Jurnal Manajemen Hutan Tropika, *31*(1), 61–71, January 2025
EISSN: 2089-2063
DOI: 10.7226/jtfm.31.1.61

Scientific Article
ISSN: 2087-0469

Factors Affecting Bird Diversity in the Wetlands of Muara Gembong, Indonesia

Muhammad Hamas Fathani[1*], Yeni Aryati Mulyani[2], Ani Mardiastuti[2], Wibowo Agung Djatmiko[3]

[1]Graduate Program of Tropical Biodiversity Conservation, Department of Forest Resource Conservation and Ecotourism, Faculty of Forestry and Environment, IPB University, Academic Ring Road, Campus IPB Dramaga, Bogor, Indonesia 16680
[2]Department of Forest Resource Conservation and Ecotourism, Faculty of Forestry and Environment, IPB University, Academic Ring Road, Campus IPB Dramaga, Bogor, Indonesia 16680
[3]Lembaga Alam Tropika Indonesia (the Indonesian Tropical Institute), Jalan Sutera 1 Situgede, Bogor, Indonesia 16115

Received April 5, 2024/Accepted January 16, 2025

Abstract

Marshlands and backswamps are among the threatened habitats in Indonesia, along with mangroves, particularly in Java due to area development and land conversion. Muara Gembong is one of the remaining wetlands in Java and serves as one of the last refuges for the bird community in wetlands, particularly mangrove and marsh-associated birds. We observed bird communities and collected eleven habitat variables in three habitats, namely mangrove, marsh, and fishpond, to see which variable affects bird abundance and diversity most. We found out that the total number of plant species, along with the number of tree, understory, and shrub species, were the strongest factors affecting bird diversity in Muara Gembong. Separate analysis in each habitat, however, reveals that different abiotic factors also strongly correlate with bird diversity. Vegetation correlates strongly with bird diversity in mangroves and marshes, while pH and turbidity play a strong role in bird diversity in fishponds.

Keywords: *bird community, mangrove, marshland, vegetation*

**Correspondence author, email*: *hamas.fathani@gmail.com*

Introduction

Muara Gembong in Bekasi Regency, West Java, is an important area for bird conservation in the coastal area of Java Island. Muara Gembong is listed as an important bird area and endemic bird area since 1999 (BirdLife International, 2022). However, further studies are required due to a lack of data. Muara Gembong was also once proposed as a nature reserve back in 1980 (Whitten et al., 2013) to preserve one of the last intact mangroves on the Javan coast. The nature refuge only applied to Muara Gembong in a short period, as Muara Gembong is now in a great decline due to habitat deforestation and land clearing (Nugraha et al., 2019). There were also reports about endangered bird species found in Muara Gembong, namely Javan lapwing (*Vanellus macropterus*, Iqbal et al., 2013) and Javan coucal (*Centropus nigrorufus*, BirdLife International, 2001), with the first report did not yield any Javan lapwing sightings.

Muara Gembong was also home to coastal marshlands. Interestingly, marshlands and backswamps are also among the threatened bird habitats in Indonesia, particularly in Java, due to area development and land conversion. These habitats, however, might still harbor a considerable amount of bird diversity and abundance. Even though there was no Javan lapwing found in Iqbal et al. (2013) reports, Muara Gembong is still considered one of the best wetlands in Java, particularly around Jakarta Bay.

Bird habitat has been widely studied around the world, particularly habitat factors that affect bird communities. Most of the papers stated that vegetation is the most contributing factor in mangroves and marshes. However, there were also other factors at play, such as wetland area (Wang & Zhou, 2022), abiotic factors, and even spatial characteristics, such as patch area (Mohd-Azlan et al., 2015). While other wetland habitats may not seem as important as mangroves, they are important to maintain high species richness in wetlands (Mohd-Azlan et al., 2015). Research about Indonesian wetlands from the perspective of ornithology has been done many times. Those research studies mostly covered bird diversity in mangroves only (Mubarrok & Ambarwati, 2019; Sabrina et al., 2019; Puttileihalat et al., 2020), while others covered the relationship between birds and their habitat (Adil et al., 2010; Nurdin et al., 2021). Research that encompasses other wetland habitats apart from mangroves is still scarce. Therefore, the objective of this study is to examine the abiotic and biotic factors, especially vegetation, that affect bird diversity in wetland habitats of Muara Gembong.

Methods

Study area Muara Gembong is one of the estuaries in the north of Bekasi Regency, Indonesia. Muara Gembong is located in the northeast of Jakarta, particularly north of Bekasi City and the Babelan subdistrict. It is also a tributary of the Citarum River that flows to the Jakarta Bay. Muara Gembong is subjected to periodic high tide twice a day with various peak tide times throughout the year (Dina 'Amalina et al., 2019; Haryono & Narni, 2004). This regular tide affects both natural and man-made habitat dynamics in Muara Gembong, as these habitats were flooded during the highest spring tide.

Muara Gembong can be characterized as a typical coastal area in Indonesia, with most of the land cover being fishponds with several fragmented mangroves. About 46% of the land cover in Muara Gembong has been used for agriculture, such as traditional fishponds and rice fields (Nugraha et al., 2019). The other 42% is covered by natural coastal habitat, such as mangroves, marshes, and riverbanks. There are some small fishermen settlements along the riverbanks that made up 3% of the land cover, while the rest (9%) are water bodies, such as rivers and floodplains. These habitats and land covers in Muara Gembong have been heavily fragmented and disturbed by human activities. Therefore, there are no clear boundaries between the habitats. Locals are frequently visiting these habitats for fishing, fish farming, or foraging the sedges for thatch mats.

Three types of habitats, namely mangroves, marshes, and fish ponds, were observed. These three habitats represent various gradients in terms of habitat disturbance and integrity. Mangrove was characterized as a land cover with dense mangrove trees and shrubs. Marshlands dominantly covered with shrubs, ferns, and understories with scarce trees. Marshlands sometimes were a product of fishponds that are no longer maintained. Fishponds are mostly made up of water bodies for fish farming with little to no vegetation at all.

Bird survey We collected the bird community data in November 2022. We observed the bird community with point samples (Bibby et al., 2000) during the bird's active period (6–9 am and 3–6 pm) on clear days. A total of 31 points were obtained in three habitats, with 10 points in fishponds and marshes each and 11 points in mangroves (Figure 1). Every observation point was carefully spaced between one another for at least 200 m apart. To eliminate the edge effect, we avoid taking points in the border of two different habitats. The observer stayed at each point for 20 minutes. The first 10 minutes were reserved for birds to settle and adapt to the observer's presence. The next 10-minute period was used to record all birds seen and/or heard within a 50 m radius.

Bird identification and classification referred to Eaton et al. (2016). Bird feeding guild classification was derived from bird major diet described in MacKinnon (1990). Data from bird surveys were analyzed to determine bird community richness, diversity, and evenness index.

Habitat variable measurement There were 11 habitat

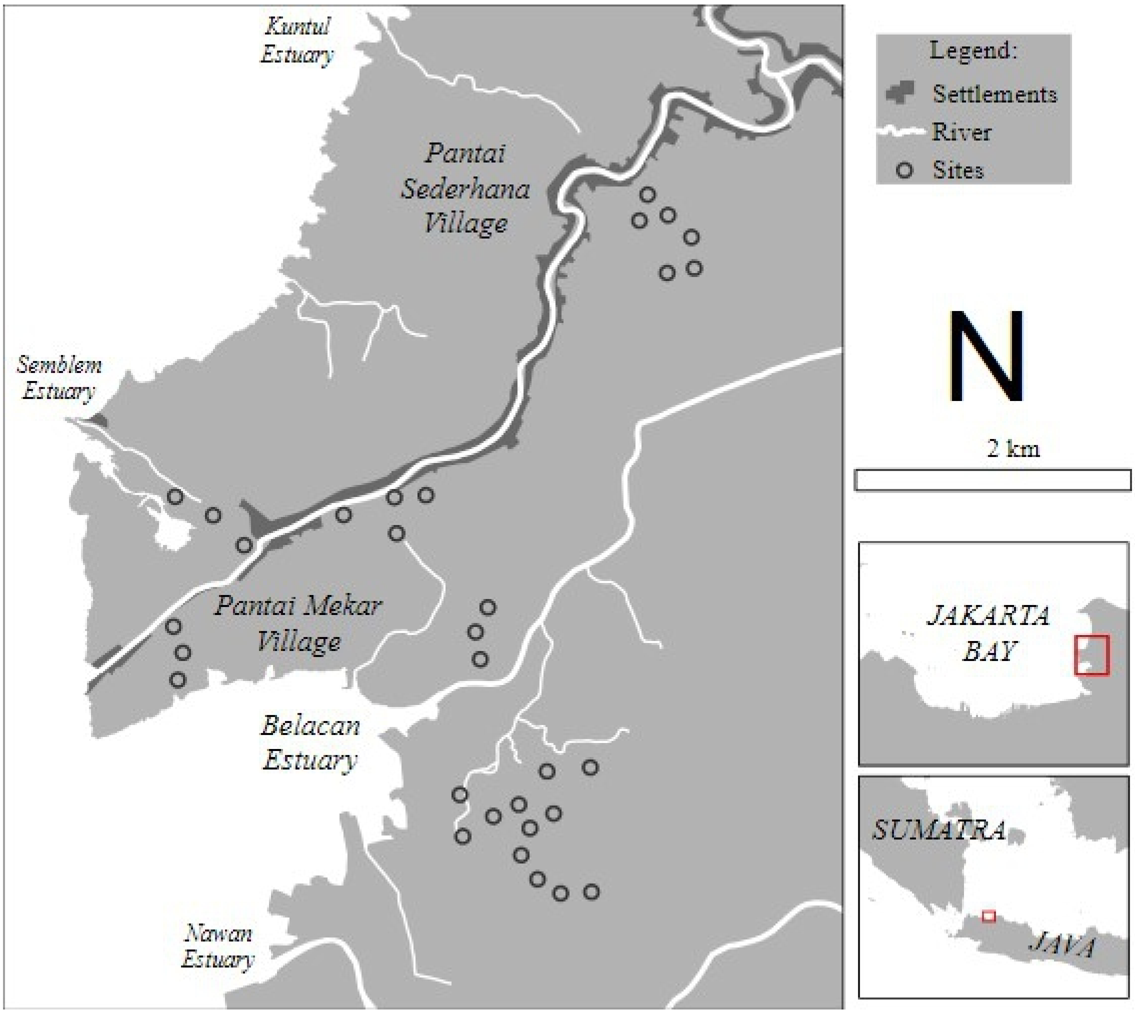

Figure 1 Map of Muara Gembong area.

Jurnal Manajemen Hutan Tropika, *31*(1), 61–71, January 2025
EISSN: 2089-2063
DOI: 10.7226/jtfm.31.1.61

Scientific Article
ISSN: 2087-0469

variables accounted for in the analysis in our study (Table 1). These habitat variables were chosen based on two previous studies (Rajpar & Zakaria, 2014; Yang et al., 2022). Four water-related habitat variables were measured in our study, namely water body depth, pH, salinity, and turbidity. Both habitat and vegetation data were collected along with bird observation points, resulting in 31 samples across the three habitats.

Vegetation variables measured were vegetation structure and vegetation composition. Vegetation structure was represented with the percent of cover over a 20 m × 20 m grid (Figure 2). The vegetation cover was classified into trees, shrubs, and understories. Vegetation cover was estimated using aerial photography. A drone was flown at a fixed height of about 25 m to get a view of the 20 m × 20 m grid. Vegetation composition was represented by the total number of species, which we classified into tree species, shrub species, and understory species. We also added the total number of plant species found in the sample point. Vegetation classification referred to Raunkiaer plant life forms with modification (Mueller-Dombois & Ellenberg, 1967). In total, seven vegetation variables were accounted for in data analysis.

We collected four abiotic variables, in which all of them were related to water properties. These variables were water pH, salinity, turbidity, and depth. Water pH was measured using a portable pH-meter that has been previously calibrated using a standard solution. Water salinity was measured using a water salinity refractometer, while the water turbidity was measured following the black disk method (West & Scott, 2016). Water depth was measured using a 2 m long ruler.

Data analysis Bird community were presented as bird species-plot matrix to be further processed in RDA (redundancy analysis). We measure the bird diversity with Shannon-Wiener's H' diversity. A Hutcheson's t-test was conducted between the habitats to see whether all three habitats were statistically different in terms of bird diversity.

Table 1 Habitat variables accounted in this study

No.	Habitat variable	Unit	Remarks
1	Number of tree species	no unit	Trees with dbh[1] >10 cm
2	Number of shrub species	no unit	Woody shrubs
3	Number of understory species	no unit	All understories with no wood
4	Total plant species	no unit	tree + shrub + understory species combined
5	Percent of tree cover	%	100% max. based on drone image
6	Percent of shrub cover	%	100% max. based on drone image
7	Percent of understory cover	%	100% max. based on drone image
8	Water pH	no unit	measured 3 times in each point
9	Water salinity	‰	sampled with pipette
10	Water turbidity	cm	measured in broad daylight (more than 20 000 lux)
11	Water depth	cm	measured in broad daylight along with water turbidity

[1]dbh = diameter at breast height, measured roughly at 130 cm from the highest buttress/stilt root.

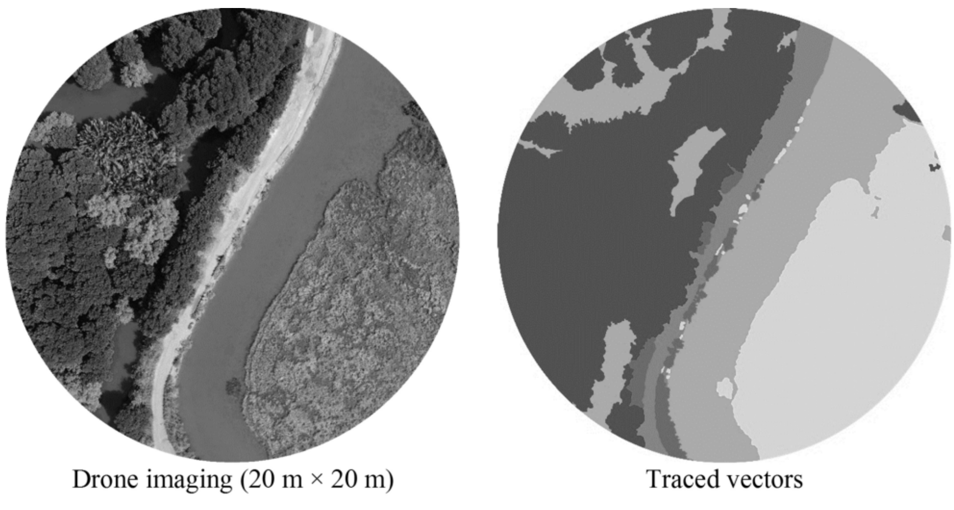

Figure 2 Drone imaging and resulted vectors for vegetation cover analysis.

We also added a Chao-1 species estimate from Chao (2006) to calculate and compare how many birds should have been in certain habitats. All indexes above were calculated using PAST software (Hammer et al., 2001) with the 'unbiased version' option unchecked. We then transformed the bird species matrix with Hellinger transformation to eliminate bird absence in the matrix before putting it into RDA. We also briefly analyzed feeding guild composition *a priori* to better understand their relationship with the habitat.

We standardize habitat variables using the standardize function in Microsoft Office Excel from each site so that the data would have a zero mean and standard deviation of one. All habitat variables were standardized, except for the number of plant species. We analyzed the relationship between bird diversity and habitat variables using RDA. All transformed habitat variables were entered as explanatory variables, while the bird species matrix was entered as a response variable.

We also put our habitat and bird diversity data from each habitat into a PCA with a covariant matrix. All the variables were first standardized before processed in PCA, except for the number of vegetation species variables. The resulting components were selected based on their eigenvalue (eigenvalue > 1) to determine the components that might explain bird diversity best. The RDA and PCA were also done using PAST software. Error (α) limit was set to 5% for every statistical analysis done in this study.

Results

Bird community structure and diversity There were 54 bird species from 23 families found in Muara Gembong (Table 2 and Table 3). Waterbirds made up 21 out of 54 species found. The Golden-Bellied Gerygone (*Gerygone sulphurea*) was the most abundant bird in our study area with 132 encounters during our survey. The second and third most abundant birds in the area were the Ashy Tailorbird (*Orthotomus ruficeps*) and the White-Breasted Waterhen (*Amaurornis phoenicurus*), respectively.

The waterbirds found in Muara Gembong were dominated by the White-Breasted Waterhen, Black-Crowned Night-Heron (*Nycticorax nycticorax*), Little Egret (*Egretta garzetta*), and Whiskered Tern (*Chlidonias hybrida*). All waterbirds found were mainly fish eaters, except for the White-Breasted Waterhen which feeds mainly on seeds and small benthic creatures. White-Breasted Waterhen, Black-Crowned Night-Heron, Little Egret, and Whiskered Tern were also a generalist bird and commonly found throughout coastal swamps and mangroves in northern coasts of Java.

As many as 22 bird species were found in all three habitats. Meanwhile, there were five, six, and four bird species found only in mangroves, marshlands, and fishponds, respectively (Figure 3). These birds may represent the abundance of specialist or mangrove interior species. Most of the birds found in Muara Gembong were insectivores (16 species), followed by omnivores (12) and piscivores (9), respectively.

RDA results Redundancy analysis for overall habitat in Muara Gembong yielded satisfactory result (R^2 = 0.59, adjusted R^2 = 0.35, p-value = 0.01). The first axis variance from the biplot constitutes more than one third of the first axis of the PCA variance from the same dataset (RDA 1st axis s^2 = 19.59%; PCA 1st axis s^2 = 53.23%). The proportion between the first axis of RDA and PCA represents how much the biplot explains variation along with response variables (Zelený, 2021). This means that our biplot was still able to represent about one-third (36.74%) of all variations.

The bird species were spread throughout the quadrants, but most of the bird species were concentrated in the first and fourth quadrants with 14 and 13 species, respectively. Most of the studied habitat factors (five out of eleven) were also plotted in the fourth quadrant. Plotted bird species were almost evenly distributed, that different sets of factors corresponded with different bird communities. The total number of plant species was represented as the longest vector in our biplot.

PCA results Our dataset unfortunately was limited by the number of samples (10–11 samples in each habitat), therefore, it was not possible to run the dataset through RDA. However, it was still possible to run our dataset through PCA. Our PCA matrices show that different habitats yield different components as well as different numbers of components that have eigenvalue > 1. Mangrove yields three components, while marsh and fishpond yield four components each.

The dataset in mangroves returned three components that could explain about 83.8% of the variations found. The resulting component was mainly constituted by vegetation variables. Abiotic variables also became strong predictors in the second and third components. The first component was non-tree vegetation characteristics that can explain almost half (43.3%) of the bird community in mangroves (Table 4). The remaining components, which partly consist of abiotic variables, share 40.4% of the variance. Water depth and turbidity has high load in second and third component, respectively.

The marshes PCA returned four components that explained 79.4% of the variations from the dataset. About 36.7% of them were explained by a vegetation component, which we labeled as the structure of marsh vegetation. The rest of the variation was explained by abiotic components. These abiotic components explained more than half of the variation in marshes. These components were highly affected by water pH, turbidity, and salinity (Table 5). Vegetation variables tend to return negative values on the second and third components.

The fishpond dataset returned four components that accommodated 83.2% of the variations found in fishponds. All four components were heavily influenced by vegetation, evidenced by high loading value in variables related to vegetation (Table 5). Aquatic vegetation structure became the highest component (34.3%) in fishponds, followed by the presence of brackish water shrubs (20.5%). The third and fourth components are the structure of submerged mangroves and aquatic vegetation richness, respectively. Both components explained less than 20% of the variation in fishponds.

Jurnal Manajemen Hutan Tropika, *31*(1), 61−71, January 2025
EISSN: 2089-2063
DOI: 10.7226/jtfm.31.1.61

ISSN: 2087-0469

Table 2 Bird species list and their encounter in three habitat

No	Common name	Scientific name	Mangrove	Marsh	Fishpond
1	Purple Heron	*Ardea purpurea*	-	2	-
2	Great Egret	*Ardea alba*	1	-	3
3	Medium Egret	*Ardea intermedia*	1	-	-
4	Little Egret	*Egretta garzetta*	19	12	14
5	Striated Heron	*Butorides striata*	1	9	11
6	Javan Pond-heron	*Ardeola speciosa*	16	3	16
7	Black-crowned Night-heron	*Nycticorax nycticorax*	14	33	-
8	Yellow Bittern	*Ixobrychus sinensis*	-	2	2
9	Black Bittern	*Ixobrychus flavicollis*	6	1	12
10	Wandering Whistling-duck	*Dendrocygna arcuata*	2	-	-
11	Ruddy-Breasted Crake	*Zapornia fusca*	14	5	-
12	White-Browed Crake	*Poliolimnas cinereus*	6	1	-
13	White-breasted Waterhen	*Amaurornis phoenicurus*	21	26	3
14	Common Moorhen	*Gallinula chloropus*	-	2	-
15	Pacific Golden-plover	*Pluvialis fulva*	7	9	3
16	Whimbrel	*Numenius phaeopus*	6	12	-
17	Common Redshank	*Tringa totanus*	2	-	-
18	Wood Sandpiper	*Tringa glareola*	-	-	3
19	Common Sandpiper	*Actitis hypoleucos*	1	7	23
20	Whiskered Tern	*Chlidonias hybrida*	13	3	29
21	White-winged Tern	*Chlidonias leucopterus*	2	-	1
22	Gray-cheeked Green-pigeon	*Treron griseicauda*	-	7	-
23	Sunda Collared-dove	*Streptopelia bitorquata*	23	17	9
24	Spotted Dove	*Spilopelia chinensis*	4	9	15
25	Plaintive Cuckoo	*Cacomantis merulinus*	1	2	-
26	Greater Coucal	*Centropus sinensis*	-	3	-
27	Lesser Coucal	*Centropus bengalensis*	-	1	-
28	Typical Swifts	*Apus sp.*	17	27	3
29	Collared Kingfisher	*Todiramphus chloris*	13	4	-
30	Cerulean Kingfisher	*Alcedo coerulescens*	12	24	8
31	Blue-Tailed Bee-eater	*Merops philippinus*	-	-	4
32	Freckle-breasted Woodpecker	*Dendrocopos analis*	1	-	-
33	Sunda Pygmy Woodpecker	*Yungipicus moluccensis*	6	6	1
34	Pacific Swallow	*Hirundo tahitica*	4	2	14
35	Sooty-headed Bulbul	*Pycnonotus aurigaster*	5	-	1
36	Yellow-vented Bulbul	*Pycnonotus goiavier*	3	6	8
37	Golden-bellied Gerygone	*Gerygone sulphurea*	38	76	18
38	Clamorous Reed-warbler	*Acrocephalus stentoreus*	6	11	13
39	Zitting Cisticola	*Cisticola juncidis*	5	15	26
40	Golden-headed Cisticola	*Cisticola exilis*	1	2	2
41	Common Tailorbird	*Orthotomus sutorius*	4	14	-
42	Ashy Tailorbird	*Orthotomus ruficeps*	33	44	2
43	Plain Prinia	*Prinia inornata*	-	-	1
44	Yellow-bellied Prinia	*Prinia flaviventris*	-	12	4
45	Malaysian Pied-fantail	*Rhipidura javanica*	7	14	-
46	White-breasted Woodswallow	*Artamus leucorhynchus*	3	-	3
47	Little Spiderhunter	*Arachnothera longirostra*	1	-	-
48	Brown-throated Sunbird	*Anthreptes malaccensis*	1	4	-
49	Ornate Sunbird	*Cinnyris ornatus*	11	3	6
50	Scarlet-headed Flowerpecker	*Dicaeum trochileum*	1	2	1
51	Javan Munia	*Lonchura leucogastroides*	4	-	1
52	Scaly-breasted Munia	*Lonchura punctulata*	1	-	2
53	White-capped Munia	*Lonchura ferruginosa*	-	36	-
54	Eurasian Tree Sparrow	*Passer montanus*	-	-	1
	Total encounter		355	504	281

Most abundant bird species in each habitat (column) were shown in bold.

Jurnal Manajemen Hutan Tropika, *31*(1), 61–71, January 2025
EISSN: 2089-2063
DOI: 10.7226/jtfm.31.1.61
Scientific Article
ISSN: 2087-0469

Table 3 Summary of the bird community variables in three habitats

Habitat	S	Chao-1	H'	E
Mangrove	**42**	**55**	**3.31**	0.65
Marsh	39	39	3.17	0.61
Fishpond	34	42	3.10	**0.65**
Overall	54	59	3.46	0.59

Highest value from each variable(column) were shown in bold.

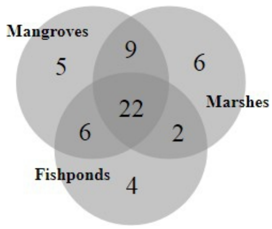

Figure 3 Venn diagram representing number of bird species found in the three habitat.

Table 4 List of components in three habitats (eigenvalue >1)

Habitat	PC	Component names	% variance
Mangrove	1	Non-tree vegetations	43.33
	2	Structure of aquatic plants and mangrove trees	27.41
	3	Characteristics of open water body	13.03
Marsh	1	Structure of marsh vegetation	36.67
	2	Water quality in water body with trees	18.60
	3	Characteristics of water body with trees	14.55
	4	Presence of puddles and small pool	9.53
Fishpond	1	Aquatic vegetation structure in fishpond	34.27
	2	Presence of brackish shrubs	20.45
	3	Aquatic vegetation richness	15.90
	4	Structure of submerged mangrove	12.57

Table 5 Loadings of habitat variables on each component

Component	Fishpond				Marsh				Mangrove		
	PC 1	PC 2	PC 3	PC 4	PC 1	PC 2	PC 3	PC 4	PC 1	PC 2	PC 3
S tree	0.01	0.25	**0.63**	-0.17	-0.36	0.04	0.01	0.15	0.37	0.16	**-0.31**
S shrub	**0.38**	0.13	<0.01	0.22	0.24	**-0.46**	-0.15	0.31	**0.39**	-0.12	0.22
S understory	0.31	-0.09	**-0.46**	0.11	**0.42**	0.09	-0.01	-0.35	0.37	0.24	0.06
S total	0.36	0.24	0.33	<0.01	**0.41**	-0.16	-0.09	-0.10	**0.43**	0.16	-0.06
pH	**0.45**	-0.16	0.03	0.20	0.16	**0.56**	-0.21	0.37	-0.25	0.37	<0.01
Salinity	-0.25	**0.45**	-0.07	0.12	0.23	0.15	**0.56**	**0.40**	-0.32	0.25	-0.02
Turbidity	-0.24	**0.40**	0.13	**0.47**	0.20	**0.39**	-0.15	**-0.53**	0.05	0.06	**0.82**
Water depth	0.37	-0.13	**0.36**	0.17	-0.18	-0.18	**0.61**	**-0.40**	-0.15	**0.47**	**0.33**
% tree	-0.13	-0.31	0.22	**-0.54**	-0.22	**0.39**	**0.29**	0.03	0.02	**0.43**	-0.22
% shrub	0.11	**0.50**	-0.23	**-0.41**	0.36	-0.20	0.25	0.04	**0.41**	-0.04	0.12
% understory	**-0.37**	-0.33	0.18	0.38	**0.38**	0.21	0.26	0.12	0.15	**0.52**	-0.06

Top three absolute values in each component (column) were shown in bold.

Discussion

Bird community The Golden-Bellied Gerygone, Ashy Tailorbird, and White-Breasted Waterhen were generalist species in Muara Gembong, evidenced by their presence in all three habitats observed. These birds were also present in fishponds, although they were rarely encountered there. The three most dominant birds confirm that the structure of the terrestrial bird community in mangroves was dominated by insectivores (Table 6). Hernowo (2016) pointed out that insectivorous birds are also abundantly present in mangroves and marshes. Interestingly, the bird community in Muara Angke (the other area within Jakarta Bay) was dominated by piscivores and omnivore birds. Andriwibowo et al. (2023) found that Muara Angke nature reserve was dominated by birds from the Anatidae and Ardeidae families, which were omnivores and piscivores. This difference can be attributed to differences in disturbance level. Although adjacently located, Muara Angke is a nature reserve and thus provides cover with less disturbance and minimum interference from human activities. Nevertheless, this study did not encompass much about human disturbance, therefore, further studies were still needed to explore the relationship between bird community and human activities in Muara Gembong.

We can infer from the proportion in Figure 3 that most birds were found in all three habitats. This finding suggests that Muara Gembong is a disturbed wetland habitat.

Table 6 Bird feeding guild composition found in our study

Guild	Mangrove	Marsh	Fishpond	Overall
Frugivores	-	1	-	1
Frugivores-Insectivores	2	1	2	2
Granivores	2	1	2	3
Granivores-Frugivores	-	-	1	1
Insectivores	13	12	12	16
Carnivores	-	2	-	2
Nectarivores	3	2	1	3
Nectarivores-Frugivores	1	1	1	1
Omnivores	10	9	6	12
Piscivores	7	7	6	9
Piscivores-Insectivores	4	3	3	4
Sum	42	39	34	54

According to Morelli (2015), a large percentage of generalist bird species indicates a disturbed habitat. The disturbance may contribute to change in bird species composition and structure. The sensitive and mangrove-interior birds may have moved away from the disturbance and thus been replaced by more common birds with broad and flexible habitat requirements.

Even though a large proportion of bird species were encountered in three habitats, the communities seem very different in terms of bird diversity. A Hutcheson's t-test run through these habitats shows that mangroves shares low similarity with marshes (t = 2.27, p-value = 0.02) and even lower similarity with fishponds (t = 3.11, p-value = 0.001). However, marshes and fishponds share high similarity compared to other pairs (t = 1.05, p-value = 0.29). The low similarity between each other was mainly due to differences in the encounter of certain species. For example, the Sunda Collared-Dove (*Streptopelia bitorquata*) and the Golden-bellied Gerygone were the third most abundant species in mangroves and the most abundant bird in marshes, respectively, both of which were rarely encountered in fishponds. Marshes and fishponds shared some common species, such as the yellow-bellied Prinia (*Prinia flaviventris*) and the Zitting Cisticola (*Cisticola juncidis*). Both species could be found in marshes and fishponds and yet were non-existent in mangroves. Fruit-eating birds, such as doves prefer habitat with many trees for foraging, while several perching birds, such as reed-warblers, cisticolas, and prinias, prefer an open area with several shrubs and grasses.

According to the Chao-1 estimate, Muara Gembong may hold up to 59 bird species that are scattered in three habitats. However, this number may be underestimated. Previous studies in Muara Gembong found up to 131 species (Purnama, 2011). The differences between the estimates and actual numbers were caused by several reasons. Differences in the numbers of habitats observed and the time spent during observation might contribute to the differences in species encountered. Regional development might also influence the bird encountered in Muara Gembong, as urbanization is highlighted to be one of the main factors in bird abundance decline (Mao et al., 2019).

The difference between Chao-1 estimates and the number of bird species may indicate a possible lack of observation points. The points observed in mangroves and fishponds might not be enough, resulting in a lot of one-time encounters. It should be highlighted that marshes have the same Chao-1 estimate with their number of species, meaning that all species in marshes have already been discovered. It is possible that the species that have not been discovered yet are residing in other habitat, e.g., some species in fishponds may also use mangroves but have not been seen there, and vice versa. This is due to the difference in overall Chao-1 estimates being only five species away from the actual number of species, lower than the difference between Chao-1 and the actual number of species in mangroves and fishponds. It means that some species have actually been seen, but only in one or two habitats.

Overall relationships between habitat variables and bird diversity Our biplot revealed that the total number of plant species (S all, Figure 4) explained most of the bird's presence in Muara Gembong, represented by the longest vector. Other variables, such as number of tree species (S tree), number of understory species (S understory), and number of shrub species (S shrub), also correspond with most of the bird species found in Muara Gembong. This result is in agreement with Rajpar & Zakaria (2014), where vegetation composition was giving positive influence in the distribution and diversity of waterbirds. Mohd-Azlan et al. (2015) also pointed out that plant species richness was associated with overall and mangrove-dependent bird species richness. The number of shrub species and the number of understory species were strongly correlated with several bird species associated with marshes, such as the Common Moorhen (*Gallinula chloropus*), the Golden-Headed Cisticola (*Cisticola exilis*), and the Yellow-Bellied Prinia (*Prinia flaviventris*). These birds prefer to forage and roost between the shrubs and understories rather than mangrove trees.

Meanwhile, the proportion of vegetation cover (% tree cover, % shrub cover, % understory) has a weak correlation with overall bird species, as those were only able to explain some of the bird species. For example, the percent of tree cover has a strong correlation with the Malaysian Pied-Fantail (*Rhipidura javanica*), White-Capped Munia (*Lonchura ferruginosa*), and Purple Heron (*Ardea purpurea*). On the other hand, Yellow Bittern (*Ixobrychus sinensis*) and Zitting Cisticola (*Cisticola juncidis*) only responded strongly to percent of shrub and understory cover.

Jurnal Manajemen Hutan Tropika, *31*(1), 61−71, January 2025
EISSN: 2089-2063
DOI: 10.7226/jtfm.31.1.61
ISSN: 2087-0469

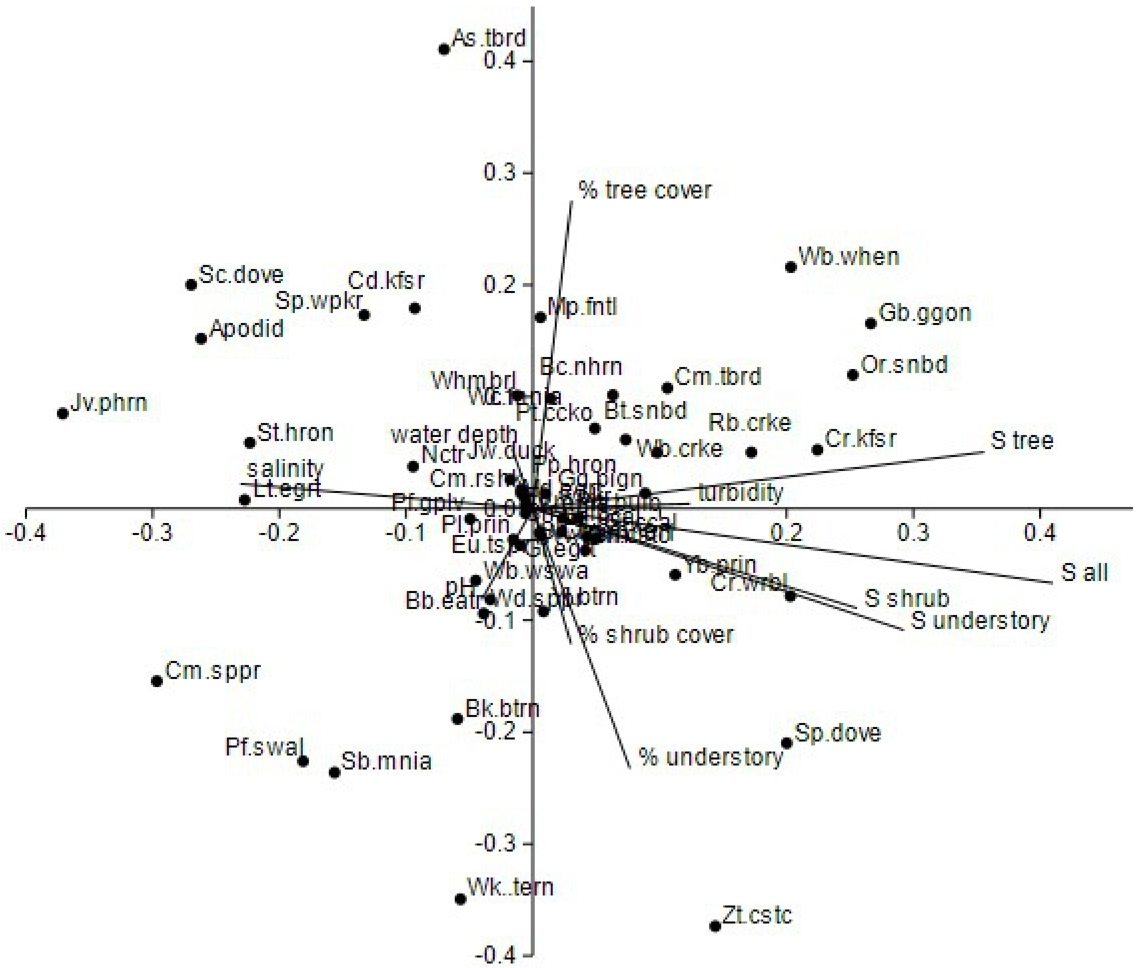

Figure 4 The RDA biplot, showing relationship between habitat variables and bird diversity.

Several bird species also correlated with low vegetation cover, such as the Whiskered Tern (*Chlidonias hybrida*) and Black Bittern (*Ixobrychus flavicollis*). The Whiskered Tern is known as an aerial insectivore and piscivore that needs wide landscapes to forage on, therefore, seen more often in low-density vegetation. Vegetation cover still becomes a strong predictor for bird diversity due to its natural function as a roost and even foraging place for some other species. The role of vegetation cover was particularly influential in a disturbed urban setting (Wang & Zhou, 2022) where vegetations are rarely found. Muara Gembong is a tropical coastal landscape, which can reach temperatures up to 33 °C (91 °F) during our observation in November 2022. Vegetation cover helps birds to find shelter during these hot days, making it an important factor in birds' cover.

Abiotic factors, such as salinity, water depth, and pH, negatively affect the overall bird community. Salinity was particularly significant towards overall bird species. It seems that the bird community in Muara Gembong correlates to low salinity habitat as shown in the biplot. There were only several birds correlated with high salinity, such as the Javan Pond-Heron (*Ardeola speciosa*), Striated Heron (*Butorides striata*), and Little Egret (*Egretta garzetta*). Pacific Golden Plover also correlates to high salinity. This was due to their diet that consists mostly of brackish and saline water fish. Waderbirds and herons also naturally spent part of their time foraging in coastlines and mudflats, thus making them have a higher tolerance to salinity. Khirani-Betrouche & Moulai (2021) also found out that Ardeidae birds have high tolerance against salinity.

Muara Gembong provides plenty of fish for the birds to feast on. Our observation found several species of fish in the water of Muara Gembong, such as mullets (*Crenimugil* spp.), whitespot (*Aplocheilus armatus*), maze rabbitfish (*Siganus vermiculatus*), and Mozambique tilapia (*Oreochromis mossambicus*). The latter being an alien species that got away from fishponds, inhabiting adjacent marshes and mangroves. Interestingly, we found that other waders from Scolopacidae and Charadriidae did not correlate to salinity. It means that these birds may have other factors that can explain their abundance more than salinity does.

Other abiotic factors (pH, water depth, and turbidity), although strongly responded to by some bird species, did not explain much of the bird community. One of the reasons was due to low variation within the variables themselves, thus it did not deliver a meaningful interpretation in the biplot. The pH, for example, has a standard deviation of 0.21 to 0.39 between the habitats. Another reason was simply because observed abiotic variables did not explain much of the overall bird communities. A similar study by Sonal et al. (2010)

reveals that pH also did not explain much due to high value throughout the year. However, a high value of pH might attract certain birds in extreme cases, such as flamingos (*Phoenicopterus roseus*) in an Algerian chott (Khirani-Betrouche & Moulai, 2021) due to its high salinity.

Bird relationships with each habitat Even though the birds found in mangroves were mostly generalist species, the bird community in mangroves was still dependent on the richness of vegetation species. This holds true for almost all habitats, even for man-made and restored wetlands (Canales-Delgadillo et al., 2019; Wong et al., 2023). Birds in the mangroves seem to respond positively to water depth, shown by positive loading values in the second and third components (Table 5). Several fish-eating birds, such as the Little Egret and Javan pond-heron, found in mangroves with deeper water due to their preference to hunt fish in deeper water. Birds can respond both positively and negatively to increases in water depth, depending on which species they are. Some Rallidae and Ardeidae birds responded positively to an increase in water depth, while Anatidae responded negatively (Baschuk et al., 2012). Birds also respond positively to increasing turbidity in the third component. However, the third component only constitutes about 13% of overall variations in mangrove. Turbidity was also not a strong predictor in RDA analysis (Figure 4). Martins et al. (2021) also found that turbidity was not a strong predictor for bird diversity in one of the two wetlands observed, due to other vegetation-related indices predicting bird diversity better. This means that birds may not be very affected by water turbidity.

The dataset from marshes made up four components that explain 79.3% of the variations in marshes. Three out of four components in marshes were related to abiotic variables, particularly about water quality in marshes. Vegetation dominates the first component but decreases in the second, third, and fourth components. The number of shrub species even has negative effects on bird diversity in the second component. This negative influence of shrubs affected 18.6% of bird variations in marshland. This was due to other variables playing a stronger role, such as pH value and the percent of tree cover. This second component also showed a non-direct relationship between the number of shrub species and the percent of tree cover, due to habitats with extensive tree cover often containing a low number of shrub species. This component was thus named 'water quality in water bodies with trees' and explained up to 18.6% of bird diversity in marshlands.

The value of pH, salinity, and water depth all contributed above 50% in components 2 and 3, respectively. These abiotic components explained up to 42.6% of bird variation in marshland. Even though pH has a high effect on bird community in the second component, their standard deviation (Table 7) does not convey much variation to the dataset. It is likely that birds were coincidentally observed in the plot where the pH was high. The salinity was also prominently significant among other abiotic variables in the RDA. This was due to the high variability of salinity in marshes in Muara Gembong. We also found that bird diversity was also affected by water depth in marshes. Bird community responds positively to an increase in water depth followed by a reduction in reeds (*Phragmites*) cover (Dinehart et al., 2023). Marshes and fishponds are scattered throughout Muara Gembong more than mangroves are. Our farthest marshes and fishponds observed were found as far as 2.5 km from the shore. The distance from shore has an effect on the salinity and, in turn, affects bird diversity as well.

The dataset from fishponds, on the other hand, returned four components that explain 83.2% of the bird variation. It is interesting to note that understory variables turned out to affect bird diversity negatively in the first and third components, meaning that the bird community may prefer fishpond habitat with less understory cover. Having a habitat with fewer trees and understories may be more preferred by birds that utilize fishponds as their habitat. The bird community that inhabited fishponds was mostly comprised of open-space insectivores, such as the Blue-Tailed Bee-Eater (*Merops viridis*), Whiskered Tern (*C. hybrida*), and Zitting Cisticola (*C. juncidis*). It was discovered that fishponds themselves are also important for wetland bird community, as the absence of them correlates with lower bird abundance (Broyer et al., 2018).

Table 7 Mean and standard deviation of observed habitat variables

No	Variable	Fishpond	Marsh	Mangrove
1	Number of tree species	2.4 ± 1.4	3.3 ± 0.5	3.0 ± 1.2
2	Number of shrub species	1.4 ± 0.7	2.0 ± 0.6	1.0 ± 0.7
3	Number of understory species	3.0 ± 0.9	3.3 ± 1.1	1.1 ± 1.3
4	Total number of species	7.0 ± 1.5	8.3 ± 1.1	4.2 ± 2.8
5	Tree cover (%)	7.9 ± 12.5	41.6 ± 11.5	50.9 ± 12.8
6	Shrub cover (%)	6.4 ± 8.3	2.2 ± 1.3	0.6 ± 1.0
7	Understory cover (%)	22.6 ± 12.1	11.6 ± 9.1	3.1 ± 5.3
8	Water pH	7.7 ± 0.2	7.5 ± 0.4	7.5 ± 0.4
9	Water salinity (‰)	1.9 ± 0.3	1.7 ± 0.4	2.1 ± 0.4
10	Water turbidity (m)	79.6 ± 19.0	119.1 ± 68.8	64.0 ± 61.0
11	Water depth (m)	49.7 ± 15.5	48.5 ± 9.5	69.6 ± 48.4

Conclusion

The total number of plant species correlates most with bird species abundance in Muara Gembong, followed by the number of tree species and the number of understory species. Vegetation cover did not correlate strongly to bird species abundance. Abiotic variables did not affect much of bird diversity. Vegetation plays a strong role in mangroves and fishponds. However, salinity still affects some of the birds in fishponds. The bird community in marshes, however, was a balanced influence between abiotic and biotic components.

Acknowledgment

The authors wished to thank Ernik Yuliana for a full funding of this research. The authors also would like to thank people and fishermen of Muara Gembong for their exhaustive support during observation and data acquisition.

References

Adil, Setiadi, D., & Hernowo, J. B. (2010). Hubungan struktur dan komposisi jenis tumbuhan dengan keanekaragaman jenis burung. *Forum Pascasarjana*, *33*(1), 55–65.

Andriwibowo, Basukriadi, A., & Nurdin, E. (2023). Spatial biodiversity of birds in land covers of wetlands on Jakarta's North Coast. *Biota: Jurnal Ilmiah Ilmu-Ilmu Hayati*, *8*(1), 51–58. https://doi.org/10.24002/biota.v8i1.5813

Baschuk, M. S., Koper, N., Wrubleski, D. A., & Goldsborough, G. (2012). Effects of water depth, cover and food resources on habitat use of Marsh birds and waterfowl in boreal wetlands of Manitoba, Canada. *Waterbirds: The International Journal of Waterbird Biology*, *35*(1), 44–55.

Bibby, C. J., Marsden, S., & Jones, M. (2000). *Bird surveys: Expedition field techniques*. BirdLife international.

BirdLife International. (2001). *Threatened birds of Asia: The BirdLife International red data book*. Cambridge: BirdLife International.

BirdLife International. (2022). *Muara Gembong-Tanjung Sedari*. BirdLife Data Zone. Retrieved from http://datazone.birdlife.org/site/factsheet/muara-gembong-tanjung-sedari-iba-indonesia/refs

Broyer, J., Richier, S., Renaud, C., Riotton-Roux, B., & Vade, J.-Y. (2018). Consequences of fish farming demise for bird and Odonate species richness in French fishponds. *Revue d'Écologie*, *73*(4), 462–473.

Canales-Delgadillo, J. C., Perez-Ceballos, R., Zaldivar-Jimenez, M. A., Merino-Ibarra, M., Cardoza, G., & Cardoso-Mohedano, J.-G. (2019). The effect of mangrove restoration on avian assemblages of a coastal lagoon in southern Mexico. *PeerJ*, *7*, Article e7493. https://doi.org/10.7717/peerj.7493

Chao, A. (2006). *Species estimation and applications* (Vol. 12). https://doi.org/10.1002/0471667196.ess5051

Dina 'Amalina, A., Atmodjo, W., & Setiyo Pranowo, W. (2019). Karakteristik pasang surut di Teluk Jakarta berdasarkan data 253 bulan. *Jurnal Riset Jakarta*, *12*(1), 25–36. https://doi.org/10.37439/jurnaldrd.v12i1.7

Dinehart, R. M., Brewer, D. E., Gehring, T. M., Pangle, K. L., & Uzarski, D. G. (2023). Ecologically scaled responses of marsh birds to invasive *Phragmites* expansion and water-level fluctuations. *Waterbirds*, *45*(3), 225–236. https://doi.org/10.1675/063.045.0302

Eaton, J. A., Balen, S. van, Brickle, N. W., & Rheindt, F. E. (2016). *Birds of the Indonesian Archipelago: Greater Sundas and Wallacea*. Lynx.

Hammer, Ø., Harper, D. A. T., & Ryan, P. D. (2001). PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, *4*(1), 1–9.

Haryono, H., & Narni, S. (2004). Karakteristik pasang surut laut di Pulau Jawa. *Forum Teknik*, *28*(1), 15.

Hernowo, J. B. (2016). Birds communities at mangrove of Batu Ampar, Kubu Raya District, West Kalimantan Province. *Jurnal Manajemen Hutan Tropika*, *22*(2), 137–147. https://doi.org/10.7226/jtfm.22.2.137

Iqbal, M., Lestiyanto, T., Wibowo, W. K., Taufiqurrahman, I., & Nazar, L. (2013). In search of the javanese lapwing *Vanellus macropterus* 2001–2012. *BirdingASIA*, *19*, 68–72.

Khirani-Betrouche, F., & Moulai, R. (2021). *Does salinity have an influence on the diversity and structure of the wintering waterbirds of the Saharan wetlands in Algeria?* [Data set]. Museu de Ciències Naturals de Barcelona. https://doi.org/10.15470/6FQD0H

MacKinnon, J. R. (1990). *Panduan lapangan pengenalan: Burung-burung di Jawa dan Bali* (S. Lusli & Y. A. Mulyani, Trans.). Gadjah Mada University Press.

Mao, Q., Liao, C., Wu, Z., Guan, W., Yang, W., Tang, Y., & Wu, G. (2019). Effects of land cover pattern along urban-rural gradient on bird diversity in wetlands. *Diversity*, *11*(6), Article 6. https://doi.org/10.3390/d11060086

Martins, C. O., Olaniyi, O. E., & Zakaria, M. (2021). Environmental factors and spatial heterogeneity affect occupancy estimates of waterbirds in Peninsular Malaysia. *Ornithological Science*, *20*(1), 39–55. https://doi.org/10.2326/osj.20.39

Mohd-Azlan, J., Noske, R., & Lawes, M. (2015). The role of habitat heterogeneity in structuring mangrove bird assemblages. *Diversity*, *7*(2), 118–136.

https://doi.org/10.3390/d7020118

Morelli, F. (2015). Indicator species for avian biodiversity hotspots: Combination of specialists and generalists is necessary in less natural environments. *Journal for Nature Conservation*, *27*, 54–62. https://doi.org/10.1016/j.jnc.2015.06.006

Mubarrok, M. M., & Ambarwati, R. (2019). Keanekaragaman burung di kawasan hutan mangrove Banyuurip Kecamatan Ujungpangkah Kabupaten Gresik. *Jurnal Riset Biologi dan Aplikasinya*, *1*(2), 54–63. https://doi.org/10.26740/jrba.v1n2.p54-63

Mueller-Dombois, D., & Ellenberg, H. (1967). A Key to Raunkiaer plant life forms with revised subdivisions. *Berichte Des Geobotanischen Institutes Der Eidg. Techn. Hochschule, Stiftung Rübel*, *37*, 56–73. https://doi.org/10.5169/seals-377651

Nugraha, R., Syaharani, L., Iska, R., Mulyana, D., Wahyudin, Y., Purbani, D., Jayawiguna, H., Triyono, Setiawan, A., & Fajar, P. (2019). The impact of land used changes on mangrove forest and shoreline dynamic in Muara Gembong, Bekasi, West Java. *IOP Conference Series: Earth and Environmental Science*, *241*, Article 012018. https://doi.org/10.1088/1755-1315/241/1/012018

Nurdin, Kosasih, D., Supartono, T., Gojali, N. M., & Rahardian, H. (2021). Keanekaragaman jenis dan karakteristik habitat burung di ekosistem mangrove Indramayu. *Logika*, *12*, 130–140.

Purnama, S. (2011). *Javan lapwing wet season survey at Muara Gembong, Bekasi, Jawa Barat*. Oriental Bird Club. https://www.orientalbirdclub.org/s/P868-Javan-Lapwing-expedition- Indonesia-1.pdf

Puttileihalat, M. M. S., Tuhumury, A., & Hitipeuw, J. Ch. (2020). Keanekaragaman jenis satwa burung di areal mangrove Desa Passo Kecamatan Teluk Ambon Baguala Kota Ambon. *Makila*, *14*(2), 126–134. https://doi.org/10.30598/makila.v14i2.2892

Rajpar, M. N., & Zakaria, M. (2014). Effects of habitat characteristics on waterbird distribution and richness in wetland ecosystem of Malaysia. *Journal of Wildlife and Parks*, *28*, 105–120.

Sabrina, H., Mardiastuti, A., & Hernowo, J. (2019). Waterbirds diversity in Bengawan Solo Estuary, Gresik, East Java. *Media Konservasi*, *24*, 103–108. https://doi.org/10.29244/medkon.24.1.103-108

Sonal, D., Rathod, J., & Padate, G. (2010). Avifaunal diversity and water quality analysis of an inland wetland. *Journal of Wetlands Ecology*, *4*, 1–32. https://doi.org/10.3126/jowe.v4i0.4151

Wang, T., & Zhou, L. (2022). The spatial-temporal patterns of bird diversity and its determinants in the small wetlands in Hefei City. *Biodiversity Science*, *30*(7), Article 21445. https://doi.org/10.17520/biods.2021445

West, A., & Scott, J. (2016). Black disk visibility, turbidity, and total suspended solids in rivers: A comparative evaluation: Black disk visibility evaluation. *Limnology and Oceanography: Methods*, *14*(10), 658667. https://doi.org/10.1002/lom3.10120

Whitten, T., Soeriaatmadja, R. E., & Afiff, S. A. (2013). *The ecology of Java and Bali*. Tuttle Publishing.

Wong, J. S. Y., Soh, M. C. K., Low, B. W., & Er, K. B. H. (2023). Tropical bird communities benefit from regular-shaped and naturalised urban green spaces with water bodies. *Landscape and Urban Planning*, *231*, Article 104644. https://doi.org/10.1016/j.landurbplan.2022.104644

Yang, X., Duan, Z., Li, S., Zhang, C., Qu, M., Hua, G., Niu, X., Hu, H., & Yu, D. (2022). Factors driving the abundance of wintering waterbirds in coastal areas of Guangdong Province, China. *Frontiers in Ecology and Evolution*, *9*, Article 808105. https://doi.org/10.3389/fevo.2021.808105

Zelený, D. (2021). *Explained variation in constrained ordination*. Analysis of community ecology data in R. https://web.archive.org/web/20230326222836/http://www.davidzeleny.net:80/anadat-r/doku.php/en:expl_var