

## Indonesian Avifauna: Some Physical and Biological Relationships

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### Abstract

Avifauna check lists were used to indicate relationships among physical and biological parameters and families/species numbers in mainly Indonesian islands and territories. Bird species and family numbers represented in territories were related to island area ( $r=0.765$  and  $0.839$ , respectively). Species numbers also correlated well with the ecoregion score ( $r=0.934$ ), which indicated special habitat zonation factors favour species diversity. The data on ecoregions was not correlated with the level of endemism found. The ease of movement of birds across straits between islands was assessed using an index of common species approach. Some support was gained for the proposition that in the past sea levels were lower, thus establishing land bridges such as from Lombok to Alor. The ranked correlation with one analysis of sea depth and species commonality returned a negative ranked correlation coefficient ( $r=-0.823$ ;  $P=0.012$ ). Separation distance between islands failed to show a significant correlation to species commonality.

**Keywords:** *Avifauna, island area, species numbers, endemism, ecoregions, sea depth*

### Introduction

The diversity of the avifauna found in Indonesian territories is one of the highest known, yet there are a number of features governing the emergence and movement of species that are not well understood. Papua stands on the eastern edge of Indonesian territories and is located on the Sahul shelf, which it shares with Australia. At the other extreme, Sumatra, Java, Bali and Kalimantan sit on the Sunda shelf that connects these islands via shallow seas to the Asian mainland. Between these two sets of territories are many islands that are collectively part of the biogeographical area termed Wallacea. It has the distinction of being separated from the Sunda and Sahul shelves by deep ocean trenches. The Wallace line runs between Borneo and Sulawesi (Makassar Strait) and between the narrow strait separating Bali from Lombok (Lombok Strait). The Lydekker Line runs close to the Papuan western boundary and delimits the Aru islands from the Kei and Tanimbar islands. These together with Halmahera and Seram sit in the Wallacean region. The natural affinities of the avifauna west of the Wallace line is with East Asia, whereas those of the fauna east of the Lydekker line is with New Guinea and Australia (Lincoln, 1975; Mayr, 1944). These associations are explained by the concept that during periods when the sea level was lower than at present, the land masses on the respective shelves were mostly joined, allowing ready movement of mammals, birds and an easier movement of floral components.

Much remains to be discovered, particularly in Papua and selected islands of Wallacea (Mittermeier et al., 2013). We have attempted to add to the discussion of some basic questions using published data on avifauna sightings. The results of our investigations are set out in this descriptive paper.

## Methods

### *Species data*

Bird species lists were taken from the International Ornithological Congress (IOC) lists for 2014 (Avibase, 2015). Introduced birds were not included in calculations for the 27 islands. In the Indonesian territories such as Kalimantan, West Timor and Papua, data for the complete territory, i.e., Borneo, Timor and New Guinea was presented so as to give a more accurate picture. The IOC lists for Sumatra, Sulawesi and Papua included birds recorded in associated islands and archipelagos. The birds specialized to these small land areas were removed by consulting the following sources (del Hoyo et al., 1992–2011; Howard & Moore, 1984; Jeyarajasingam & Pearson, 2012; Pratt, Beehler, Anderton & Kóky, 2015). In calculations of the relationship of bird species and bird families to island area, species diversity in Biak, Missol, Salawati, Waigeo and Yapen were presented as separate entities from mainland New Guinea. Data on endemism was collected during this process.

An index of species commonality (ICS) was calculated in order to assess the movement of birds across straits between islands. The index was calculated as follows:  $cs_{a \text{ cf. } b}/n_a + cs_{a \text{ cf. } b}/n_b/2$  [ $cs$  = common species;  $n$  = number of species of birds; the letters  $a$  and  $b$  refer to the territories compared]. The index had similarities to that constructed by Lincoln (1975).

Plumage differences noted between the sexes were colour differences, striping patterns, iridescence and differences in dullness. Records of differences came principally from well-recognized sources (del Hoyo, et al., 1992–2011; Howard & Moore, 1984; Jeyarajasingam & Pearson, 2012; Pratt et al., 2015). The territories of Flores, Papua, Kalimantan, Java, Halmahera, Seram, Sulawesi and Sumatra were studied.

### *Land areas and distances*

Area figures used were from official sources where possible or from island area lists (High Commission of the Independent State of Papua New Guinea, 2015; Republik Indonesia, 2015; Wikipedia, list of islands 2015). Where species lists existed for smaller islands associated with principal islands, land areas were adjusted accordingly. Hence, for Sulawesi, the land area did not incorporate the Sangihe archipelago land estimates. The same treatment was accorded Sumatra and New Guinea and its associated archipelagos and larger associated islands.

Island strait distances were taken from published lists or estimated from scale maps (Wikimapia) and allowance was made for small island stepping stones in the estimates.

### *Ecological features*

Islands (19) were given a score according to the occurrence of certain ecosystem and environmental features (ecoregions). The ecoregions identified for the study areas were those of Wikramanayake et al., (2002). These were based on vegetation maps and the boundaries were delimited by climate, elevation and biogeographical considerations. A value of 1 was allocated for every ecoregion category listed for a particular island by Wikramanayake et al. (2002). This included grasslands and mangroves. Consultation of the *Atlas of Mangroves* (Spalding, Kainuma & Collins, 2010) for islands resulted in those with mangroves and yet not classified as possessing an ecoregion component being given a value of 0.25. All islands possessed the specialized habitats associated with seashores apart from that given to isolated patches of mangroves. This means that no additional score was given for this feature.

Habitats encouraging birds associated with wetlands are featured in the ecoregion classification (fresh water swamp forests, peat swamp forests and flooded grasslands). We made no extra provisions for the presence of freshwater lakes and rivers as all islands possessed some characteristic areas of this type. Some consideration was given to the presence of significant areas of

grasslands. Grassland ecoregions specifically identified were given a value of 1, but other localities also possessed variable areas of grasslands. These were assessed principally by consulting specialized accounts for the island groups (MacKinnon, Hata, Halim & Mangalik, 1997; Whitten, Damanik, Anwar & Hisyam, 1997; Whitten, Soeriaatmadia & Atiff, 1997; Whitten, Mustafa & Henderson, 2002; UNCCD, 2015). The figures presented in these papers require updating for greater accuracy, but such research is a future activity. The species commonly encountered in grassland are *Imperata*, *Paspalum*, *Chloris*, *Eleusine*, *Themeda*, *Tetrapogon*, *Polytrias* and *Desmodium* (Nitis, 2006). Specific island group information established that some islands possessed extensive grasslands (e.g., Timor has over 15 percent of its area occupied) and others a lesser amount (Monk, de Fretes & Reksodiharjo-Lilley, 1997; Trainor, Imanuddin, Aldy, Verbelen & Walker, 2009). The former category was allocated a value of 0.5 and those with lesser amounts a value of 0.25.

The cumulative scores established as a result of this exercise were used to estimate the correlation between ecoregions and bird diversity. In this calculation, Kalimantan, West Timor and Papua are represented by data for Borneo, Timor and New Guinea respectively, as ecoregions in part of an island may not always represent that found in the entire territory leading to a distortion of the association being investigated.

## Results

The number of species of birds increased with the size of the island territory according to expectations. The data analysed incorporated islands from Sumatra to Papua (New Guinea). The relationship between log area vs log species was linear (correlation coefficient 0.765—Figure 1). A log:log plot of the number of bird families represented against area showed a similar and even

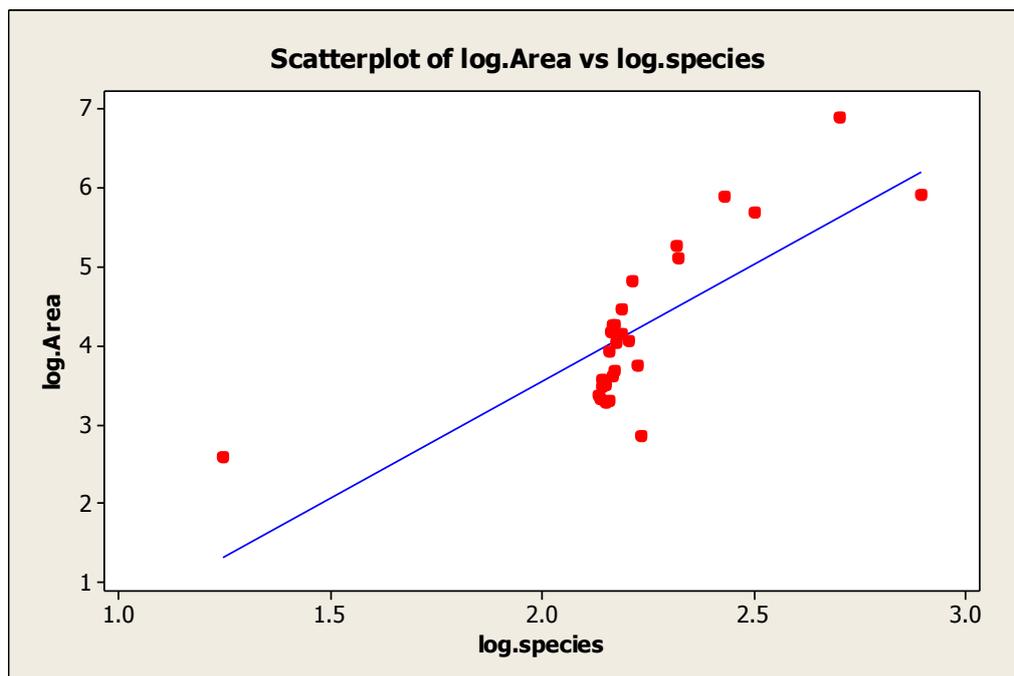


Figure 1. Relationship between Log Species and Log Area across Many Indonesian Islands

stronger linear relationship ( $r=0.839$ —Figure 2). There seemed to be no observable relationship between the dichromatic status of birds and the location, number of species of birds, or area occupied. The figures ranged from 25.7 to 34 percent over eight territories, with Papua showing 30.3, Java 29.5 and Flores a figure of 29 percent. Sumatra and Kalimantan returned figures of 32 and 34 percent respectively. The number of endemic species observed did not bear any relationship to the area occupied (data not shown). Some small islands like Biak and Waigeo supported endemics, whereas larger islands like Bangka and Timor recorded none.

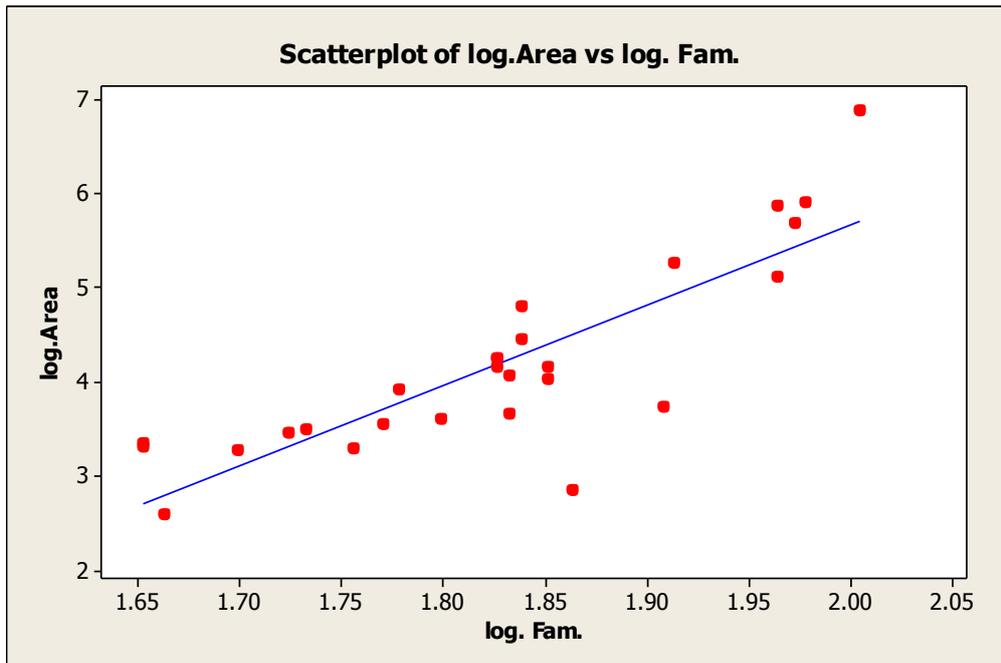


Figure 2. Relationship between Log Families and Log Area across Many Indonesian Islands

The relationship between the size of an island territory and ecological niches available for colonization yielded useful data. Recognized ecoregions on islands was supplemented with other information considered important to species colonization and expressed as a numeric value. When these figures were plotted against species numbers, a linear relationship was observed as illustrated in Figure 3 ( $r=0.934$ ). The ecoregion figures did not bear any relationship to the number of endemic species observed. Endemic occurrence figures were usually below 8 percent, although Sulawesi was in the region of 19 percent.

We investigated the proposition that on account of suggested sea water level changes in past ages giving rise to shallower seas, evidence of bird movement between islands would be greatest near islands now surrounded by shallow ocean depths and which were close to their neighbour. The details are given in Table 1. Here the ICS's are listed for a selection of islands where adequate data were available. Channel depth between islands is presented together with separation distance. The Table might be taken to indicate that islands surrounded by shallow seas experienced greater prior bird exchange accounting somewhat for the diversity observed. Analysis was difficult as sill depths are not known with precision. Thus, depth intervals were ranked and a test of association between sill depth and ICS was sought. This analysis revealed a negative correlation ( $0.823$ ;  $P=0.012$ ), indicating that low sea depths were associated with higher indices of common species. Notable exceptions were recorded to the suggested relationship. The most notable from our perspective was the comparison of Bali and Lombok. The index of common species was  $0.71$ ; we expected it to be lower. Other exceptions also are noted in Table 1. When separation distance was considered, the relationship with the ICS values did not reach a level of significance.

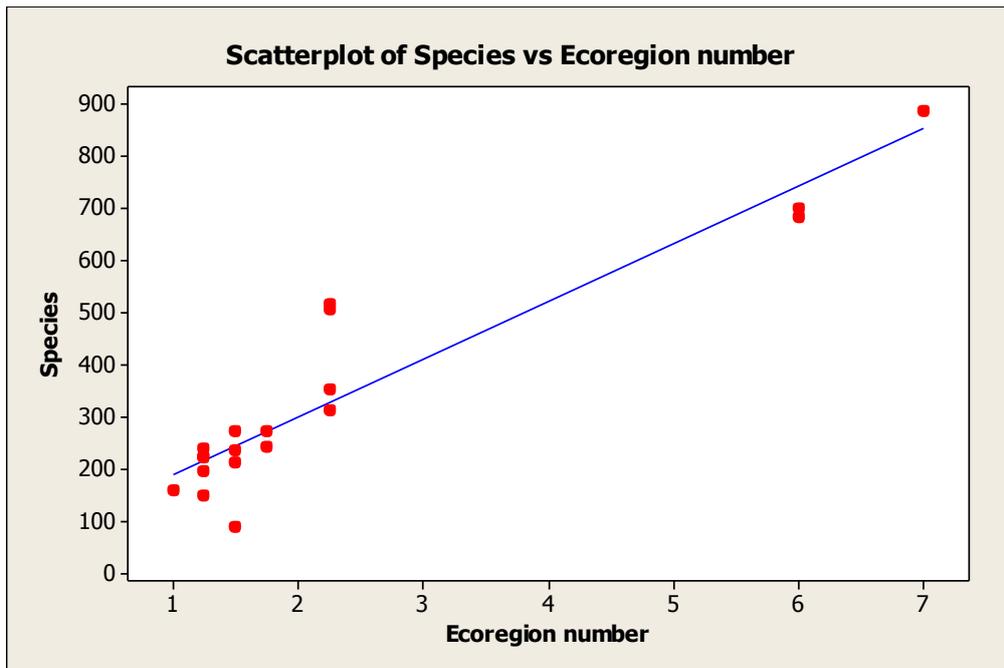


Figure 3. Relationship of Ecoregions Encountered to Bird Species Numbers Observed in Many Indonesian Islands

In seeking to identify the features facilitating spread, various known ecological, behavioural and flight characteristics of birds were studied among those not crossing the Lombok Strait. The pink-headed fruit dove (*Ptilinopus porphyreus*) appeared to be restricted by habitat considerations (altitude and food); some members of the cuckoo family were migratory, but did not venture across the strait. This also indicated the possible significance of habitat factors. A number of species not moving across the Lombok Strait were able to cross other water expanses (e.g. *Aerodramus maximus*—Black-nest Swiftlet; *Anthraceros albirostris*—Oriental Pied Hornbill; *Rhyticeros undulates*—Wreathed Hornbill). Subspecific specialization was noted in a number of birds restricted to the Sumatra–Java–Bali region, such as in *Aegithina tiphia*—Common Iora, *Dicrurus paradiseus*—Greater Racket-tailed Drongo and *Psittacula alexandri*—Red-breasted Parakeet. If the subspecific status was discounted, then the basal species enjoyed a widespread distribution.

## Discussion

The influence of area available for colonization and species richness or bird family representation was strongly related as commonly found (Newton, 2003). Until around 50,000 km<sup>2</sup> (or 5x10<sup>4</sup> to 10<sup>5</sup> our data), the species added tapered off as additional area was made available (MacArthur & Wilson, 1967; Whittaker, 1998). The data mean that the probability of encountering a species increases with colonisable area.

The strong relationship between species richness and ecoregions noted in this study is of interest, but fails to identify the most significant ecological features involved for particular families or species. The system of ecoregion classification adopted by Wikramanayake et al. (2002) was heavily dependent on vegetation features, but did not consider the small patches of divergent vegetation types present.

**Table 1.** Index of Common Species (ICS) calculated between islands and territories across barriers separated by deep ocean trenches and shallow seas. Sea, shore birds, ducks and diurnal birds of prey were excluded from calculations. Separation distances were derived from López Martin (2010), Pigram & Davies (1987) and Wikimapia. Sea depth data came from a variety of sources (Feng, Liu, Wang, Yu & Yuan, 2013; Ghofar 2002; Gordon, Giulivi & Ilahude, 2003; Hope & Aplin 2005; Metzger et al., 2010; Tomczak & Godfrey 2003; Wyrki 1961)

Movement	ICS	Separation Distance (km)	Sea Depth–Sill or Bottom (m)
<b>Shallow Sea Separation</b>			
Sumatra–Bangka	0.67	~13	~50–80
Sumatra–Java	0.71	8	~50–80
Java–Bali	0.75	3.2	~50–80
Lombok–Sumbawa	0.57	~11	<200
Sumbawa–Flores*	0.61	~14	<200
Papua–Salawati	0.62	~2 km	<80
Papua–Misool	0.60	~70	<115
Papua–Aru Islands	0.58	110	<115
<b>Deep Sea Trench Separation</b>			
Aru–Kei Islands	0.36	130	>1000
Kei Islands–Papua	0.38	~140	>1000
Waigeo–Halmahera	0.36	~225	≥580
Misool–Seram	0.28	~95	≥580
Kalimantan–Sulawesi	0.31	~100	>680
Bali–Lombok	0.71	~18	300
Wetar–Timor	0.81	~50	>1000
Flores–Timor	0.63	~150	>1000

\* Sape Strait is between Pulau Kelapa Island (just east of Sumbawa) and Komodo. Its waters represent the effective sill depth found between Sumbawa to Flores.

We adjusted for this feature in several instances by giving a notional value to the presence of smaller areas of mangroves and grasslands. Habitat diversity generally increases with island size and is significant to colonization and maintenance of species as well as accounting for the generating of new species. There is no easy way to separate area and habitat factors, so both can be considered determinants of species richness (Ricklefs & Lovette, 1999; Whittaker, 1998). In this mix might be added factors such as latitude (not relevant in Indonesia) and distance to the nearest mainland or larger island (Martin, Gaston & Hittier, 1995; Power, 1972).

The failure to find a relationship between the incidence of sexual dichromatism and factors such as island size and ecoregions is not surprising, since the discrimination available to birds is much greater than that possible via the unaided human eye (Santos, Edward & Lumeij, 2006).

Since Wallace’s time, the differences between the avifauna east and west of the Lombok Strait has intrigued scientists. Lincoln (1975) has stated correctly that observing the presence or absence of a particular bird species gives different impressions than when both presence and frequency figures are considered. Lincoln was of the conviction that the wetter islands to the west of the Strait

with their relatively greater abundance of fruiting trees giving succulent food accounted for the predominance of fruit eaters in Java/Bali as against seed and nectar eaters further east. The eastern islands are much drier than those westward and with less extensive cultivation. He considered that the habitat was of greater significance than the width of the sea gaps between islands in determining species richness. Mayr (1944) also believed that ecological factors rather than distances across straits were the most significant factor in species occurrence. We essentially agree with this conclusion. However, our data, which is also based on the presence or absence of species, differ from Mayr's in that he considered the Lombok Strait to be a more efficient barrier in interfering with transfer than the others in the Lesser Sunda group of islands.

The popular concept is that these straits ceased to exist during times when lower ocean levels prevailed while the Lombok Strait continued to exist, although its width changed with the lower sea levels (Heinsohn & Hope, 2006; van Oosterzee, 2006). While we are not challenging this proposition, our data may be taken to suggest that the expression of avifaunal diversity has not been overly hindered by the Lombok Strait. Bird diversity undoubtedly is influenced by multiple factors. This is in accordance with Carlquist's early data as reported by Whittaker (1998) for the islands from Bali to Alor. We do not question that the Strait has interfered with the colonization of islands east by some species originating in Asia.

The Lombok Strait contrasts favourably with straits further east that have relatively small separation distances. In our analysis there was greater similarity in the avifauna (excluding sea, shore-birds, the duck family and diurnal birds of prey) when Bali and Lombok were compared (Lombok Strait) than when Lombok and Sumbawa (Alas Strait) and Sumbawa and Flores (Sape Strait) were compared. Again it appears that the ecological features and niches found in these islands were major factors determining whether a species established, adapted and flourished.

Separation of islands by shallow seas, that are presumed previously to be land bridges, does appear to have some impact on colonization by some birds. For example, the presence of cassowaries on Biak, Salawati and Yapen islands speaks to their previous connection by dry land to mainland Papua. The absence of birds of paradise beyond the islands of Misool and Waigeo in the westward direction from Papua could be taken as evidence of a previous land connection, but it probably also relates to suitable habitats within a reasonable flying distance of the mainland. In these small island domains, endemic species were sometimes present (e.g., Biak, Misool and Waigeo). Failure of these to move elsewhere and establish may simply be an expression of the pre-emptive exclusion principle rather than exclusivity. Similarly, the much greater similarity of species found on Aru to those in Papua rather than on the Kei group could be taken to indicate that previous land connections with Papua played some significance. The Aru Islands also are distinguished by having a cohesive group of large islands making for more conducive bird habitats with its larger combined land area (~ six times larger) than on the Kei Islands.

The long separation distance between Kalimantan and Sulawesi could reasonably be expected to inhibit some bird movement, a feature also apparently operating with movement from Papua west to other large islands (Seram and Halmahera). In our brief study of bird movement, the overwhelming impression was gained that distribution was primarily determined by habitat and food availability, and not the depth of the strait functioning as a physical barrier to colonization in the past. Selective pressure undoubtedly contributed to subspecific specialization noted with a number of species.

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