detection rates, depending the elevation zone. These results indicated that changes were not constant across elevation zones or among species.

To investigate whether detection rate changes across years were associated with habitat change, we created a series of generalized models that included detection rates as a response variable and the proportion of disturbed habitat at each elevation zone as an explanatory variable. Results indicated that detection rates for 2 of 16 were positively associated with anthropogenic habitat (*Myzomela rubratra* and *Aerodramus vanikorensis*) and that 8 of 16 were negatively associated (*Phaethon lepturus*, *Anous* spp., *Gygis alba*, *Ptilinopus porphyraceus*, *Ducula oceanica*, *Trichoglossus rubiginosus*, *Myiagra pluto* and *Rhipidura kubaryi*). We speculate that positive associations with agroforest and forest edge are present because they create additional foraging areas for *M. rubratra* and *A. vanikorensis*. Disturbed habitat was negatively associated with habitat specialist species, including 3 of the 6 endemics (*T. rubiginosus*, *M. pluto*, and *R. kubaryi*).

Pohnpei habitats change gradually among elevation zones. To investigate whether Pohnpei birds are generalists or specialists we regressed detection rates across elevation zones and tested whether each species was evenly distributed across the island, or whether there were associations with specific elevation zones. Regression analysis indicated that *M. rubratra*, *Todiranphus reichenbachii* and *T. rubiginosus* are associated with lower elevation habitats (respectively $r^2 = 0.87$, $r^2 = 0.57$, $r^2 = 0.65$). Contrarily,

Zopteros semperi, *R. longirostra* and *D. oceanica* regression showed that detection rates increased on higher elevation zones (respectively $r^2 = 0.70$, $r^2 = 0.98$, $r^2 = 0.52$). These associations suggest that while some species are common throughout the island, others are associated with specific habitats.

In the second study we further explored the associations between Pohnpei birds and the island's habitats. We used the 2012 survey data to identify whether each species was associated with specific habitat composition and configuration measures. We analyzed detections for 10 and 13 species, respectively, with density (λ) and occupancy (Ψ) approaches. For each species we created a series of linear models including variables for habitat composition and configuration. We followed a two-stage process. In the first stage we accounted for factors having an effect in bird detections, and in the second stage we incorporated habitat-specific factors with the potential to affect species density and occupancy. We used nine habitat variables, including percent of undisturbed habitat, percent mangrove, percent of agroforest, percent of secondary vegetation, extent of forest edge, patch number, canopy cover, canopy height, and tree stocking rate.

We used occupancy and distance-sampling protocols to analyze data collected in 247 survey stations. We used an information theoretic approach to model species density and occupancy associations with Pohnpei habitat composition and configuration. Results provided strong indications of habitat associations for most species, including Pohnpei endemics. Additionally, occupancy and density results suggested that many species on Pohnpei are habitat specialist, especially those associated with Pohnpei climax forest structure (e.g. *Rukia longirostra*). Model results generally indicated positive associations to Pohnpei climax forest and negative associations to anthropogenic habitats.

Importantly, the results also provide indications of how Pohnpei bird populations may change if anthropogenic effects of forest composition and configuration continue on the island.

CHAPTER 1

AVIAN POPULATION RESPONSES TO THREE DECADES OF LANDSCAPE CHANGES IN POHNPEI ISLAND, MICRONESIA

ABSTRACT

We used avian detections rates from three avian surveys (1983, 1994, and 2012) and vegetation information from three corresponding decades from the island of Pohnpei, Federated States of Micronesia, to investigate population responses to habitat change. We compared 1994 and 2012 species detections in 6 elevation zones (sea level [Mangroves], 0-100 m, 100-200 m, 200-400 m, 400-600 m, 600-800 m) for 23 species. Comparisons elucidated increasing detection for 3 species and declining detection for 4 species in all elevation zones. Changes in detection rate were related to elevation zone for 13 species were dependent on elevation zone. Long-billed white-eye (*Rukia longirostra*) and Micronesian pigeon (*Ducula oceanica*) showed the largest overall increase (respectively 359% and 220%). The largest overall declines were observed for noddy terns (*Anous* spp.) and Micronesian honeyeater (*Myzomela rubratra*) (respectively -51% and -22%). We found associations between species detections and disturbed habitat across surveys and elevation zones for 10 species. Detections of Micronesian pigeon, Pohnpei fantail (*Rhipidura kubaryi*), Pohnpei flycatcher (*Myaigra pluto*), Pohnpei lorikeet (*Trichoglossus rubiginosus*), white-tailed tropicbird (*Phaethon lepturus*), white tern (*Gygis alba*), noddy tern species and purple-capped fruit-dove (*Ptilinopus prorphyraceus*) were all negatively associated with disturbed habitat. Micronesian honeyeater and island swiftlet (*Aerodramus vanikorensis*) were the only

species showing positive associations. Regression analysis of detection and elevation zones for six species suggested uneven bird distribution and species-habitat associations. Micronesian honeyeater, Micronesian kingfisher (*Toridamphus reichenbachii*) and Pohnpei lorikeet detections declined as elevation increased, suggesting mangrove associations (respectively $r^2 = 0.869$, 0.574 , and 0.649). Contrarily Caroline Islands white-eye (*Zosterops semperi*), long-billed white-eye and Micronesian pigeon detections increased as elevation increased suggesting Pohnpei climax forest associations (respectively $r^2 = 0.471$, 0.981 and 0.519). Our results indicated that habitat modification is a major driving factor for Pohnpei avian populations.

INTRODUCTION

The Pacific regions of Micronesia, Melanesia and Polynesia encompass more than 22,000 islands that vary in size, type and isolation. Islands range from small sandpits to islands with areas of 35,000 km² (Mayr and Diamond 2001). Most islands are either low atolls or high volcanic islands. . The islands' unique avifaunal assemblages have been shaped by isolation from other landmasses, and by size and ecological complexity (Baker 1951; MacArthur and Wilson 1967; Steadman 2006). Further, today's island communities are influenced by those that existed in the past and by the order in which inhabitants arrived from afar (Diamond 1975; Keddy 1992; Wright and Steadman 2012).

Despite the high biodiversity of the insular Pacific, however, the region's species and systems are facing dire conservation challenges. Island birds are going extinct at a rate many times greater than continental species (Temple 1985; Frankham 1998), and comprise 90% of the recorded avian extinctions that have been documented in recent

history (Myers 1979; Frankham 1998; Blackburn 2004). Habitat degradation and human-associated processes are considered to be principal causes of wildlife extinctions and population declines worldwide (Diamond 1989; Wilson 2002), and Oceania exemplifies the patterns. These effects are especially profound on islands where human settlement is associated with the introduction of invasive species and with the subsequent changes to undisturbed habitat and local fauna (Steadman 2006).

Pohnpei's vegetation communities are unique, bearing >110 endemic plants. The island's avifauna evolved in a matrix of island climax systems composed of gallery forest, palm forest and dwarf forest, among others (Raynor 1994; Mueller-Dombois and Fosberg 1998, Buden 2000; Merlin and Raynor 2005). Pohnpei's unique climatic conditions helped to shape habitat configuration and composition, such that the island had large tracts of productive forest. Pohnpei highlands (>200 m elevation) are publicly held, and have been protected by local government and conservation entities (e.g., Conservation Society of Pohnpei; Merlin and Raynor 2005). Lowlands are mostly held in private ownership, or are managed communally by nearby residents.

The island of Pohnpei, Federated States of Micronesia, has been affected by anthropogenic factors for centuries. Pohnpei's Micronesian settlers used island forests since their first arrival, building materials and firewood were obtained from mangrove forest while croplands and housing displaced undisturbed forests in the lowlands (Merlin et al. 1992; Raynor 1994). Pohnpeian traditional forestry practices and natural resource uses were considered to benefit biodiversity (Lee 2001; Brosi et al. 2007), but in the last 2 decades living styles have changed and impacts have increased. One of the greatest changes to Pohnpei's landscape has been the loss of 36% of native undisturbed

vegetation between 1975 and 2002. Apparently changes were due to Sakau (*Piper piper*) farms and other plantation crops (Trustum 1996; Buden 2000; Merlin and Raynor 2005).

In 1983 the United States Fish and Wildlife Service (USFWS) conducted a comprehensive assessment of bird populations in the four states of the Federated States of Micronesia; Pohnpei, Yap, Chuuk and Kosrae (Engbring et al.1990). In 1994 a repeat survey was conducted on Pohnpei following the same general protocols used previously (Buden 2000). Both studies employed multiple observers to record bird observations at stations situated approximately every 200m along transects distributed throughout the island. Engbring et al. (1990) estimated bird densities that were combined with the areas surveyed to develop overall population estimates. Buden (2000) reported results for each species in two elevation zones (above and below 200 meters above sea level), and he compared his records to Engbring et al. (1990). Buden (2000) also reported the mean number of forest-dwelling birds detected at each station in six elevation zones and those too were assessed against the previous survey. Results of that comparison indicated substantial population declines in every one of the Pohnpei bird species surveyed, many of which showed a 78% to 80% decline in the overall abundance (Buden 2000). Encounter rates for 14 forest dweller species decreased by more than 50% and detections did not increase for any species. A 68% decline in encounter rates was documented in mangrove habitats (Buden 2000).

Habitats on Pohnpei have changed substantially in the last 2 decades with increased anthropogenic incursions (Saunders et al. 1991; Murcia 1995; Watson et al. 2004). However, recent studies indicate that species could have differential responses to habitat modification, reflecting the complexity of factors underpinning avian populations

(Banko et al. 2002, 2013). To assess the current condition of Pohnpei avifauna, we conducted a third systematic avian survey in 2012 and we compared our observations with those collected previously. We explored whether Buden's findings of avian populations declines continued in recent years. Also, we used three decades of vegetation information from the whole of the island of Pohnpei to study whether apparent changes in bird populations over the recent three decades were associated with anthropogenic processes and habitat change.

METHODS

STUDY SITE

Research was conducted on the island of Pohnpei, Federated States of Micronesia (6°52' N, 158°13' E; Figs.1, 2). Pohnpei is circular with an approximate diameter of 20 km circumscribing the highest peak in the Micronesian chain (c.800 m, Engbring et al. 1990). Lowland coastal plateau and mangrove forests surround inner areas of higher elevation. Vegetation on Pohnpei has been summarized elsewhere (Mueller-Dombois and Fosberg 1998, Buden 2000), but in short, early succession and agricultural forest vegetation include lower canopy (2–20 m) hibiscus (*Hibiscus tiliaceus*), banana (*Musa sapientum*), coconut (*Cocos nucifera*), breadfruit (*Artocarpus altilis*), and sakau (*Piper methysticum*). Climax forests have higher canopy (25–30 m) dominated by mango (*Mangifera indica*), dohng (*Camptosperma brevipetiolata*), sadak (*Elaeocarpus carolinensis*), karara (*Myristica insularis*), ais (*Parinari laurina*), and tree ferns (*Cyathea* spp.; Mueller-Dombois and Fosberg 1998, Buden 2000). Approximately 44 km² of mangroves composed of *Rhizophora apiculata*, *Bruguiera gymnorrhiza*, *Sonneratia alba*,

Xylocarpus granatum and *Nypa frutycans* form a belt around the island, which in some cases reaches 2 km wide (Buden 2000; BalicK 2009). Additional characteristics of the island have been described elsewhere (McClellan et al. 1998; Buden 2000; Kesler 2002, 2006a, 2006b).

BIRD SURVEYS

We used information available from 3 avian surveys regarding Pohnpeian avifauna.

Study 1: Engbring et al. (1990) conducted the first systematic survey for the Federated States of Micronesia in 1983 using 8-minute variable distance circular plots (Reynolds et al. 1980). The group surveyed 458 stations, each separated by approximately 200 m, on 19 transects. Roughly half the survey stations were located above, and half below 200 m in elevation. The group reported avian density and abundance for 6 elevation zones (Mangrove [sea level], 0-100 m, 100-200 m, 200-400 m, 400-600 m and 600-800 m), and in 4 Pohnpei municipalities (Sokehs, Uh, Kitti and Madolenihmw). We used data published in the associated report (Engbring et al. 1990) for comparisons.

Study 2: The second systematic survey of birds on Pohnpei was conducted in 1994 (Buden 2000). Buden (2000) followed protocols similar to those used by Engbring et al. (1990), by surveying 303 stations on 19 transects that were situated similarly to those used in 1983. Buden (2000) calculated 2 different encounter rates, including the number of birds observed at each station at 6 elevation zones, and the number of bird detections per hour above and below the 200m elevation line. Additional information was provided about previous survey, transect locations in 2012 (Buden, pers. com).

Survey 3: We conducted surveys of Pohnpei birds from January to March 2012 at 247 stations on 19 transects placed in locations similar to those used previously (Fig. 1.2.) (Table 1.3). As with previous studies (Engbring et al. 1990, Buden 2000), transects were distributed across the whole of the island to obtain representation of the diverse habitats. Survey stations were separated by >200 m, which we determined using global positioning systems (GPS; Garmin Ltd., Olathe, Kansas). We located four transects in mangrove habitats and 15 were distributed in terrestrial forests within low, midland and upland areas. All transects were conducted on foot or by using kayaks. Observations were conducted while rain was not present, light rain, and when wind was less than 4 points on the Beaufort scale.

Survey protocols in 2012 were similar to those used previously (e.g. Engbring et al. 1990, Buden 2000, Kesler and Haig 2007a). We conducted eight minutes variable-distance circular plot point counts surveys at each survey station between sunrise and 11:00 h (Reynolds et al. 1980). Mainland observers spent one week training with colleagues from Conservation Society of Pohnpei prior to the onset of surveys to hone species identification skills and standardize protocols and techniques. Teams comprised of Pohnpei and mainland surveyors were present for all surveys.

POHNPEI VEGETATION

Digital vegetation data were obtained from previous vegetation surveys, which documented the structure of Pohnpei habitats in 1975 (MacLean et al. 1986), 1995 (Newsome et al. 2003), and 2002 (Newsome et al. 2003). The three vegetation models were developed using a similar technique, and although habitat models and bird surveys

were not perfectly aligned temporally, we assumed that later vegetation assessments reflected later patterns, and thus were better associated with later bird populations. We used ArcGIS (ESRI 2011) to identify the proportion of native and non-native habitats within each elevation zone during each of the three vegetation model periods.

Vegetation models from 1975, 1994, and 2002 were derived using similar techniques. Pohnpei's maps included polygons illustrating vegetation coverages in fourteen different classifications including agroforest, atoll forest, coconut plantation, cropland, grassland, savanna, mangrove, marsh, dwarf forest, palm forest, secondary vegetation, swamp forest, undisturbed vegetation, urban and water (citation for maps). These categories represent all habitats present on Pohnpei and described as primary vegetation.

We amalgamated vegetation categories from each map into two larger habitat classes, including undisturbed and disturbed. *Undisturbed vegetation* habitats were comprised of merged vegetation polygons of upland forest, palm forest, dwarf forest, atoll forest, and included the amalgamation of polygons representing areas with water-obligated vegetation including mangroves and several small patches of inland water (often emergent vegetation), swamp forest, and marsh habitats. *Disturbed vegetation* habitat included merged polygons of disturbance and anthropogenic habitats including those labeled as secondary vegetation, cropland, grassland or savanna, barren, urban land, and incorporated polygons of vegetation managed for subsistence and commercialization of staple crops (e.g. banana [*Musa* spp.] and breadfruit [*Artocarpus* spp.]), which were classified as agroforest, plantation forest and coconut plantation.

ANALYSIS

We compared the rate (birds detected/8 minute survey period; hereinafter “detections”) at which observers detected each species in 2012 with detections reported for surveys in 1983 (Enbring et al. 1990) and 1994 (Buden 2000) in each of six elevation zones, including sea level (Mangrove), 0-100, 100-200m, 200-400m, 400-600m, and 600-800m. We used a χ^2 analysis (Peck and Devore 2010) to determine whether detections of each species differed between 1994 and 2012 surveys. We considered differences to be significant at $\alpha < 0.05$ here and elsewhere in this investigation.

We also assessed the relationship between anthropogenic/disturbed habitats and changes in Pohnpei bird detections over the course of the last three decades. We used vegetation and bird survey data to model the relationship between anthropogenic habitat change and Pohnpei avifauna in the 16 species (Table 1.1) for which at least 30 detections were made in at least two of the three surveys periods. For each species, we used generalized linear mixed models with fixed and random effects (glmer) in R version 2.15.1 (R Core Team 2012). Data for each species were fitted to a model that included detections (rates were standardized to 10 hours) for the associated elevation zone and year as a response variable, and the proportion of anthropogenic habitat within that zone during the most recent vegetation survey as an explanatory variable. Survey year (1983, 1994, or 2012), and elevation zone were included as random effects in the model because our aim was to assess associations between native vegetation and bird detections, regardless of survey period or location. Thus, after accounting for survey year and elevation zone, we determined whether there was a relationship between the proportion of anthropogenic habitat and bird detections by assessing whether the 95% confidence

interval (95% CI hereinafter) for the anthropogenic habitat parameter overlapped with zero. Further, we used the sign of the associated parameter to determine whether there was a positive or negative relationship between bird detections and anthropogenic habitats.

Additionally, we regressed detection rates across elevation zones to determine whether species with detections-disturbed habitat associations were distributed evenly throughout the island elevation zones or if changes in detections across elevations followed the volume of disturbed habitat at the associated elevation zone. We created regression lines between detection rates at each elevation zone for each survey year to identify detection patterns. Only species for which at least 30 detections were made during each survey were included in the assessment.

Given previous surveys data availability, analysis and comparisons were restricted to published data. Information from the 1983 survey was limited to published data (Engbring et al. 1990). In the case of the 1994 survey we used published data (Buden 2000) and information provided by D. Buden.

RESULTS

We detected 3,582 birds representing 23 of the 24 species reported previously (Engbring et al. 1990; Buden 2000) (Table 1.1). We detected 627 *Myzomela rubratra*, 587 *Ptilinopus prophyraceus*, 445 *Zosterops cinereus*, 413 *Trichoglossus rubiginosus*, 406 *Aplonis opaca*, 205 *Rukia longirostra*, 195 *Todiramphus recheinbachii*, 183 *Myiagra pluto*, 164 *Rhipidura kubaryi*, 78 *Aerodramus vanikorensis*, 76 *Annous* species, 75 *Ducula oceanica*, 66 *Gygis alba*, 25 *Zosterops semperi*, 10 *Phaeteron lepturus*, 8

Coracina tenuirostris, 5 *Gallicolumba kubaryi*, 5 *Acrocephalus syrinx*, 5 *Lochura hunsteini* and 4 *Erythrura trichroa*. *Asio flammeus*, *Gallicolumba kubaryi* and *Egretta sacra* were not detected during surveys in 2012, but these species persist on Pohnpei based on observer detections outside of surveys and when traveling between sites, and based on the observation of an owl pellet. *Porzana cinerea* was not detected in at all in 2012, however Pohnpei residents reported observations of the species occasionally (Adaltrick and Kirino *pers. comm.*).

The mean number of detections across elevation zones in 2012 was 14.3 (SD 1.4) birds/station, compared to 15.4 (SD 3.4) birds/station in 1994. In 2012 the elevation zones with the highest and lowest number of birds/station was 16.0 (SD 42.5) and 11.8 (SD 13.3) birds/station at 200-400m and 600-800m zones respectively. *Ptilinopus porphyraceus*, *M. rubratra* and *Z. cinereus* were the most common species at the 200-400m elevation zone; and *R. longirostra*, *P. porphyraceus*, *Z. cinereus* and *M. rubratra* were the most common species > 600 amsl.

Many species were unevenly distributed across the island in 2012, depending on elevation zone (Table 1) (Fig. 4). For example *M. rubratra*, *T. reichenbachii*, *T. rubiginosus* detections declined as elevation increased (respectively $r^2 = 0.869$, 0.574 , and 0.6498). Contrarily *Z. semperi*, *R. longirostra* and *D. oceanica* detections increased as elevation increased (respectively $r^2 = 0.471$, 0.981 and 0.519). Additionally mangroves (at sea level) had the highest and lowest detection rates for several species. Detections of *Aplonis opaca*, *Z. cinereus* and *R. longirostra* were lowest in mangroves, whereas detections of *T. reichenbachii*, *T. rubiginosus* and *M. rubratra* were highest in mangroves (Table 1.1).

When compared to Buden (2000), detection rates in 2012 were not markedly lower for most species, indicating no strong declining overall trends. Mean detection rates increased the most in *R. longirostra* (359%), *D. oceanica* (220%) and *Z. cinereus* (117%). The greatest declines in detection rates occurred in *A. syrinx* (77.3%), *Anous* spp. (50.9%), *M. rubratra* (28.9%) and *A. opaca* (21.6%). However, positive and negative changes in mean detection rates were not evenly distributed among elevation zones. Detections of *R. longirostra* increased by 949% between 100-200m but declined (8%) in areas >600m. During 2012, *D. oceanica* detections in mangroves were 321% greater than in 1994. However, detections of the same species increased by only 10% in the 100-200m elevation zone (Table 1.2). Disparities among elevation zones were also apparent in species that exhibited declines. For example, in *M. rubratra* island-wide detections declined 28.9% but increased by 10.5% at the 600-800m. Similarly in *A. opaca* the island-wide detections declined by 21.6%, but increased 22.8% at the 600-800m areas. The endemic *T. rubiginosus* presented an overall negative trend and detection rates declined 20%. However when analyzed by specific elevation zones, detection rates increased 67% in mangroves and 13.8% at 0-100m; simultaneously detection rates declined 31.5% at 100-200m, 58.4% at 200-400m, 63.6% at 400-600m, and 49.8% at 600-800m (Table 1.2). *Myiagra pluto* was the only species with lower rates in all elevation zones in 2012 when compared to 1994, overall detection rates declined a 19.1%.

Pohnpei habitats changed substantially between the three vegetation survey periods, and changes differed among elevation zones (Fig. 1.3.). Larger changes in habitat occurred between 1975 and 1994; habitat changes trend observed during this

period tapered between 1994 and 2002. In general, lower elevation zones and areas along the coast changed dramatically between survey periods, whereas alterations of uplands and mangroves were rare. For example in the 0-100 m elevation zone, the percentage of disturbed habitat increased from 20.7 to 33.3 between 1975 and 1994 and declined to 32.9 % by 2002. In the mangrove and 600-800 m elevation zones, changes during the same time period were inferior to the 2%. Changes in lower areas (0-100 m and 100-200 m) had a greater effect in Pohnpei forest given that these areas enclose >58% of the island. We tested for an association between each of 16 species and anthropogenic vegetation by fitting species detections to vegetation conditions across the 6 elevation zones, and across three different survey periods. We found associations to the proportion of altered habitat for 10 species at the >95% level. *Mizomela rubratra* (0.411, SE= 0.137) and *A. vanikorensis* (1.344, SE= 0.469) were the only two species for which there were positive associations between detections and disturbed habitats. Detections were negatively associated with disturbed habitats in *D. oceanica* ($\beta = -1.595$, SE= 0.605), *R. kubaryi* ($\beta = -1.112$, SE= 0.368), *M. pluto* ($\beta = -1.583$, SE= 0.280), *T. rubiginosus* ($\beta = -1.590$, SE= 0.194), *P. lepturus* ($\beta = -1.418$, SE= 0.410), *G. alba* ($\beta = -1.993$, SE= 0.568), *Anous* spp. ($\beta = -2.163$, SE= 0.350) and *P. porphyraceus* ($\beta = -0.723$, SE= 0.165). No relationships were identified between disturbed habitats and detections of *Rukia longirostra* ($\beta = 0.501$, SE= 0.375), *A. opaca* ($\beta = 0.127$, SE= 0.165), *T. reichenbachii* ($\beta = 0.295$, SE= 0.286), *Z. semperi* ($\beta = -0.618$, SE= 0.564), *Z. cinereus* ($\beta = -0.192$, SE= 0.209), and *A. syrinx* ($\beta = -0.487$, SE= 1.163).

DISCUSSION

Surveys of Pohnpei avifauna were conducted in 1983 (Engbring et al 1990), 1994 (Buden 2000), and in 2012. When compared to the 1983 survey results, Buden (2000) reported substantial declines in detections of most species on Pohnpei (c. 60%). Buden (2000) proposed that factors driving population declines between his and the earlier survey may have included invasive species and introduced predators, but he suggested that habitat alteration and transformation of native upland forest during the same period of time was the main reason for avian population change.

Comparisons between Buden (2000) and this study indicate that the declining trend previously reported for the period between 1983 and 1994 has not continued. When compared to 1994, results from 2012 surveys indicated mean detection rates declined in thirteen species and they increased in 9 species. These patterns have been observed on other Pacific islands and congeneric species had differential responses. For example, on the island of Rota, Commonwealth of the Northern Mariana Islands, detections of the generalist *A. opaca* increased between 1998 and 2004, whereas detections of seven other species declined dramatically (Amar et al. 2008). Additionally, the occurrence of native and introduced generalist species in Mauna Kea declined while native Hawai'ian Amakihi (*Hemignathus virens*) abundance and distribution did not change significantly (Banko et al. 2013). The Tinian Monarch (*Monarcha takatsukasae*) population showed signs of recovery after vegetation density increased between 1982 and 1996 on Tinian (Lusk et al. 2000). Differential population response patterns also were present in Pohnpei 2012 avian survey, in that *D. oceanica* and *R. longirostra* detections increased and *M. rubratra* and *A. opaca* detections declined.

Our results indicated that changes in detections across three decades have associations with anthropogenic changes to Pohnpei habitats. Detections for 10 of 16 species exhibited an association (positive or negative) to the proportion of disturbed habitat in Pohnpei forests. Detections of 2 species were positively associated with disturbed habitats. Disturbed habitat may provide additional structure for native or nonnative food resources for *M. rubrata*, which is a generalist leaf gleaner. Similarly, disturbed habitats often include open areas and forest edge, which appears to be a preferred foraging habitat for *A. vanikorensis*. However, results indicated negative associations between anthropogenic habitats and detections in 8 species. More importantly, our results showed that detection rates for endemic *M. pluto*, *R. kubaryi* and *T. rubiginosus* are negatively associated with modified landscapes. These species are climax and understory forest obligates (Engbring et al. 1990, del Hoyo et al. 2006, Bird Life International 2014), and because disturbance often moves habitats away from these more developed structures, negative associations with anthropogenic change are not unexpected. Similarly, *Ducula oceanica*, and *P. porphyraceus* are common throughout Micronesia and depend on large tracts of undisturbed mangrove and Pohnpei climax forest, and they too illustrated negative relationships.

Several patterns emerged from the analyses of detection rates and altered habitats. The amount of area at the 0-100 m elevation zone represents approximately 42% of the island surface, followed by approximately 17% in the 100-200m zone and approximately 17% in the 200-400m elevation zone. Between 1994 and 2002, some disturbed habitats returned to undisturbed classifications in the 0-100m and 100-200m zones as traditional agroforestry farming practices changed and some areas were abandoned.

Simultaneously, several species associated with disturbed habitat exhibited elevated detections in the same zones. The detection rate for *R. longirostra*, increased substantially in the 0-100m zone while *M. rubratra* showed decline in detection rate. However *T. rubiginosus* and *A. syrinx*, which are both negatively associated with disturbed habitats showed significant declines at the 200-400m zone.

Our results generally confirm suggestions by Buden (2000) that landscape changes are a primary driving force of Pohnpei avifauna populations. Changes in Pohnpei human population densities, and land use traditions have translated into different forest uses, especially in sakau farming techniques. With forest fragmentation significant abiotic and biotic changes can alter bird-habitat relationships as well as change the way in which species interact (Case et al. 1979; Doutrelant et al. 2000; Robinson-Wolrath and Owens 2003; Gaston 2003). Increasing detection rates in *Zootheros* ssp. and *R. longirostra* in 2012 could be the response to the decline in *A. opoca* (Sachtleben 2005; Berry and Taisacan 2008; Jankowski et al. 2010).

Even though that Pohnpei avifauna includes several common Micronesian species (Pratt et al. 1987), there is a lack of demographic and life history information for most species on the island. Our results illustrating the relationship between localized bird detection rates, and by extension bird population densities indicate a need for conservationists to consider the potential effects of future habitat changes. Similar to other Pacific islands, Pohnpei forests could suffer from further alterations. Forest alterations include native forest loss to development, coral dredging, and future climate change. Additional research should focus extensively in incorporating additional habitat information and evaluate site-specific and station-specific correlations between bird

occupancy and density. Further study of the relationship between species and island habitat compositions and configurations may also lend insight into why the results presented here are occurring.

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FIGURES

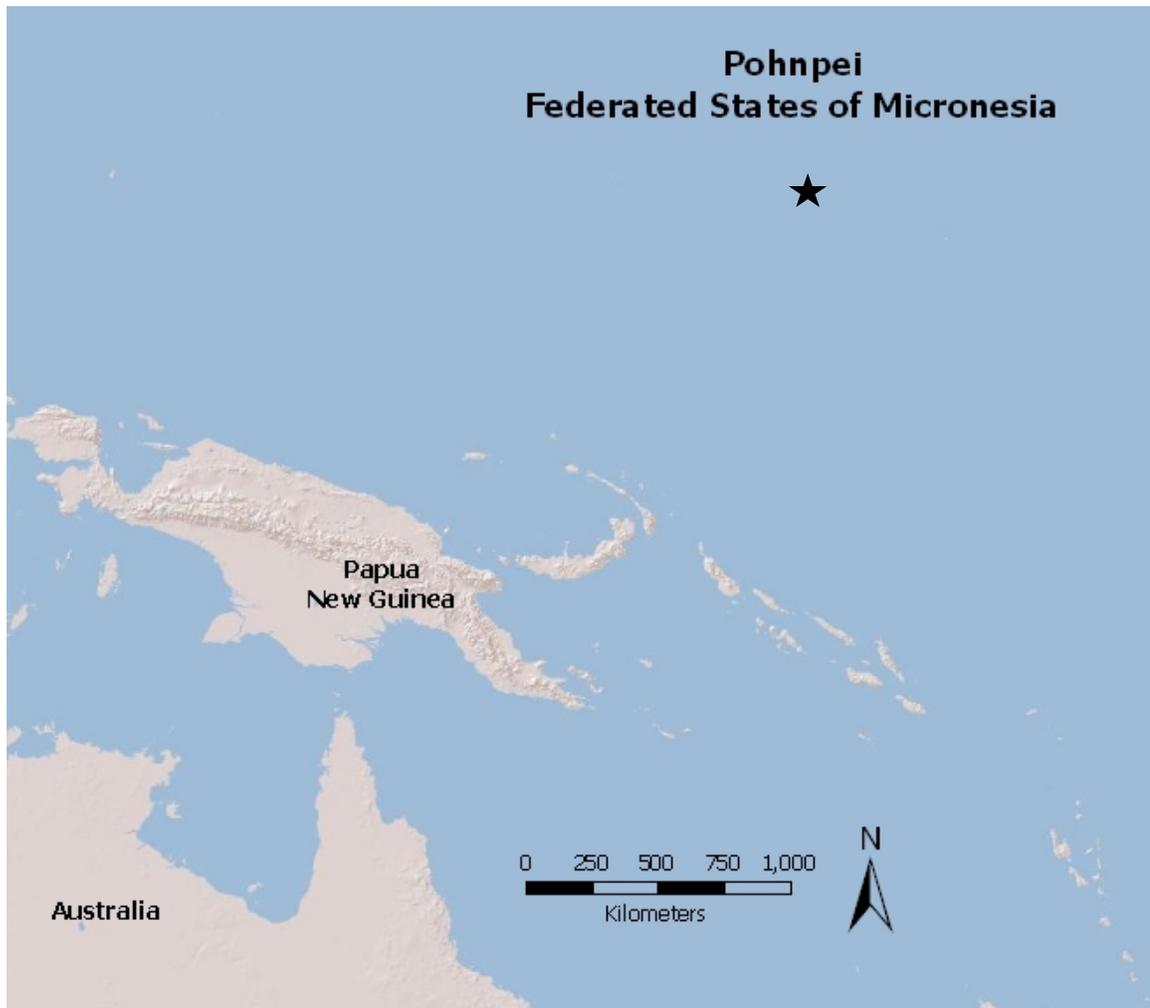


Figure 1.1. Global locator for Pohnpei Island, Federated States of Micronesia.

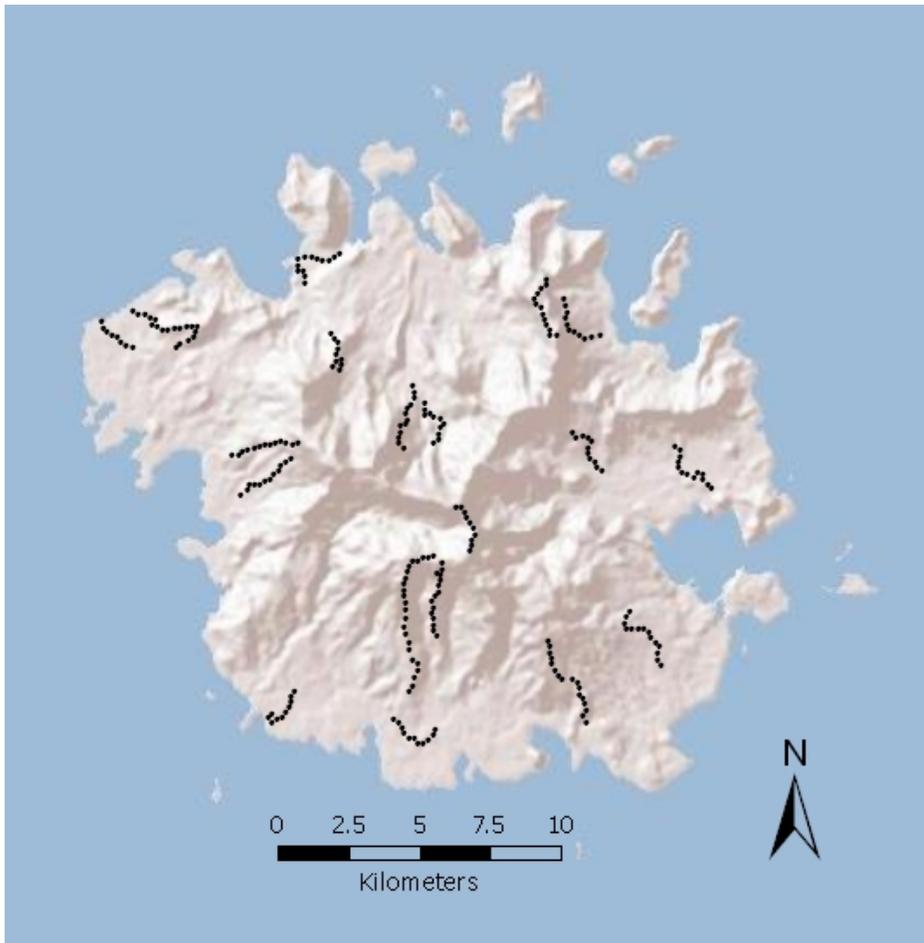


Figure 1.2. Island of Pohnpei, Federated States of Micronesia. Survey stations (n=247) visited Between January and February 2012.

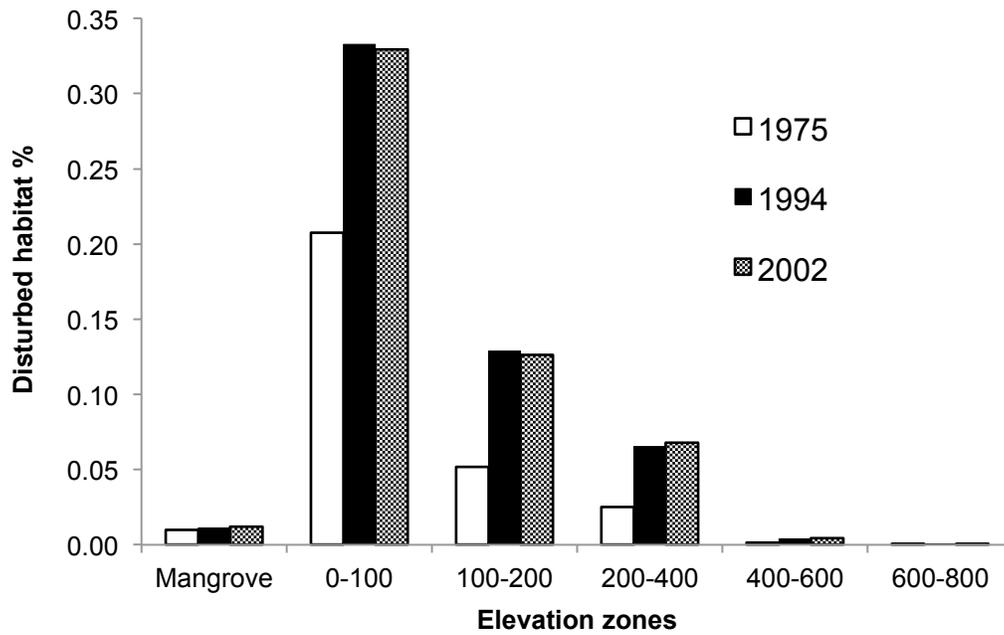


Figure 1.3. Pohnpei disturbed habitat proportion in 6 elevation zones and across three different vegetation surveys (1975: MacLean et al. 1986, Newsome et al 2003a; 1995: Newsome et al. 2003; 2002: Newsome et al. 2003)

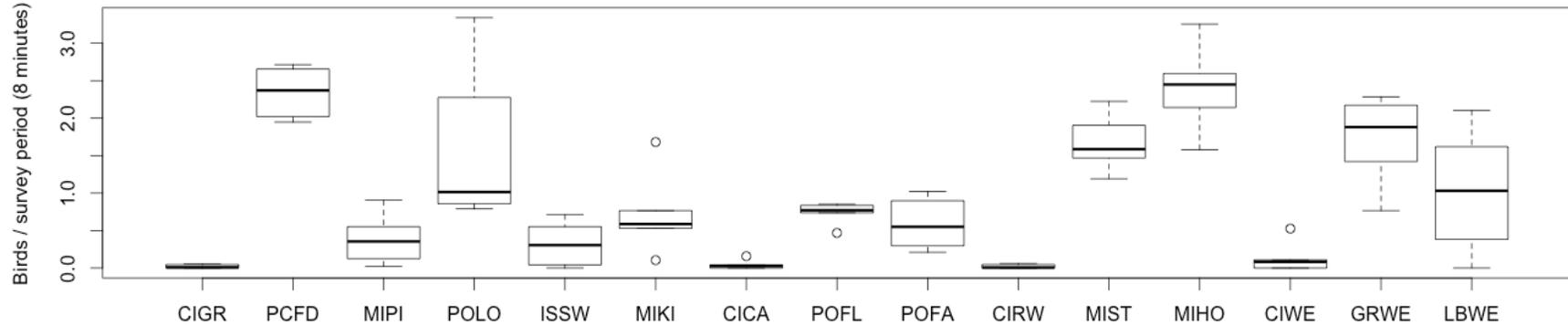
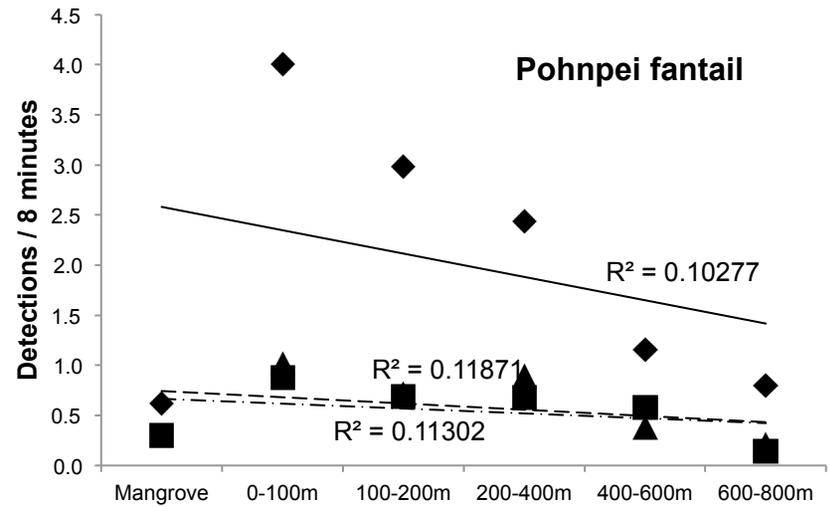
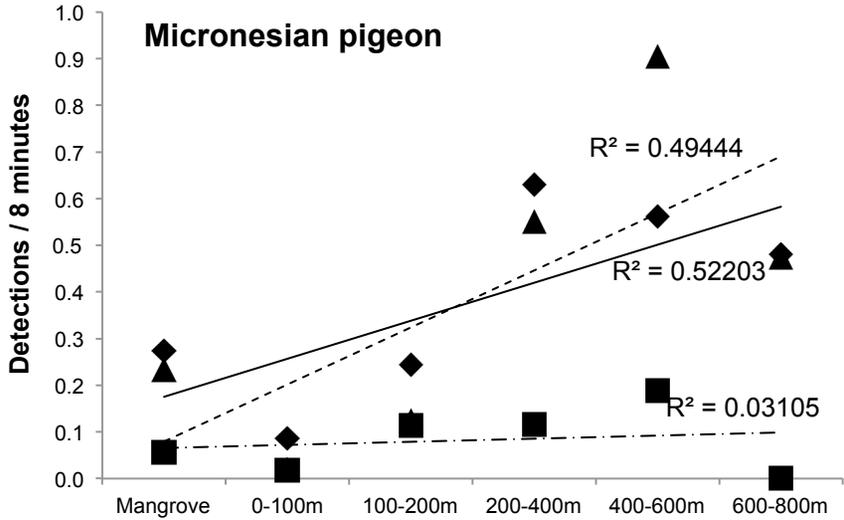
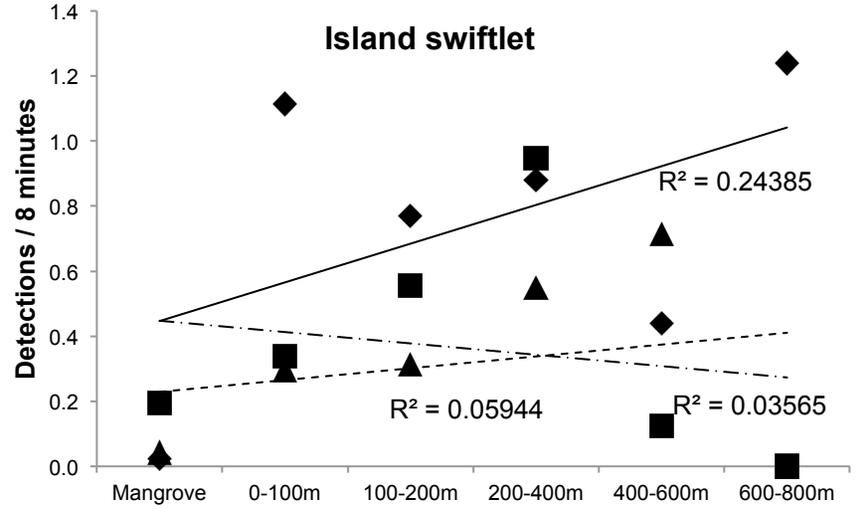
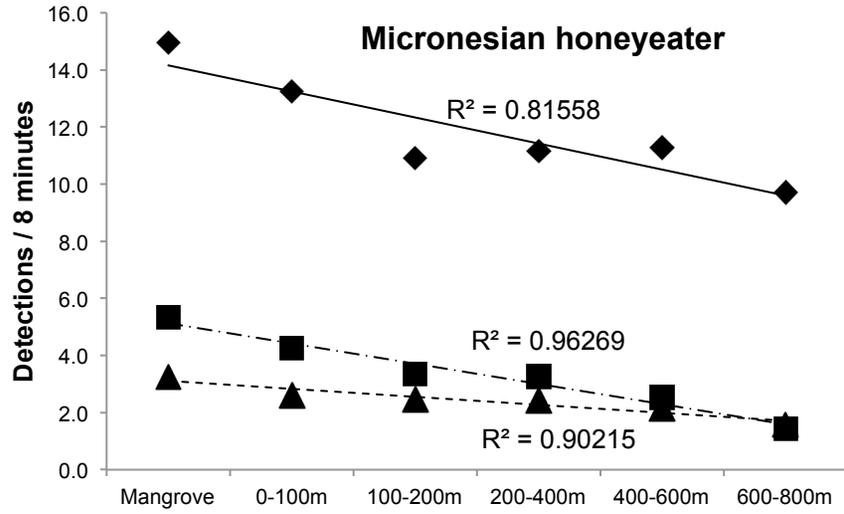
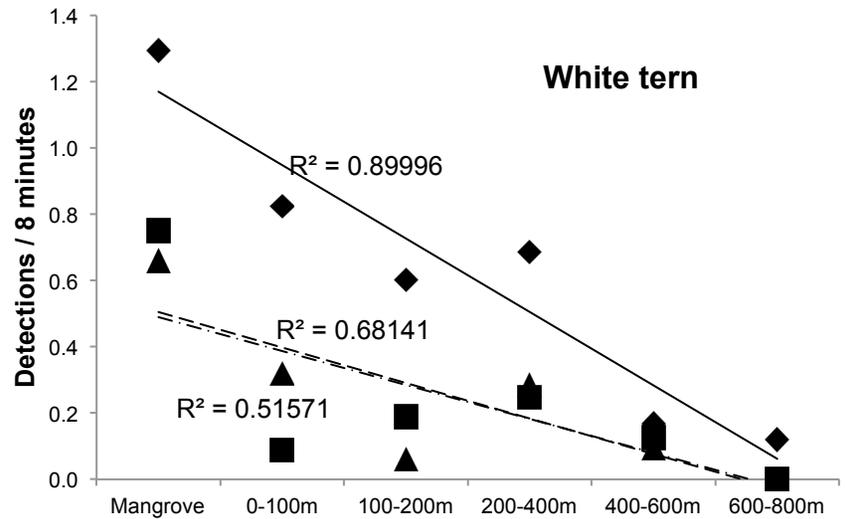
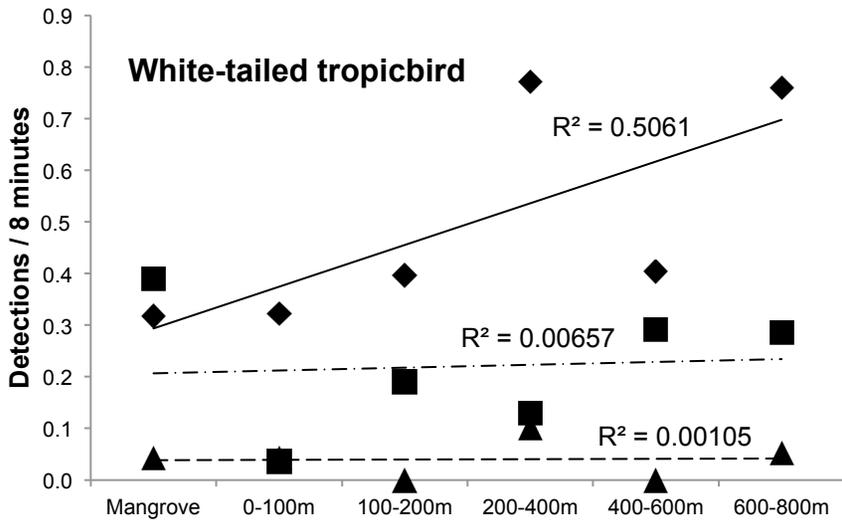
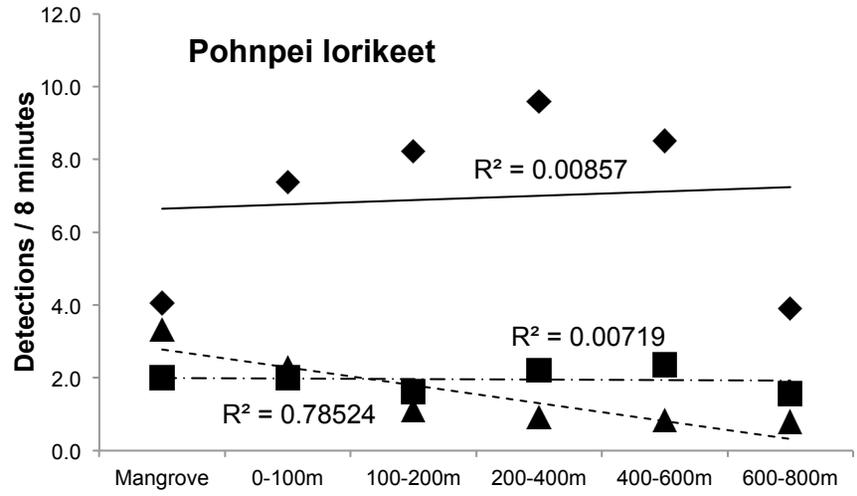
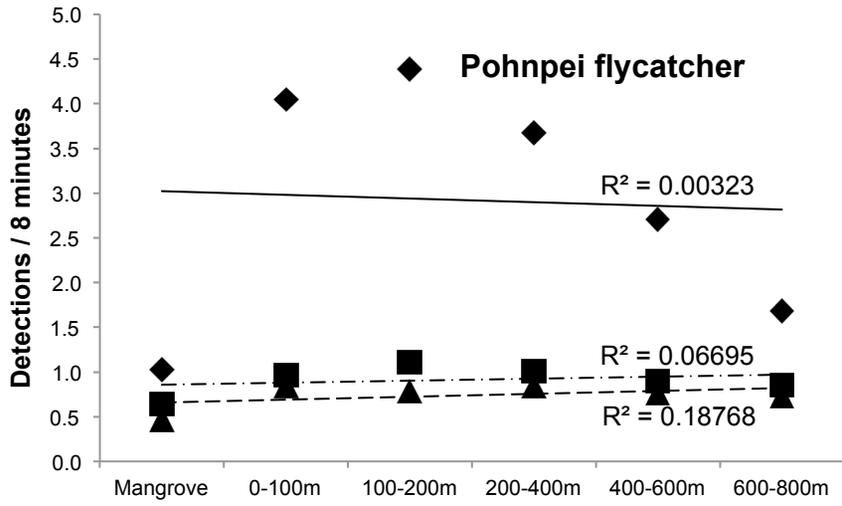


Figure 1.4. Forest obligated species detection rates, birds per unit time (individuals /8 minutes) across six elevation zones. CIGR= *Gallicolumba kubaryi*, PCFD= *Ptilinopus porphyraceu*, MIPI= *Ducula oceanica*, POLO = *Trichoglossus rbiginosus*, WBCR= white-browed crane, ISSW = *Aerodramus vanikorensis*, MIKI = *Toridamphus reichenbachii*, CICA = *Coracina tenurostris*, POFL = *Myigra pluto*, POFA = *Rhipidura kubaryi*, CIRW = *Acrocephalus syrinx*, MIST = *Aplonis opaca*, MIHO = *Myzomela rubratra*, CIWE = *Zosterops semperi*, GRWE = *Zosterops cinereus*, LBWE = *Rukia longirostra*





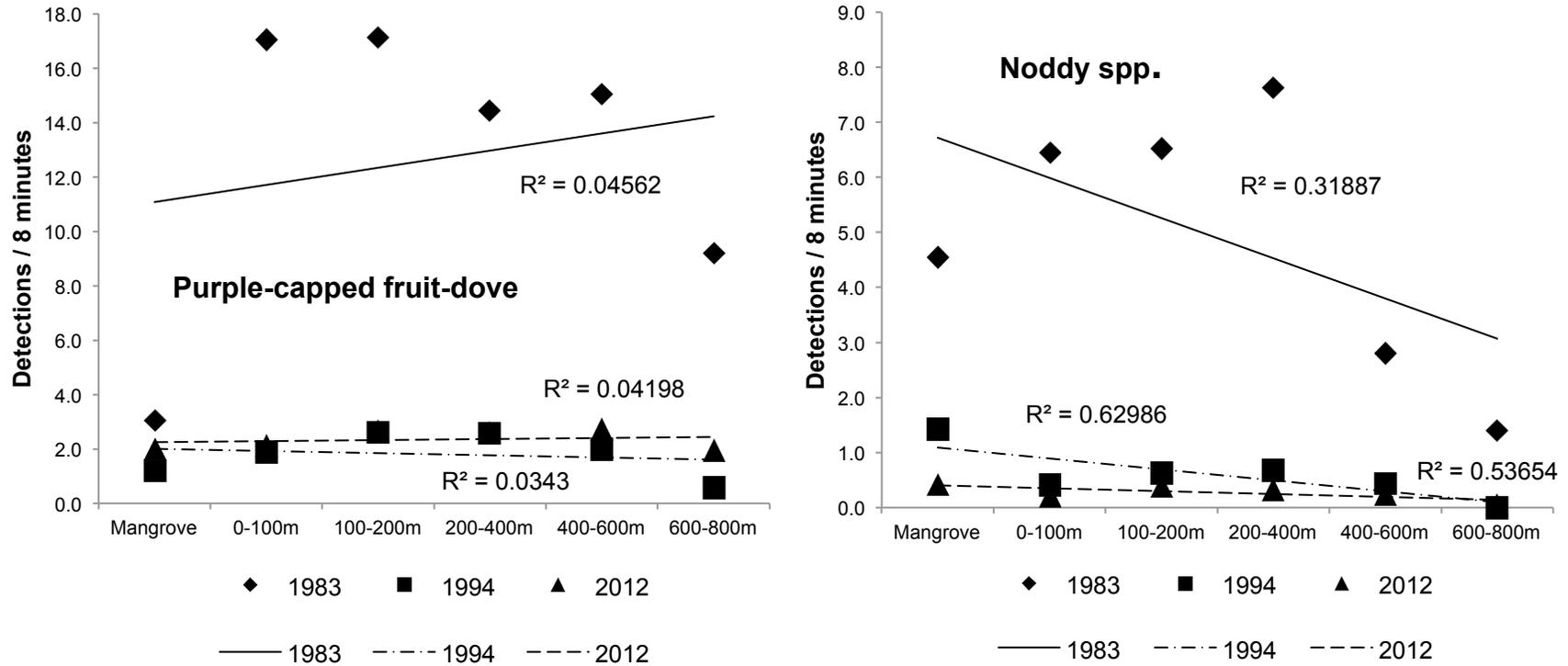


Figure 1.5. Average species detection rates across 6 elevation zones (Mangrove, 0-100m, 100-200m, 200-400m, 400-600m, 600-800m) in 1983, 1994 and 2012 surveys.

TABLES

Table 1.1. Species detection rates (birds detected/8 minutes) observed in 1983, 1994, and 2012 on the island of Pohnpei, Federated States of Micronesia at six elevation zones.

Species	Mangrove			0-100m			101-200m			201-400m			401-600m			601-800m		
	1984	1994	2012	1984	1994	2012	1984	1994	2012	1984	1994	2012	1984	1994	2012	1984	1994	2012
<i>P. lepturus</i> (1)	0.318	0.389	0.043	0.323	0.036	0.043	0.397	0.190	0.000	0.772	0.130	0.102	0.404	0.292	0.000	0.760	0.286	0.053
<i>E. sacra</i>	0.114	0.111	0.000	0.000	0.018	0.000	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<i>Anous spp.</i> (1)	4.545	1.417	0.426	6.454	0.411	0.213	6.526	0.620	0.375	7.630	0.675	0.327	2.809	0.438	0.238	1.400	0.000	0.053
<i>G. alba</i> (1)	1.295	0.750	0.660	0.823	0.089	0.319	0.603	0.190	0.063	0.685	0.247	0.286	0.169	0.125	0.095	0.120	0.000	0.000
<i>G. kubaryi</i> *	0.000	0.000	0.000	0.031	0.000	0.000	0.192	0.038	0.047	0.000	0.026	0.020	0.000	0.000	0.000	0.000	0.000	0.053
<i>P. porphyraceus</i> (1)	3.045	1.194	2.021	17.046	1.875	2.128	17.141	2.620	2.656	14.446	2.584	2.612	15.045	2.000	2.714	9.200	0.571	1.947
<i>D. oceanica</i> (1)	0.273	0.056	0.234	0.085	0.018	0.021	0.244	0.114	0.125	0.630	0.117	0.551	0.562	0.188	0.905	0.480	0.000	0.474
<i>T. rubiginosus</i> (1)	4.045	2.000	3.340	7.369	2.000	2.277	8.218	1.620	1.109	9.587	2.208	0.918	8.506	2.354	0.857	3.920	1.571	0.789
<i>P. cinerea</i>	0.000	0.028	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<i>A. flammeus</i>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<i>A. vanikorensis</i> (1)	0.023	0.194	0.043	1.115	0.339	0.298	0.769	0.557	0.313	0.880	0.948	0.551	0.438	0.125	0.714	1.240	0.000	0.000
<i>T. reichenbachii</i> (1)	4.977	1.194	1.681	2.646	0.661	0.553	1.833	0.608	0.766	1.728	0.844	0.531	1.843	0.896	0.619	1.640	0.429	0.105
<i>C. tenuirostris</i>	0.068	0.000	0.043	0.000	0.000	0.000	0.077	0.013	0.031	0.163	0.052	0.020	0.045	0.063	0.000	0.000	0.000	0.158
<i>M. pluto</i> (1)	1.023	0.639	0.468	4.046	0.964	0.851	4.385	1.114	0.781	3.674	1.013	0.837	2.708	0.896	0.762	1.680	0.857	0.737
<i>R. kubaryi</i> (1)	0.614	0.306	0.298	4.000	0.875	1.021	2.987	0.684	0.719	2.435	0.675	0.898	1.157	0.583	0.381	0.800	0.143	0.211
<i>A. syrinx</i> (1)	0.000	0.000	0.000	1.285	0.375	0.000	0.410	0.405	0.016	0.359	0.234	0.061	0.090	0.125	0.048	0.000	0.000	0.000
<i>A. opaca</i> (1)	4.591	1.500	1.191	9.277	2.786	1.468	9.756	2.899	1.594	8.293	3.351	2.224	7.090	2.021	1.905	8.000	1.286	1.579
<i>A. pelzelni</i> **	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<i>M. rubratra</i> (1)	14.955	5.333	3.255	13.262	4.250	2.596	10.923	3.354	2.469	11.152	3.260	2.429	11.270	2.521	2.143	9.720	1.429	1.579
<i>Z. semperi</i> (1)	1.114	0.000	0.000	1.123	0.071	0.064	1.782	0.266	0.109	1.152	0.156	0.102	0.640	0.042	0.000	0.160	0.000	0.526
<i>Z. cinereus</i> (1)	3.864	0.250	0.766	9.308	1.911	2.000	8.526	1.595	2.172	6.533	2.078	2.286	3.876	1.167	1.762	3.440	0.286	1.421

<i>R. longirostra</i> (1)	0.000	0.000	0.000	0.262	0.071	0.383	0.679	0.076	0.797	2.217	0.299	1.265	4.236	0.833	1.619	4.160	2.286	2.105
<i>E. trichroa</i>	0.000	0.000	0.000	0.154	0.143	0.021	0.000	0.013	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<i>L. hunsteini</i>	0.000	0.000	0.000	0.854	0.196	0.085	0.103	0.089	0.016	0.043	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(*): Vulnerable, (**): Critically endangered (IUCN 2013); (1): species modeled with >29 detections in at least 2 of the 3 surveys.

Table 1.2. Percent change in numbers of birds detected / 8 minutes in each elevation zone between 1994 and 2012 on the island of Pohnpei, Federated States of Micronesia. Numbers in each column represent the % change. Negative values indicate declines since previous surveys and positive values represent higher detection rates in 2012.

Species	Mangrove	0-100m	100-200m	200-400m	400-600m	600-800m
<i>P. lepturus</i> (N)	-89.06	19.15	-	-21.43	-	-81.58
<i>E. sacra</i>	-	-	NA	NA	NA	NA
<i>Anous spp.</i> (N)	-69.96*	-48.2	-39.54	-51.65	-45.58	+
<i>G. alba</i> (N)	-12.06	257.45*	-67.08	15.79	-23.81	NA
<i>G. kubaryi</i>	NA	NA	23.44	-21.43	NA	+
<i>P. porphyraceus</i> (N)	69.22	13.48	1.37	1.08	35.71	240.79*
<i>D. oceanica</i> (N)	321.28	19.15	9.72	371.43*	382.54*	+
<i>T. rubiginosus</i> (e) (N)	67.02*	13.83	-31.53	-58.40*	-63.59*	-49.76
<i>P. cinerea</i>	-	-	NA	NA	NA	NA
<i>A. flammeus</i>	NA	NA	NA	NA	NA	NA
<i>A. vanikorensis</i> (P)	-78.12	-12.21	-43.89	-41.88	471.43*	NA
<i>T. reichenbachii</i> (e)	40.72	-16.27	26.01	-37.14	-30.9	-75.44
<i>C. tenuirostris</i>	+	NA	146.88	-60.71	-	+
<i>M. pluto</i> (e) (N)	-26.73	-11.74	-29.87	-17.4	-14.95	-14.04

<i>R. kubaryi</i> (e) (N)	-2.51	16.72	5.15	32.97	-34.69	47.37
<i>A. syrinx</i>	NA	-	-96.14*	-73.81*	-61.9	NA
<i>A. opaca</i>	-20.57*	-47.30*	-45.02*	-33.61	-5.74	22.81
<i>A. pelzelni</i> (e)	NA	NA	NA	NA	NA	NA
<i>M. rubrata</i> (P)	-38.96*	-38.92*	-26.4	-25.5	-14.99	10.53
<i>Z. semperi</i>	NA	-10.64	-58.85	-34.52	-	+
<i>Z. cinereus</i>	206.38*	4.67	36.17	10	51.02	397.37*
<i>R. longirostra</i> (e)	NA	436.17*	949.22*	323.60*	94.29	-7.89
<i>E. trichroa</i>	NA	-85.11	270.31	NA	NA	NA
<i>L. hunsteini</i>	NA	-56.67	-82.37	-	NA	NA

NA: no comparison, insufficient data available; - : Species detected in 1983 and 1994, not detected in 2012; + : species detected in 2012 and not detected in previous surveys; (e): Pohnpei endemic; (N): negative association to disturbed habitat; (P): positive association to disturbed habitat; *: 1994 vs 2012 Percentage change significant with χ^2 goodness of fit test (df=1 and p <0.05) of individuals detected per unit of time (bird/8 minutes) for species with at least 10 detections in the specific elevation zone in 1994 or 2012.

Table 1.3. Percentage of area on each elevation zone, and number of survey stations (with survey proportions %) at each elevation zone for the 1994 and 2012 surveys conducted in Pohnpei. Island areas and 1994 information was obtained from Buden 2000.

Elevation Zone (amsl)	Island Area (%)	Survey	
		1994	2012
Mangrove	15.7	36 (11.9 %)	47 (19.0 %)
0-100	40.7	56 (18.5 %)	47 (19.0 %)
100-200	17.5	79 (26.1 %)	64 (25.9 %)
200-400	15.8	77 (25.4 %)	49 (19.8 %)
400-600	8.4	48 (15.8 %)	21 (8.5 %)
600-800	1.9	7 (2.3 %)	19 (7.7 %)

CHAPTER 2

POHNPEI ISLAND AVIFAUNA OCCURRENCE AND DENSITY ANALYSIS

ABSTRACT

Previous studies of avifauna in Pohnpei, Federated States of Micronesia (FSM) indicated that anthropogenic habitat alterations have the potential to affect bird populations on the island. However, associations between populations and landscape change in recent decades remain unclear, especially for Pohnpei endemic species. We surveyed the island of Pohnpei to identify species-habitat associations, and to determine how changes on the island could influence species population density and site occupancy. We conducted a systematic bird survey in 2012 and estimated density (λ) and occupancy (Ψ) for 10 and 13 terrestrial bird species, respectively. Density and occupancy models showed positive and negative relationship with habitat composition and patch configuration. The Pohnpei fantail (*Rhipidura kubaryi*) occupancy was positively affected by increases in forest edge associated with forest fragmentation, and that the Micronesian pigeon (*Ducula oceanica*) was negatively affected by reductions in forest canopy height from agricultural incursions. Density and occupancy of the endemic long-billed white-eye (*Rukia longirostra*), Micronesian kingfisher (*Toridamphus reichenbachii*), and Pohnpei lorikeet (*Trichoglossus rubiginosus*) were related to low amounts of forest edge, high canopy height and crown closure, which are characteristics of island climax forest. Island species are often considered habitat generalists, but our results indicated that several Pohnpei bird species are specialists and that they have strong associations with specific

habitat types and configurations. We believed continued anthropogenic and climate-drive habitat changes have the potential to strongly influence island populations of birds.

INTRODUCTION

Oceanic islands host unique biological assemblages (Kier et al. 2008), and the biotas therein are often considered naïve because they are especially susceptible to anthropogenic forces of habitat alteration, and the introduction of invasive predators and competitors from exogenous origins (Steadman 1989, Loope and Giambelluca 1998, Wilson 2002, Blackburn et al. 2004). Some island systems have been heavily impacted by these forces, which have caused population declines and the highest rate of avian extinctions of any region (Myers 1979, Temple 1985, Frankham 1998). Now, island endemics are being put at risk by impending climate changes (Jankowski et al. 2010).

The islands of the Federated States of Micronesia exemplify these patterns. For example, the island of Pohnpei hosts >110 endemic plant species and mosaic forests that provide habitat for more than 40 birds, including residents, migrants, and 6 endemic species (Pratt et al. 1989, Engbring et al 1990, Merlin and Raynor 2005). Endemic birds of Pohnpei include the last native lorikeet, Pohnpei lorikeet (*Trichoglossus rubiginosus*), in the region, the Micronesian kingfisher (*Toridamphus reichenbachii*), the monarch Pohnpei flycatcher (*Myiagra phuto*), the Pohnpei fantail (*Rhipidura kubaryi*), the long-billed white-eye (*Rukia longirostra*) and the elusive Pohnpei mountain starling (*Aplonis pelzelni*), which are all associated with Pohnpei climax forest (Oleiro and Kesler *Ch. 1*). Topography on the island is characterized by a diverse range of habitats, including low

costal areas with mangroves, river valleys and high steep ridges, with old-growth climax forest and the world's lowest mountane cloud forest.

Two systematic avian surveys were conducted on Pohnpei (Engbring et al. 1990, Buden 2000), and a comparison illustrated a striking decrease in the island's avifauna. Results indicated a 78% to 80% decline in species detection rates between 1983 and 1994 and the studies showed declines of > 50% in detection rates for 14 forest dweller species (Buden 2000). Authors speculated about the causes of the apparent declines, indicating that avian populations may have been affected by invasive species and introduced predators (e.g., *Sus* spp. and *Rattus norvegicus*), or that population changes were caused by conversion of native vegetation types into anthropogenic habitats (Trustum 1996). Recent changes in Pohnpeian culture and traditions have altered forest use and farming techniques, shifting farms into higher undisturbed regions (Merlin and Reynolds 2005).

Despite previous efforts to investigate the island's avifauna, little is known about the relationships between the species and the landscapes they inhabit. Birds of oceanic island are often thought to be generalist species (Scott et al. 2003) because the island residents must have transited across any number of islands in order to arrive from their continental origins. Generalist tendencies would likely facilitate such dispersal across the diversity of islandscapes (Diamond 1970, Scott et al. 2003, Moyle et al. 2009). Further, because most islands appear to include depauperate species assemblages when compared to continental systems, there are arguably reduced rates of competition and thus fewer drivers for the evolution of specialization.

There are indications, however that island resident bird species specialize in some ways, or at the very least, they appear differentially vulnerable to habitat changes (Oleiro and Kesler *Ch. 1*). Results from a recent 3rd avian study exhibited that the previously reported declining trends for Pohnpei Island populations were not consistent across species (Oleiro and Kesler *Ch. 1*). Species detections varied greatly, indicating that some birds have unique habitat associations and unique responses to global change. The extent of anthropogenic habitats in the last three decades was strongly associated with changes in populations of Pohnpei avifauna. Detections of many island species, including the endemic Pohnpei lorikeet and Pohnpei fantail, were linked to native and anthropogenic habitats. Understanding differences in natural histories could lend insights into the function of ecological communities on islands, as well as providing information for conservation designs.

We conducted a study of bird-habitat associations and population densities on the island of Pohnpei, Federated States of Micronesia to better understand the relationship between Pohnpei birds and the habitats they populate. We conducted systematic surveys to estimate density (λ) and occupancy (ψ) (Reynolds et al. 1980, MacKenzie 2006), and we used results from those efforts to identify inter- and intra-specific habitat associations. We identified bird associations with native and non-native habitat types, and associations with alterations in forest composition and configuration.

METHODS

STUDY SITE

Pohnpei hosts the highest peak (~800 m, Engbring et al. 1990) in the Federated States of Micronesia (6°52' N, 158°13' E; Figure1). The island is approximately circular in shape (20km in diameter) with a surface of ~351km², and it is surrounded by a mangrove belt and an internal lagoon between the island and an outer reef barrier. Pohnpei forests include mangroves, gallery forest, and high altitude dwarf forest (Engbring et al. 1990, McClean et al. 1998, Buden 2000, and Kesler 2002, 2006a, 2006b). Mangroves surround the lower costal areas reaching up to 2km wide and consist of ~12.5% of native forest (55 Km²). Mangroves are mainly composed o *Rhizophora apiculata*, *Bruguiera gymnorhiza*, *Sonneratia alba*, *Xylocarpus granatum* and *Nypa frutycans* stands (Buden 2000, BalicK 2009). From costal areas to high ridges, climax forests are dominated by *Mangifera indica*, *Camptosperma brevipetiolata*, *Elaeocarpus carolinensis*, *Myristica insularis*, *Parinari laurina*, and tree ferns (*Cyathea* spp.) (Mueller-Dombois and Fosberg 1998, Buden 2000). Agroforest stands are dominated by *Hibiscus tiliaceus*, *Musa sapientum*, *Cocos nucifera*, *Artocarpus altilis*, and “sakau” *Piper methysticum* (Buden 2000, BalicK 2009).

BIRD SURVEY

We surveyed 247 stations on 19 transects from January to March 2012. Similar to previous studies (Engbring et al. 1990 and Buden 2000) transect locations were distributed to obtain a representation of diverse habitats. We surveyed 19 transects across

Pohnpei, 4 transects were located in mangrove habitats and 15 were distributed in midland and upland areas. Transect routes were dictated somewhat by local topography because of dangerous terrain and impassably dense vegetation. Upland transect observations depended upon favorable weather conditions and accessibility, and mangrove surveys depended on low tide for accessibility. Along each transect, survey stations were separated by >200 m, which was determined using global positioning systems (GPS; Garmin Ltd., Olathe, Kansas).

Survey protocols were similar to those used previously (Kesler and Haig 2007a). In short, at each survey station we conducted eight minutes variable-distance circular plot surveys (Buckland et al. 1993, Buckland et al. 2001). A single observer recorded the first detection (visual or aural) for each individual bird and for all species encountered. We measured radial distance to the first detection with the aid of a rangefinder (Nikon Rifle Hunter, Nikon Inc., Melville, NY). When topography or vegetation made impossible the use of rangefinders, observer-bird distances were estimated. Observers also recorded start time, date, wind (Beaufort scale, Lusk et al. 2000), rain (no rain, medium rain, heavy rain), ambient noise (low 1 to 10 high) and cloud cover. We recorded vegetation metrics including forest overstory density (spherical densitometer) and stocking rate (2 factor wedge prism) at each survey station (Lemmon 1956, Wensel et al. 1980). Surveys began at sunrise and no surveys were initiated after 1100 hours. We created species detection-history for occupancy modeling by surveying each station 4 times using these methods. No station was surveyed more than once on any given day, and we assumed population closure because the 4 visits were all conducted within two weeks for each station.

POHNPEI AVIAN HABITATS

Digital habitat data were obtained from the last vegetation survey conducted in 2005 and consisted of polygons that mapped fourteen primary vegetation classes: agroforest, atoll forest, coconut plantation, cropland, grassland or savanna, mangrove, marsh, palm forest, secondary vegetation, swamp forest, undisturbed vegetation, urban and water (USDAFS 2005). We amalgamated vegetation categories into four larger habitat classes that were presumed relevant to bird populations: undisturbed vegetation, secondary vegetation, mangroves, and agroforest (Table 2.1). Undisturbed vegetation habitats were comprised of merged vegetation polygons of upland forest, palm forest, dwarf forest and atoll forest. Secondary vegetation habitat included merged polygons of disturbed and anthropogenic habitats including those classified as secondary vegetation, cropland, grassland or savanna, barren, and urban land. The mangrove habitat category included the amalgamation of polygons representing areas with water-obligated vegetation including mangroves and several small patches of inland water (often emergent vegetation), swamp forest, and marsh habitats. Agroforest incorporated polygons of vegetation managed for subsistence and commercialization of staple crops (e.g. banana [*Musa* spp.] and breadfruit [*Artocarpus* spp.]), which were classified as agroforest, plantation forest and coconut plantation. Additional vegetation metrics obtained at each survey stations included: 1) canopy height; 2) canopy cover (spherical densitometer); and 3) tree stock rate (dbh >8 in using 2 factor wedge prism)

ANALYSIS

Model variables. We used 9 different variables to model the relationship between avian density and occupancy. Variables were selected from a larger number of vegetation categories and information. The selected variables represented major Pohnpei habitat types, forest configuration and structure and have ecological importance. We used GIS to assess habitat composition within 50 m of observation stations. Habitat polygons were amalgamated into functional habitat types with relevance to birds. Habitat designations were drawn from USDA Forest Service Remote Sensing Applications Center for Federated States of Micronesia Historic Vegetation Digitization Project (2005). Habitat variables included: 1) Mangrove: mangrove and wetland represents c.19 % of Pohnpei undisturbed forests. Mangrove has unique characteristics and may be greatly affected by sea level rise and anthropogenic processes. We identified mangrove and wetland habitats by amalgamating areas classified by USDAFS (2005) as mangroves, marshes, swamp forest and fresh water bodies; 2) Agroforest: agricultural forest includes areas with subsistence or commercial staple crops mixed with undisturbed forest. Agricultural forest patches are used by several Pohnpei bird species, especially those that consume fruit. We identified agricultural forest habitats by amalgamating habitat polygons identified as agroforest, plantation forest, cropland and coconut plantation; 3) Undisturbed vegetation: upland and undisturbed forest habitats are common in Pohnpei higher elevation zones and in isolated patches in lowland areas. Although we did not directly include undisturbed vegetation in modeling efforts, the habitat type was represented with intercept variables and it factored into simulation scenarios. We

identified undisturbed vegetation habitats by amalgamating upland forest, palm forest, dwarf forest and atoll forest; 4) Secondary vegetation: represents anthropogenic habitats (e.g., savannah) and early colonizers and invasive species (e.g. *Hibiscus spp.* and *Merremia peltata*). We identified secondary vegetation habitat on Pohnpei by amalgamating habitat polygons designated as secondary vegetation, grassland or savanna, barren, and urban land; 5) Patch number: the number of discrete habitat patches within a 50 m radius of the survey station. Patch number was included in modeling efforts to represent habitat heterogeneity/fragmentation at sites where surveys were conducted; 6) Edge: the length of habitat edge (boundary between two habitat patches), as identified by the GIS. Some species use habitat edge (e.g. foraging perches) whereas others may be negatively affected by edge habitat; 7) Crown closure: was measured using a densitometer, and values represent the gap fraction in overhead canopy. Some birds may be dependent on older growth forest or forest with higher density canopy; 8) Canopy height: observers used laser range finders to estimate the maximum height of canopy at each survey station. Stations with higher canopy may be characterized by more complex understories; 9) Tree stocking rate: stocking rate was measured with a 2-factor wedge prism. Stocking rate provides an index of the number of trees (DBH>8 in). Birds dependent on larger or older growth trees may be more likely to occupy sites with higher stocking rates.

Density models. To study the relationship between Pohnpei forest and its avian species abundance we followed distance sampling methods and estimated species density (D = number per unit of area) (Buckland et al. 1993). We incorporated bird detections (radial

distance to surveyor) and environmental factors to estimate species density and therefore infer population. To estimate species density functions, we used R statistical software (R Core Team 2012) and package unmarked (Royle et al. 2004, Fiske and Chandler 2011) in program RStudio (2012) and a distance-based approach.

Density modeling followed a two-stage process. The first stage included selecting the factors that best predicted the probability of detection (p) to account for nuisance variables, or factors related to effectiveness of survey efforts but otherwise not of interest. We used a half normal function for our probability of detection. Environmental and anthropogenic factors with the potential to affect bird detections during surveys included: 1) rain (no rain, light rain and heavy rain); 2) wind (modified Beaufort scale); 3) ambient noise (1-10 being 10 the loudest); 4) ordinal day; 5) survey time (minutes after sunrise); and 6) cloud cover. Observer identification was included as a covariate to account for difference among experience and skills (Alldredge et al. 2007, Kendrick et al. 2013). Survey data were fitted to all possible linear combinations of nuisance variable models, which were then ranked by resulting Akaike's Information Criterion (AIC_c ; Burnham and Anderson 2002) values, and the top-ranked models were selected to represent p . To eliminate outlier effects we omitted detections with distances $>90^{\text{th}}$ percentile.

In the second stage of the analysis, top-ranked detection (p) model covariates were combined with biologically relevant site covariates. We used function *distsamp* from package unmarked in R to estimate distance detection functions for each species at each survey station, densities and detection function analysis followed a Poisson distribution (Royle et al. 2004, Fiske and Chandler 2011, Kendrick et al. 2013). For each

survey station we used observer records and the geographic information system (GIS; ArcGIS, ESRI 2011) to assess conditions within 50 m of observers, including: 1) the percent area comprised of mangrove habitat; 2) the percent agroforest habitat; 3) the percent secondary vegetation; 4) the number of habitat patches; and 5) the length of habitat edge (as defined by abutting habitats). From survey records we also drew 6) estimated canopy height at the survey station; 7) canopy closure at the survey station; and 8) estimated tree stocking. We used MuMIn package (Bartoń 2012) to rank models based on AIC_c . Model coefficients from the top-ranked model were fixed to the global abundance site model. We then used *dredge* function from MuMIn package to create all possible linear combinations of biologically relevant site covariates and models were ranked based on AIC_c (Burnham and Anderson 2002). Best approximating model(s) ($\Delta AIC_c < 2$) were identified and we used model averaging to identify density functions if > 1 model was in competition (Burnham and Anderson 2002).

We present the 95% confidence interval (95% CI) for parameter estimates, and we considered those to be informative only when they did not overlap with 0 for density and occupancy models. For each species we tested for lack of fit with \hat{c} and assessed the fit of the top-ranked or model-averaged best approximating model with area under the curve (AUC) (Freeman and Moisen 2008).

Occupancy models. To evaluate bird-habitat relationships using contemporary data, we developed occupancy functions for Pohnpei's native avifauna. Occupancy (Ψ) or probability of occurrence is defined as the probability that a specific area is occupied by the species of interest (MacKenzie et al. 2006). Occupancy modeling is commonly used

when species have a detection probability < 1 . Rare or secretive species may not be detected at the time of surveys, and occupancy modeling provides a solution to false absences by creating a detection history for each survey location and species and estimating the probability of detection (Bayley and Peterson 2001, Kéry 2002, MacKenzie et al. 2002, Royle and Nichols 2003, Dorazio et al. 2006). We developed occupancy models for 13 species for which we obtained enough data ($n > 40$ detections) including Pohnpei lorikeet, Pohnpei flycatcher, Pohnpei fantail, Micronesian honeyeater, Micronesian pigeon, purple-capped fruit-dove, Micronesian starling, gray white-eye, long-billed white-eye, Micronesian kingfisher, Caroline Islands reed-warbler (*Acrocephalus syrinx*), Caroline Islands white-eye (*Zosterops semperi*), and cicadabird (*Coracina tenuirostris*).

Similar to density modeling we first considered detection nuisance factors and developed models for p for each species. Environmental and anthropogenic factors were: 1) rain; 2) wind; 3) ambient noise; 4) ordinal day; 5) survey time; 6) cloud cover; and 7) observer. We used *occu* function from package *unmarked* (Fiske and Chandler 2011) and MuMIn package (Bartoń 2012) to obtain top ranked model coefficients. Models were ranked using AIC_c , and the top-ranked model was considered best approximating. Variables from that model were then incorporated into the development of occupancy functions relating biological factors with the probability of site occupancy.

We evaluated all possible combinations of the same variables used in the density analysis. Undisturbed vegetation was fitted as model intersect. Each species was analyzed individually and models that did not converge were eliminated. For each

species, biologically relevant models were then ranked by AIC_c value, and those within 2 AIC_c units of the top-ranked model ($\Delta AIC_c < 2$) were considered to compete for best approximating. When more than one model was identified in the top-ranked set for a species, we model-averaged parameter estimates to create a model-averaged Ψ function (Table 2.6).

We present the 95% CI for parameter estimates, and we considered those to be informative only when they did not overlap with 0 for occupancy models. For each species we tested for lack of fit with \hat{c} and assessed the fit of the top-ranked or model-averaged best approximating model with area under the curve (AUC) (Freeman and Moisen 2008).

RESULTS

DENSITY

We modeled density for each of 10 Pohnpei bird species for which >40 detections were collected. We detected 271 Pohnpei lorikeet, 166 Pohnpei flycatcher, 97 Pohnpei fantail, 532 Micronesian honeyeater (*Myzomela rubratra*), 63 Micronesian pigeon (*Ducula oceanica*), 523 purple-capped fruit-dove (*Ptilinopus porphyraceus*), 303 Micronesian starling (*Aplonis opaca*), 327 gray white-eye (*Zosterops cinereus*), 158 long-billed white-eye and 180 Micronesian kingfisher across 247 stations in 19 transects. Mean Freeman-Tukey χ^2 , and \hat{c} calculations for all species were ~ 1 , indicating no overdispersion. The AUC measures for all species range between 0.59 (Pohnpei flycatcher) and 0.74 (Micronesian pigeon) (Table 2.3), indicating no lack of fit.

Detection functions included observer identification for 6 of 10 species, including: Micronesian pigeon, Micronesian kingfisher, Purple-capped fruit-dove, Micronesian honeyeater, and Gray white-eye. The null model was the top-ranked detection model for Micronesian starling; the top-ranked detection function model for Pohnpei fantail included wind, ordinal day, cloud cover, and ambient noise; and the top-ranked detection function for Long-billed white-eye included only rain, ordinal day, ambient noise, and cloud cover. Minutes after sunrise was only included in Pohnpei lorikeet detections models (Appendix 2, Table 2.27). Results from the model ranking analysis for density indicated that three biologically relevant models were in competition for best approximating for Micronesian pigeon, five and six models competed for Pohnpei fantail and Micronesian kingfisher respectively. Eight models competed for Micronesian honeyeater, nine models for Long-billed white-eyes, and ten models competed for Pohnpei flycatcher and Pohnpei lorikeet. There were 12 models competing for Gray white-eye and 14 models were averaged for Micronesian starlings (Appendix 2, Table 2.27). Model-averaged parameter estimates for species density analyses are provided in Table 2.5.

Results indicated that, after accounting for the effects of nuisance variables and individual species detection probabilities, that density of 8 of 10 species was related to the proportion of agricultural forest within 50 m of survey stations (Appendix 2, Table 2.28). The 95% CI for 4 species did not overlap with zero, including Micronesian kingfisher, which was predicted to be in higher densities in agricultural forest ($\hat{\beta} = 0.220$, 95% CI 0.065 to 0.375), Micronesian starling and endemics Pohnpei fantail and Long-

billed white-eye ($\hat{\beta} = -0.133$, 95% CI -0.262 to -0.003; $\hat{\beta} = -0.358$, 95% CI -0.089 to -0.626; $\hat{\beta} = -0.446$, 95% CI -0.128 to -0.763 respectively) densities were negatively related to the volume of agricultural forest. The amount of forest edge within 50 m of survey stations was included as a parameter in the model-averaged density models for 9 species, however Micronesian pigeon was the only species density related to the amount of forest edge ($\hat{\beta} = 0.415$, 95% CI 0.164 to 0.666). The number of discrete habitat patches within 50 m of survey stations was included as a parameter in the density models for 9 species, and 95% CI for Micronesian pigeon density indicated a significant negative relationship to number of habitat patches ($\hat{\beta} = -0.566$, 95% CI -0.196 to -0.936). Gray white-eye ($\hat{\beta} = 0.165$, 99.9% CI 0.029 to 0.300) and Micronesian kingfisher ($\hat{\beta} = 0.184$, 95% CI 0.039 to 0.329) densities were associated with the volume of secondary vegetation. In the other hand Micronesian starling ($\hat{\beta} = -0.207$, 99% CI -0.060 to -0.354) density was negatively related to secondary vegetation. The volume of secondary vegetation within 50 m was included in model-averaged results for 6 other species, however the 95% CI overlapped with 0.

Mangrove habitats were associated with model-averaged density functions for 9 species, and 95% CI did not overlap 0 for 6 species. Micronesian honeyeater ($\hat{\beta} = 0.117$, 99% CI 0.037 to 0.197), Pohnpei lorikeet ($\hat{\beta} = 0.333$, 99.9% CI 0.221 to 0.444) and Micronesian kingfisher ($\hat{\beta} = 0.593$, 99.9% CI 0.438 to 0.747) densities were positively related to the volume of mangrove at surveyed areas. Gray white-eye ($\hat{\beta} = -0.413$, 99.9% CI -0.605 to -0.221), Micronesian starling ($\hat{\beta} = -0.261$, 99.9% CI -0.404 to -0.118) and

Pohnpei fantail ($\hat{\beta} = -2.81$, 99.9% CI -1.675 to -0.499) densities were negatively related to the volume of mangrove habitat at surveyed areas. Confidence intervals for the rest of the species overlap with zero.

Canopy height was present in models for all species, however Micronesian pigeon ($\hat{\beta} = 0.415$, 99% CI 0.164 to 0.666) was the only species density related to this forest structure. Confidence intervals associated with the canopy height variable for the rest of the species overlapped with zero. Purple-capped fruit-dove ($\hat{\beta} = 0.119$, 95% CI 0.011 to 0.227), Gray white-eye ($\hat{\beta} = 0.142$, 95% CI 0.007 to 0.277), and Long-billed white-eye ($\hat{\beta} = 1.004$, 99.9% CI 0.624 to 1.384) densities were all related to forest crown closure at surveyed areas. The parameter estimates indicated that densities for these 3 species increased with crown closure, whereas the 95% CI for the rest overlapped with zero. Tree stocking rate was included in models for 6 species, however the 95% CI for all of them overlapped with zero.

OCCUPANCY

We visited, between January and March 2012, a total of 985 survey stations along 19 transects to create species detection histories. We visited 244 stations 4 times and 3 stations were visited only 3 times. We obtained sufficient detections to develop occupancy functions for purple-capped fruit-dove, Micronesian pigeon, Pohnpei lorikeet, Micronesian kingfisher, Pohnpei flycatcher, Pohnpei fantail, cicadabird, Caroline Islands reed-warbler, Micronesian starling, Micronesian honeyeater, Caroline Islands white-eye,

gray white-eye and long-billed white-eye (Figure 5). Mean Freeman-Tukey χ^2 , and \hat{c} calculations for all species were ~ 1 , indicating no overdispersion. The AUC measures for all species range between 0.6 (Caroline Islands white-eye) and 0.98 (Micronesian starling) (Table 2.4), indicating no lack of fit.

Detection functions differed among species (Appendix 2, Table 2.28). Observer identification was included in the top-ranked detection function model for 10 of the 13 species. Ordinal day was included in the top models for 8; noise, rain and wind were included for 4 species in the top models; cloud cover was included for 2 species top models; and minutes after sunrise was included in 2 species top detection model (Appendix 2, Table 2.28).

We used model selection to identify occupancy functions with biologically relevant metrics for each species. There were 10 models competing for occupancy functions for Micronesian pigeon. Eight models competed for best approximating occupancy function for Gray white-eye and Pohnpei lorikeet, 7 models competed for best approximating for Pohnpei flycatcher and Purple-capped fruit-dove, 6 models Cicadabird, Long-billed white-eye and Micronesia kingfisher, 5 models competed for Micronesia starling, Pohnpei lorikeet, and Caroline Islands reed-warbler, 4 models competed for Caroline Islands white-eye, and 1 top-ranked model was identified for Micronesian honeyeater.

Model averaged parameter estimates and their associated 95% confidence intervals provided insight into the magnitude and strength of each variable on each species' probability of occupying survey stations (Table 2.6). Caroline Islands reed-

warbler ($\hat{\beta} = -0.8$, 95% CI -1.35 to -0.25), Gray white-eye ($\hat{\beta} = -1.6$, 95% CI -2.57 to -0.63), Long-billed white-eye ($\hat{\beta} = -1.61$, 95% CI -2.21 to -0.99) and Pohnpei fantail ($\hat{\beta} = -1.74$, 95% CI -2.44 to -1.04) occupancies were related to the volume of mangrove at survey stations. As mangrove habitat increased, occupancy probabilities for these species declined. Long-billed white-eye occupancy declined the most (~95%), followed by Caroline Islands reed-warbler (~20%), Pohnpei fantail (~60%), and gray white-eye (~3%) (Appendix 2, Figure 21-25).

Occupancy function parameters for Gray white-eye ($\hat{\beta} = 1.012$, 95% CI 0.11 to 1.89) were positively associated with tree stocking rate at survey stations. Differently Micronesian kingfisher ($\hat{\beta} = -0.88$, 95% CI -1.46 to -0.29) and Pohnpei lorikeet ($\hat{\beta} = -1.04$, 95% CI -1.72 to -0.36) occupancies were negatively related with tree stocking rate. Canopy height was positively related with occupancy in Micronesian kingfisher ($\hat{\beta} = 0.74$, 95% CI 0.11 to 1.37), Micronesian pigeon ($\hat{\beta} = 0.64$, 95% CI 0.26 to 1.02), Pohnpei fantail ($\hat{\beta} = 1.99$, 95% CI 0.81 to 3.17) and Pohnpei lorikeet ($\hat{\beta} = 1.47$, 95% CI 0.65 to 2.29). Long-billed white-eye ($\hat{\beta} = 0.7$, 95% CI 0.32 to 1.08), and Caroline Islands reed-warbler ($\hat{\beta} = -0.7$, 95% CI -1.25 to -0.149) occupancies were positively and negatively related to the forest crown closure. Micronesian pigeon ($\hat{\beta} = 0.49$, 95% CI 0.03 to 0.83) and Pohnpei fantail ($\hat{\beta} = 1.04$, 95% CI 0.26 to 1.82) occupancy probabilities were positively related to the volume of forest edge at surveyed areas. Micronesian pigeon ($\hat{\beta} = -0.49$, 95% CI -0.11 to -0.87) occupancy probability was negatively related to the number of discrete habitats encountered at surveyed areas.

DISCUSSION

Results from our analysis of density and occupancy elucidated a number of habitat associations, and differences in population densities of Pohnpei island birds. In short, many of the Pohnpei residents were habitat specialists. Seven of 13 species, including 4 of the 6 endemics, exhibited associations with specific habitat structure. Gray white-eye, Micronesian honeyeater, Micronesian starling, Pohnpei lorikeet, and Pohnpei flycatcher were positively associated with undisturbed upland forests, and that Micronesian honeyeater, Micronesian kingfisher, and Pohnpei lorikeet were associated with mangroves. Similarly, Micronesian kingfisher, gray white-eye, and Caroline Islands reed-warbler were associated with landscapes highly impacted by anthropogenic changes.

Some have speculated that oceanic island birds are often habitat generalists because in recent evolutionary history generalist tendencies enhanced the ability to colonize islands after dispersal events from source populations on continents (Diamond 1970). Further, after a viable founder cohort arrives, a lacking competitor community may result in few of the ecological pressures that drive the evolution of specialization (Slikas et al. 2000, Coyne and Price 2000). Unlike other Pacific islands, however, Pohnpei's avifauna is extremely diverse and the island's topography supports a range of complex forest systems. Coupled with Pohnpei's low predation pressure (Kesler and Haig 2007c) and the coexistence of closely related taxa (e.g. *Zosterops* spp.), birds on Pohnpei may face more pressure to specialize than those on other islands (e.g. Kosrae).

Thus, our findings of ecological specialization, in the form of strong species habitat associations are somewhat novel but not altogether unexpected.

The cohort of three white-eyes (*Zosteropse* spp.) illustrates the likely specialization of Pohnpei Island birds. Whereas the gray white-eye population is strongly associated with anthropogenic habitats, and the long-billed white-eye was positively associated with upland climax forests. Caroline Islands white-eye occupancy associations were not significant, perhaps reflecting the generalist tendencies in the species that is also represented on other islands and thus might also be the newest arrival on Pohnpei. Similarly, density and occupancy functions indicated specialization among the flycatching Pohnpei fantail and the Pohnpei flycatcher, in that the fantail was strongly associated with canopy height and forest edge and the flycatcher was associated with undisturbed forest. And as has been demonstrated previously (Diamond 1970, 1974; Flemming et al. 1987; McConkey et al. 2005), the frugivorous purple-capped fruit dove was found throughout Pohnpei, whereas Micronesian pigeon occupancy and densities were strongly associated with canopy height, forest edge and negatively influenced by forest fragmentation. The strong and often mutually exclusive habitat associations among members of each guild indicate ecological specializations on Pohnpei that are not typical of remote oceanic island in the Central Pacific.

Anthropogenic changes to island forests can exert a range of potential ecological pressures that may affect birds. For example, changes in forest composition and configuration have been shown to affect arthropod abundance and richness (Aguirre and Dirzo 2008), which in turn may affect insectivorous birds. And indeed, our results

indicated that the long-billed white-eye, Pohnpei fantail and Micronesian starling were less likely to occupy areas with fragmented forests (greater edge) because of anthropogenic development. Similarly, Micronesian pigeon, Micronesian honeyeater, purple-capped fruit-dove, Pohnpei lorikeet, Pohnpei fantail, Micronesian kingfisher, and long-billed white-eye were more likely to occupy, and found in higher densities in, undisturbed mangroves or upland forests. Further, we feel our result illustrated patterns reflecting potential to influence overall bird populations, because although density has the potential to be a misleading indicator of habitat quality (Van Horne 1983), our results are consistent with previous research linking Pohnpei Island avian populations to island's native and anthropogenic habitat types (Buden 2000, Oleiro and Kesler *in prep*).

We found that several of Pohnpei's species are rare, and even though they occur throughout the region the birds exist in low population densities that may be cause for conservation concern. Micronesia pigeons are extensively hunted on the island and have the lowest density. Cicadabirds and Caroline Islands white-eye were detected in undisturbed areas at very low numbers. White-browed crane (*Porzana cinerea*), Caroline Islands ground-dove (*Gallicolumba kubaryi*), and short-eared owl (*Asio flemus*) detections were <10. Contrarily to Micronesian pigeons, these species appear to cope with habitat disturbance (BirdLife International 2014) – these species occur on lowlands and areas with waterways, which are the most altered areas. Additionally, ground-nesting species may be affected by introduced predators (e.g., *Felis catus* and *Rattus norvegicus*).

The diverse avifauna of Pohnpei likely evolved under stable climates buffered by tropical oceanic conditions of the central Pacific. Further, the island is somewhat unique for the region in its lack of susceptibility to disturbances such as typhoons and tsunamis (Spennemann 2009). These conditions resulted in large tracts of old-growth native forests, and a correspondingly stable and diverse avifauna. In recent years, however, technology and economic development have enabled the island's inhabitation to bring substantial change to the landscape, which is most strongly exhibited in the lowland forests, and least apparent in the island's uplands and mangrove forests. Historic and contemporary changes to Pohnpei's habitats have the potential to be cause for conservation concern. In fact, the Pohnpei Mountain Starling (*Aplonis pelzelni*) is a Pohnpei endemic species that may have already gone extinct because of habitat change (Buden 1996, 2000, Bird Life International 2014).

Species associated to mangrove habitat such as Micronesian honeyeater, Micronesian kingfisher and Pohnpei lorikeet, have shown changes in populations during recent decades. Micronesian honeyeater detections in mangroves declined since 1994, Micronesian kingfisher and Pohnpei lorikeet detections increased (Oleiro and Kesler in prep). However, mangroves are now threatened in Pohnpei and elsewhere (Luther and Greenberg 2009). Mangrove-associated species may be affected directly by development and land reclamation, as well as by indirect climate-related changes associated with sea level rise and increased storm frequencies. Sea level rise projections indicate that the Micronesia region is vulnerable to great changes from thermal expansion, higher tides, and increased wave events (Hoeke et al. 2013). All of these processes may greatly

impact, if not eliminate the island's mangrove systems and the associated avifauna populations.

Species associated with native Pohnpei forest are also of conservation concern. Analyses of historic landscape change illustrate substantial losses in native Pohnpei forests (Merlin and Raynor 2005), which should also be cause for conservation concern for species such as the endemic Pohnpei lorikeet, Pohnpei fantail, and long-billed white-eye, which were positively associated with old-growth forest characteristics in uplands. In fact, density and occupancy results indicated strong associations between old growth forest and Micronesian pigeon, Micronesian honeyeater, and Micronesian kingfisher species. Continued changes to the Pohnpei's forested landscapes may put all of these species at risk.

We conducted an analysis of bird density and occupancy on the island of Pohnpei, Federated States of Micronesia, and used those data to identify bird-habitat associations and species and regions of potential conservation concern. Our results indicated habitat associations in some species, although the findings based on surveys cannot identify the behavioral or ecological mechanism underpinning those relationships. Similarly, we can speculate about the way in which bird populations will be affected by habitat changes, the benchmark for future species life history traits of Pohnpei bird studies, and finally we provide sound information needed in order to develop the most robust conservation strategies.

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FIGURES

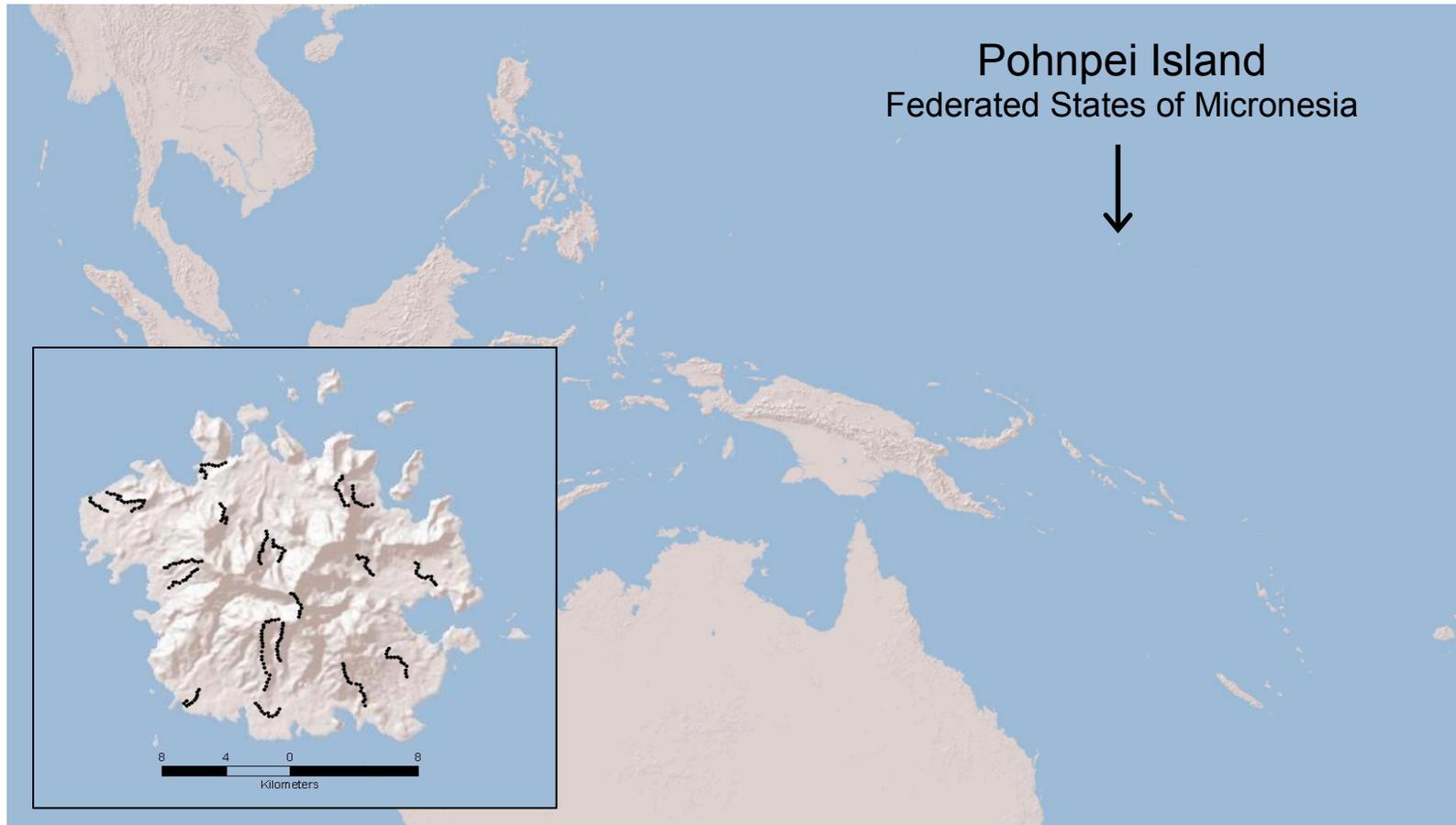


Figure 2.1. Global locator for Pohnpei island, Federated States of Micronesia. Insert; island map with survey stations visited in 2012 (n=247).

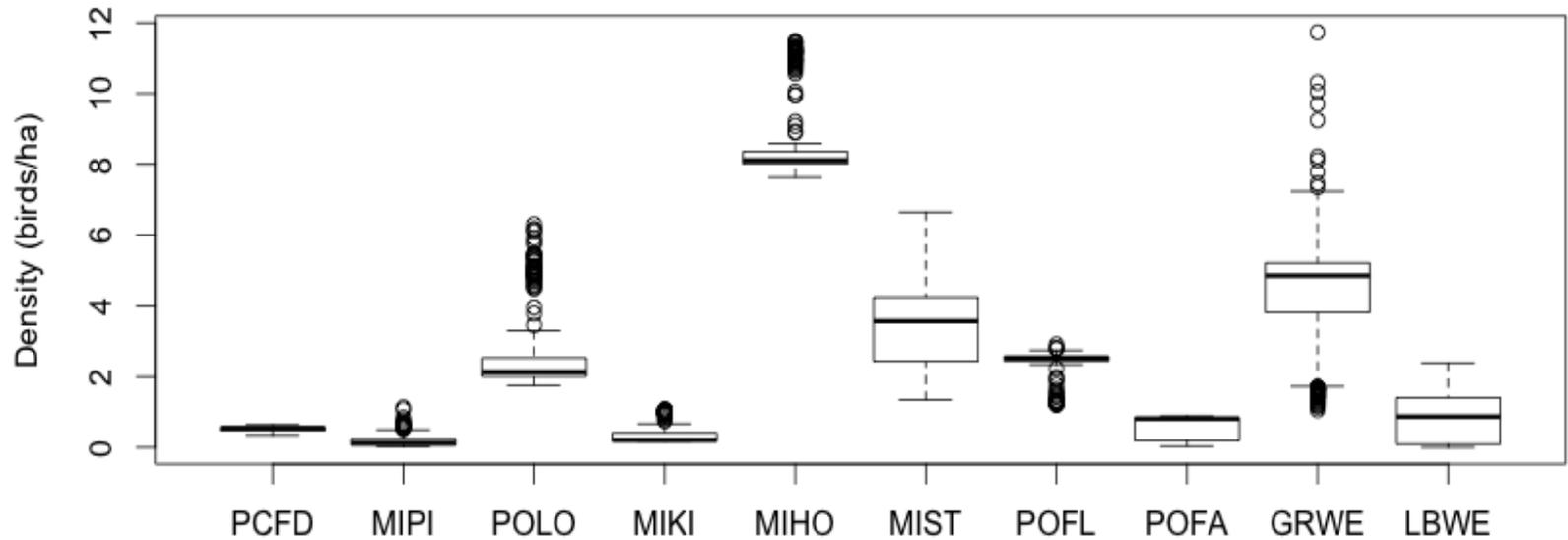


Figure 2.2. Model-averaged avian species density estimates for 247 survey stations distributed throughout the island of Pohnpei, Federated States of Micronesia. Density functions were derived from variable distance point transect observations at sites in 2012. Density functions account for the confounding influences of nuisance variables, detectability of individual species, and site habitat characteristics. Species predicted to ubiquitous and similarly dense throughout the island are represented by narrow distributions. Rare species are represented by lower means and distributions, and species associated with specific or widely distributed habitats are represented with widely spread distributions.

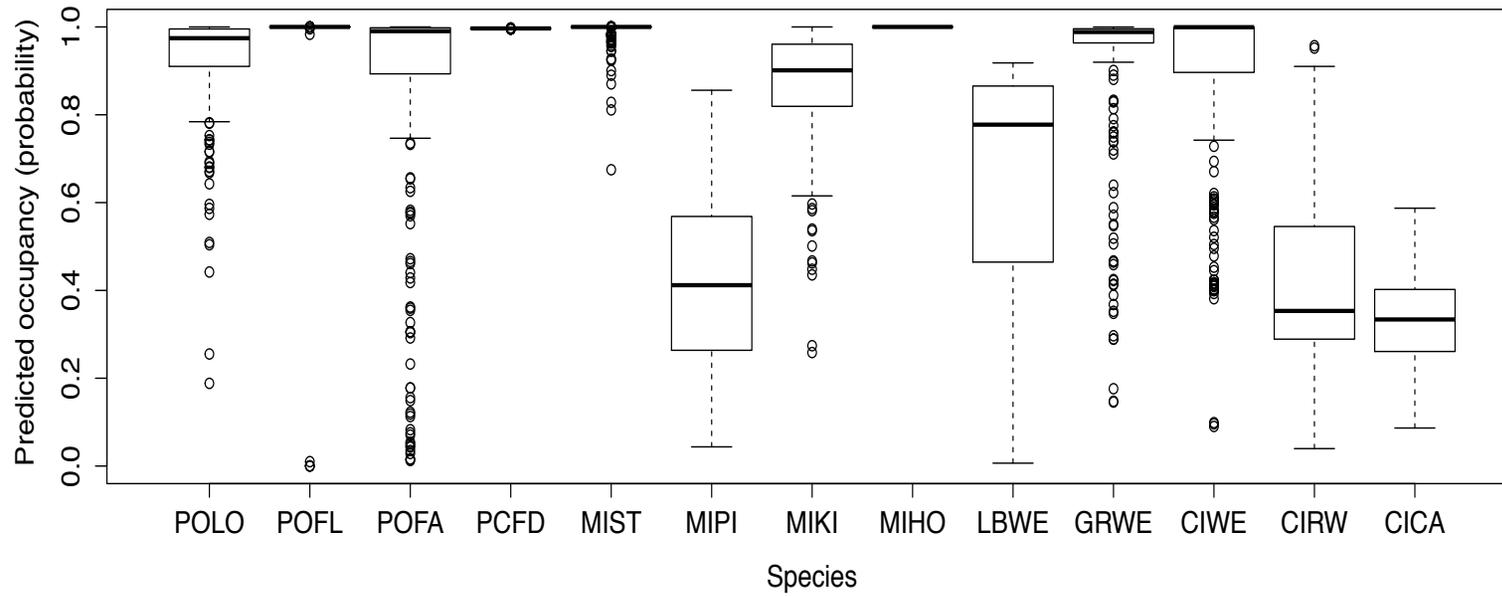


Figure 2.3. Model-averaged avian species occupancy Ψ estimates predicted for 247 survey stations distributed throughout the island of Pohnpei, Federated States of Micronesia. Occupancy functions were derived from repeat survey visits to the sites in 2012. Occupancy estimates near 1 indicate a high probability that a species occupied a particular station, after accounting for the confounding influences of nuisance variables, and even if that species was not detected there. Species predicted to ubiquitous and common throughout the island are represented by distributions clustered in high values. Those rare are represented by lower means and distributions, and species associated with specific or widely distributed habitats are represented with broad distribution.

TABLES

Table 2.1. Biologically relevant variables used to model the relationship between avian occupancy and density on the island of Pohnpei, Federated States of Micronesia. Habitat designations were drawn from USDA Forest Service Remote Sensing Applications Center for Federated States of Micronesia Historic Vegetation Digitization Project (2005), and the GIS was used to assess habitat composition within 50 m of observation stations. Habitat polygons were amalgamated into functional habitat types with relevance to birds. Measures for the remaining variables were collected by observers during site visits.

Variable	Description	Mean	SD	Max	Min
Mangrove	Mangrove and areas with water-obligated vegetation	1334.2	2865.3	7854.0	0.0
AgroFo	Areas with agricultural forest, mainly composed of subsistence and commercial crops	947.6	2311.1	7854.0	0.0
Intercept	Areas of undisturbed vegetation composed of native habitat	4867.1	3548.3	7854.0	0.0
SecVeg	Areas of secondary vegetation, mainly composed of introduced vegetation and altered habitats	642.5	1713.8	7854.0	0.0
PN	Number of discrete habitats within 50 m of survey stations	1.3	0.6	4.0	1.0
Edge	Length of forest edge created between abutting habitat patches	63.8	61.0	235.3	0.0
CanCvr	Percentage of forest crown closure at survey station	68.2	27.1	98.0	0.0
CanHt	Canopy height at survey stations (m).	16.5	7.1	42.3	1.0
StockRt	Number of tree per hectare (>8 in DBH)	97.9	61.9	250.0	0.0

Table 2.2. Mean avian densities (individuals per hectare) for ten species at six elevation zones, and mean avian density at each for each elevation zone for Pohnpei 2012. Density estimates were modeled from data collected in 247 survey stations. Territorial species (e.g., *D. oceanica*) showed smaller density values. Species with significant (95% CI) positive or negative mangrove associations showed larger or smaller density values in comparison to other elevation zones.

Species	Mangrove	SE	0-100	SE	100-200	SE	200-400	SE	400-600	SE	600-800	SE
<i>Ptilinopus porphyraceus</i>	0.446	0.007	0.512	0.010	0.558	0.006	0.562	0.006	0.569	0.005	0.530	0.009
<i>Ducula oceanica</i>	0.118	0.015	0.132	0.024	0.186	0.020	0.218	0.024	0.330	0.055	0.192	0.040
<i>Trichoglossus rubiginosus (e)</i>	4.919	0.125	2.320	0.046	2.107	0.025	2.108	0.024	2.021	0.023	2.041	0.039
<i>Todiramphus reichenbachii (e)</i>	0.905	0.029	0.267	0.014	0.270	0.012	0.227	0.009	0.209	0.006	0.213	0.012
<i>Myiagra pluto (e)</i>	1.407	0.044	2.557	0.012	2.564	0.014	2.532	0.011	2.515	0.011	2.516	0.012
<i>Rhipidura kubaryi (e)</i>	0.063	0.007	0.688	0.034	0.656	0.035	0.803	0.018	0.844	0.004	0.804	0.035
<i>Aplonis opaca</i>	2.211	0.073	3.739	0.161	3.540	0.121	3.895	0.142	3.937	0.128	3.695	0.120
<i>Myzomela rubratra</i>	10.777	0.112	8.076	0.025	8.142	0.024	8.095	0.023	8.049	0.030	8.077	0.039
<i>Zosterops cinereus</i>	1.722	0.095	4.909	0.198	5.173	0.152	5.330	0.188	5.258	0.108	4.856	0.114
<i>Rukia longirostra (e)</i>	0.570	0.061	0.449	0.060	0.722	0.059	0.902	0.062	1.232	0.075	0.734	0.076
Average density	2.314		2.365		2.392		2.467		2.496		2.366	

(e) Pohnpei endemic; * Mangrove negative associated at the 95% level; ** Mangrove positive associated at the 95% level

Table 2.3. Lack of fit test for global density models (Freeman-Tukey χ^2), and area under the curve (AUC) for final model (averaged) used to estimate species density for the data collected in Pohnpei 2012. AUC threshold was given at the 0.5 value, and AUC values larger than 0.5 indicate that observed-predicted models for species occupancy performed better than global.

Species	Freeman-Tukey χ^2	<i>P</i>	\hat{c}	ROC - AUC
<i>P. porphyraceus</i>	388.0	0.956	1.0009	0.6918
<i>D. oceanica</i>	84.7	0.325	0.9995	0.7360
<i>T. rubiginosus</i>	302.0	0.000	1.0012	0.6924
<i>T. reichenbachii</i>	210.0	0.112	0.9999	0.7202
<i>M. pluto</i>	208.8	0.285	0.9999	0.5970
<i>R. kubaryi</i>	130.9	0.099	0.9992	0.6843
<i>A. opaca</i>	317.6	0.157	0.9985	0.6967
<i>M. rubratra</i>	430.9	0.043	0.9998	0.6843
<i>Z. cinereus</i>	378.0	0.000	1.0012	0.6479
<i>R. longirostra</i>	211.1	0.000	1.0005	0.6771

Table 2.4. Lack of fit test for global occupancy models (Freeman-Tukey χ^2), and area under the curve (AUC) for final model (averaged) used to estimate species occupancy for the data collected in Pohnpei 2012. AUC threshold was given at the 0.5 value, and AUC values larger than 0.5 indicate that observed-predicted models for species occupancy performed better than global.

Species	Freeman-Tukey χ^2	P	\hat{c}	ROC - AUC
<i>P. porphyraceus</i>	60.8	0.522	0.9997	0.8496
<i>D. oceanica</i>	174.0	0.552	0.9998	0.7190
<i>T. rubiginosus</i>	194.0	0.653	1.0017	0.8567
<i>T. reichenbachii</i>	241.0	0.672	0.9991	0.7524
<i>C. tenuirostris</i>	49.3	0.352	1.0003	0.6290
<i>M. pluto</i>	274.0	0.334	0.9984	0.7284
<i>R. kubaryi</i>	236.0	0.489	0.9982	0.8252
<i>A. syrinx</i>	80.3	0.433	1.0005	0.7218
<i>A. opaca</i>	184.0	0.424	0.9989	0.9878
<i>M. rubratra</i>	42.6	0.486	1.0002	NA
<i>Z. semperi</i>	124.5	0.405	1.0001	0.6005
<i>Z. cinereus</i>	232.0	0.639	0.9981	0.8288
<i>R. longirostra</i>	223.0	0.466	0.9982	0.8028

NA: AUC value for *M. rubratra* was not estimated given the species was detected in all survey stations.

Table 2.5. Model averaged density parameter estimates for Pohnpei avifauna, as derived from distance analysis of variable distance point transect surveys conducted in 2012. Positive values represent positive associations between covariate and densities, and values indicate lower densities in association with covariates.

Species	Intercept	AgroFo	Stocking Rate	Canopy Ht.	Canopy Cvr.	Sec. Veg	Mangrove	Edge	PN
<i>P. porphyraceus</i>	-0.65 (0.08)***		-0.07 (0.05)	-0.04 (0.05)	0.12 (0.06)*	-0.02 (0.04)	-0.06 (0.05)	0.03 (0.04)	0.05 (0.04)
<i>D. oceanica</i>	-2.12 (0.24)***	-0.10 (0.8)		0.57 (0.17)***	0.42 (0.26)		-0.04 (0.15)	0.49 (0.15)**	-0.60 (0.19)**
<i>T. rubiginosus</i>	0.91 (0.09)***	-0.07 (0.08)		0.12 (0.07)	-0.13 (0.07)	0.05 (0.07)	0.33 (0.06)***		0.08 (0.06)
<i>T. reichenbachii</i>	-1.20 (0.13)***	0.22 (0.079)**	0.10 (0.08)	0.04 (0.08)	0.09 (0.08)	0.18 (0.07)*	0.60 (0.08)***	-0.05 (0.08)	-0.07 (0.09)
<i>M. pluto</i>	0.81 (0.13)***	0.06 (0.07)	0.05 (0.08)	0.05 (0.08)	-0.04 (0.08)	-0.08 (0.08)	-0.25 (0.13)*	-0.09(0.09)	0.10 (0.08)
<i>R. kubaryi</i>	-0.88 (0.24)***	-0.44 (0.16)**	0.09 (0.10)	0.06 (0.10)	0.05 (0.11)		-1.09 (0.30)***	-0.08 (0.10)	
<i>A. opaca</i>	1.19 (0.10)***	-0.13 (0.07)*	-0.11 (0.07)	0.09 (0.07)	-0.08 (0.07)	-0.21 (0.07)**	-0.26 (0.07)***	-0.04 (0.06)	-0.08 (0.06)
<i>M. rubratra</i>	2.14 (0.07)***			-0.06 (0.05)	0.06 (0.05)	0.02 (0.04)	0.12 (0.04)**	-0.06 (0.05)	0.06 (0.05)
<i>Z. cinereus</i>	1.40(0.10)***	0.08 (0.05)		-0.06 (0.06)	0.14 (0.07)**	0.16 (0.07)***	-0.41 (0.10)***	-0.07 (0.06)	-0.09 (0.06)
<i>R. longirostra</i>	-0.72(0.13)***	-0.36 (0.14)**	0.07 (0.08)	0.13 (0.09)	1.00 (0.19)***	0.04 (0.08)		0.10 (0.08)	-0.10 (0.10)

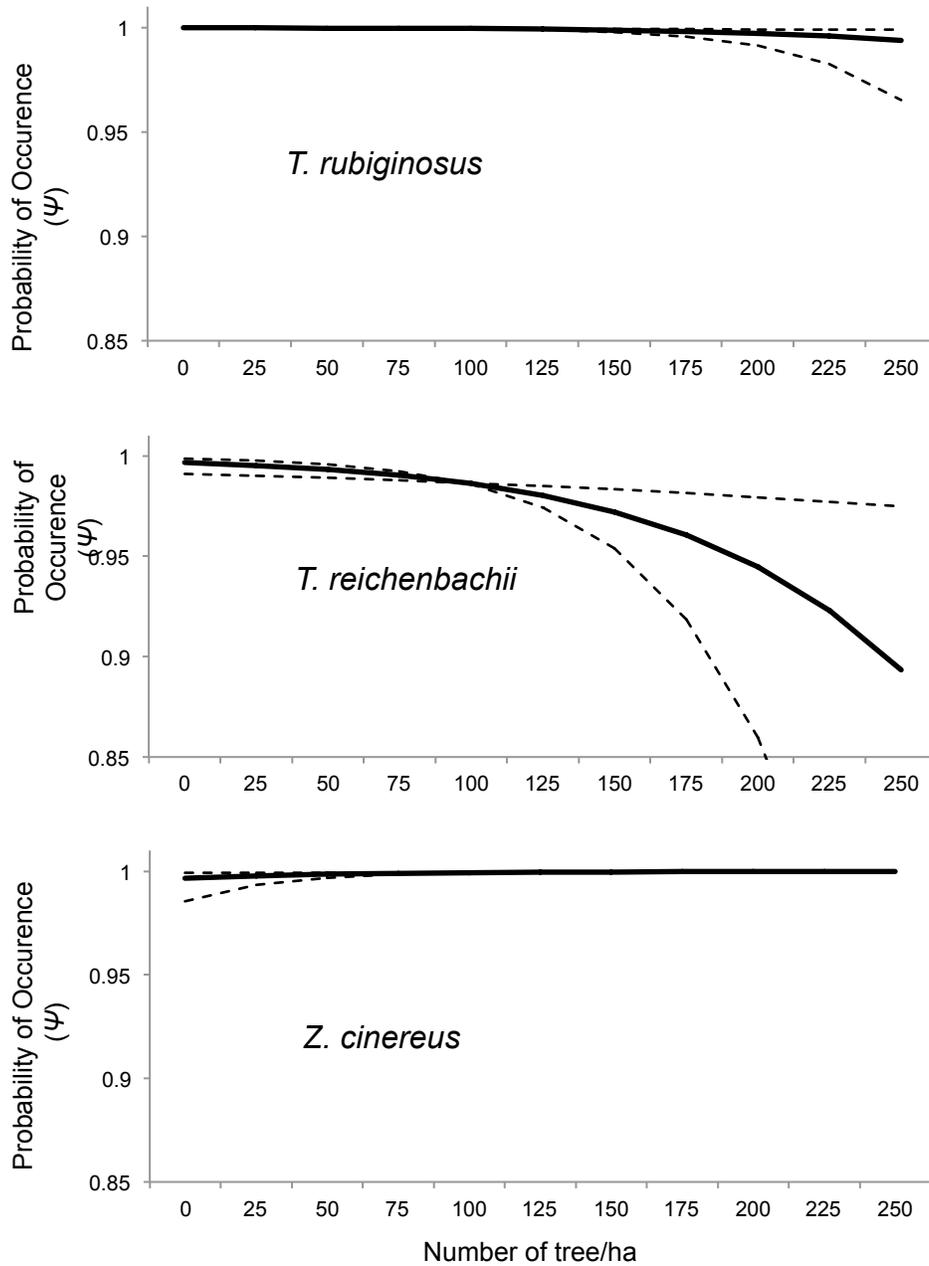
(***) Significant at the 0.001 confidence level; (**) significant at the 0.01 confidence level; (*) significant at the 0.05 confidence level.

Table 2.6. Model averaged occupancy parameter estimates for Pohnpei avifauna, as derived from repeated surveys conducted throughout the island in 2012. Positive values represent positive associations between covariate and species occupancy, and negative values indicate lower occupancy in association with covariates.

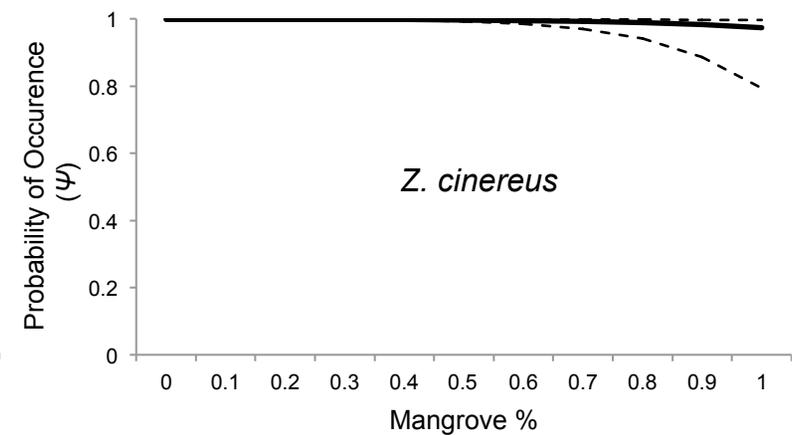
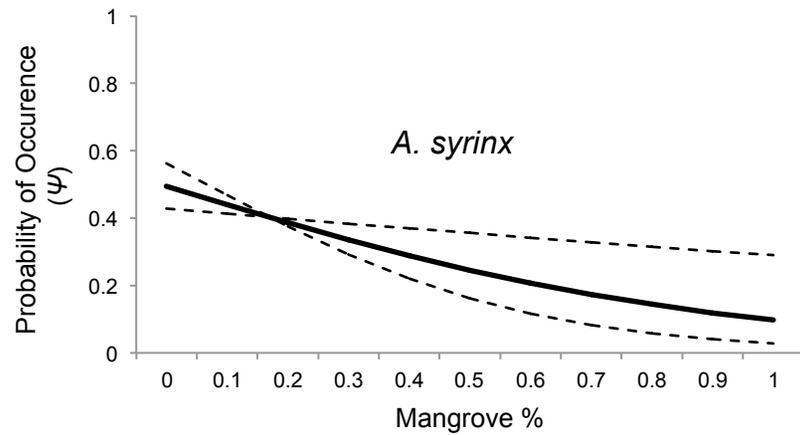
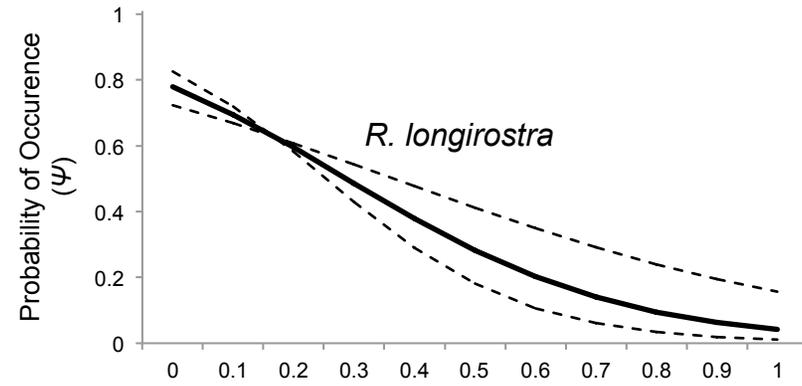
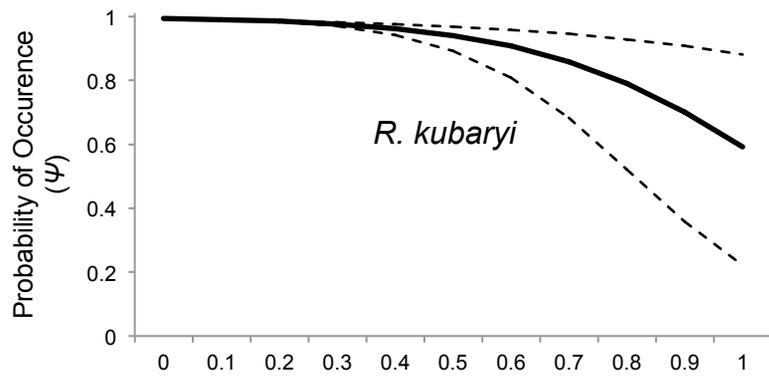
Species	Intercept	AgroFo	Stocking Rate	Canopy Ht.	Canopy Cvr.	Sec. Veg	Mangrove	Edge	PN
<i>P. porphyraceus</i>	7.23 (4.15)			1.38 (2.53)				1.82 (3.62)	1.81 (8.06)
<i>D. oceanica</i>	-0.49 (0.18)**	-0.19 (0.17)	0.24 (0.21)	0.65 (0.2)**	0.44 (0.22)	-0.35 (0.22)	0.21 (0.17)	0.49 (0.18)**	-0.49 (0.2)*
<i>T. rubiginosus</i>	7.64 (68.49)	-0.12 (0.24)	-1.04 (0.36)**	1.47 (0.43)***	0.20 (0.39)	1.42 (1.65)	9.68 (147.08)		0.24 (0.42)
<i>T. reichenbachii</i>	4.29 (6.29)		-0.88 (0.31)**	0.74 (0.33)*		0.82 (0.98)	4.93 (13.54)	-0.25 (0.29)	0.66 (0.61)
<i>C. tenuirostris</i>	-0.8 (0.61)	-0.2 (0.29)	0.17 (0.35)	-0.59 (0.35)	0.77 (0.44)	-0.29 (0.36)			
<i>M. pluto</i>	5.08 (22.23)	0.63 (0.81)		1.9 (1.32)	-0.21 (0.37)		-0.3.97 (0.34)	0.23 (0.50)	2.78 (59.5)
<i>R. kubaryi</i>	4.33 (0.89)***	1.21 (1.07)	-0.45 (0.37)	1.99 (0.62)**	0.20 (0.34)	0.23 (0.32)	-1.74 (0.37)	1.04 (0.41)*	1.01 (0.71)
<i>A. syrinx</i>	-0.4 (0.41)	0.54 (0.37)	-0.210(0.32)	0.14 (0.29)	-0.7 (0.29)*		-0.8 (0.3)**	0.13 (0.27)	
<i>A. opaca</i>	25.1 (88.5)		0.63 (1.87)	-3.46 (4.14)	-9.66 (7.35)		-7.38 (38.86)		
<i>M. rubratra</i>	11.6 (20.7)						0.00 (20.7)		
<i>Z. semperi</i>	180.1 (1703)	-75.96 (713)				-47.91 (81.3)	-96.16 (844)	1.01 (0.96)	-7.83 (69.03)
<i>Z. cinereus</i>	7.28 (9.69)	0.49 (0.70)	1.0 (0.47)*		0.5 (0.41)	12.2 (29.1)	-1.6 (0.51)**	0.31 (0.38)	0.27 (0.49)
<i>R. longirostra</i>	0.51 (0.25)*	-0.11 (0.19)		-0.25 (0.23)	0.7 (0.2)***		-1.6 (0.32)***	0.41 (0.24)	-0.25 (0.21)

(***) significant at the 0.001 confidence level; (**) significant at the 0.01 confidence level; (*) significant at the 0.05 confidence level

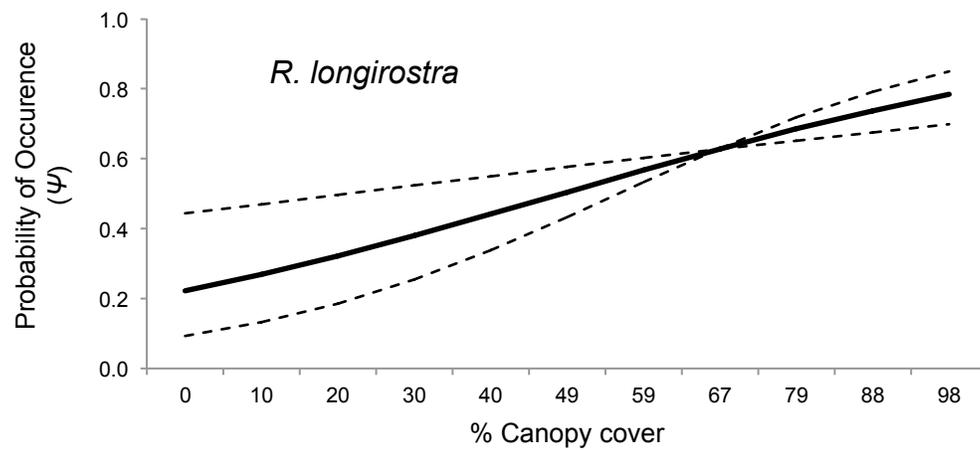
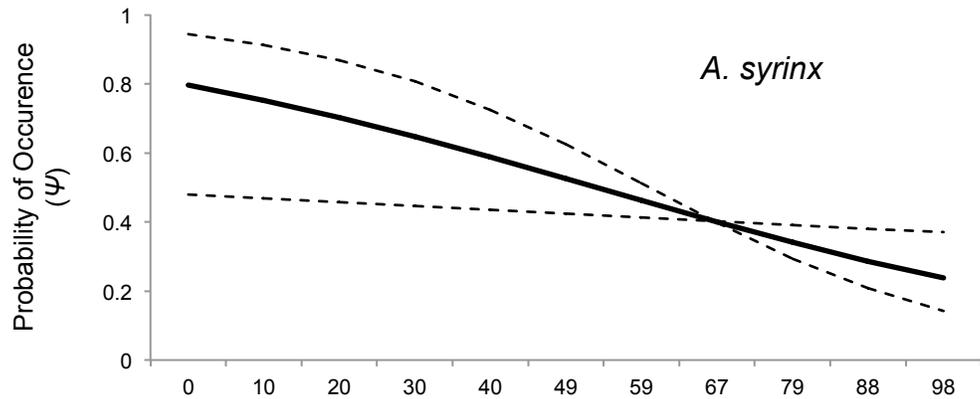
APPENDICES



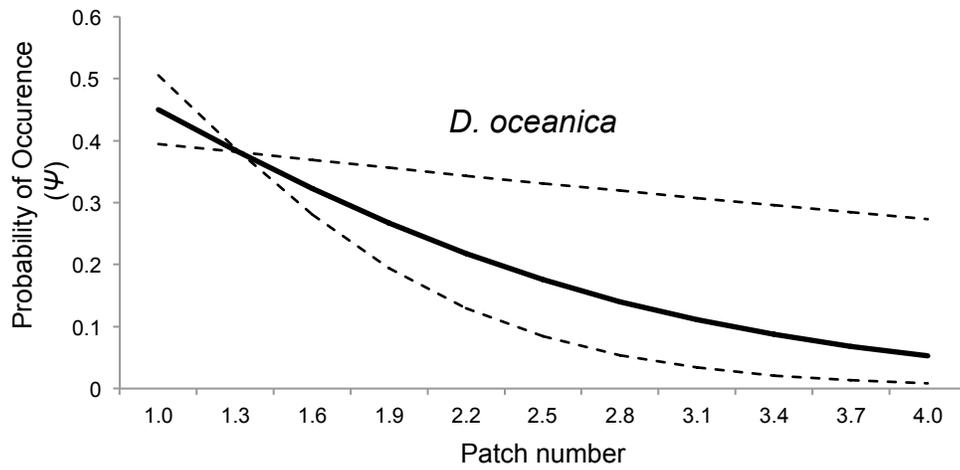
Appendix 2.1. Tree stocking rate effect on three species' occupancy. Stocking rate was measured with a 2-factor wedge prism providing an index of the number of trees / ha (DBH>8 in). Tree stocking rate values ranged from 0 to 250 trees per ha.



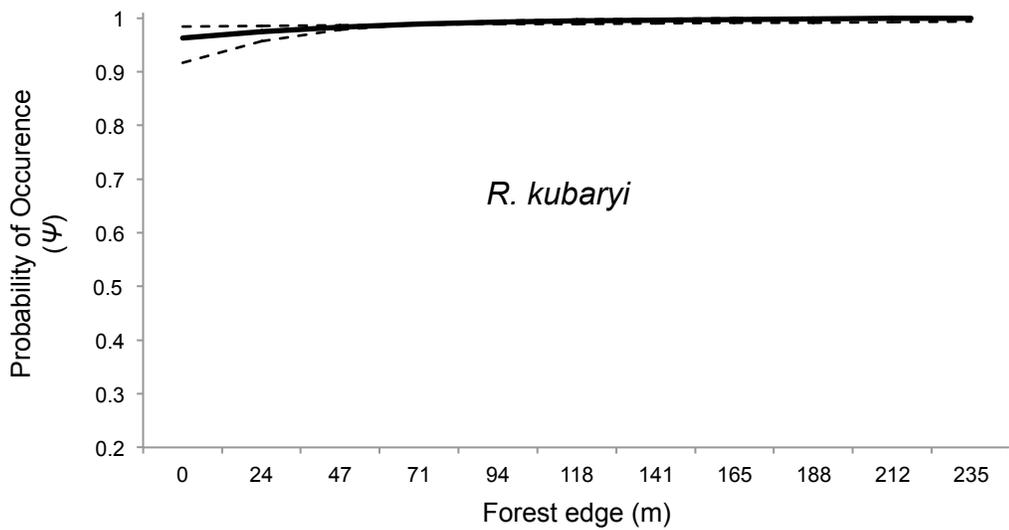
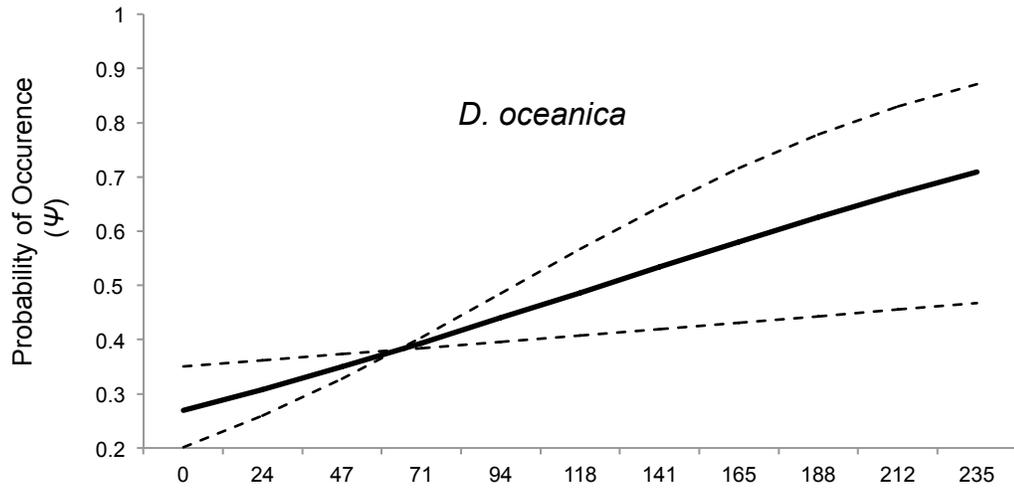
Appendix 2.2. Effect of mangrove % area within 50 m of the observer (0.785 ha) on species occupancy (Ψ) while other covariates were fixed at their means. Dashed lines indicate upper and lower CI at the 95% level.



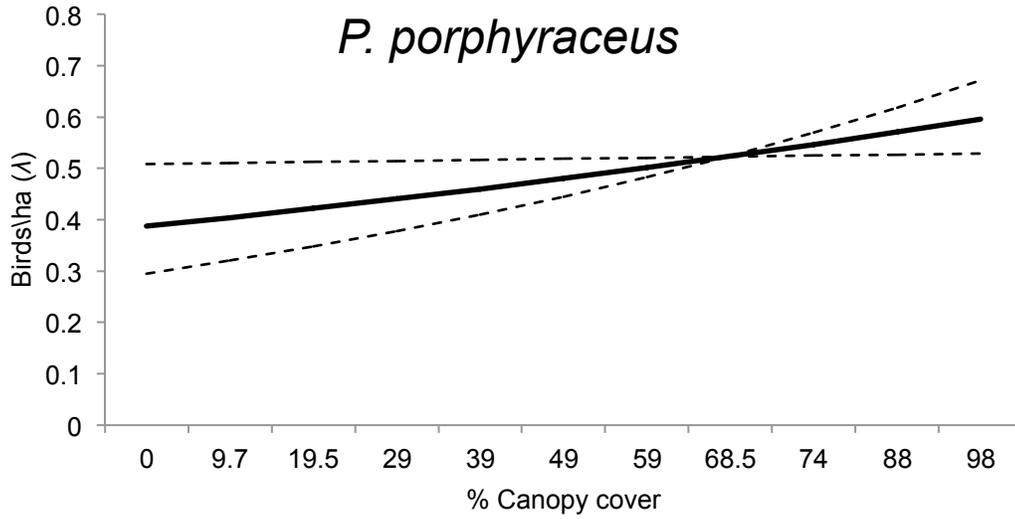
Appendix 2.3. Canopy cover effect on species occupancy (Ψ) while other covariates were fixed at their means. Dashed lines indicate upper and lower CI at the 95% level.



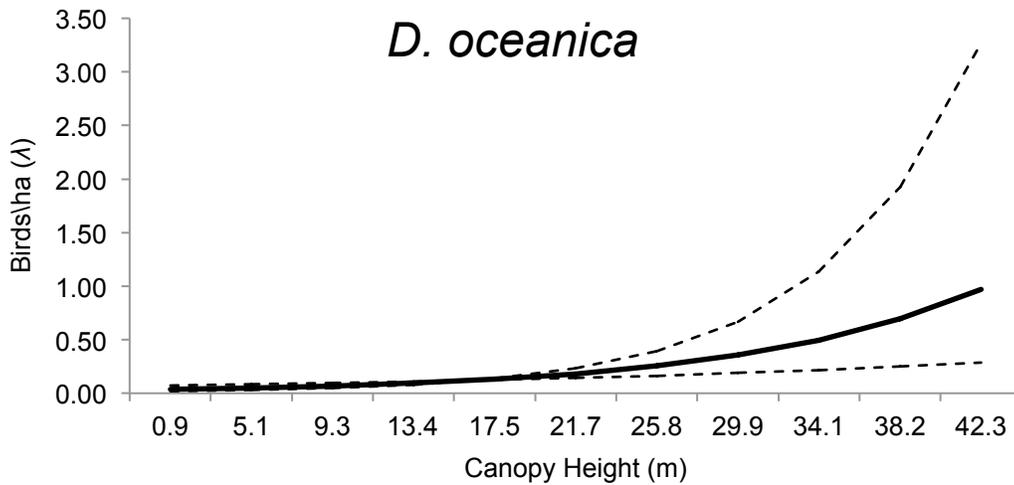
Appendix 2.4. Patch number of discrete habitats effect on *D. oceanica* occupancy (Ψ) while other covariates were fixed at their means. Dashed lines indicate upper and lower CI at the 95% level.



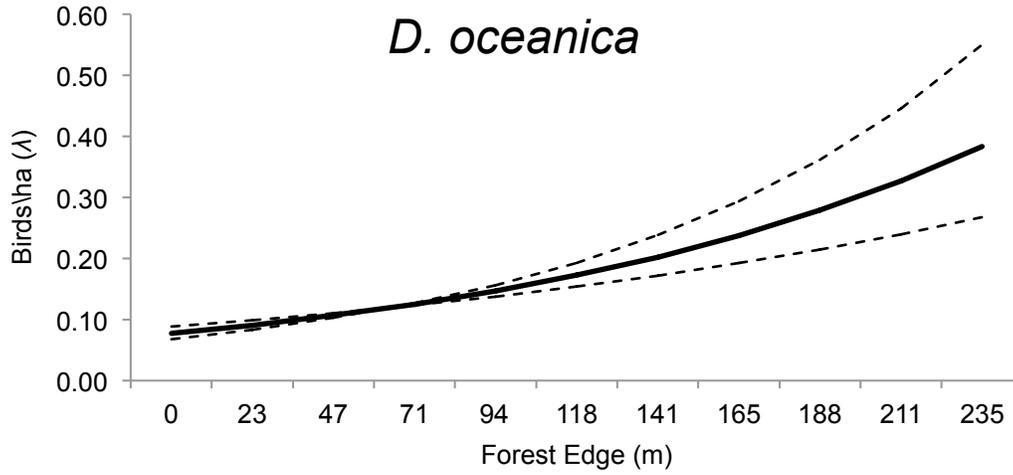
Appendix 2.5. Habitat edge effect on species occupancy (Ψ) created from abutting habitats as identified by the GIS while other covariates were fixed at their means. Dashed lines indicate upper and lower CI at the 95% level.



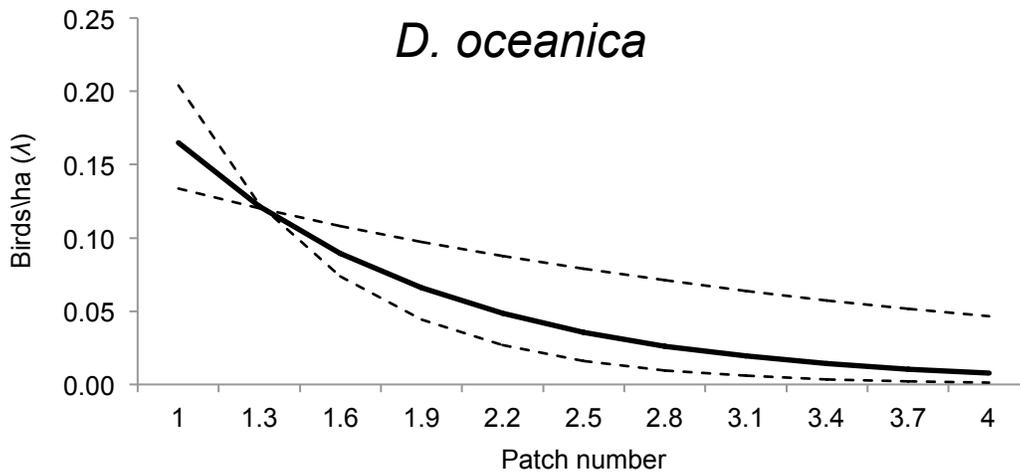
Appendix 2.7. Canopy cover effect on purple-capped fruit-dove density (λ). Dashed lines indicate upper and lower CI at the 95% level.



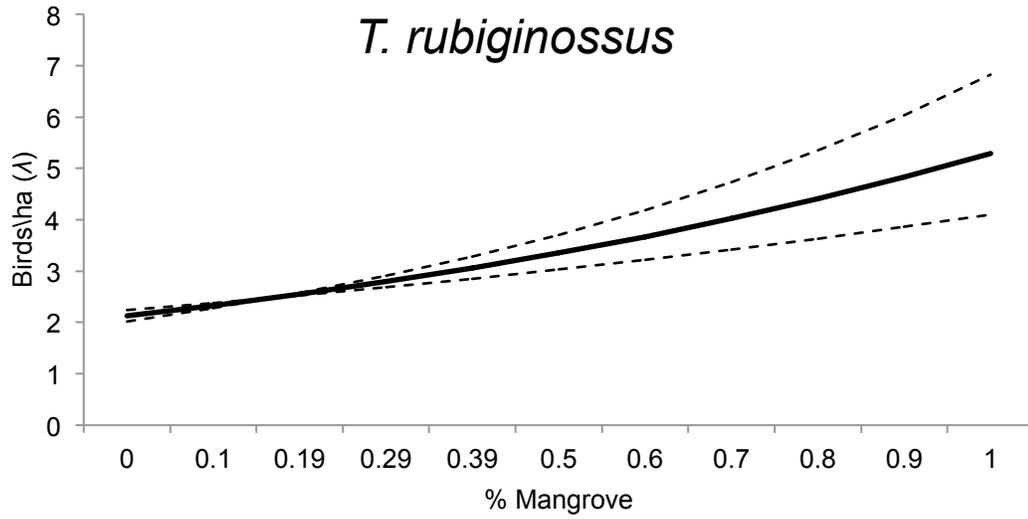
Appendix 2.8. Canopy height effect on Micronesian pigeon density (λ). Dashed lines indicate upper and lower CI at the 95% level.



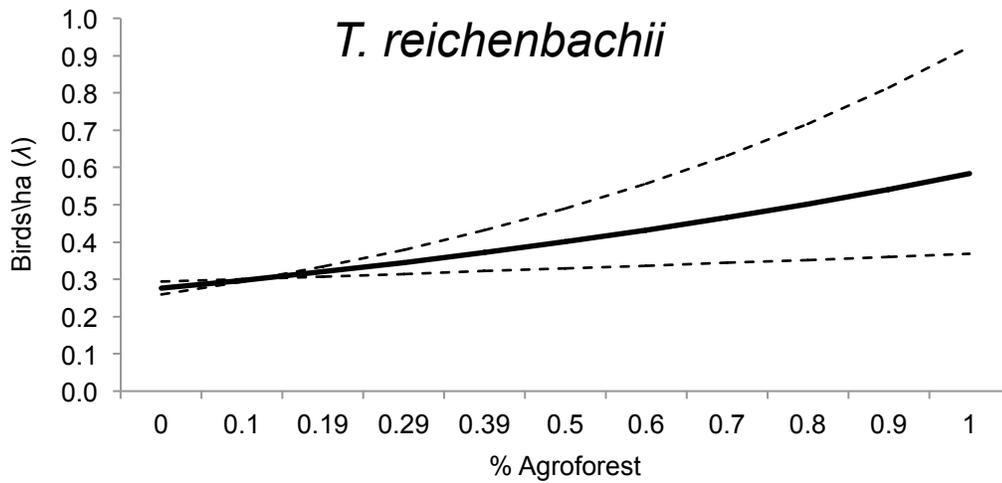
Appendix 2.9. Forest edge effect on Micronesian pigeon density (λ). Dashed lines indicate upper and lower CI at the 95% level.



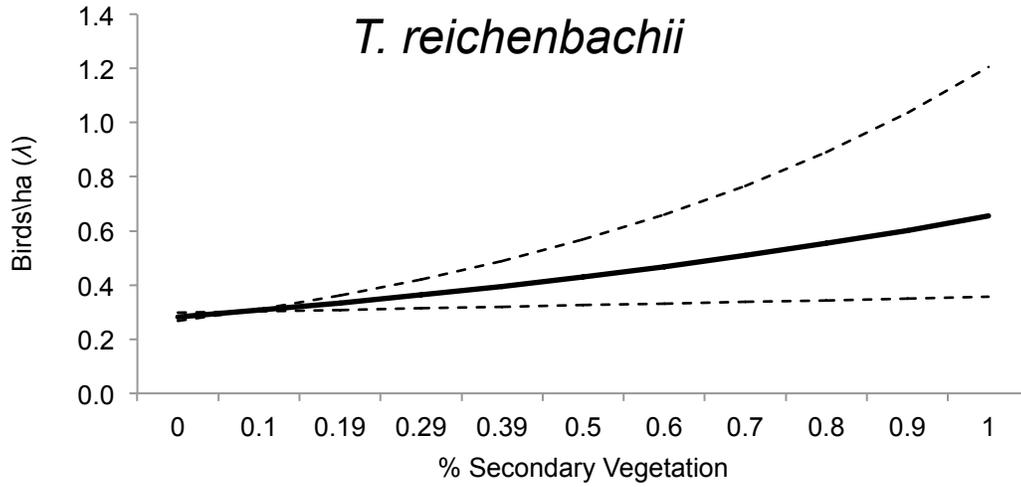
Appendix 2.10. Effect of number of discrete habitat patches on Micronesian pigeon density (λ). Dashed lines indicate upper and lower CI at the 95% level.



Appendix 2.11. Mangrove affect on Pohnpei lorikeet density (λ). Dashed lines indicate upper and lower CI at the 95% level.

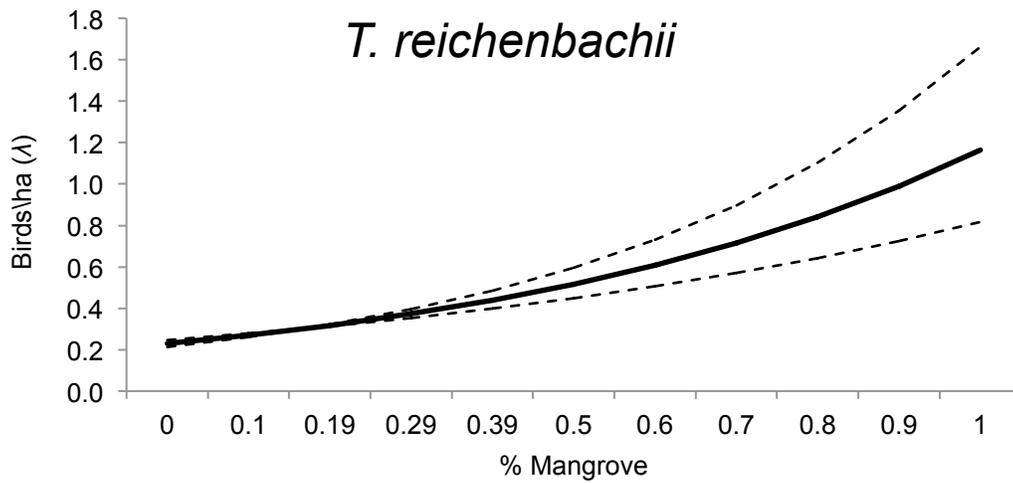


Appendix 2.12. Effect of Agroforest on Micronesian kingfisher density (λ). Dashed lines indicate upper and lower CI at the 95% level.



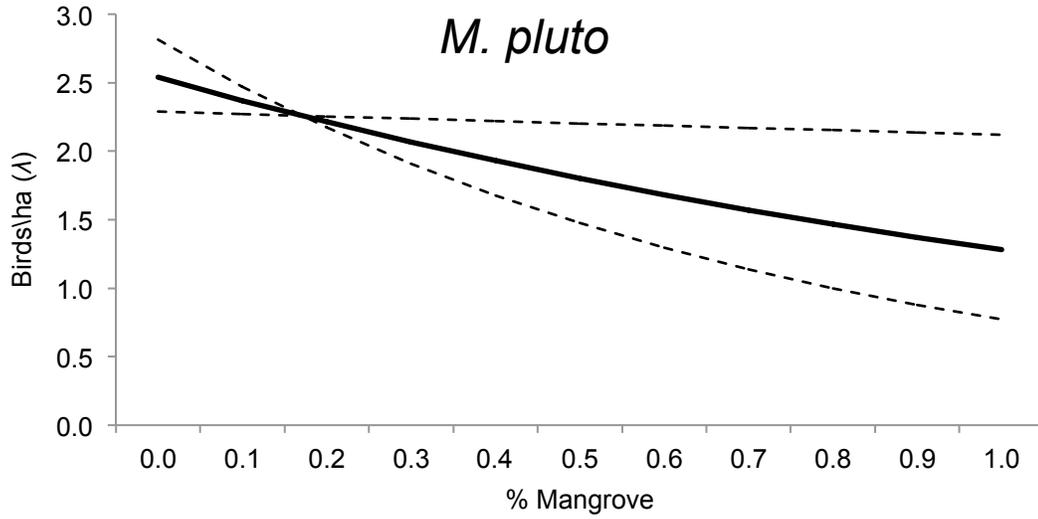
Appendix 2.13. Effect of Secondary vegetation on Micronesian kingfisher density (λ).

Dashed lines indicate upper and lower CI at the 95% level.

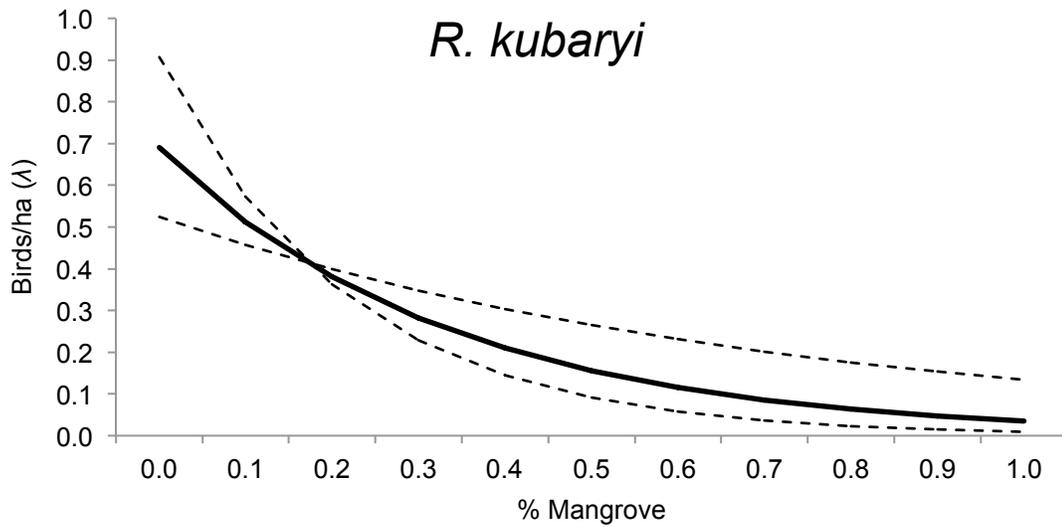


Appendix 2.14. Effect of Mangrove on Micronesian kingfisher density (λ). Dashed lines

indicate upper and lower CI at the 95% level.

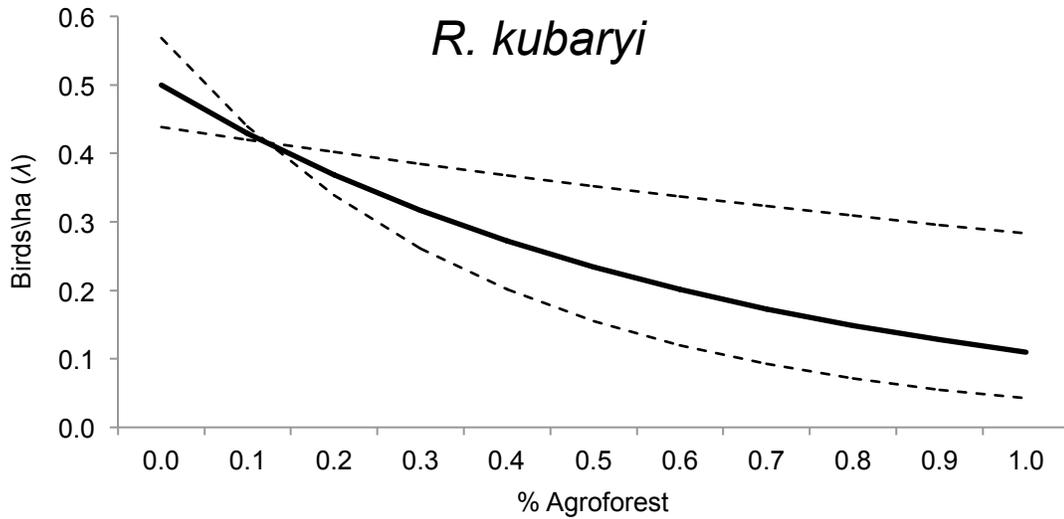


Appendix 2.15. Effect of Mangrove on Pohnpei flycatcher density (λ). Dashed lines indicate upper and lower CI at the 95% level.

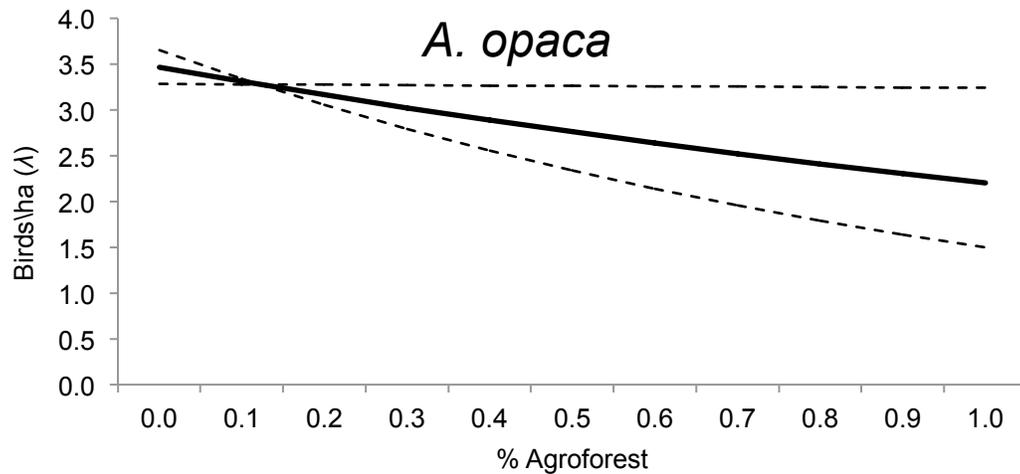


Appendix 2.16. Effect of Mangrove on Pohnpei fantail density (λ). Dashed lines indicate

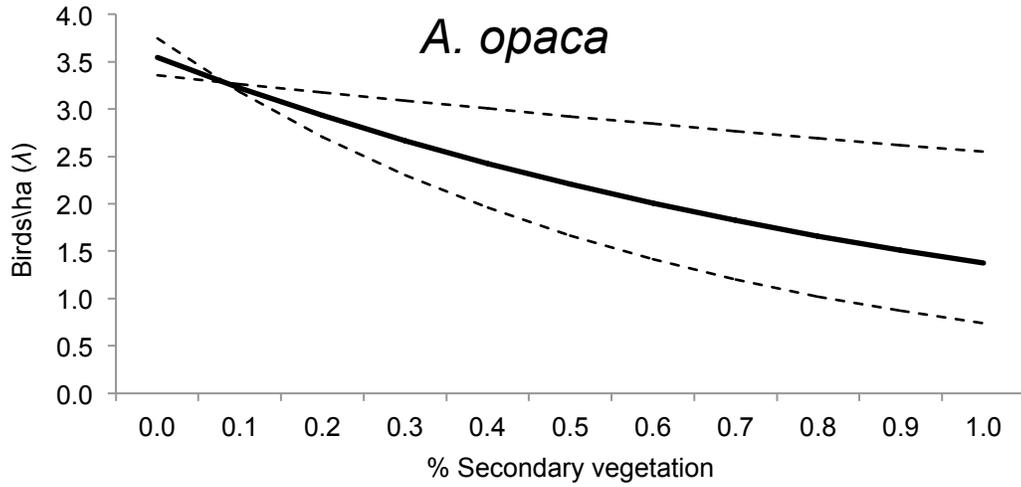
upper and lower CI at the 95% level.



Appendix 2.17. Effect of Mangrove on Pohnpei fantail density (λ). Dashed lines indicate upper and lower CI at the 95% level.

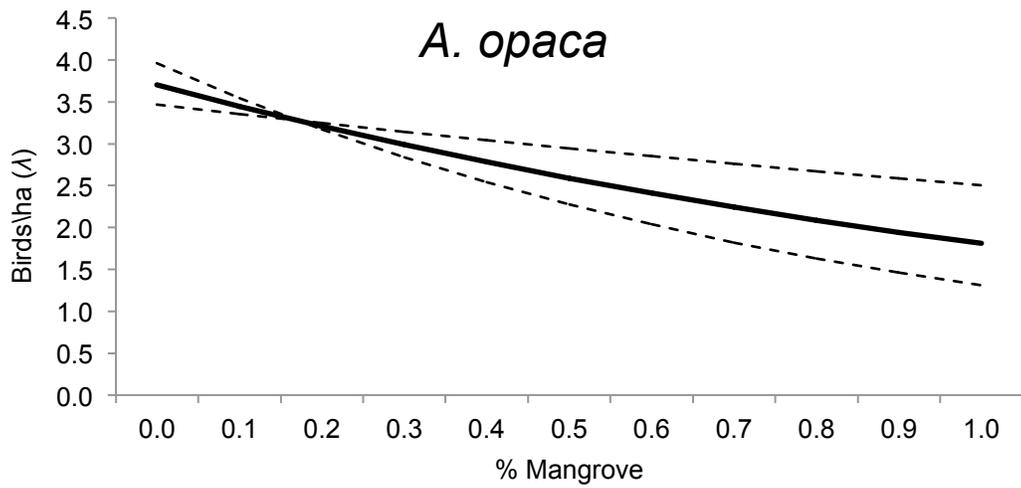


Appendix 2.18. Effect of Agroforest on Micronesian starling density (λ). Dashed lines indicate upper and lower CI at the 95% level.



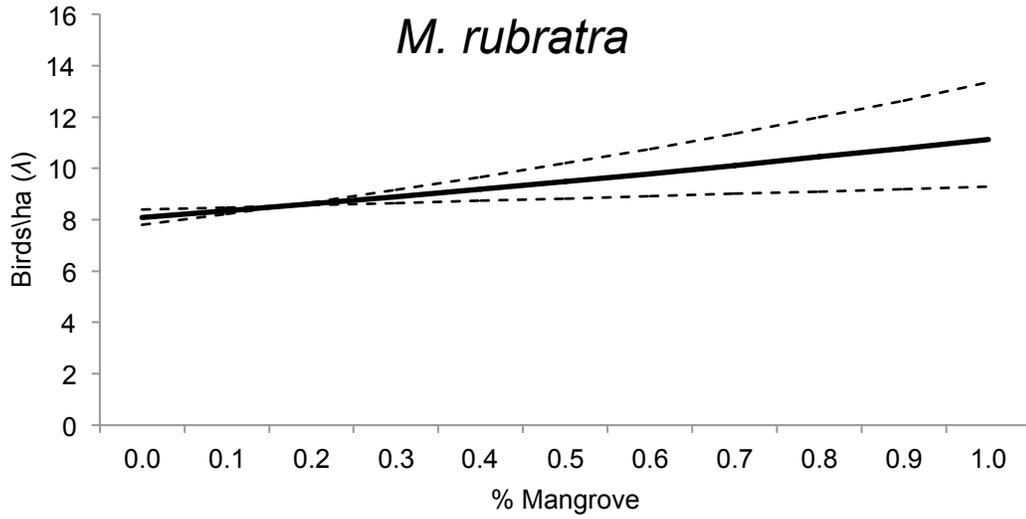
Appendix 2.19. Effect of Secondary vegetation on Micronesian starling density (λ).

Dashed lines indicate upper and lower CI at the 95% level.

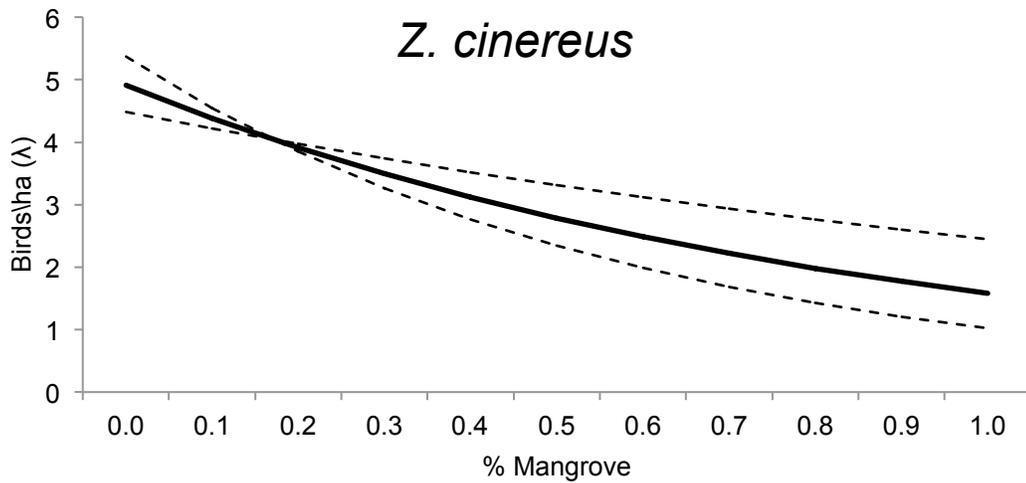


Appendix 2.20. Effect of Mangrove on Micronesian starling density (λ). Dashed lines

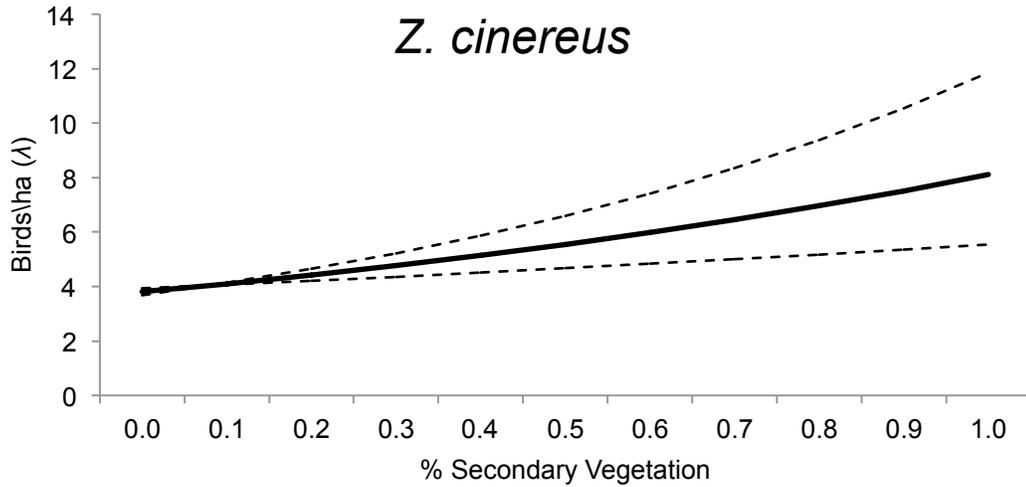
indicate upper and lower CI at the 95% level.



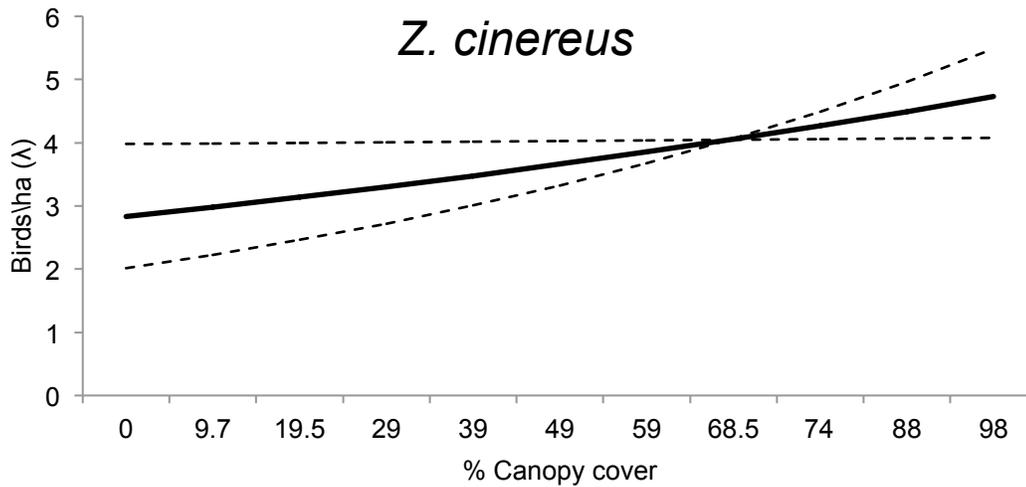
Appendix 2.21. Effect of Mangrove on Micronesian honeyeater density (λ). Dashed lines indicate upper and lower CI at the 95% level.



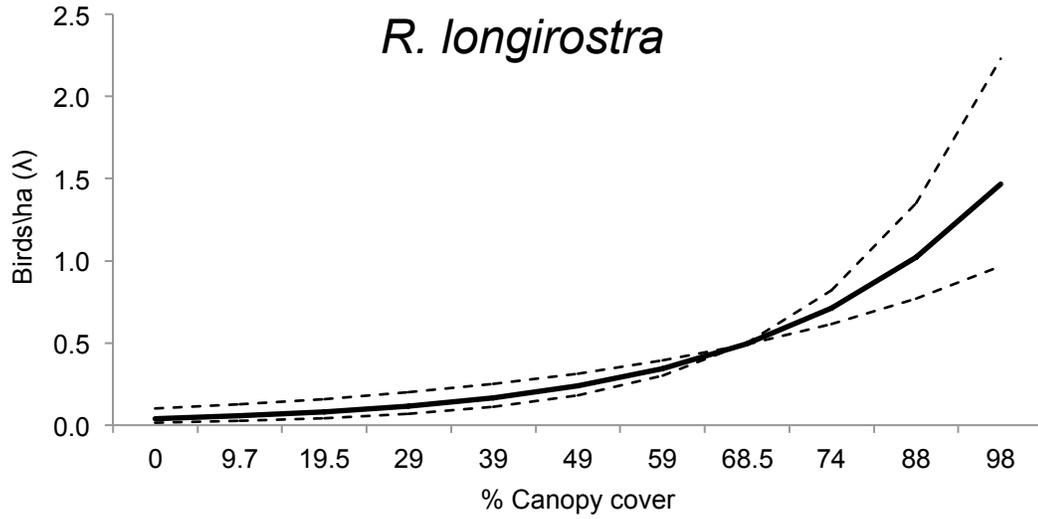
Appendix 2.22. Effect of Mangrove on gray white-eye density (λ). Dashed lines indicate upper and lower CI at the 95% level.



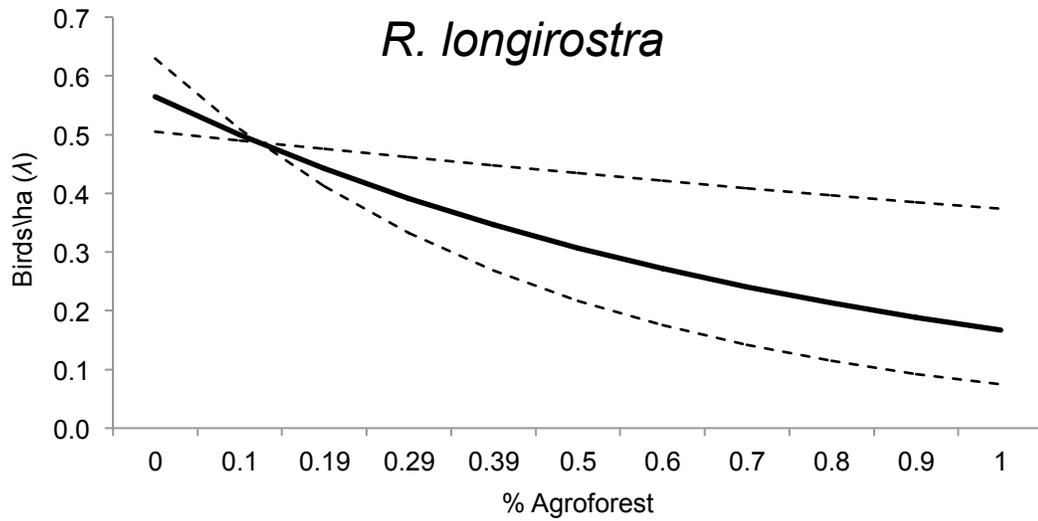
Appendix 2.23. Effect of Secondary vegetation on gray white-eye density (λ). Dashed lines indicate upper and lower CI at the 95% level.



Appendix 2.24. Effect of Canopy cover on gray white-eye density (λ). Dashed lines indicate upper and lower CI at the 95% level.



Appendix 2.25. Effect of Canopy cover on long-billed white-eye density (λ). Dashed lines indicate upper and lower CI at the 95% level.



Appendix 2.26. Effect of Agroforest on long-billed white-eye density (λ). Dashed lines indicate upper and lower CI at the 95% level.

Appendix 2.27. Top ranked Density Models Density (λ) function models for 10 species of birds from the island of Pohnpei, Federated States of Micronesia. Models were developed using point-transect survey data collected in 2012. We developed models in a 2-stage process that included identifying a detection function (p), and then identifying the density function associated with biologically relevant factors. All possible combinations of variables were considered, and those within 2 AICc units ($\Delta AICc < 2$) were considered to compete for best approximating. Only models competing for best approximating are depicted below.

<i>Ptilinopus porphyraceus</i>			K	AICc	Δ AICc	w_i
p	(ObsE+ObsJ+ObsP+Cloud)	λ (StockRt+CanCv+Mangrove)	8	1950.8	0.00	0.068
p	(ObsE+ObsJ+ObsP+Cloud)	λ (CanCv+Mangrove)	7	1950.8	0.00	0.068
p	(ObsE+ObsJ+ObsP+Cloud)	λ (PN+CanCv+Mangrove)	8	1951.4	0.59	0.051
p	(ObsE+ObsJ+ObsP+Cloud)	λ (StockRt+PN+CanCv+Mangrove)	9	1952.1	1.35	0.035
p	(ObsE+ObsJ+ObsP+Cloud)	λ (CanHt+CanCv+Mangrove)	8	1952.3	1.48	0.032
p	(ObsE+ObsJ+ObsP+Cloud)	λ (Edge+CanCv+Mangrove)	8	1952.5	1.69	0.029
p	(ObsE+ObsJ+ObsP+Cloud)	λ (StockRT+Edge+CanCv+Mangrove)	9	1952.6	1.85	0.027
p	(ObsE+ObsJ+ObsP+Cloud)	λ (StockRT+SecVeg+CanCv+Mangrove)	9	1952.7	1.91	0.026
<i>Ducula oceanica</i>			K	AICc	Δ AICc	w_i
p	(ObsE+ObsJ+ObsP+Wind+Cloud+Day)	λ (Mangrove+CanHt+Edge+CanCv+PN)	12	445.3	0.00	0.232

<i>p</i>	(ObsE+ObsJ+ObsP+Wind+Cloud+Day)	λ	(Mangrove+CanHt+Edge+PN)	11	446.3	0.98	0.142
<i>p</i>	(ObsE+ObsJ+ObsP+Wind+Cloud+Day)	λ	(Mangrove+CanHt+Edge+AgroFo+CanCv+PN)	13	447.2	1.90	0.089
<i>Trichoglossus rubiginosus (E)</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(Day+Time+Wind)	λ	(Mangrove+CanHt+CanCv)	8	1406.4	0.00	0.052
<i>p</i>	(Day+Time+Wind)	λ	(Mangrove+CanCv)	7	1407.0	0.57	0.039
<i>p</i>	(Day+Time+Wind)	λ	(Mangrove+CanHt+CanCv+PN)	9	1407.2	0.78	0.035
<i>p</i>	(Day+Time+Wind)	λ	(Mangrove+CanCv+PN)	8	1407.6	1.17	0.029
<i>p</i>	(Day+Time+Wind)	λ	(Mangrove)	6	1407.8	1.34	0.027
<i>p</i>	(Day+Time+Wind)	λ	(Mangrove+PN)	7	1407.9	1.47	0.025
<i>p</i>	(Day+Time+Wind)	λ	(Mangrove+CanHt+AgroFo+CanCv)	9	1408.0	1.62	0.023
<i>p</i>	(Day+Time+Wind)	λ	(Mangrove+CanHt+CanCv+SecVeg)	9	1408.1	1.69	0.022
<i>p</i>	(Day+Time+Wind)	λ	(Mangrove+AgroFo+CanCv)	8	1408.2	1.83	0.021
<i>p</i>	(Day+Time+Wind)	λ	(Mangrovet+AgroFo+CanCv+PN)	9	1408.4	1.95	0.020
<i>Todiramphus reichenbachii (E)</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(ObsE+ObsJ+ObsP+Wind+Day+Noise+Time)	λ	(Mangrove+AgroFo+SecVeg)	12	1024.1	0.00	0.110
<i>p</i>	(ObsE+ObsJ+ObsP+Wind+Day+Noise+Time)	λ	(Mangrove+AgroFo+SecVeg+StockRt)	13	1024.8	0.67	0.079
<i>p</i>	(ObsE+ObsJ+ObsP+Wind+Day+Noise+Time)	λ	(Mangrove+AgroFo+CanCv+SecVeg)	13	1025.0	0.85	0.072

<i>p</i>	(<i>ObsE+ObsJ+ObsP+Wind+Day+Noise+Time</i>)	λ	(Mangrove+AgroFo+PN+SecVeg)	13	1025.8	1.62	0.049
<i>p</i>	(<i>ObsE+ObsJ+ObsP+Wind+Day+Noise+Time</i>)	λ	(Mangrove+Edge+AgroFo+SecVeg)	13	1025.9	1.79	0.045
<i>p</i>	(<i>ObsE+ObsJ+ObsP+Wind+Day+Noise+Time</i>)	λ	(Mangrove+CanHt+AgroFo+SecVeg)	13	1026.1	1.97	0.041
<i>Myiagra pluto (E)</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(<i>Wind+Day+Noise</i>)	λ	(Mangrove)	6	1005.4	0.00	0.055
<i>p</i>	(<i>Wind+Day+Noise</i>)	λ	(Mangrove+PN)	7	1006.4	1.00	0.033
<i>p</i>	(<i>Wind+Day+Noise</i>)	λ	(Mangrove+SecVeg)	7	1006.7	1.24	0.029
<i>p</i>	(<i>Wind+Day+Noise</i>)	λ	(Mangrove+Edge+PN)	8	1006.7	1.29	0.029
<i>p</i>	(<i>Wind+Day+Noise</i>)	λ	(Mangrove+Edge)	7	1006.9	1.49	0.026
<i>p</i>	(<i>Wind+Day+Noise</i>)	λ	(Mangrove+AgroFo)	7	1006.9	1.50	0.026
<i>p</i>	(<i>Wind+Day+Noise</i>)	λ	(Mangrove+CanHt)	7	1007.1	1.63	0.024
<i>p</i>	(<i>Wind+Day+Noise</i>)	λ	(Mangrove+StockRt)	7	1007.1	1.66	0.024
<i>p</i>	(<i>Wind+Day+Noise</i>)	λ	(Mangrove+PN+SecVeg)	8	1007.3	1.86	0.022
<i>p</i>	(<i>Wind+Day+Noise</i>)	λ	(Mangrove+CanCv)	7	1007.3	1.90	0.021
<i>Rhipidura kubaryi (E)</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(<i>Wind+Cloud+Day+Noise</i>)	λ	(Mangrove+AgroFo+CanCv)	8	647.8	0.00	0.136
<i>p</i>	(<i>Wind+Cloud+Day+Noise</i>)	λ	(Mangrove+AgroFo+CanCv+StockRt)	9	649.2	1.41	0.067

<i>p</i>	(Wind+Cloud+Day+Noise)	λ	(Mangrovet+Edge+AgroFo+CanCv)	9	649.4	1.55	0.063
<i>p</i>	(Wind+Cloud+Day+Noise)	λ	(Mangrove+CanHt+AgroFo+CanCv)	9	649.6	1.80	0.055
<i>p</i>	(Wind+Cloud+Day+Noise)	λ	(Mangrove+AgroFo+CanCv)	9	649.8	1.97	0.051
<i>Aplonis opaca</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(Null)	λ	(Mangrove+AgroFo+SecVeg+StockRt)	6	1474.8	0.00	0.059
<i>p</i>	(Null)	λ	(Mangrove+AgroFo+PN+SecVeg+StockRt)	7	1475.0	0.20	0.053
<i>p</i>	(Null)	λ	(Mangrove+AgroFo+SecVeg)	5	1475.2	0.41	0.048
<i>p</i>	(Null)	λ	(Mangrove+AgroFo+CanCv+SecVeg)	6	1475.4	0.56	0.044
<i>p</i>	(Null)	λ	(Mangrove+CanHt+AgroFo+PN+SecVeg+StockRt)	8	1475.4	0.61	0.043
<i>p</i>	(Null)	λ	(Mangrove+CanHt+AgroFo+SecVeg+StockRt)	7	1475.5	0.71	0.041
<i>p</i>	(Null)	λ	(Mangrove+CanHt+AgroFo+CanCv+SecVeg)	7	1476.1	1.34	0.03
<i>p</i>	(Null)	λ	(Mangrove+CanHt+AgroFo+CanCv+SecVeg+StockRt)	8	1476.2	1.40	0.029
<i>p</i>	(Null)	λ	(Mangrove+CanHt+AgroFo+CanCv+PN+SecVeg+StockRt)	9	1476.2	1.42	0.029
<i>p</i>	(Null)	λ	(Mangrove+AgroFo+CanCv+PN+SecVeg)	7	1476.3	1.52	0.028
<i>p</i>	(Null)	λ	(Mangrove+AgroFo+PN+SecVeg)	6	1476.4	1.57	0.027
<i>p</i>	(Null)	λ	(Mangrove+AgroFo+CanCv+SecVeg+StockRt)	7	1476.4	1.62	0.026
<i>p</i>	(Null)	λ	(Mangrove+Edge+AgroFo+SecVeg+StockRt)	7	1476.5	1.69	0.025

<i>p</i>		λ		K	AICc	Δ AICc	w_i
<i>p</i>	(Null)	λ	(Mangrove+AgroFo+CanCv+PN+SecVeg+StockRt)	8	1476.7	1.94	0.022
<i>Myzomela rubratra</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(ObsE+ObsJ+ObsP+Cloud)	λ	(Mangrove+CanCv)	7	2080.2	0.00	0.053
<i>p</i>	(ObsE+ObsJ+ObsP+Cloud)	λ	(Mangrove+CanCv+PN)	8	2081.3	1.08	0.031
<i>p</i>	(ObsE+ObsJ+ObsP+Cloud)	λ	(Mangrove+Edge+CanCv+PN)	9	2081.3	1.12	0.03
<i>p</i>	(ObsE+ObsJ+ObsP+Cloud)	λ	(Mangrove+Edge+CanCv)	8	2081.4	1.21	0.029
<i>p</i>	(ObsE+ObsJ+ObsP+Cloud)	λ	(Mangrove+CanCv)	8	2081.5	1.29	0.028
<i>p</i>	(ObsE+ObsJ+ObsP+Cloud)	λ	(Mangrove+CanHt+CanCv)	9	2081.5	1.30	0.028
<i>p</i>	(ObsE+ObsJ+ObsP+Cloud)	λ	(Mangrove+CanHt+CanCv)	8	2081.6	1.39	0.027
<i>p</i>	(ObsE+ObsJ+ObsP+Cloud)	λ	(Mangrove+CanCv+SecVeg)	8	2082.1	1.87	0.021
<i>Zosterops cinereus</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(ObsE+ObsJ+ObsP+Wind+Noise+Day)	λ	(Mangrove+CanHt+Edge+CanCv+SecVeg)	11	1663.8	0.00	0.064
<i>p</i>	(ObsE+ObsJ+ObsP+Wind+Noise+Day)	λ	(Mangrove+CanHt+Edge+CanCv+PN+SecVeg+StockRt)	13	1663.8	0.03	0.063
<i>p</i>	(ObsE+ObsJ+ObsP+Wind+Noise+Day)	λ	(Mangrove+CanHt+Edge+CanCv+PN+SecVeg+StockRt)	12	1664.2	0.36	0.053
<i>p</i>	(ObsE+ObsJ+ObsP+Wind+Noise+Day)	λ	(Mangrove+CanHt+Edge+CanCv+SecVeg)	12	1664.3	0.52	0.049
<i>p</i>	(ObsE+ObsJ+ObsP+Wind+Noise+Day)	λ	(Mangrove+CanHt+Edge+CanCv+SecVeg+StockRt)	12	1664.4	0.58	0.048
<i>p</i>	(ObsE+ObsJ+ObsP+Wind+Noise+Day)	λ	(Mangrove+CanHt+Edge+CanCv+SecVeg+StockRt)	13	1664.9	1.12	0.036

<i>p</i>	<i>(ObsE+ObsJ+ObsP+Wind+Noise+Day)</i>	λ	(Mangrove+CanHt+Edge+CanCv+SecVeg)	12	1664.9	1.13	0.036
<i>p</i>	<i>(ObsE+ObsJ+ObsP+Wind+Noise+Day)</i>	λ	(Mangrove+CanHt+Edge+CanCv+SecVeg)	13	1665.1	1.33	0.033
<i>p</i>	<i>(ObsE+ObsJ+ObsP+Wind+Noise+Day)</i>	λ	(Mangrove+CanHt+Edge+CanCv+PN+SecVeg)	13	1665.2	1.40	0.032
<i>p</i>	<i>(ObsE+ObsJ+ObsP+Wind+Noise+Day)</i>	λ	(Mangrove+CanHt+Edge+CanCv+PN+SecVeg+StockRt)	14	1665.4	1.56	0.029
<i>p</i>	<i>(ObsE+ObsJ+ObsP+Wind+Noise+Day)</i>	λ	(Mangrove+CanHt+Edge+CanCv+PN+SecVeg+StockRt)	14	1665.6	1.80	0.026
<i>p</i>	<i>(ObsE+ObsJ+ObsP+Wind+Noise+Day)</i>	λ	(Mangrove+CanHt+Edge+CanCv+PN+SecVeg)	13	1665.7	1.90	0.025
<i>Rukia longirostra (E)</i>				K	AICc	Δ AICc	w_i
<i>p</i>	<i>(Noise+Day+Clouds+Rain)</i>	λ	(AgroFo+CanCv+SecVeg)	9	971.7	0.00	0.139
<i>p</i>	<i>(Noise+Day+Clouds+Rain)</i>	λ	(CanHt+AgroFo+CanCv+SecVeg)	10	972.0	0.23	0.124
<i>p</i>	<i>(Noise+Day+Clouds+Rain)</i>	λ	(Edge+AgroFo+CanCv+SecVeg)	10	972.7	0.99	0.085
<i>p</i>	<i>(Noise+Day+Clouds+Rain)</i>	λ	(CanHt+Edge+AgroFo+CanCv+SecVeg)	11	973.0	1.27	0.074
<i>p</i>	<i>(Noise+Day+Clouds+Rain)</i>	λ	(AgroFo+CanCv+SecVeg+StockRt)	10	973.1	1.41	0.069
<i>p</i>	<i>(Noise+Day+Clouds+Rain)</i>	λ	(Edge+AgroFo+CanCv+PN+SecVeg)	11	973.2	1.45	0.067
<i>p</i>	<i>(Noise+Day+Clouds+Rain)</i>	λ	(AgroFo+CanCv+PN+SecVeg)	10	973.2	1.48	0.066
<i>p</i>	<i>(Noise+Day+Clouds+Rain)</i>	λ	(CanHt+Edge+AgroFo+CanCv+PN+SecVeg)	12	973.2	1.50	0.066
<i>p</i>	<i>(Noise+Day+Clouds+Rain)</i>	λ	(CanHt+AgroFo+CanCv+PN+SecVeg)	11	973.3	1.58	0.063

Appendix 2.28. Top-ranked occupancy (Ψ) function models for 13 species of birds from the island of Pohnpei, Federated States of Micronesia. Models were developed using repeated survey data collected in 2012. Models were developed in a 2-stage process that included identifying a detection function (p), and then in a second-stage analysis to identify the occupancy function associated with biologically relevant factors. All possible combinations of variables were considered, and those within 2 AICc units ($\Delta \text{AICc} < 2$) were considered to compete for best approximating. Only competing models are included below.

<i>Ptilinopus porphyraceus</i>				K	AICc	ΔAICc	w_i
p	(Obs+Noise+Rain+Time)	Ψ	(Null)	8	449.2	0	0.052
p	(Obs+Noise+Rain+Time)	Ψ	(Edge)	9	450	0.88	0.033
p	(Obs+Noise+Rain+Time)	Ψ	(CanHt)	9	450.5	1.37	0.026
p	(Obs+Noise+Rain+Time)	Ψ	(StockRt)	9	451	1.84	0.021
p	(Obs+Noise+Rain+Time)	Ψ	(AgroFo)	9	451.1	1.92	0.02
p	(Obs+Noise+Rain+Time)	Ψ	(PN)	9	451.1	1.93	0.02
p	(Obs+Noise+Rain+Time)	Ψ	(SecVeg)	9	451.1	1.97	0.019
<i>Ducula oceanica</i>				K	AICc	ΔAICc	w_i
p	(Obs)	Ψ	(PN+CanCvr+CanHt+SecVeg+PN)	10	764	0	0.075
p	(Obs)	Ψ	(PN+CanCvr+CanHt+PN)	9	764.6	0.61	0.055

<i>p</i>	(Obs)	Ψ	(PN+CanCvr+CanHt+SecVeg+PN+Mangrove)	11	764.7	0.64	0.054
<i>p</i>	(Obs)	Ψ	(PN+CanCvr+CanHt+PN+Mangrove)	10	764.8	0.74	0.052
<i>p</i>	(Obs)	Ψ	(PN+CanCvr+CanHt+SecVeg+PN+AgroFo)	11	764.8	0.78	0.051
<i>p</i>	(Obs)	Ψ	(PN+CanCvr+CanHt+SecVeg+PN+StockRt)	11	765.2	1.23	0.04
<i>p</i>	(Obs)	Ψ	(PN+CanCvr+CanHt+PN+StockRt)	10	765.6	1.58	0.034
<i>p</i>	(Obs)	Ψ	(PN+CanCvr+CanHt+SecVeg+PN)	10	765.8	1.74	0.031
<i>p</i>	(Obs)	Ψ	(PN+CanHt+SecVeg+PN+StockRt)	10	765.8	1.76	0.031
<i>p</i>	(Obs)	Ψ	(PN+CanCvr+CanHt+SecVeg+PN+Mangrove+AgroFo)	12	765.9	1.87	0.029
<i>Trichoglossus rubiginosus</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(Day+Wind+Rain)	Ψ	(Mangrove+SecVeg+StockRt+CanHt)	9	1149	0	0.178
<i>p</i>	(Day+Wind+Rain)	Ψ	(Mangrove+StockRt+CanHt)	8	1150.7	1.64	0.078
<i>p</i>	(Day+Wind+Rain)	Ψ	(Mangrove+SecVeg+StockRt+PN+CanHt)	10	1150.8	1.76	0.074
<i>p</i>	(Day+Wind+Rain)	Ψ	(Mangrove+SecVeg+CanVcr+StockRt+CanHt)	10	1150.9	1.86	0.07
<i>p</i>	(Day+Wind+Rain)	Ψ	(Mangrove+SecVeg+AgroFo+StockRt+CanHt)	10	1151	1.91	0.068
<i>Todiramphus reichenbachii</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(Day+Wind+Rain+Time)	Ψ	(Mangrove+StockRt+CanHt)	12	1185.5	0	0.084
<i>p</i>	(Day+Wind+Rain+Time)	Ψ	(Mangrove+StockRt+CanHt+PN)	13	1185.8	0.26	0.074
<i>p</i>	(Day+Wind+Rain+Time)	Ψ	(Mangrove+StockRt+CanHt+SecVeg)	13	1185.9	0.35	0.071

<i>p</i>	(Day+Wind+Rain+Time)	Ψ	(Mangrove+StockRt+CanHt+PN+SecVeg)	14	1186	0.5	0.066
<i>p</i>	(Day+Wind+Rain+Time)	Ψ	(Mangrove+StockRt+CanHt+PN+Edge+SecVeg)	15	1187.3	1.74	0.035
<i>p</i>	(Day+Wind+Rain+Time)	Ψ	(Mangrove+StockRt+CanHt+PN+Edge)	14	1187.5	1.92	0.032
<i>Coracina tenuirostris</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(Day+Wind+Obs)	Ψ	(CanCvr+CanHt)	9	268.3	0	0.063
<i>p</i>	(Day+Wind+Obs)	Ψ	(CanCvr)	8	269.5	1.19	0.035
<i>p</i>	(Day+Wind+Obs)	Ψ	(SecVeg+CanCvr+CanHt)	10	269.8	1.47	0.03
<i>p</i>	(Day+Wind+Obs)	Ψ	(Null)	7	269.9	1.55	0.029
<i>p</i>	(Day+Wind+Obs)	Ψ	(AgroFo+CanCvr+CanHt)	10	270	1.68	0.027
<i>p</i>	(Day+Wind+Obs)	Ψ	(StockRt+CanCvr+CanHt)	10	270.2	1.91	0.023
<i>Myiagra pluto</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(Day+Noise+Obs)	Ψ	(CanHt)	8	1333.5	0	0.063
<i>p</i>	(Day+Noise+Obs)	Ψ	(CanHt+PN)	9	1334	0.43	0.051
<i>p</i>	(Day+Noise+Obs)	Ψ	(CanHt+Mangrove)	9	1334.6	1.1	0.036
<i>p</i>	(Day+Noise+Obs)	Ψ	(CanHt+PN+AgroFo)	10	1335	1.52	0.03
<i>p</i>	(Day+Noise+Obs)	Ψ	(CanHt+PN+Mangrove)	10	1335.1	1.54	0.029
<i>p</i>	(Day+Noise+Obs)	Ψ	(CanHt+CanCvr)	9	1335.4	1.88	0.025
<i>p</i>	(Day+Noise+Obs)	Ψ	(CanHt+Edge)	9	1335.5	1.95	0.024

<i>Rhipidura kubaryi</i>			K	AICc	Δ AICc	<i>Wi</i>
<i>p</i>	(Cloud+Time+Day+Obs)	Ψ (Mangrove+AgroFo+Edge+CanHt+PN)	13	1160.7	0	0.09
<i>p</i>	(Cloud+Time+Day+Obs)	Ψ (Mangrove+AgroFo+Edge+CanHt)	12	1161	0.32	0.077
<i>p</i>	(Cloud+Time+Day+Obs)	Ψ (Mangrove+Edge+CanHt+PN)	12	1161.2	0.46	0.072
<i>p</i>	(Cloud+Time+Day+Obs)	Ψ (Mangrove+AgroFo+Edge+CanHt+StockRt)	13	1161.4	0.72	0.063
<i>p</i>	(Cloud+Time+Day+Obs)	Ψ (Mangrove+AgroFo+Edge+CanHt+StockRt+PN)	14	1161.7	1.01	0.054
<i>p</i>	(Cloud+Time+Day+Obs)	Ψ (Mangrove+Edge+CanHt+StockRt)	13	1162.2	1.48	0.043
<i>p</i>	(Cloud+Time+Day+Obs)	Ψ (Mangrove+AgroFo+Edge+CanHt+PN+SecVeg)	14	1162.4	1.71	0.038
<i>p</i>	(Cloud+Time+Day+Obs)	Ψ (Mangrove+AgroFo+Edge+CanHt+PN+CanCvr)	14	1162.6	1.91	0.035
<i>Acrocephalus syrinx</i>			K	AICc	Δ AICc	<i>Wi</i>
<i>p</i>	(Day+Wind+Obs)	Ψ (CanCvr+AgroFo+Mangrove)	10	414.6	0	0.111
<i>p</i>	(Day+Wind+Obs)	Ψ (CanCvr+AgroFo+Mangrove+PN)	11	416	1.42	0.055
<i>p</i>	(Day+Wind+Obs)	Ψ (CanCvr+AgroFo+Mangrove+StockRt)	11	416.4	1.8	0.045
<i>p</i>	(Day+Wind+Obs)	Ψ (CanCvr+AgroFo+Mangrove+Edge)	11	416.6	1.95	0.042
<i>p</i>	(Day+Wind+Obs)	Ψ (CanCvr+AgroFo+Mangrove+CanHt)	11	416.6	1.97	0.041
<i>Aplonis opaca</i>			K	AICc	Δ AICc	<i>Wi</i>
<i>p</i>	(Rain+Clouds)	Ψ (Mangrove+CanCvr)	6	1063.8	0	0.085
<i>p</i>	(Rain+Clouds)	Ψ (Mangrove+CanCvr+CanHt)	7	1064.1	0.36	0.071

<i>p</i>	(Rain+Clouds)	Ψ	(Mangrove+CanCvr+CanHt+StockRt)	8	1065.3	1.56	0.039
<i>p</i>	(Rain+Clouds)	Ψ	(Mangrove+CanHt)	6	1065.5	1.7	0.037
<i>p</i>	(Rain+Clouds)	Ψ	(Mangrove+CanCvr+StockRt)	7	1065.7	1.93	0.033
<i>Myzomela rubratra</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(Rain+Noise)	Ψ	(Mangrove)	5	354.8	0	0.124
<i>Zosterops semperi</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(Noise+Obs)	Ψ	(Mangrove+AgroFo+PN)	9	614.2	0	0.117
<i>p</i>	(Noise+Obs)	Ψ	(Mangrove+AgroFo+PN+Edge)	10	614.3	0.13	0.109
<i>p</i>	(Noise+Obs)	Ψ	(Mangrove+SecVeg+AgroFo+PN)	10	615.1	0.88	0.075
<i>p</i>	(Noise+Obs)	Ψ	(Mangrove+AgroFo)	8	615.8	1.57	0.053
<i>Zosterops cinereus</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(Day+Noise+Clouds+Obs)	Ψ	(Mangrove+SecVeg+StockRt)	11	1182.2	0	0.078
<i>p</i>	(Day+Noise+Clouds+Obs)	Ψ	(Mangrove+SecVeg+CanCvr+StockRt)	12	1182.4	0.21	0.07
<i>p</i>	(Day+Noise+Clouds+Obs)	Ψ	(Mangrove+SrockRt)	10	1182.8	0.65	0.056
<i>p</i>	(Day+Noise+Clouds+Obs)	Ψ	(Mangrove+SecVeg+AgroFo+StockRt)	12	1183.8	1.59	0.035
<i>p</i>	(Day+Noise+Clouds+Obs)	Ψ	(Mangrove+SecVeg+Edge+StockRt)	12	1183.8	1.59	0.035
<i>p</i>	(Day+Noise+Clouds+Obs)	Ψ	(Mangrove+CanCvr+StockRt)	11	1183.8	1.61	0.035
<i>p</i>	(Day+Noise+Clouds+Obs)	Ψ	(Mangrove+SecVeg+Edge+StockRt)	13	1183.9	1.76	0.032

<i>p</i>	(Day+Noise+Clouds+Obs)	Ψ	(Mangrove+SecVeg+PN+StockRt)	12	1184.1	1.9	0.03
<i>Rukia longirostra (E)</i>				K	AICc	Δ AICc	w_i
<i>p</i>	(Day+Time+Clouds+Obs)	Ψ	(Mangrove+Edge+CanCvr)	11	972.8	0	0.099
<i>p</i>	(Day+Time+Clouds+Obs)	Ψ	(Mangrove+CanCvr)	10	973.7	0.89	0.063
<i>p</i>	(Day+Time+Clouds+Obs)	Ψ	(Mangrove+Edge+PN+CanCvr)	12	973.7	0.9	0.063
<i>p</i>	(Day+Time+Clouds+Obs)	Ψ	(Mangrove+Edge+CanHt+CanCvr)	12	973.9	1.06	0.058
<i>p</i>	(Day+Time+Clouds+Obs)	Ψ	(Mangrove+Edge+AgroFo+CanCvr)	12	974.7	1.85	0.039
<i>p</i>	(Day+Time+Clouds+Obs)	Ψ	(Mangrove+CanHt+CanCvr)	11	974.8	1.96	0.037