Avifaunal Biodiversity and Land Use on Indonesia's Palau Penida Archipelago

By

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ABSTRACT

Understanding anthropogenic alterations to land use and their effects can inform conservation efforts in tropical biodiversity hotspots. In 2004 the Indonesian Palau Penida Archipelago, off the coast of Bali, was established as an unofficial bird reserve; however, studies of the islands' land use and avian biodiversity were never conducted and have not been monitored. I surveyed birds across 32 transects in land use categories designated: agriculture, deforested, developed, and forest. Forest transects presented the greatest endemic species richness, but overall Shannon diversity different significantly among land use categories, particularly forested and deforested. ANOVA indicated exotic bird density was significantly higher than endemic bird density across all transects. Birds serve as a common biodiversity barometer and this study can serve to inform land use management decisions on the Archipelago and throughout reserves and protected areas throughout the tropics.

Keywords: Biodiversity, Land Use, Deforestation, Invasive Species, Endangered, Ancillary reserve

INTRODUCTION

Greater than two thirds of all known species exist between the Tropics, making these regions incredibly biodiverse (Pimm & Raven, 2000; Gardner et al., 2009; Brown, 2014). Maintenance of this biodiversity is essential to a tropical ecosystem's structure and function (Cardinale et al., 2012; Allan et al., 2015). Anthropogenic changes in land use can negatively affect biodiversity, especially in hotspots such as the tropics (Moura et al., 2013; Newbold et al., 2015), potentially impairing ecosystem function. Natural reserves and other protected areas are often established as conservation tools to mitigate the potential detrimental effects of land use alterations on biodiversity (Juffe-Bignoli et al., 2014). "Ancillary" reserves are conservation areas established outside of International Union for Conservation of Nature (IUCN) standards or government regulation, such as the one established in 2004 on Indonesia's Palau Penida Archipelago (PPA) and are also intended as instruments of biodiversity conservation (Borrini-Feyerabend et al., 2013).

Biotic diversity is important to assess ecosystem stability and for determining overall ecosystem health (Allan et al., 2015). Asserting the importance of greater diversity across the biological components of a healthy ecosystem stems from examination across its spatial and temporal variabilities. Productive and diverse ecosystems recycle biologically important nutrients, affecting atmospheric, hydrologic, and biogeochemical processes tied to the physical health and function of an ecosystem (Srivastava and Vellend, 2005). Biodiversity has also been correlated with maintenance of an ecosystem's biomass (Cardinale et al., 2012), its vulnerability to disturbance (Gardner et al., 2009), as well as the services it provides (Hooper et al., 2005; Martinez et al., 2009).

Historically, humans have modified every landscape they interact with, altering land use to suit the needs at a given time or place (Kareiva et al., 2007; Gardner et al., 2009). According the United Nations' Food and Agriculture Organization, land use is "the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it" (fao.org). Today, change in land use is mankind's most profound effect on the environment and the leading cause of biodiversity decline across the globe (Vitousek et al., 1997). Anthropogenic manipulation of a landscape can damage or destroy habitats impair biogeochemical processes and exploit native flora and fauna, ultimately instigating a decrease in biodiversity (Foley et al., 2005).

Habitat fragmentation created without conservation in mind has the potential to reshape an ecosystem's carbon storage, the services it provides, and the community's trophic structure (Hooper et al., 2005; Laurence, 2008). Rates of extinction are disproportionately higher in nations between the tropics, which includes Indonesia, a center for biodiversity (Beaudrot et al., 2016). Loss of habitat has been acknowledged as the primary cause of declines in threatened populations and their eventual extinction (Myers et al., 2000). Removal of primary and secondary forest is often necessary to facilitate increased agriculture, improved infrastructure, or tourism-related development (Chazdon, 2008). Exploitation of a forest's natural resources, by altering land use, often expedites industrial advances though it is done at the cost of eliminating habitats, destroying food sources, causing marked fluctuations in species distributions (Gardner et al., 2009), and driving species to decline if not to extinction (Gaston, 2000). Dupouey et al. (2002) warn that land use modification stemming from deforestation can have irreversibly negative effects on biodiversity.

Natural reserves or protected areas are created with the overarching goal of preservation and maintenance of biodiversity, often facilitated by minimizing changes in land use. IUCN defines a protected area as: "A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley, 2008). Protected areas that do not have the legal or governmental support are classified as ancillary. The PPA, established as a bird reserve by two non-government organizations, falls into this category.

Only 9.8% of all tropical forests are protected, but reserve designation and landscape alteration are not mutually exclusive (Schmitt et al., 2008; Gardner et al., 2009). Protected areas that continue to permit alterations in land use face increasing challenges in fulfilling their conservation mission. Establishing a reserve on islands such as the PPA requires more than accounting for the aforementioned economic and biophysical attributes; social and cultural realities need to be taken into account. Striking an effective balance is complex; there is not a single metric to effectively report or qualify religious or cultural traditions that a given ancillary reserve has to take into account. Changes in land use within a reserve that do not take these conservation considerations into account diametrically oppose them (Maron et al., 2013; Bull et al., 2015).

Anthropogenic land use can affect biodiversity of a given region, making conservation management of islands home to critically endangered species challenging (Moura et al., 2013; Newbold et al., 2015). Effectively quantifying biodiversity at the ecosystem level is complicated, as a consistent set of metrics have yet to be defined. Avian biodiversity, used in this study, can serve as a proxy for overall diversity (Lees et al., 2012; Moura et al., 2013). Intrinsic physical and biological challenges to avifaunal biodiversity on islands have historically been exacerbated by human presence (Steadman, 1995; Brown, 1997).

The presence of species with ecologically essential function can positively influence the ecosystem's productivity (Isbell et al., 2013). Birds are one of the largest vertebrates on these islands and serve as ecosystem engineers, seed dispersers, as pollinators. Their ecosystem services complement other roles as insectivores, scavengers, and seed predators (Whelan et al., 2008). Functional traits of key endemic species can mitigate resource capture and alter biogeologic processes (Cardinale et al., 2012). Invasive species can imperil a productive avian community if their presence diminishes endemic biodiversity and affect the other aforementioned ecosystem attributes.

These Indonesian islands, host to several threatened and endangered species, are also a release site for the critically endangered Bali Starling, *Leucopsar rothschildi*, despite never having a formal avifaunal biodiversity survey conducted (Juniartha, 2007). This study examined avian presence and quantities across distinct anthropogenic land uses on the PPA. Community structure assessing unique species, habitat parameters, and endemic status were taken into account. Patterns illuminated diminished endemic populations in the fragmented forests of the PPA as well as exotic species dominating the landscape. This preliminary survey can serve as a tool to inform future conservation management decisions in hopes of maintaining biodiversity on the ancillary reserve that is Indonesia's Palau Penida Archipelago.

MATERIALS & METHODS

Study Area:

Nusa Penida, Nusa Lembongan, and Nusa Ceningan are a trio of islands identified as the Palau Penida Archipelago (PPA). These are three of Indonesia's 13,466 islands, located between the Indian and Pacific Oceans. This study was conducted on the islands of Nusa Penida and Nusa Lembongan, part of Bali's Klungkung Regency. Nusa Penida, the largest of the three islands, is located at 8.727°S, 115.544°E. Nusa Lembongan is accessible by foot from Nusa Ceningan, which is approximately 600 meters from Nusa Penida. Nusa Penida's overall elevation ranges from 0 to 529 meters, where Nusa Lembongan peaks at 29 meters.

The PPA's juxtaposition of proximity and isolation from mainland Bali created a complex history of human occupation land use. In the 19th century, separation from mainland Bali by the twelve turbulent kilometers of the Badung Strait made Nusa Penida an ideal prison for mainland Bali (Sidemen, 1984). By the turn of the 20th century agriculture dominated the small Indonesian island. A 1924 Dutch survey of the entire island documented 17,800 ha or 86% of the island had been deforested and cultivated (Gertis, 1925). Heavy deforestation included parts of the mangrove forest occupying approximately one quarter of Nusa Lembongan. Deforestation of the PPA made way for proportionately large-scale agriculture leaving primary and secondary forest, serving as vital avian habitats, fragmented and in short supply. As of 2017, the largest remaining forested portion of the island is less than ten hectares in area at the top of Mount Mundi, with slopes up to a 30-40% grade. The steep hillside is transected by a single north-south road with forest surrounding it and Puncak Mundi, a Hindu temple, at the highest point on the island.

Farming is difficult due to shallow soil above karst topography, steep terrain on abundant hills, and Nusa Penida's potential for destruction by tropical storms. These agricultural challenges were met by production of stone terraces in the 1800's to level and hold cultivable earth across Nusa Penida (Gertis, 1925). Rice cannot be grown on Nusa Penida due to inconsistent and insufficient rainfall, but the island sustains crops of cassava, maize, teak, papaya, and bananas, among others.

One hundred and fifty years later, Nusa Penida is now a mere one-hour boat ride from the Bali ports of Sanur and Padang Bai. Today, depleted landscapes across the Nusas have made even subsistence farming impractical for many. Though these islands had been nearly decimated a century ago, they are now seeing a surge in development in response to increases in tourism. According to the most recent census, Nusa Penida is home to approximately 45,000 permanent residents; 26% of the Regency's population is spread across 84% of its total land area (Government of Klungkung Regency, 2014). Nusa Penida's land area is several times larger than that of Nusa Lembongan, however, Lembongan's accessibility, size and its extensive sea life makes tourism its primary industry whereas Penida's villages rely on traditional agriculture and seaweed farming. The archipelago has some infrastructure though many areas are difficult to access due to incomplete or nearly destroyed roads.

Bird Sampling:

Thirty-two line transects were created throughout the islands based upon accessibility of the area and type of land use. I attempted to sample equal numbers of transects for each land use category, but areas defined as *Forest* for this study were sparse. Accessibility was determined by my ability to walk the line transect safely with little impeding the path, avoiding physical barriers that could interfere with wildlife observation. Transect elevation ranged from the mangroves of *Forest* transect 18 to a *Developed* transect 31 at the temple Puncak Mundi, at 5 and 503 meters respectively. Different land uses were found across the range of elevations per Appendix 1. Each transect was surveyed over the month of May 2017. The dry season on Nusa Penida is typically from April to October. Average temperature during the study was 27.5°C, which is in keeping with the recent historical mean during the same month. Precipitation occurred on three days during the study; 120 mm is the current average precipitation for the month of May (University of Maine, 2017).

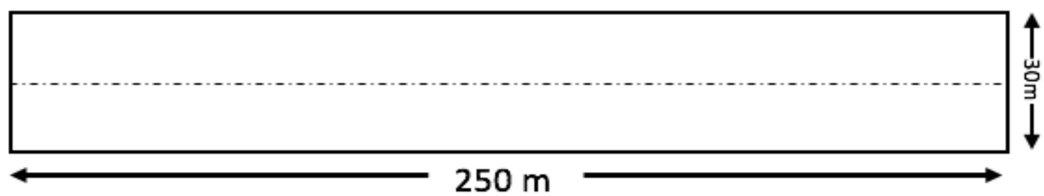

Figure 1: Format of each 7500m2 transect; dotted line marks the position and route of observer.

Each unique 30-meter-wide transect was measured and marked with flagging tape so I could quickly identify the survey location upon return in the evening. Transects were walked down the middle, with 15 meters on each side, to a length of 250 meters as measured by GPS from a Garmin 735XT (Garmin Ltd., Lenexa, KS) for a total area of 7500 m^2 per transect (Figure 1). Two survey sites were on Nusa Lembongan because a Bali Starling population was recently reported there by the Begawan Foundation (Halaouate, 2015); the remainder were performed on Nusa Penida (Figure 2). Transects were completed within 30 minutes, accounting for pauses to count, confirm identification, or scale terrain. The 32 transects were cumulatively surveyed 60 times; four transects were surveyed only once due to flooding of the only access routes (Appendix 1).

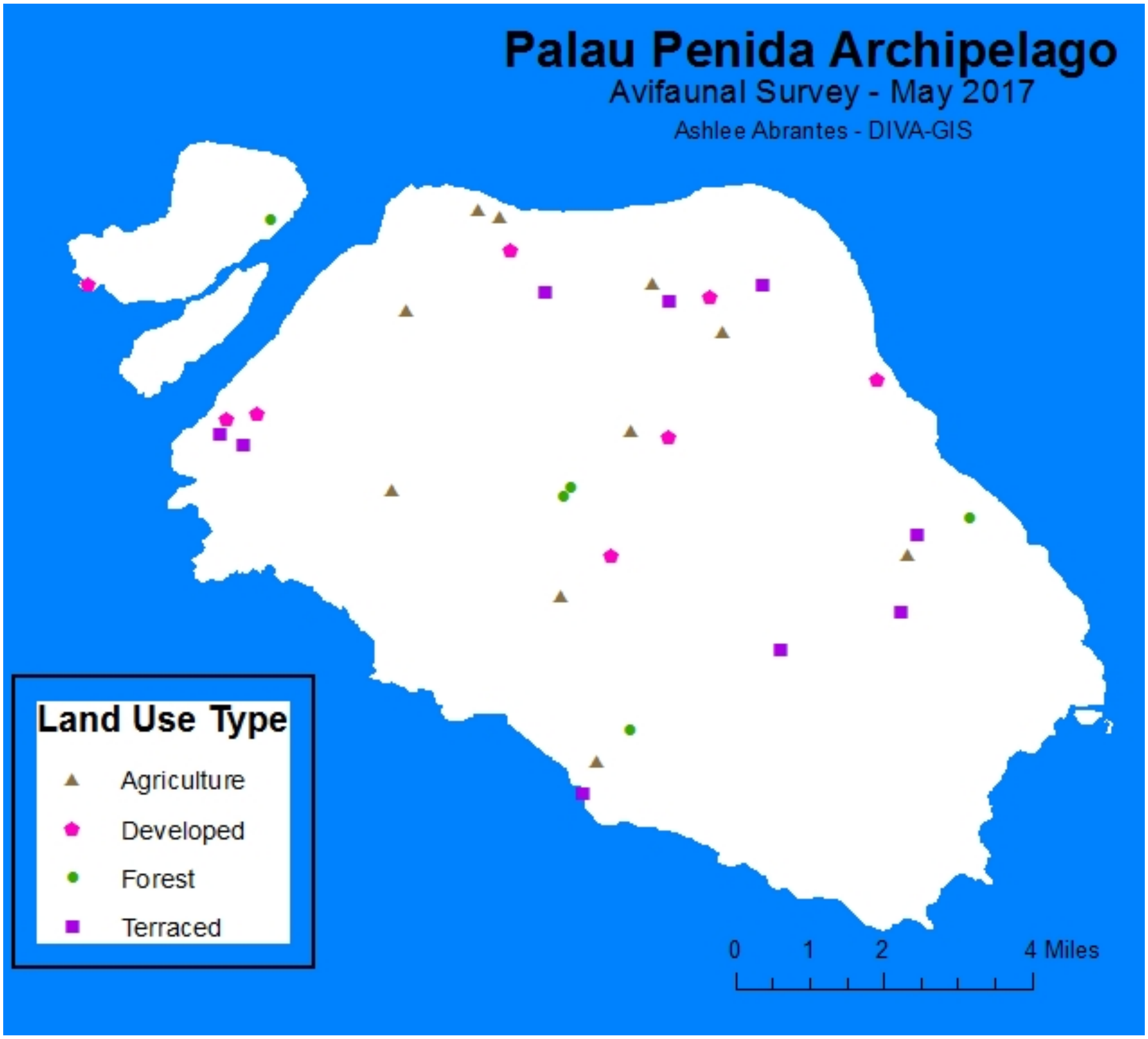

Figure 2: Map of all survey locations on Nusa Penida and Nusa Lembongan according to land use type.

Surveys commenced between 0600 and 0730 and 1700-1830 to account for the matutinal and crepuscular nature of bird activity. I identified birds by sight only; distance could not be accurately ascertained audibly due to the recurring hilly nature of the islands. All birds were counted individually in the field, except for flocks of *Lonchura.* These flocks were initially counted via video and numbers were estimated for flocks with greater than 50 members. Fly-over birds, those clearing the canopy or tallest tree in the transect, were not counted as protocol dictated in previous avifaunal studies (Lees et al., 2012; Moura et al., 2013). Identification was made on site by two observers, walking together, with the aid of 10x binoculars and a Nikon DSLR camera using an 18-55mm lens (Nikon, Tokyo, Japan).

Land Use Designation:

Land use categories *Agriculture, Deforested, Developed,* and *Forest* were appointed to every transect. Transects that are currently cultivated for crops such as cassava, banana, and corn were designated *Agriculture*. *Deforested* land was similar, but these transects were not as close to domiciles and showed no recent signs of disturbance beyond the established century old stone-terraced farming steps. Banana trees, coconut trees, various shrubs and grasses were regularly found among these transects. Land that has distinctly been developed for tourism, has recently been cleared for home expansion, or tracts of limestone excavation are all collectively labeled *Developed*. These transects had the sparsest flora, typically shrubs and grasses with trees on the periphery. Designation as *Forest* was limited to primary or secondary forest that had not been destroyed, replanted, or significantly modified over the last century. Mature mangrove forest found on Nusa Lembongan was also included in these transects. Teak, Banyan, bamboo, palm trees, and very dense shrubs littered these limited landscapes. Land cover was not uniform among all transects of a given land use category. Quantity of transect type varied based upon perceived prevalence of that land use across the islands. Ten *Agriculture,* nine *Deforested,* eight *Developed,* and five *Forest* transects were evaluated during this study.

Endemic Designation:

Avibase (avibase.org) was used as a guide to define the endemic versus exotic species of Bali and its Klunkung Regency. Of the 410 bird species listed for Bali in the database, the Bali

Starling or Bali Myna (*Leucopsar rothschildi*) is the sole endemic bird listed as unique to Bali itself. Because of the proximity to neighboring islands Java and Lombok and the study's focus on a volant organism, the 38-species labeled "endemic (country/region)" in the database are considered endemic for the purposes of this study.

Data Analysis:

Endemic species richness, exotic species richness, density, and evenness were quantified for each survey. Simpson and Shannon-Weiner indices were used to calculate biodiversity. I calculated species density of individual birds for each meter squared per transect. Jaccard indices were used to quantify similarities in the bird communities among different land use categories in this study, with land use categories as the operational taxonomic units. Jaccard similarity coefficients were calculated by comparing the presence of every species across all transects in two land use categories, shown as a percentage of species in common divided by total unique species found in each land use comparison. Statistical examination of biodiversity indices and subcomponents such as density and evenness across land use categories was done using a one-way analysis of variance (ANOVA) with a 95% confidence interval. Average values were used to compensate for lack of replicate surveys not performed at four transects. Treatment effect for values of significance ($p < 0.05$) was followed by a Tukey post-hoc test. We created a Pearson Correlation Matrix to examine relationships between variables not analyzed via ANOVA. Statistical analysis was executed on SPSS Version 24 (IBM, New Castle, NY).

RESULTS

I counted 3,475 birds throughout the study, observed among 60 species across the 32 transects on Nusa Penida and Nusa Lembongan. The most species rich surveys were dawn transects 1 (*Deforested*; 44 meters), 5 (*Deforested;* 33 meters), 10 (*Developed;* 68 meters), and dusk transect 3 (*Developed*; 16 meters); all with 12 species each. The least species rich survey was transect 17 (*Forest;* 429 meters) at dusk with only two species present, the fork-tailed swift *(Apus pacificus)* and sooty-headed bulbul (*Pycnonotus aurigaster)*. *Deforested* transects had the greatest mean overall species richness (Appendix 1; 7.71 ± 2.82) and *Forest* transects had the lowest (Appendix 1; 5.86 ± 3.31) but these trends were not significant. All individual survey data can be found in Appendix 1.

I counted fourteen species (23%) categorized as endemic to Bali and the Nusa Islands. Of the 3,475 birds counted, 719 (20.69%) were endemic. However, only two species, the Javan munia (*Lonchura leucogastroides)* and the black-faced munia (*Lonchura molucca),* accounted for 77.61% (558 of 719) of the individuals of these endemic species. Among the exotic species, the invasive sooty-headed bulbul *(Pycnonotus aurigaster)* was nearly ubiquitous throughout the island, noted in 30 of 32 transects (94%). Sooty-headed bulbuls accounted for 31.13% (858 of 2756) of all individual invasive birds and 24.69% (858 of 3475) of the total individuals across all surveys. Eight transects (25%) did not have a single endemic bird present.

Examination of exotic species richness across each land use type was marginally significant ($F_{3,28} = 2.91$, $p = 0.052$) though we did not find a significant relationship between overall species richness (including endemics) and land use ($F_{3,28} = 1.38$, $p = 0.27$). The strongest distinction in exotic richness was among *Forest* and *Deforested* transects with *Forest* transects having dramatically lower exotic species richness. Endemic species richness was not significantly different across land use categories ($F_{3,28} = 0.14$, $p = 0.94$). However, endemic species richness and exotic species richness were significantly positively correlated (Table 1).

Repeated measures ANOVA showed that species richness of exotics (9.2 ± 0.5) was consistently greater than that of endemic species (2.3 ± 0.2) (Appendix 1; $F_{1,28} = 252.93$, $p < 0.0001$).

Land-use category had a significant effect on the difference between endemic and exotic species richness ($F_{3,24} = 3.89$, $p < 0.02$), again with *Forest* being substantially lower than any other transect type. There was no significant effect of land use category, species density ($F_{3,28} = 2.29$, $p = 0.10$), and species evenness ($F_{3,28} = 0.27$, $p = 0.85$). However, species density significantly decreased with elevation (Table 1).

Table 1. Pearson correlation matrix for indices of avian community structure. Exotic richness shares the most positive significant correlation, followed closely by Simpson Diversity and Evenness. Species density shares the strongest negative correlations with elevation and evenness. *p < 0.05, **p < 0.01

	Total Richness	Endemic richness	Exotic richness	Shannon	Simpson	Evenness	Density
Elevation	-0.16	-0.21	-0.11	0.04	0.13	0.14	-0.49**
Total richness		0.65**	0.94**	0.57**	0.001	-0.39*	0.56**
Endemic richness			0.36*	0.18	-0.21	-0.38*	0.19
Exotic richness				0.62**	0.10	-0.31	0.60**
Shannon index					0.72**	0.43*	0.10
Simpson index						0.89**	-0.23
Evenness							-0.48**

Among diversity indices, there was a significant relationship between land-use type and the Shannon-Weiner diversity index (Appendix 1; $F_{3,28} = 3.18$, $p = 0.039$). The most substantial difference, again, was between Shannon indices for *Deforested* and *Forest* transects with *Forest* transects being significantly less biodiverse (Tukey $p < 0.05$). However, there was no significant relationship between land use category and the Simpson index (Appendix 1; $F_{3,28} = 0.97$, $P = 0.43$). Shannon diversity was positively correlated ($p < 0.05$) with both overall species richness and evenness (Table 1) whereas Simpson diversity was correlated with evenness but not overall richness (Table 1). *Deforested* transects had the greatest mean Shannon diversity (Appendix 1; 1.52 ± 0.49) and the lowest mean Simpson diversity (Appendix 1; 0.58 ± 0.25). We found the lowest mean Shannon diversity among *Forest* transects (Appendix 1; 1.18 ± 0.55) where the highest Simpson diversity mean was in *Developed* transects (Appendix 1; 0.691 ± 0.19).

Overall, we found no significant difference in cumulative species richness between morning and evening transects (Appendix 1; $F_{1,58} = 0.34$, $p = 0.57$). There was no significant difference between transects at different times of day for the Shannon index (Appendix 1; $F_{1,58} = 0.012$, $P = 0.91$), Simpson index (Appendix 1; $F_{1,58} = 0.20$, $P = 0.66$), or evenness (Appendix 1; $F_{1,58} = 0.53$, $P = 0.47$).

Deforested and *Agriculture* transects had the most similar avian communities, with a Jaccard coefficient of 68.09 (Table 2), and a greater proportional similarity despite having the fewest total species in common, 47. Forest and Agriculture had the least similarity with the lowest Jaccard index, 38.30 (Table 2), and 48 species in common.

Table 2: Jaccard Index coefficients and species in common among land use categories.

Category	# of Species in common	Jaccard Coefficient
Terraced-Agriculture	47	68.09
Developed-Agriculture	50	55.10
Developed-Terraced	55	48.15
Developed-Forest	48	41.30
Terraced-Forest	50	40.82

DISCUSSION

By count alone, exotic birds observed throughout this study dramatically outnumbered endemic species nearly fourfold (2756:719), however proportion does not paint a complete picture of the avifauna of these Indonesian islands. Two species, *Lonchura leucogastroides* and *L. molucca*, accounted for greater than three quarters of all observed birds categorized as endemic. Excluding the two *Lonchura* species, the total of all 161 individual endemic birds account for only 4.63% of total birds surveyed. Examining total species, only 60 (14.63%) of the 410 of the previously documented species of birds were observed.

Most striking among the results was the low species density in *Forest* transects. Intuitively, forests make a likely candidate for avian habitat, including for the Bali Starling. Small tree stands and forest edges that back up to homes or roads on all three Nusa's are being taken down or pushed back to accommodate small, rentable tourist accommodations. Forested area at higher elevations remain unlikely candidates for development and agriculture due to the steep slope and heavy wind exposure, the same reasons most endemic and exotic birds alike are not making their homes above 250 meters (Appendix 1). Of the 11 individual critically endangered Bali starlings observed, none were found in *Forest* transects.

Comparison of surveys at dawn and dusk highlighted more matutinal activity across surveys by more individual birds, though fewer species. Forty-three species were represented in the 1793 birds counted during morning surveys (mean overall richness = 7.82, ±2.42) versus the 1682 birds among 56 species (mean overall richness = 7.16, ±2.50) in evening transects. Mornings on the PPA are cooler and more moist. Though birds are still present and active at dusk, without midday precipitation, morning conditions are likely more ideal for bird activity than the hot dry evenings after hours of near-Equatorial sun.

Higher overall species richness was observed at transects of lower elevation, with the greatest species richness at transects below 50 meters. These conditions exacerbate the fragmentation of forested areas and decrease the habitability of the island's primary forests. These forest fragments account for the highest and lowest points on these islands. Fewer species and individual birds were found in transects designated *Forest* compared to any other land use category. *Deforested* transects averaged nearly two species greater per survey than forested areas.

Creation of a natural reserve to protect a given group or species is not exclusive of continuing development and other potential change in land use on the PPA of Bali's Klungkung Regency**.** This study surveyed avifauna across different land use types on an ancillary reserve. It was not a definitive guide to quantify every bird and name every species that can be present on these islands. Sampling technique, walking a straight-line transect, was chosen as the least invasive and most practical method to survey avifauna, an assessment that had not been made until I arrived on the island. As these islands are small and the survey took place during a single month, more transient, seasonal species are likely not represented. These facts do not detract from the patterns noted and statistical significance of the state or lack of biodiversity on these tropical islands.

Neither Nusa Penida or Nusa Lembongan had the avian diversity of mainland Bali, likely due to their smaller sizes and lack of Bali's lush landscape (McTaggart, 1989). The calcareous nature of Nusa Penida's soil means the ground does not hold water well, therefore streams only run briefly after significant rainfall (McTaggart, 1989; Giambelli, 1999). Precipitation was sporadic during the month of May, but one day's puddles were quickly evaporated in the next day's dry tropical sun. This geohydrologic attribute requires species to be specially adapted to sporadic water availability. Deforestation can change soil composition and increase runoff (Vitousek et al., 1997). This augments difficulties meeting the hydration needs of the islands' native inhabitants and this anthropogenic action increased the islands' invasibility, making way for birds that can handle longer periods without water (Elton, 1958; Lonsdale, 1999).

Deforestation accompanied by changes in land use and mixed vegetative cover have opened the door for invasive species, particularly those with adaptations to thrive in Nusa Penida's locally-reported worsening dry season (Giambelli, 1999). This exacerbates the challenges imposed by the PPA's natural hydrogeology. The landscape is still littered with stone terraces created to stabilize the soil for agriculture as trees were removed. Some terraces continue to serve an agricultural purpose, while others act as reminders of fluctuations in the island's productivity and disturbance impairing biotic resistance, in turn increasing the potential for invasive avian species (Elton, 1958; Lockwood et al., 2007; Blackburn et al., 2008).

Exotic species such as the frugivorous sooty-headed bulbul are outcompeting the rarer endemic birds. Papaya, a bulbul favorite native to the Americas, are found throughout the islands benefiting invasive birds who thrive on them. Dominance by exotic bird species is also likely to indicate the prevalence of exotic species in other genera, such as the seeds of non-native vegetation invasive birds can and have spread (Dawson et al., 2017). Reforestation, when well-monitored and protected, stands to promote endemic bird survival and overall island biodiversity. Small reforestation attempts have been made and continue to be made on Nusa Penida though monitoring the trees post-sapling is inconsistent.

The Bali Starling was the only IUCN red-listed endangered or critically endangered bird (BirdLife International, 2016) observed throughout this study, despite the six other critically endangered species of bird previously documented on Nusa Penida (avibase.org). Though a direct result of propagule pressure, visibility of 11 Bali starlings is a beacon of hope, though meager compared to the 2015 Begawan survey reporting several times the Bali Starling population (Halaouate, 2015). Unfortunately, these and other birds face threats beyond habitat destruction. Those living around agricultural or developed areas can easily be captured and exported by boat from Bali and the Nusa's to Lombok, Java, and beyond to be sold with the steep price tag their rarity brings (Jepsen, 2016). A recurring theme in island biogeography, birds faced few natural predators on the islands before anthropogenic interference. Feral cats, a human introduction, run rampant across the islands and also pose threats to birds. This does not mean endangered birds in this region are doomed in the wild; a more thorough survey of the islands is required to definitively assess their presence or absence.

As exotic species continue to adapt to the conditions on the PPA, outcompeting and exploiting each island's resources, the fate of many endemic species could potentially be imperiled. Cumulative species richness as presented in this study and incorporated into biodiversity indices calculations here is useful, but understanding functional characteristics of several dominant invasive or endangered endemic species could play a more effective role in predicting this ecosystem's response to land use change (Loreau et al., 2001; Hooper et al., 2005).

There are currently no reliable statistics available tracking the increase in tourism on the Nusa's, which would be necessary to make correlations regarding development impacting the islands' flora and fauna. Dyer et al. (2017) demonstrated the prevalence in exotic species invasions in rapidly developing countries, including parts of many Southeast Asian island nations. Intensified changes in land use are also likely to increase outside species introductions (Dawson et al., 2017) and the PPA is unlikely to be an exception to this observation. If care is not taken as tourism increases and island nations develop, potential positive effects on flora and fauna from the cessation and reversal of deforestation are likely to be insufficient if not negated.

Maintenance of biodiversity on the PPA is essential to the islands' ecosystem and the many services it provides. Recently, the ancillary avian reserve was established on these islands in an attempt to promote biodiversity, preserve endangered species, and mitigate the significant, detrimental anthropogenic changes in land use of the recent past. Observations and correlations derived from this study are a gauge of the direction of land use reflecting on biodiversity of the landscape, not an absolute count of populations of avian species.

When a reserve is established the primary motive, be it to protect wildlife, maintain biodiversity, or increase ecotourism, needs to balance the other two elements in consideration of its formation. Villages of an entire island collaborating to create a bird reserve, particularly without government funding, is a rare entity. Limited financial resources coupled with status as a subordinate island of Bali in the developing Indonesian nation make success in preservation of endemic populations a challenge, even with the best of intentions. Changes in land use are beginning to have an impact on avian populations on the PPA, particularly in its forests. Further studies of the avian populations on these islands are likely to provide a model for human interference and the fate of Indonesia's marine and terrestrial biodiversity.

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Transect	Time	LandUse	Elevation	ENRichness	EXRichness	Shannon	Simpson	Density	Evenness
1	A	T	44	3	9	1.860986128	0.758064516	0.008266667	0.748915911
2	A	T	121	0	9	1.860091986	0.801541025	0.013066667	0.846564345
1	P	T	44	0	7	1.547531708	0.717948718	0.0052	0.79527398
2	P	T	121	1	10	2.04033667	0.282051282	0.014266667	0.850886481
3	A	D	16	2	7	1.228166979	0.565462582	0.0108	0.558962881
4	A	D	83	1	5	1.389715455	0.706666667	0.004	0.775614963
3	P	D	16	3	9	1.673365707	0.691253056	0.012933333	0.673411899
4	P	D	83	0	6	1.618400451	0.780348879	0.007066667	0.90324649
5	A	T	33	5	7	1.632655994	0.710947862	0.0132	0.657029106
6	A	A	69	2	3	0.986631176	0.508088889	0.01	0.613028417
5	P	T	33	2	7	1.899234278	0.811421773	0.005466667	0.86437877
6	P	A	69	1	10	2.061339476	0.84441198	0.009866667	0.859645331
7	A	D	170	2	4	1.537349666	0.75443787	0.006933333	0.858011185
8	A	A	386	1	10	2.226211361	0.878892734	0.004533333	0.928402248
9	A	F	91	2	6	1.846997271	0.805293006	0.003066667	0.888217935
10	A	D	68	2	10	1.643155153	0.729528849	0.0168	0.661254278
9	P	F	91	1	5	1.493328199	0.736328125	0.004266667	0.833442337
10	P	D	68	2	7	1.505935681	0.677861622	0.012933333	0.685380865
11	A	D	50	1	4	1.077870406	0.571055306	0.011066667	0.669718538
12	A	D	374	2	5	1.3495931	0.621957815	0.005733333	0.693553657
11	P	D	50	1	4	1.359236701	0.68	0.001333333	0.844541246
12	P	D	374	0	6	1.229098531	0.570637119	0.002533333	0.685972951
13	A	A	154	3	8	1.473434075	0.583880788	0.010533333	0.614469736
14	A	A	14	0	5	1.237812038	0.650887574	0.0052	0.769095862
13	P	A	154	2	5	1.241433213	0.5734375	0.010666667	0.63797047
14	P	A	14	1	5	1.627407391	0.7792	0.006666667	0.908273359
15	A	T	276	1	3	1.185820313	0.660493827	0.0024	0.855388542
16	A	T	231	0	4	0.953964025	0.523148148	0.0048	0.688139584
15	P	T	276	1	8	1.847777246	0.808431953	0.006933333	0.840959665
16	P	T	231	2	6	1.392538376	0.616489515	0.007866667	0.669669403
17	A	F	429	2	6	1.211197324	0.523009496	0.004933333	0.551239658
18	A	F	5	4	6	1.297679842	0.476990504	0.010933333	0.563575195
17	P	F	429	0	2	0.682908105	0.489795918	0.001866667	0.985228136
18	P	F	5	1	4	0.788874921	0.385798817	0.008666667	0.490155547
19	A	A	242	1	7	1.484903463	0.710138889	0.016	0.714087621
20	A	A	14	2	8	1.716853472	0.727981859	0.014	0.745619989
19	P	A	242	2	8	1.72399975	0.747404844	0.0068	0.748723578
20	P	A	14	1	3	0.824539117	0.561236623	0.003866667	0.594779248
21	A	T	244	1	5	1.196711129	0.569444444	0.0032	0.667897198
22	A	D	107	0	8	1.572246982	0.73875	0.010666667	0.756090975
21	P	T	244	0	10	1.990779877	0.833963215	0.0084	0.864584715
22	P	D	107	1	4	1.418785303	0.724655978	0.011866667	0.881540873
23	A	A	51	3	5	1.85863911	0.820451843	0.003866667	0.893816476
24	A	A	228	2	5	1.73920435	0.786703601	0.005066667	0.893774233
23	P	A	51	2	6	1.227927687	0.559453032	0.007733333	0.590508395
24	P	A	228	0	5	1.170503941	0.600054083	0.011466667	0.72727499
25	A	T	123	0	6	1.289389371	0.662037037	0.0048	0.71962191
26	A	T	132	1	6	0.97394743	0.415059688	0.0088	0.50050997
25	P	T	123	1	6	1.720224549	0.782380013	0.0052	0.884020544
26	P	T	132	1	5	1.255529673	0.6176	0.003333333	0.700724453
27	A	A	178	0	9	1.522386263	0.693841225	0.014133333	0.692867847
28	A	A	282	0	6	1.289418024	0.640595463	0.012266667	0.719637901
27	P	A	178	0	4	1.011949428	0.588888889	0.004	0.72996721
28	P	A	282	0	5	0.845054528	0.453678055	0.0076	0.5250619
29	A	F	192	1	2	1.039720771	0.625	0.000533333	0.94639463
30	P	F	488	2	5	1.767009191	0.8	0.002	0.908063094
31	A	D	503	1	9	1.657339422	0.685546875	0.004266667	0.719773366
31	P	D	503	3	7	1.612193207	0.746530612	0.0092	0.700166613
32	A	T	20	1	6	1.418305573	0.676176593	0.013066667	0.728864883
32	P	T	20	1	8	1.67201232	0.736111111	0.0064	0.760965601

Appendix 1: Biodiversity indices, density, evenness, and overall richness for all 60 surveys performed in May 2017. Times “A” and “P” indicate morning and evening surveys, respectively. Land Use “A” represents Agriculture, “D” Developed, “F” Forest, and “T” Deforested.

Common Name	Genus species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Javan Myna*	*Acridotheres javanicus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
White-breasted Waterhen	*Amaurornis phoenicurus*	0	0	1	0	2	0	0	0	2	0	0	1	0	0	0	0	0	1	1	0	4	0	0	0	1	0	1	1	0	5	1	0
House Swift	*Apus nipalensis*	0	7	4	14	6	0	18	0	0	0	0	0	5	9	16	2	0	0	10	9	6	0	0	0	11	2	0	13	0	0	21	4
Fork-tailed swift	*Apus pacificus*	6	48	5	15	3	8	10	4	9	16	16	2	2	17	15	6	33	14	2	0	0	8	0	0	0	16	0	0	0	0	1	6
White-faced Heron	*Ardea novaehollandaiae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Lesser coucal	*Centropus bengalensis*	0	0	3	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Javan Plover*	*Charadrius javanicus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Short-Toed Eagle	*Circaetus gallicus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
White-rumped Shama	*Copsychus malabaricus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Slender-billed crow	*Corvus enca*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	3	0	0	0	0	2
Large billed-crow	*Corvus macrorhynchos*	1	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2	0	0
Wandering Whistling-Duck	*Dendrocygna arcuata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Red-chested flower pecker*	*Dicaeum maugei*	2	0	3	1	5	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	1	0	1	3	2	0	0	0	0	0	0	0
Yellow-vented Flowerpecker	*Dicaeum chrysorrheum*	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Dark-backed Imperial Pigeon	*Ducula lacernalata*	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	0	0	0	0	0	0	0	4	0	0	0	0	4
Intermediate Egret	*Egretta intermedia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Black-winged Kite	*Elanus caeruleus*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Dollarbird	*Eurystomus orientalis*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
Peregrine Falcon	*Falco peregrinus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Little Pied Flycatcher	*Ficedula westermanni*	0	0	2	4	0	0	0	2	0	0	0	5	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Watercock	*Gallicrex cinerea*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Green Junglefowl*	*Gallus varius*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0
Zebra Dove	*Geopelia striata*	14	12	0	11	7	10	0	3	2	0	0	4	12	4	0	6	0	0	14	7	0	0	10	0	3	0	2	8	0	0	2	2
Javan Kingfisher	*Halcyan cyanoventris*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
White-bellied Fish Eagle	*Haliaeetus leucogaster*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Brahminy Kite	*Haliastur indus*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Black-winged flycatcher shrike	*Hemipus hirundinaceus*	4	8	7	8	0	0	0	2	2	3	1	0	2	0	0	1	0	0	0	0	0	10	0	0	0	4	0	0	0	0	17	7
Black-naped Monarch	*Hypothymis azurea*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Yellow Bittern	*Ixobrychus sinensis*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
White-shouldered Triller*	*Lalage sueurii*	0	0	0	0	1	2	0	0	2	0	1	0	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Long-tailed shrike	*Lanius schach (bentet)*	3	7	0	0	8	14	14	6	0	4	0	0	4	0	2	0	1	0	0	2	0	25	5	9	4	0	23	3	0	0	2	11
Lesser Adjutant	*Leptoptilos javanicus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bali Starling*	*Leucopsar rothschildi*	0	0	0	0	0	0	6	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indonesian honeyeater*	*Lichmera limbata*	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Javan munia*	*Lonchura leucogastroides*	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	100	0	0	0	34	0	0	0	0	0	0	0	0	24	50
Black-faced munia*	*Lonchura molucca*	0	0	100	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0
Scaly-breasted munia	*Lonchura punctulata*	27	0	0	0	45	50	0	0	0	0	50	0	0	0	0	35	0	0	50	50	18	0	0	50	0	0	50	50	0	0	0	0
Blue-tailed Bee Eater	*Merops philippinus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0	2
Olive-backed Sunbird	*Nectarinia jugularis*	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Changeable Hawk Eagle	*Nisaetus cirrhatus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Black-naped oriole	*Oriolus chinensis*	2	0	0	0	0	1	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Olive-backed Tailorbird*	*Orthotomus sepium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	6	0	0	0	0	0	0	0	0	1
Collared Scops-owl	*Otus lempiji*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Green Peafowl	*Pavo muticus*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
White-tailed Tropicbird	*Phaethon lepturus*	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Elegant Pitta*	*Pitta elegans*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bar-Winged Prinia*	*Prinia familiaris*	2	0	0	0	8	1	2	4	0	0	3	2	0	0	0	4	0	0	8	5	0	0	2	5	0	0	0	0	0	0	0	0
Black-backed fruit dove*	*Ptilinopus cinctus*	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black-naped Fruit-Dove	*Ptilinopus melanospila*	0	0	2	0	5	2	0	0	3	2	0	0	0	0	0	0	0	16	0	0	0	27	0	0	4	2	0	0	0	0	0	0
Pink-headed Fruit Dove	*Ptilinipus porphyreus*	6	9	17	0	0	0	0	0	12	14	0	0	10	0	5	23	0	0	6	0	12	0	3	9	5	4	8	12	0	0	2	14
Black-headed bulbul	*Pycnonotus atriceps*	0	0	5	0	0	3	0	0	2	0	0	0	0	4	5	0	0	0	2	0	13	0	0	3	0	0	3	0	0	0	0	0
Sooty-Headed Bulbul	*Pycnonotus aurigaster*	29	64	21	28	40	23	2	4	14	58	20	37	6	24	19	15	8	4	59	32	21	59	45	32	26	8	41	58	0	3	19	39
Pied Fantail	*Rhipidura javanica*	0	4	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	2
Island Collared-Dove	*Streptopelia bitorquata*	2	22	5	1	0	21	0	0	1	7	0	0	2	0	0	0	0	0	2	12	0	4	4	7	0	0	0	2	0	0	0	0
Black-winged Starling	*Sturnus melanopterus*	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Collared kingfisher	*Todirhamphus chloris*	0	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	1
Barn Owl	*Tyto alba*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Pink-necked Green-Pigeon	*Treron vernans*	0	16	0	0	4	8	0	6	0	7	0	0	5	27	0	0	1	0	6	12	0	0	6	0	14	0	0	0	0	0	2	0
Lemon-billed white eye*	*Zosterops chloris*	0	6	0	0	3	5	0	0	4	0	0	6	2	3	0	0	4	1	5	0	0	0	1	0	0	1	0	0	0	0	1	0
Oriental White eye	*Zosterops palpebrosus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
N		101	205	178	83	140	149	52	34	55	223	93	62	159	89	70	95	51	147	171	134	87	169	87	124	162	91	136	149	4	15	101	146
RICHNESS		15	12	16	9	16	14	6	11	13	16	8	11	15	8	11	10	8	13	17	10	14	9	14	10	12	11	10	10	3	7	19	15

Appendix 2: Names and quantities of all birds observed over 32 unique transects across the PPA.
*indicate a species designated as endemic by avibase.org