Evaluating Plant and Bird Species Diversity and Abundance and Trash Pollution at three Nature Reserves in Singapore

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ABSTRACT. Singapore contains over 40,000 non-microbial organisms, many of which are nationally and/or regionally threatened. Significant ecosystems in Singapore include primary/old secondary forest, coastal hill secondary forest, and mangroves, each representing a unique portion of Singapore's native tropical ecology. This led to Labrador Nature Reserve, Bukit Timah Nature Reserve, and Sungei Buloh Wetland Reserve being chosen as field sites for understanding bird and plant diversity and abundance, and trash pollution. Bird and plant species were recorded using a transect and/or trail observation method at least thrice per field site. Data shows species diversity, species abundance, and locations of wildlife and trash pollution, allowing for analysis and comparisons between the ecosystems, as well as relationships between the data sets. This survey found a total of 31 bird species and 20 plant species across the three ecosystems and that primary/old secondary forest was overall more species diverse than coastal hill secondary forest over the period of surveying. This included seven notable migratory bird species present at the mangrove ecosystem, as well as defining organisms of the ecosystems and globally threatened species. Trash pollution was also found to be distributed more heavily in areas with heavy tidal movement at the mangrove ecosystem, however there was no relationship observed between trash pollution and number of birds. A clear positive relationship was found between plant and bird species diversity, however the three ecosystems differ greatly with regards to the relationship between plant and bird abundance. Overall, this study seeks to answer a number of ecological questions regarding biodiversity, ecosystem change through time, and species interactions, as well as collect data regarding the influence of human activity on Singapore's native ecology.

Keywords. Singapore, biodiversity, primary/old secondary forest, coastal hill secondary forest, mangrove, trash pollution

Introduction

The city-state of Singapore is situated in South East Asia below the Malaysian Peninsula and near the equator. Prior to large-scale human interference, Singapore's coasts were covered with mangrove forest (13% of total forest cover), and its inland portion was dominated by lowland dipterocarp forest and some freshwater swamp forest (Corlett 411) (figure 1). As large-scale clearing of forests and land reclamation have transformed the biogeography of Singapore, only a few fragments of old-growth forest remain (figure 2). This has unfortunately restricted species (particularly endemic species highly specialized to a certain ecosystem) to comparatively small areas of habitat (Noreen and Webb 1). Today Singapore contains four government-designated Nature Reserves and 20 Nature Areas that represent many of these ecosystems, which include primary and secondary forest, mangroves, freshwater swamp forest, and coral reefs

(National Parks Board Singapore 12). They therefore play an instrumental part in protecting and ensuring diverse ecosystems and places of study.

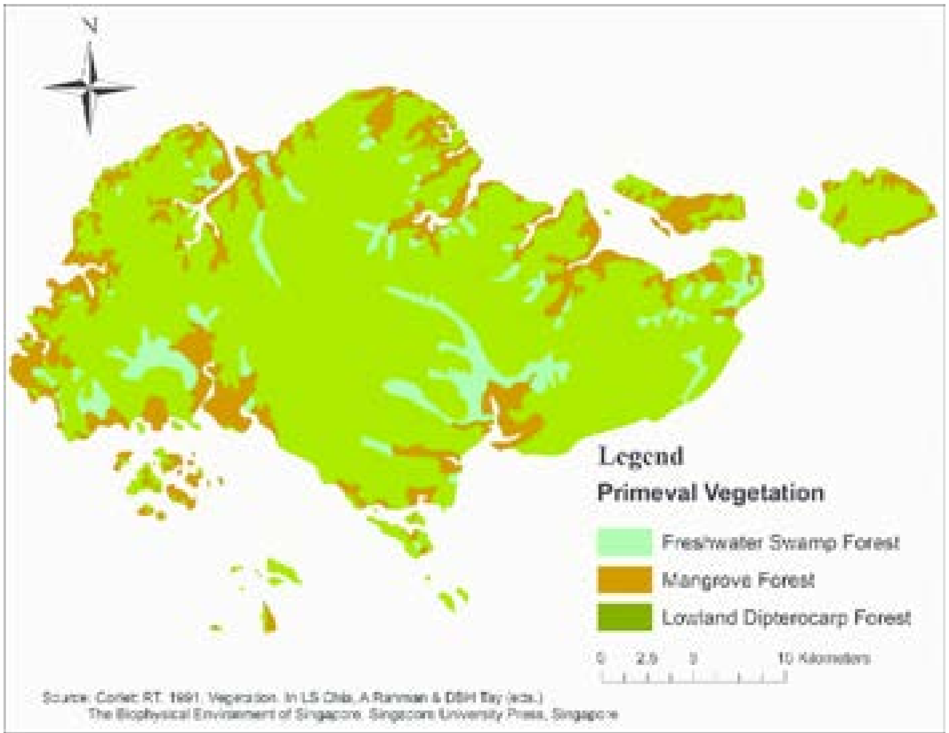


Fig. 1: Primeval vegetation of Singapore
(Yee et al. 206)

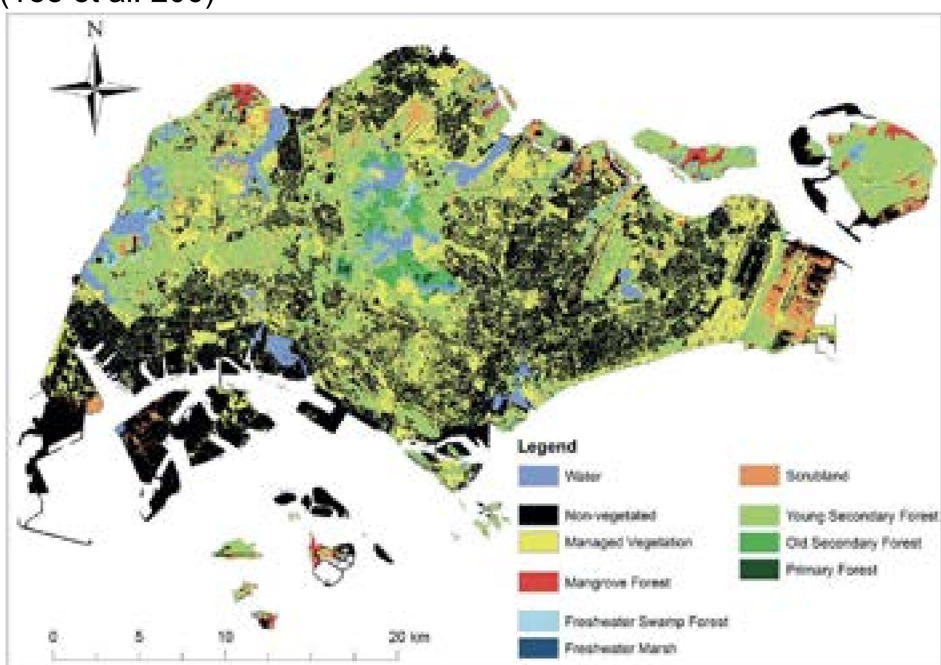


Fig. 2: Current vegetation of Singapore
(Yee et al. 209)

Singapore's ecosystem diversity created high species diversity, with 3729 vascular plant species and 404 bird species as of 2018 (National Parks Board Singapore 12), and the International Union for Conservation of Nature (IUCN) classifies some of these species between Near Threatened and Critically Endangered (IUCN). This diversity of species, both endemic and introduced, makes Singapore an ecologically significant and interesting area to research.

There are also many concerns with regards to Singapore's ecology, one of which is the threat of introduced and invasive species. Existing studies note that invasive species biologically invade ecosystems largely by outcompeting native species due to possessing different adaptations and competing with native species for resources such as nesting space, ultimately jeopardizing native biodiversity (Peh 1086). Specifically, Lim et al. found that the *Corvus splendens* and *Acridotheres javanicus* populations have grown substantially since their introduction, becoming widely observed across Singapore (Lim et al. 692). Tan and Tan highlight that extended periods of human disturbance, which is occurring in most areas in Singapore, encourages the proliferation of introduced species, suggesting that these species are a significant threat towards biodiversity of endemic species (Tan and Tan 60). This emphasizes the value of nature reserves as remnants of larger ecosystems. Despite being quite fragmented and covering small areas, they are the few remaining areas in Singapore that are minimally disturbed, therefore resisting invasive species and providing native species with habitat. Furthermore, most nature reserves in Singapore are quite fragmented and cover small areas.

Another concern is the impact of trash pollution. One study has found microplastics distributed in all waters surrounding Singapore, including those made from polypropylene, polyethylene, thermoplastic polyester, and foam (Curren and Leong 4). Some impacts of trash pollution on ecosystems include animals consuming and becoming entangled in trash pollution which decreases movement, feeding, and reproduction, threatening their populations. Trash pollution has also harmed plants through decreasing their growth, diversity, and health (Gondal et al. 6902-6903). These effects are particularly pronounced in aquatic ecosystems, which makes the nature reserves in Singapore particularly valuable to study as they all lie within close proximity of water, and the lack of existing research specific to Singapore in particular prompts the study of how trash pollution impacts local ecology and discussion for why keeping trash pollution under control is important for the health of aquatic ecosystems.

The main motivation of this study was to analyze plant and bird species diversity across different ecosystems in Singapore, as well as to investigate the influence of trash pollution on these ecosystems. This study is driven by the broad questions:
How do the primary and old secondary, secondary, and mangrove ecosystems present at Bukit Timah, Labrador, and Sungei Buloh Wetland Reserves in Singapore differ in terms of plant and bird species and trash pollution? Are there any relationships?

In order to address these driving questions, I studied three specific nature reserves in Singapore (figures 3-5, table 1), which play an instrumental part in protecting and ensuring diverse ecosystems and places of study.

Labrador Nature Reserve (field site A with 2 survey locations) is situated at the south end of Singapore and consists of secondary coastal hill forest (Low and Lim 1). These ecosystems tend to be characterized by vegetation growing near the sea, and organisms are tolerant to salt and poor soil (Ng and Siew). This field site is known to contain: plants *Tristaniopsis obovata* (critically endangered) (Ashton 274), *Syzygium grande*, *Ixonanthes reticulata*, *Rhodamnia cinerea*, *Terminalia catappa*, *Dipteris conjugata*; birds *Malacocincla abbotti*, and *Loriculus galgulus* (Yam et al. 265).

Bukit Timah Nature Reserve (field site B with 2 survey locations) is situated in the central region of Singapore and consists of primary and old secondary forest (both long-term undisturbed and recently planted trees) (Ho et al. 41). These ecosystems tend to be characterized by endemic dipterocarp trees and high species diversity (Goh). This field site is known to contain: plants *Shorea curtisii* (endangered), *Dipterocarpus sublamellatus* (endangered); birds *Pycnonotus zeylanicus* (critically endangered), *Cyornis brunneatus* (vulnerable), *Irena puella*, and *Psilopogon rafflesii* (near threatened) (Lim 204).

Sungei Buloh Wetland Reserve (field site C with 1 survey location) is situated in the North West of Singapore next to the Malaysian Peninsula and consists of mangrove trees surrounding wet mudflats (National Parks Board Singapore). These ecosystems tend to be characterized by a mixture of freshwater and saltwater. This field site is known to contain: plants *Bruguiera gymnorhiza*, *Heritiera littoralis* (endangered), *Ceriops zippeliana*, *Cassine viburnifolia* (endangered), *Sonneratia alba*, *Xylocarpus granatum*; birds *Tringa totanus*, *Tringa nebularia*, *Numenius phaeopus*, *Pluvialis fulva*, *Egretta garzetta*, and *Haliaeetus leucogaster* (Nai).

As primary/old secondary forest (Bukit Timah Nature Reserve/Field Site B) is older than secondary coastal hill forest (Labrador Nature Reserve/Field Site A), I hypothesized that I would find higher plant and bird species diversity in the former ecosystem. I hypothesized that I would find higher trash pollution abundance at Sungei Buloh Wetland Reserve/Field Site C, because it is the only field site directly next to a body of water. I also hypothesized that I would find a positive relationship between the number of plant and bird species as they may engage in beneficial relationships, as well as a negative relationship between trash pollution and the number of bird species as high density of trash pollution may deter birds from living in certain areas.

At Field Site A, I anticipated finding representative coastal hill forest plant species (*Tristaniopsis obovata*, *Syzygium grande*, *Ixonanthes reticulata*, *Rhodamnia cinerea*, *Terminalia catappa*, *Dipteris conjugata*) and more generalist bird species, as it is a secondary forest. At Field Site B, I expected to find primary/old secondary forest representative plant species (*Shorea curtisii*, *Dipterocarpus sublamellatus*) and some highly significant endemic bird species, as it more closely resembles Singapore's original rainforests. At Field Site C, I expected to find representative mangrove plant species (*Bruguiera gymnorhiza*, *Heritiera littoralis*, *Ceriops zippeliana*, *Cassine* *viburnifolia*, *Sonneratia alba*, *Xylocarpus granatum*) and migratory bird species that are not found in the other sites, as it represents a more specialized ecosystem.

Materials and Methods

Labrador Nature Reserve was Field Site A and had two survey locations; Bukit Timah Nature Reserve was Field Site B and had two survey locations; Sungei Buloh Wetland Reserve was Field Site C and had one survey location. Each survey location was selected to be surveyed for bird and plant diversity and abundance of trash (table 1).

Singapore in Google Earth, showing field sites

Fig. 3: Annotated map of Singapore from Google Earth

Field Sites and Survey Locations

Table 1: Field sites, survey locations within a field site, and descriptors.

Field Site Code, Official Nature Reserve Name, Descriptors	**Survey Location Code(s) and Descriptors**
A: Labrador Nature Reserve (1.2666° N, 103.8022 ° E) - Coastal hill forest - Young and old secondary forest - Southern Singapore	A1: Along Nature Footpath, a worn stone footpath with extensive surrounding vegetation and further inside reserve A2: Along WWII Footpath, similar to A1 with but with a wide artificial clearing at 50m end
B: Bukit Timah Nature Reserve (1.3486° N, 103.7767° E) - Lowland dipterocarp forest - Primary and old secondary forest - Central Singapore	B1: Along Catchment Trail, sandy footpath near Macritchie Reservoir and close to Bukit Timah Expressway, tall surrounding vegetation B2: Along Cave Path, hilly and rocky footpath off the main path and with vegetation on cliffs
C: Sungei Buloh Wetland Reserve (1.4466° N, 103.7234° E) - Wetlands, mangroves, mudflats - Northwestern Singapore	C: Along Migratory Bird Trail, between the Main Hide and Main Bridge, between Sungei Buloh Besar and Buloh Tidal Ponds Only one survey location was used, as the Migratory Bird Trail is a circular footpath.

Field Site A (Labrador Nature Reserve)

Survey Location A1 Survey Location A2

Field Site B (Bukit Timah Nature Reserve)

Survey location B1

Survey location B2

Field Site C (Sungei Buloh Wetland Reserve)

Survey location C

Fig. 4: Map of field sites and pictures from survey locations

Survey Locations

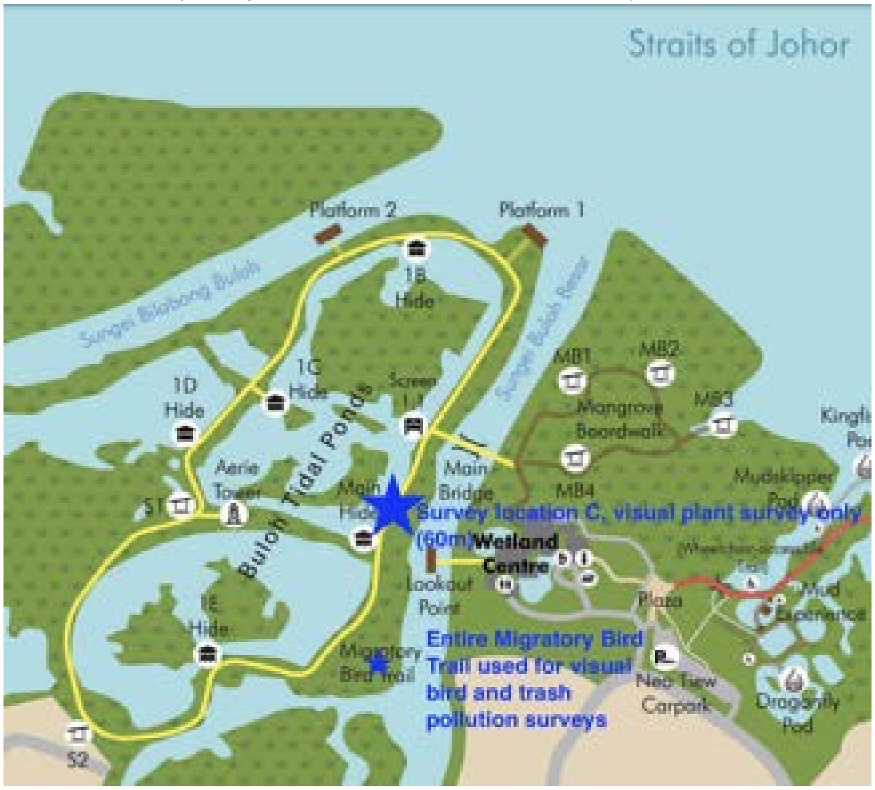
Field Site A (Labrador Nature Reserve)

(National Parks Board Singapore)

Field Site B (Bukit Timah Nature Reserve)

(National Parks Board Singapore)

Field Site C (Sungei Buloh Wetland Reserve)



(National Parks Board Singapore)

Fig. 5: Survey locations on official National Parks Board Singapore maps

Sampling Methods

At each survey location, a 40-60 meter transect was measured using a transect tape. Surveys were carried out from December 2023 to January 2024. The criteria for choosing survey locations was that they had to be along a pre-existing footpath to minimize disturbance to the environment by going off the path. The survey locations were selected by mapping out and numbering possible 40-60m transects (survey locations) throughout the field sites and choosing them using a random number generator.

Visual plants survey (survey locations A1-2, B1-2, C): a camera (0.5 lens on iPhone 13 Pro Max) was used to video record vegetation on either side of a transect while the researcher walked slowly along the transect, recording data for alternating 5m segments (e.g. 0-5m, 10-15m, etc.).

Audio bird survey (survey locations A1-2, B1-2): As birds are quite difficult to spot visually at these two sites, audio data was used. Along the same alternating 5m segments on the transects as stated earlier, birdsong was audio recorded (Voice Memo app on iPhone 13 Pro Max) as the researcher walked slowly along the transect.

Visual bird survey (location C): each bird that could be visually seen throughout the Migratory Bird Trail (along the outer edge of the mangrove and on the mudflats in the center) in two hours was videotaped and photographed (iPhone 13 Pro Max).

Visual trash pollution survey (location C): No trash pollution was spotted at survey locations A1-2 or B1-2 in any surveys, so this portion of the study only applies to survey location C. Each piece of trash that could be visually seen next to the footpath of the Migratory Bird Trail was documented by a photo (iPhone 13 Pro Max). Note that trash pollution was along the footpath, however birds (visual bird survey) were a further distance away.

Site C (Sungei Buloh Wetland Reserve) was unique from Site A (Labrador Nature Reserve) and Site B (Bukit Timah Nature Reserve) in that it consisted of a circular footpath surrounding mudflats with birds in the center, making a transect-based audio bird survey inappropriate. Therefore, C was surveyed for birds visually through photos and videos which were collected in a two-hour walk along the entire Migratory Bird Trail footpath (2152m). Segments of the survey transect were determined by using distances between pre-existing landmarks such as hides, shelters, and bridges. This method was also used to survey trash pollution at survey location C.

Surveys were conducted in a three-week span in December 2023 and January 2024. A preliminary survey was conducted at each survey location to confirm the survey methods, and then each location was surveyed according to Tabel 2. Surveys were spaced out by at least 24 hours and commenced at 9:00 AM each day.

Table 2: Summary of survey methods

Field Site and Survey Location(s)	**Visual plant survey (transect)**	**Audio bird survey (transect) - 3 repeats**	**Visual Bird Survey (non-transect) - 3 repeats**	**Visual trash pollution Survey (non-transect)**
A (A1, A2)	Yes	Yes	No	No
B (B1, B2)	Yes	Yes	No	No
C (C)	Yes	No	Yes	Yes

Upon arrival and throughout surveying, any qualitative observations were noted about the environment, such as weather, sound pollution, wind, tide/water level, evidence of human interference, general ambience, etc.

Species Identification
Google Lens and the Singapore NParks Flora Fauna Web were used to identify and count the visual plant and bird species shown in the videos/photos. Audio recordings were then compared with online databases (eBird) of bird calls to identify the species and number of times each call was heard.

Data Analysis
Using Google Sheets, raw data tables were compiled based on the visual and audio data collected at the field sites/survey locations. Data was processed through Google Sheets functions: averages were calculated to have an average and standard deviation for each location per 5m, which allowed researchers to quantify species diversity and abundance and create data tables (see tables 3-7). These processed data tables then led to the creation of graphs (see figures 6-12).

Results

A total of five 40-60m transects and one full 2152m footpath was surveyed between December 2023 and January 2024.

Audio Bird Survey Results
Survey locations surveyed using the audio bird survey method (survey locations A1, A2, B1, B2) had an average number of different bird calls heard in a 5m segment ranging from 1.9-2.2 (s.d. 0.4-0.6) over the duration of surveying. Note that it is possible that during another season or time of day, results may be different.

Table 3: Comparing bird species diversity between survey locations in field sites A and B

Survey Location	Avg number of different bird calls in each 5m segment of a 40-60m transect	Standard deviation
A1 (Labrador Nature Reserve), 50m transect	2.5	0.4
A2 (Labrador Nature Reserve), 40m transect	1.9	0.5
B1 (Bukit Timah Nature Reserve), 50m transect	2.2	0.6
B2 (Bukit Timah Nature Reserve), 50m transect	1.9	0.5

The results on bird species diversity between field sites A and B suggest that field site A was overall more species diverse in terms of birds than field site B within the duration of surveying, and that the degree of difference in bird species diversity between 5m segments was greater in field site B than in field site A on the days where they were surveyed (table 3, figure 6).

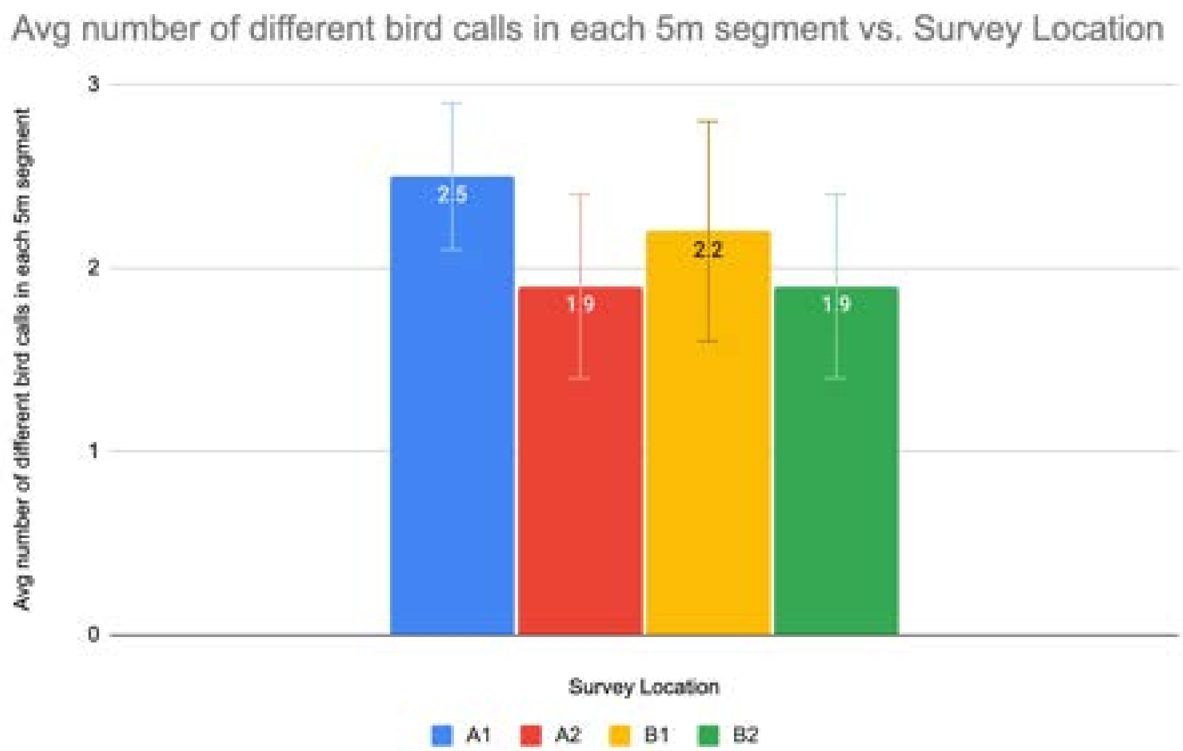


Fig. 6: Graph showing average number of different bird calls in each 5m segment vs survey location (A1 was 50 meters long; A2 was 40 meters long; B1 was 50 meters long; B2 was 50 meters long)

In this study, five different bird calls were heard at field site A (Labrador Nature Reserve), with 1-8 number of repeats per call, while seven different bird calls were heard at field site B, with 1-5 number of repeats per call. These different bird calls are therefore suggestive of different species.

Visual Plants Survey Results

Survey locations surveyed using the visual plants survey method (survey locations A1, A2, B1, B2, C), had an average number of different plant species in a 5m segment ranging from 4.8-6.4 (s.d. 0.5-1.5) over the duration of surveying. Note that it is possible that during another season, results may be different.

Table 4: Comparing plant species diversity between survey locations in field sites A and B

Survey Location	Avg number of different plant species in each 5m segment	Standard deviation
A1 (Labrador Nature Reserve)	5.6	1.3
A2 (Labrador Nature Reserve)	4.8	0.5
B1 (Bukit Timah Nature Reserve)	6.4	1.5
B2 (Bukit Timah Nature Reserve)	5.8	0.8
C (Sungei Buloh Wetland Reserve)	4.8	0.8

The results on plant species diversity between field sites A, B, and C suggest that field site B , followed by site sites A and C, was the most species diverse in terms of plants within the duration of surveying, and that the degree of difference in plant species diversity between 5m segments was greatest in field site B, followed by field sites A and C on the days where they were surveyed (table 4, figure 7).

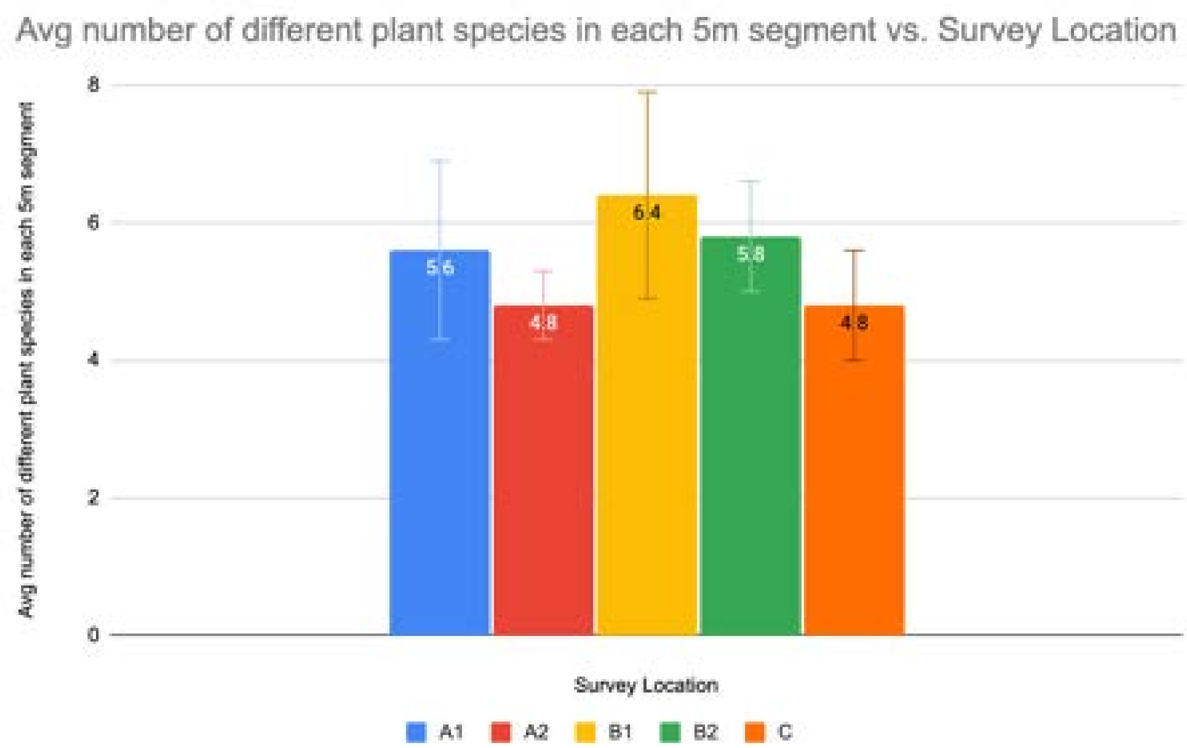


Fig. 7: Graph showing average number of different plant species in each 5m segment vs survey location (A1 was 50 meters long; A2 was 40 meters long; B1 was 50 meters long; B2 was 50 meters long; C was 60 meters long)

In this study, 6 plant species were found at field site A, 9 plant species were found at field site B, and 5 plant species were found at field site C.

Scatter plots were used to compare and contrast relationships between the bird and plant data, as well as similarities and differences between the ecosystems (figures 8-10).

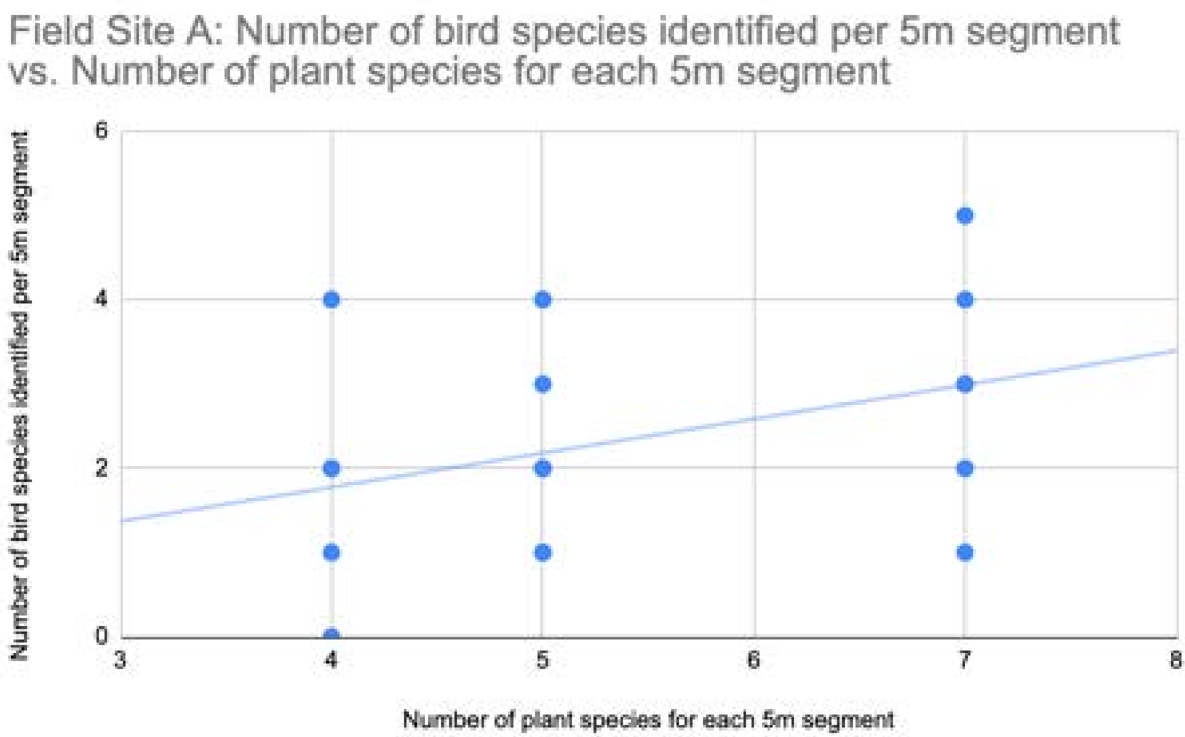


Fig. 8: Graph showing number of bird species identified per 5m segment vs number of plant species for each 5m segment (Field Site A)

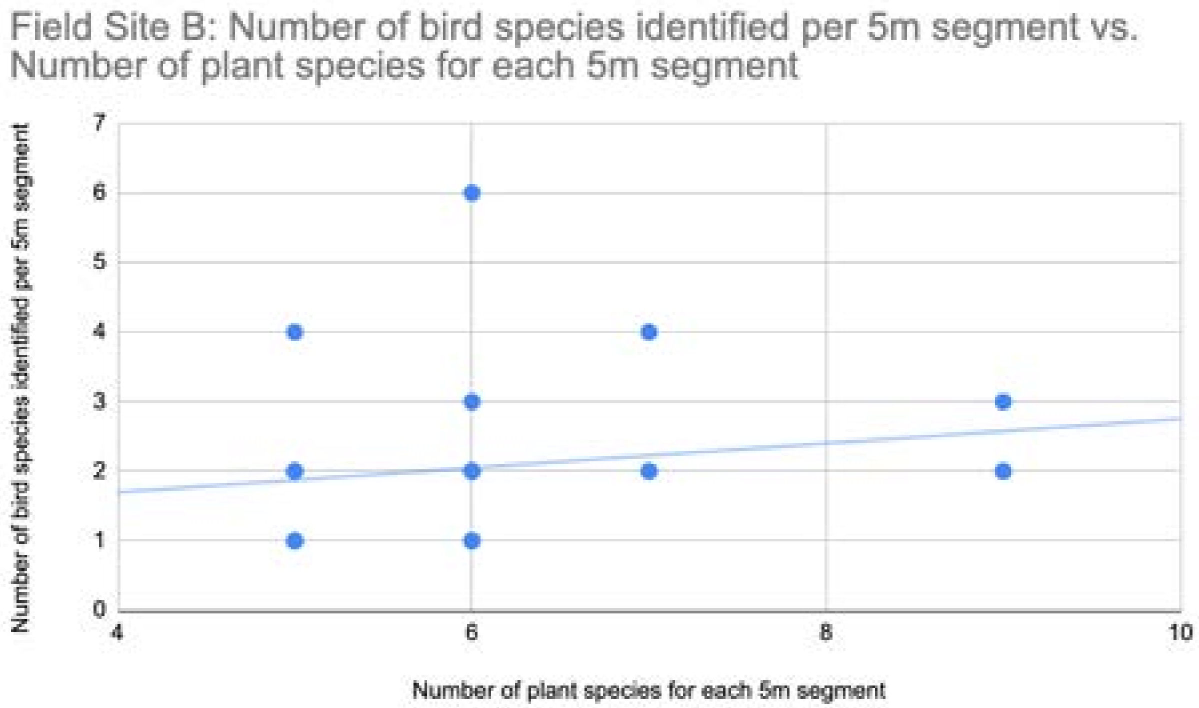


Fig. 9: Graph showing number of bird species identified per 5m segment vs number of plant species for each 5m segment (Field Site B)

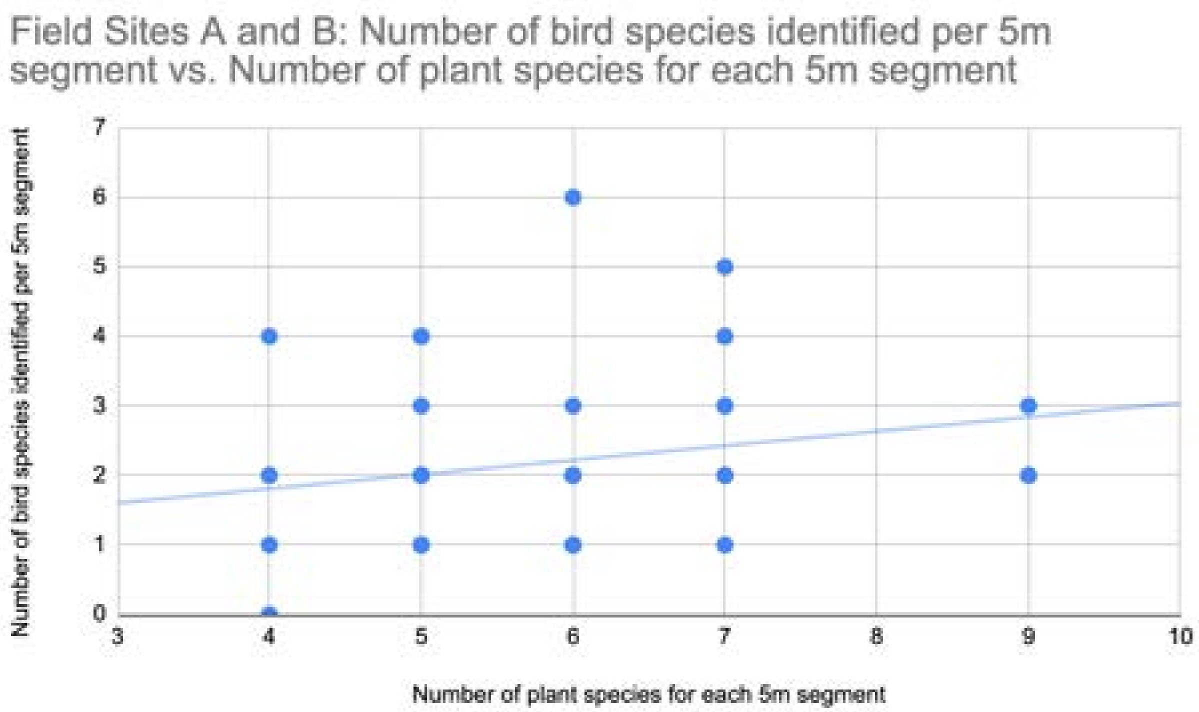


Fig. 10: Graph showing number of bird species identified per 5m segment vs number of plant species for each 5m segment (Field Sites A and B)

These graphs suggest that on the days the field sites were surveyed, there was a slight positive relationship between the number of plant species and the number of bird species identified (figures 8-10). This may suggest notable interactions and interdependence between plant and bird species.

Visual Bird Survey Results
At field site C, the number of different bird species per distance in each segment greatly varied, which may be correlated to the different environmental conditions of the various segments, as seen in the table below (table 5).

Table 5: Characteristics and bird species found at each segment in field site/location C

		Number of different bird species					
Segment along Migratory Bird Trail (m)	Segment characteristics	Location C.1	Location C.2	Location C.3	Segment average	Avg number of different bird species per distance (n/m)	Cumulative avg number of different bird species per distance (n/m)
0-207.27	bodies of water and trees on either side of footpath; mudflats visible on one side; water movement; quite wet	5	3	3	3.7	0.018	
207.27-549.17	bodies of water and trees on either side of footpath; mudflats visible on one side; water movement; quite wet	4	4	3	3.7	0.011	
549.17-676.38	bodies of water and trees on either side of footpath; mudflats slightly further away on one side; soil is drier, fewer mangrove trees	3	3	5	3.7	0.029	
676.38-1187.43	trees on either side of footpath; body of water on one side; mudflats barely visible and far away; soil is very dry, few mangrove trees	2	0	1	1.0	0.002	
1187.43-1480.02	bodies of water and trees on either side of footpath; mudflats slightly further away on one side; soil is drier, fewer mangrove trees and lower water level	1	2	1	1.3	0.005	
1480.02-1757.22	bodies of water and trees on either side of footpath; mudflats visible on one side; water movement; quite wet; elevated footpath (higher water level)	1	2	0	1.0	0.004	
1757.22-2152.07	bodies of water and trees on either side of footpath; mudflats visible on one side; water movement; lower water level	0	1	1	0.7	0.002	0.010

Over the three spaced visual bird surveys of field site/location C, a total of 19 bird species, both resident and migratory and including some artificially introduced species were identified. An average of 132 individuals and 12 different bird species were identified per survey, of which *Numenius phaeopus*, *Egretta garzetta*, *Tringa totanus*, and *Mycteria cinerea* occupy a large proportion of individual numbers. Bird species found also include notable migratory bird species *N. phaeopus*, *Ardea alba*, *T. totanus*, *Tringa stagnatilis*, *Tringa nebularia*, *Ardea intermedia*, and *Alcedo atthis*, which travel on the East Asian-Australasian Flyway (BirdLife International) and typically are present in Singapore during the winter months of October-February. Two resident introduced bird species, *M. cinerea* and *Mycteria leucocephala*, occupied a larger proportion of total individuals than some native species.

In order to find potential relationships between total number of plant species and total number of bird species, and compare this data between ecosystems, the researcher plotted a scatter graph (figure 11).

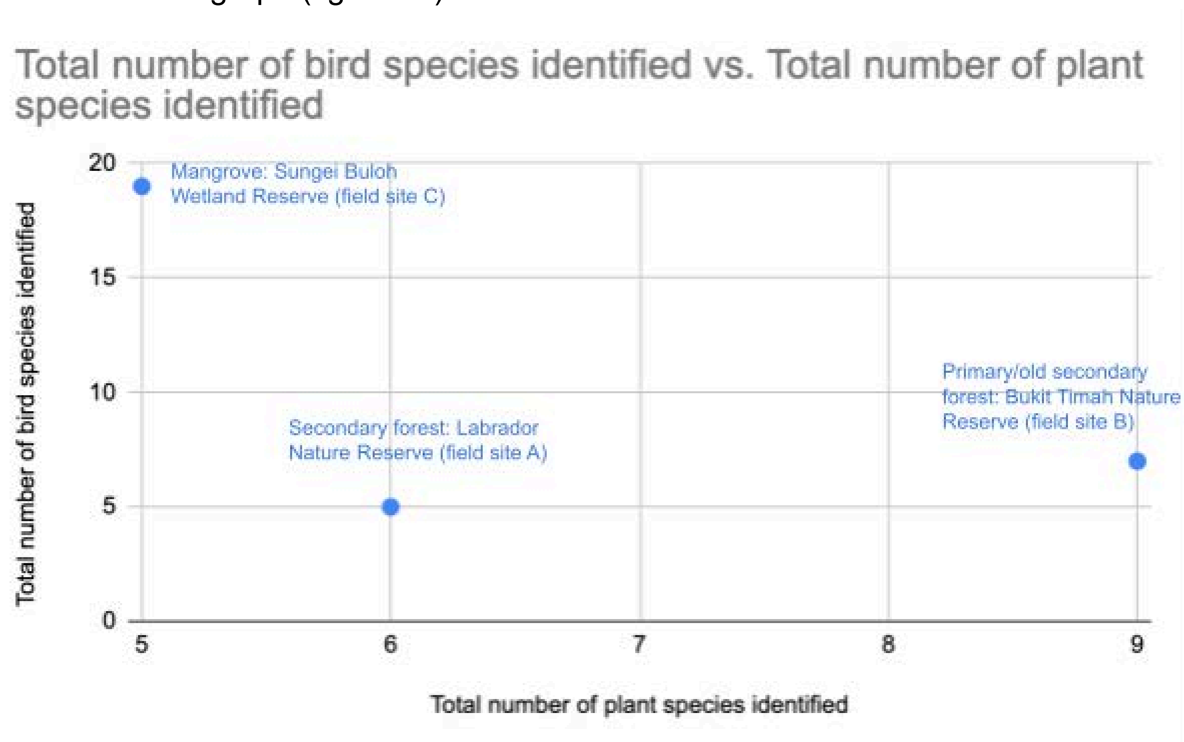


Fig. 11: Graph showing total number of bird species identified vs total number of plant species identified

From this graph, it can be seen that there may be a positive relationship between total number of plant species and total number of bird species through the Field Site A (6,5) and B (9,7) data points, however Field Site C differs substantially from the other two in that it has the lowest total number of plant species, but the highest total number of bird species (figure 11).

Table 6: Summary table of notable plant and bird species

Field Site	Notable species	Status
A (Labrador Nature Reserve)	*Gallus gallus*	Common
	Malacocincla abbotti	Representative of ecosystem type
	Rhodamnia cinerea	Representative of ecosystem type
	Cinnamomum iners	Common
	Syzygium grande	Representative of ecosystem type
B (Bukit Timah Nature Reserve)	*Pycnonotus zeylanicus*	Critically endangered
	Irena puella	Representative of ecosystem type
	Dipterocarpus sublamellatus	Endangered
	Rhodamnia cinerea	Common
C (Sungei Buloh Wetland Reserve)	*Numenius phaeopus*	Migratory/representative of ecosystem type
	Ardea alba	Migratory/representative of ecosystem type
	Tringa totanus	Migratory/representative of ecosystem type
	Tringa stagnatilis	Migratory/representative of ecosystem type
	Tringa nebularia	Migratory/representative of ecosystem type
	Ardea intermedia	Migratory/representative of ecosystem type
	Bruguiera gymnorhiza	Representative of ecosystem type
	Rhizophora stylosa	Representative of ecosystem type

Visual Trash Pollution Survey Results

During the trash pollution survey, the researcher found 109 pieces of trash, including styrofoam boxes, bottle caps, plastic bags, and rubber items (table 7). On average, the researcher observed pieces of trash spread over the entirety of the outer-facing portion of the Migratory Bird Trail (2152m), with the largest quantity of trash found in segments 0-207.27m, 207.27-549.17m, and 1480.02-1757.22m, which were the segments that were closest to the edge of the mangrove and where water level was highest (table 5 for segment characteristics).

Table 7: Abundance of trash pollution types in Field site/location C

Type of Trash Pollution	Quantity	% occupied
Bottle caps	32	29.4%
Plastic Bottle	18	16.5%
Styrofoam	40	36.7%
Feed bags (polypropylene)	3	2.8%
Rubber items	4	3.7%
Plastic Bags	7	6.4%
Soft plastic wrappers (e.g. tissue packet, snacks)	5	4.6%

As birds present at the water-adjacent ecosystem at Field Site C may be in close contact with trash pollution while finding food, distribution of birds may be influenced by abundance of trash pollution. To see if there was a relationship between abundance of trash pollution and abundance of individual birds, the researcher plotted a scatter graph (figure 12).

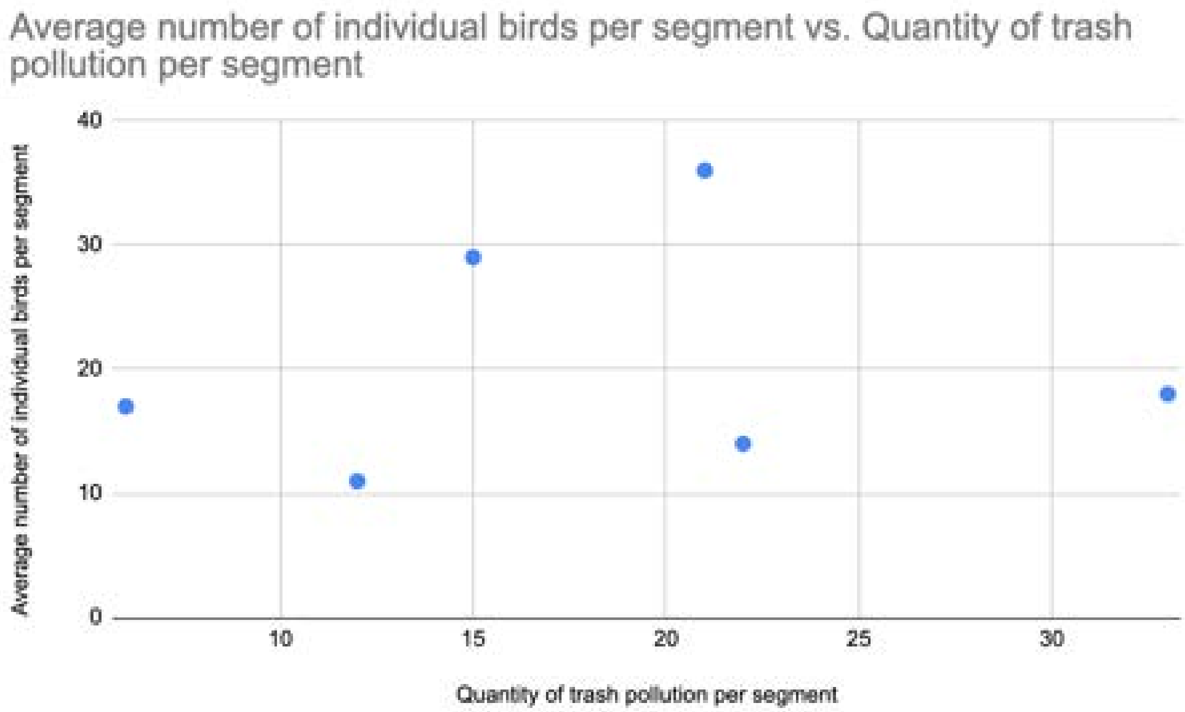


Fig. 12: Graph showing average number of individual birds per segment vs quantity of trash pollution per segment (Field Site C only)

The graph suggests that there is little relationship between trash pollution and abundance of birds at Field Site C (figure 12).

Discussion

Over the duration of the research, a total of 31 bird species and 20 plant species were observed across the three ecosystems (primary/old secondary forest, coastal hill forest, mangrove), which display quite a high level of species diversity. Some of the bird and plant species observed also display ecological relationships with each other, such as mangrove roots (e.g. those of *Rhizophora stylosa*) providing shelter for fish that aquatic birds (e.g. *Ardea spp*.) require for nutrition.

This study also identified a number of introduced species and/or generalists across the three ecosystems, including *Gallus gallus* and *Acridotheres javanicus*. These species being spread across and rather abundant in the three surveyed ecosystems may lead to negative consequences, such as outcompeting native and more specialized species for habitat space and nutrients. Such bird and tree species tend to adapt more easily and with less resistance to ecosystems subject to human disturbance, suggesting that the ecosystems surveyed in this study have experienced notable human disturbance. Field Site B (Bukit Timah Nature Reserve) is notable in that it had the fewest number of introduced/generalist species and a higher abundance of endemic and IUCN “at risk” species out of the three field sites/ecosystems, which aligns with its categorization as a primary and old secondary rainforest.

Patterns of ecosystem-specific species were also identified, where the species that are known to be defining inhabitants of certain ecosystems and/or more threatened were only present at one field site/ecosystem. This indicates that their ecological niches are very specific, and that their specialization as opposed to the generalists requires more emphasis to be given to their conservation and continued ecological study. These findings also support the researcher's argument that the continued protection of remaining ecosystems in Singapore is necessary in order to prevent further habitat loss for highly specialized bird and plant species.

My results of primary forest at Bukit Timah Nature Reserve being largely dominated by *Dipterocarpae* and *Ixonanthaceae* also corroborated Corlett's study, which found plant species from the above groups in higher proportions than other trees. Rattans (genera *Calamus, Daemonorops, Korthalsia, Plectocomia*) were also abundant across the primary/old secondary forest I surveyed, which was also a result of the surveying done by Corlett. However, there are very few academic studies regarding species surveys of the other two field sites/ecosystems (coastal hill and mangrove). Despite this, the results of this study have overlaps with the species found in official National Parks Board Singapore species guides for the ecosystems. This suggests that the results of this survey are in agreement with those of existing scholarly research, which serves to bolster their arguments that the ecosystems of Singapore, despite fragmentation, remain biodiverse and unique from one another.

Most of my results are in line with my hypotheses: I found greater diversity of plant and bird species at Bukit Timah Nature Reserve/Field Site B (primary/old secondary forest) than at Labrador Nature Reserve/Field Site A (secondary forest). There is evidence in the literature that this is a pattern– in their study, Turner et al. found that secondary forest contained significantly fewer tree species than primary forest (Turner et al. 537). Castelletta et al. also found that 94% of birds recently extinct in Singapore were reliant on primary and old secondary forest, indicating the higher biodiversity in primary/old secondary forest than secondary forest, noting the example of bird species *Dryocopus javensis*, *Chloropsis cyanopogon* and *C. sonnerati* being likely to go extinct due to habitat loss in upper and middle rainforest layers (Castelletta et al. 1870, 1876-1877).

A positive relationship was observed between the number of different plant species and number of different bird species identified in field sites A and B. This suggests that species richness of plants and birds influence one another, and that certain bird species may be highly dependent on certain plant species for survival and vice versa. Existing literature has also found a similar positive relationship between plant species richness and animal species richness (Castagneyrol and Jactel 2119). Such findings indicate beneficial relationships and ecological interactions between local plant and bird life in Singaporean ecosystems, which may inform future conservation efforts– propagating plants which directly benefit endemic birds and other animals may therefore be an effective method of conservation and restoring local ecosystems. Species richness can therefore be used to inform conservation efforts by functioning as a partial measurement of biodiversity (Castagneyrol and Jactel 2123).

Trash pollution included both industrial and domestic waste, which may have washed into the mangroves as a result of the tides from nearby aquaculture businesses, industrial warehouses, and residential areas. A notable incident occurred where researchers spotted a group of crows using a styrofoam takeaway container to build a nest, indicating noticeable interactions between organisms and trash pollution.

Interestingly, the graph showed little relationship between trash pollution and abundance of birds at Field Site C/Sungei Buloh Wetland Reserve (figure 12), which may indicate that birds at this site have not yet changed their distribution to avoid trash pollution. However, it should be noted that due to ocean currents and tides, the distribution of trash pollution is highly variable (Curren and Leong 4). The vast majority of birds found across survey sessions at this site were also located inside the oval footpath on the mudflats, whereas trash pollution remained on the outskirts of the footpath due to the protective area of mangrove trees. Therefore, the results did not suggest that trash pollution interfered significantly with plant and bird interactions, however more long-term research across multiple ecosystems with trash pollution is necessary to further understand this. It is definitely important to pay attention to and systematically study trash pollution, as it continues to accumulate and impact many ecosystems and organisms, particularly aquatic ones.

However, it is worth noting that as these ecosystems were surveyed using an observational method and only within a three-week period, results may differ from other times of the year or using different survey methods (mark-capture-release-recapture, wildlife camera traps, etc.). Future research could consider surveying ecosystems year-round to capture any possible shifts in species composition and trash pollution, as well as obtaining permits to engage in non-observational research as these methods may provide more accurate understanding of these ecosystems. The method used in field site C (Sungei Buloh Wetland Reserve) also differed from sites A and B due to constraints of the nature reserve, but the researcher surveyed it nonetheless as it is an ecologically significant site. If possible, further research should aim to standardize methodology across all sites/locations. This would improve comparability of data sets between the ecosystems, allowing researchers to more clearly investigate the similarities and differences between birds, plants, and trash pollution across distinct ecosystems.

Finally, this study and existing literature highlight the value of nature reserves, as they are ways to preserve remaining ecosystems and prevent them from experiencing extensive human disturbance. This is particularly evident in Singapore, where ecosystems have become heavily fragmented due to urbanization. It is therefore important to continually monitor these ecological areas of concern for issues such as invasive species and trash pollution, making a case for the continuation of nature reserves and conserving remaining biodiversity.

Conclusions

Overall, during this study it was found that some generalist species existed across multiple ecosystems (*Rhodamnia cinerea*, *Gallus gallus*, *Cinnamomum iners*) and were relatively noticeable throughout the duration of surveying, whereas some specialist species where only observed at one ecosystem/field site (*Pycnonotus zeylanicus*, *Syzygium grande*, *Dipterocarpus sublamellatus*, *Bruguiera gymnorhiza*, *Rhizophora stylosa*, *Tringa spp.*). However, most species were not observed to inhabit multiple field sites/ecosystems during the period of surveying, suggesting that differences in abiotic and biotic factors between the three ecosystems surveyed (primary forest, secondary forest, mangrove) have led to largely distinct plant and bird species compositions.

The ecosystems of Singapore still deserve continued scientific study of their species composition and how humans have impacted them, as they remain unique and specialized from each other. Singapore's ecosystems have become increasingly fragmented due to urbanization and continued expansion of the city-state's residential and industrial areas, which puts its variety of ecosystems under increased stress. A number of ecologically significant and globally threatened species also inhabit local ecosystems, such as *Pycnonotus zeylanicus* (critically endangered), as a specialized inhabitant of primary rainforests; and mangrove tree species, which provide invaluable coastal protection and have been restricted to the very Northwest corner of Singapore.

Understanding these ecosystems and their species would inform increased conservation efforts to protect Singapore's remaining ecosystems. This is integral towards supporting not only Singapore's native ecology, but also human society, as ecology involves both natural and human factors; ecosystems provide the foundations for the continued survival of life on Earth, and continued ecological research is needed in order to better protect them and promote their survival. Southeast Asia's ecosystems as a whole also remain biodiversity hotspots and some of the most productive biomes on Earth, but also one of the most highly threatened– the rapid urbanization of many of these countries may place more ecosystems at risk, and increased ecological surveys would be a crucial step towards communicating their importance and actioning conservation.

In order to monitor the health of remaining ecosystems in Singapore, multiple data sets must be collected across longer time frames and cover a number of different ecosystems. This would enable future research to understand not only how various species interact with each other and how they have been impacted by trash pollution, but also provide valuable insights into how changes that occur over longer periods of time (e.g. seasons) influence these relationships.

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