Mathematical Modeling of Avifaunal Diversity via Shannon-Wiener and Simpson Diversity Indices Toward Comprehensive School Conservation Planning

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Abstract- ***Natural spaces in schools are increasingly converted into infrastructure, highlighting the need for regular biodiversity assessment. This study assessed avifaunal diversity at San Miguel National High School using the Shannon–Wiener and Simpson Diversity Indices. A quantitative descriptive biodiversity assessment was conducted through the line-transect method in two sampling areas: the school oval or athletic grounds and the forested strip behind the Grade 11 building. Bird surveys were conducted on March 3, 5, and 7, 2026, during morning and afternoon observation periods. Six bird species from five families were documented, with a total of 96 individuals recorded. The Eurasian Tree Sparrow (Passer montanus) was the most abundant species, while the Chestnut Munia (Lonchura atricapilla) was the least abundant. The Shannon–Wiener Diversity Index value of 1.39 indicated moderate species diversity, whereas the Simpson Diversity Index value of 0.70 indicated relatively high biodiversity. Bird populations were most concentrated around the Track Oval and surrounding grassy areas in Area 1, while Area 2 showed concentrations around vegetated and tree-covered portions. Higher bird populations were observed during relatively lower temperatures and higher humidity. The findings highlight the ecological value of remaining green spaces within the school and support a comprehensive conservation plan involving the preservation of existing vegetation, planting of native and fruit-bearing trees, regular biodiversity monitoring, environmental education, and active participation of students, teachers, and other stakeholders in protecting avifaunal habitats.***

Keywords: Avifaunal diversity, Shannon–Wiener Diversity Index, Simpson Diversity Index, line-transect method, school conservation planning, San Miguel National High School.

I. INTRODUCTION

Birds (Class Aves) are among the most diverse vertebrates and contribute significantly to ecological balance through seed dispersal, pollination, pest control, and nutrient cycling. Because they are sensitive to environmental changes, they are widely recognized as reliable bioindicators of ecosystem health. School campuses with trees and green spaces provide important habitats for bird species, especially in urban and semi-urban areas. However, rapid urbanization, habitat fragmentation, and land-use changes have reduced these habitats, contributing to declines in bird diversity. Consequently, integrating biodiversity conservation into campus planning and management is essential to support wildlife and promote environmental sustainability.

Biodiversity loss has become one of the greatest environmental concerns worldwide, and birds are among the groups that are most affected by human activities. According to Xiao et al. (2024), an estimated 1,300–1,500 bird species have already become extinct due to factors such as urbanization, habitat destruction, land conversion, and environmental degradation [24]. As cities continue to expand, natural habitats are increasingly disrupted, making it more difficult for birds to find food, shelter, and breeding areas. Elmqvist et al. (2013) projected that urban land surrounding protected areas will grow from about 450,000 km² in 2000 to more than 1.2 million km² by 2030 [10], nearly 4% of global biodiversity hotspots at risk. In the Philippines, the situation is also concerning. Tanalgo (2025) reported that around 15% of the country's bird species are threatened with extinction [21], while nearly half (48%) of endemic bird species are being affected by habitat loss.

Monitoring avifaunal diversity is an important step toward understanding the condition of habitats and developing effective conservation strategies. In Bulacan, Illescas et al. [3] documented 53 bird species

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from 31 families across different land-use types in the City of Malolos and found that areas with more vegetation supported a greater variety of bird species than highly urbanized locations. Duco et al. (2021) recorded 67 bird species from 37 families within a karst forest ecosystem in Bulacan [9], showing that habitats with richer vegetation and greater structural diversity provide better conditions for bird communities.

Building on these findings, systematic monitoring of avifaunal diversity using ecological diversity indices provides a practical and scientific approach to evaluating bird communities. Birds are widely recognized as effective bioindicators because changes in their abundance, distribution, and diversity often reflect broader environmental conditions and habitat quality. Among the most commonly used measures are the Shannon–Wiener Diversity Index and the Simpson Diversity Index, which quantify species richness, abundance, and community structure. The quantitative information generated by these indices can support habitat assessment, evaluate the effectiveness of conservation initiatives, and provide a scientific basis for environmental management and decision-making. In educational institutions, biodiversity assessments also promote environmental awareness by encouraging students and teachers to appreciate local biodiversity and participate in conservation efforts.

This study supports Sustainable Development Goal (SDG) 15: Life on Land, which promotes the protection, restoration, and sustainable use of terrestrial ecosystems while reducing biodiversity loss. This study assessed the avifaunal diversity within the San Miguel National High School campus using the Shannon–Wiener and Simpson Diversity Indices to provide scientific information on bird species richness, abundance, and overall diversity. The findings may assist school administrators, educators, and local policymakers in developing conservation-oriented practices, such as preserving green spaces and planting native vegetation. These initiatives can enhance habitat protection, promote biodiversity conservation, and support sustainable environmental management at the local level, contributing to the achievement of Sustainable Development Goal 15.

II. LITERATURE REVIEW

Biodiversity or biological diversity is all life on Earth among the living organisms and diversity within species, representing the complexity of ecosystems and the genetic makeup of plants, animals, and microorganisms stated by World Health Organization (2025) [23]. Consequently, bioindicators are commonly used in biodiversity monitoring and conservation planning to detect disturbances in our environment [2].

Numerous infrastructures are present in urban areas, which are characterized by extensive human activities. However, in order to compensate the loss caused by mass urbanization, urban green areas provide opportunities of protecting and promoting diverse ecosystems [22]. Despite these efforts, urban environments exhibit elevated levels of heavy metal bioaccumulation in numerous common avian species. Additionally, many bird species avoid areas with anthropogenic noise pollution because they are highly sensitive to disturbance. Consequently, heavily built-up or covered areas become unsuitable habitats, resulting in limited or no available foraging and breeding sites for birds [19].

Educational institutions often contain natural or semi-natural green spaces that can serve as habitats for various flora and fauna, even within urban landscapes [18]. Similarly, built anthropogenic landscapes such as school campuses influence habitat vitality of avian diversity in community composition, as bird species react dynamically to land conversion and ecological state [12]. Despite the acknowledged importance of biodiversity conservation education, there is a lack of studies assessing students' awareness and attitudes toward biodiversity conservation in the school setting [6].

Studying these factors along environmental gradients provides vital data regarding the specific points at which anthropogenic stress begins to impact biodiversity [7]. Moreover, existing models are held back by the limited availability of high-resolution remote sensing data and gridded climate products, resulting in gaps in accurately characterizing microclimates [4].

Because birds roam across large areas, are found across different regions, and react quickly to changes in the environment, birds serve as effective indicators of biodiversity. In addition, bird diversity is commonly described using population density, species abundance, trait diversity, and habitat distribution to prevent population decline and extinction. Furthermore, areas with exceptionally high biodiversity, like Key Biodiversity Areas (KBAs), are identified by conservation scientists and policymakers based on their priority for protection [15]. Similarly, aves are vital indicators for our environment due to their highly sensitive reaction to anthropogenic factors, disturbances, changes, and stress in the habitat structure that urbanization induces [25]. Through these services, ecosystems provide benefits to humans both directly and indirectly. As a result, birds are effective bioindicators of overall ecosystem health because aves can act as early warning signs of environmental change [11]

Systematic bird surveys are essential for obtaining reliable information on species composition, abundance, and distribution. Bibby (1992) described standardized bird census techniques that can be used to document bird populations across defined survey areas [5]. Such approaches provide a basis for collecting quantitative data that can subsequently be analyzed using ecological diversity measures.

The Merlin app, developed by the Cornell Lab of Ornithology, is designed to identify bird species. Specifically, it uses detailed descriptions, range maps, and recordings of bird calls and songs, supported by an intuitive interface, a comprehensive database, and advanced identification algorithms [8, 20]. The app also integrates geospatial data by considering the user's location and time of year to refine search results, improving species identification by focusing on birds that are most likely to be observed in a particular area. Traditionally, expert ornithologists identify bird species through printed field guides and direct visual or auditory observations, which require extensive training and experience. These conventional methods may limit accessibility and are challenging to apply across large spatial and temporal scales. Nevertheless, ongoing research on AI-driven technology for avifaunal identification remains promising, with studies focusing on improving model accuracy and expanding identification capabilities [1].

Previous studies have documented avifaunal diversity in school-campus environments, such as at Colegio de San Juan de Letran–Bataan [16]. Saka et al. (2022) demonstrated the application of the Shannon–Wiener and Simpson diversity indices in quantifying avifaunal diversity in Bodel Forest Reserve [17], Nigeria. However, limited studies have applied both indices to quantitatively assess avifaunal diversity within secondary school campuses. Therefore, the present study applies the Shannon–Wiener and Simpson Diversity Indices to mathematically model the avifaunal diversity of San Miguel National High School and provide baseline information for comprehensive school conservation planning.

III. PROBLEM STATEMENT

This study aims to mathematically model the avifaunal diversity within the campus of San Miguel National High School using the Shannon–Wiener Diversity Index and Simpson Diversity Index as measures of species diversity and dominance. Specifically, it seeks to provide quantitative information on bird species composition, richness, abundance, and diversity to serve as a scientific basis for comprehensive school conservation planning within the school campus.

IV. OBJECTIVES

The main objective of this study is to assess and mathematically model the avifaunal diversity of San Miguel National High School.

1) To identify and classify the bird species present within the San Miguel National High School campus based on their observable characteristics and ecological behaviors.
2) To determine the species richness, abundance, and composition of the identified bird species.
3) To identify the areas within the two sampling sites where bird populations are most concentrated.
4) To examine the relationship between bird observations and the recorded temperature and humidity conditions.
5) To use the Shannon–Wiener and Simpson Diversity Indices to develop a basis for a comprehensive school conservation plan.

V. METHODOLOGY

2.1. Materials and Instruments

The materials and instruments used in the study included binoculars, a digital camera or smartphone, thermometer, hygrometer, measuring tape, stopwatch or timer, notebook, and data sheets. Binoculars were used to improve the visual detection of birds, while the camera or smartphone was used to photograph birds for documentation and species verification. A thermometer and hygrometer were used to record temperature and relative humidity during the surveys. A measuring tape was used to establish the transect distance, while a stopwatch or timer was used to monitor the duration of each observation. A notebook and data sheets were used to record the identified species, number of individuals, date, time, location, behavior, and environmental conditions. The Merlin Bird ID application was also used as an identification aid to assist in verifying bird species through photographic and other available identification features [1, 8].

2.2. Research Design and Study Area

A quantitative descriptive biodiversity assessment was conducted to determine the avifaunal diversity within the campus of San Miguel National High School (SMNHS), San Juan, San Miguel, Bulacan. The study used the line-transect method to document bird species and their abundance and applied the Shannon–Wiener Diversity Index (H′) and Simpson Diversity Index (1 − D) to quantify species diversity and community structure [18]. Two sampling areas were selected within the school campus: Area 1, the school oval or athletic grounds, and Area 2, the forested strip located behind the Grade 11 building. A 150-m transect was established in each area.

2.3. Bird Survey and Data Collection

Field observations were conducted on March 3, 5, and 7, 2026, during two observation periods, 6:00 A.M.–9:00 A.M. and 3:00 P.M.–5:00 P.M. Surveys were conducted during periods of favorable weather and were suspended during heavy rainfall or strong winds because these conditions could reduce bird activity and detectability [13]. Each 150-m transect had an observation width of 50 m on both the left and right sides. Observers proceeded slowly along the transect while maintaining a 180° forward field of view and recorded birds detected visually or through vocalizations. Each transect survey lasted approximately 20 minutes. For every observation, the researchers recorded the species, number of individuals, date, time, location, and observed behavior. Binoculars were used to improve visual detection, while photographs were taken for documentation and species verification. Birds that could not be confidently identified at the species level were excluded from species-level diversity analysis. Environmental conditions were also recorded during each survey, with temperature (°C) and relative humidity (%) measured using a thermometer and hygrometer at the beginning and end of each transect [13].

2.4. Species Identification and Classification

Bird species were identified using direct field observations, photographic documentation, and the Merlin Bird ID application developed by the Cornell Lab of Ornithology [1]. The application was used as an identification aid through its image-recognition, species-description, and location-based identification features [18, 21]. Developments in artificial intelligence-assisted bird identification also support the use of such technological tools in avifaunal assessment [22]. Final verification was based on direct observations and photographic records. Species were classified using observable characteristics including plumage coloration, body size, bill shape, flight behavior, feeding habits, and habitat preference.

2.5. Data Analysis

The recorded observations were encoded into a standardized master data sheet and summarized according to species, abundance, and sampling area. Species richness, abundance, and relative abundance were determined before calculating the Shannon–Wiener and Simpson Diversity Indices [25, 26]. The Shannon–Wiener Index was used to measure species diversity based on species richness and the distribution of individuals among species, while the Simpson Diversity Index (1 − D) was used to describe community diversity and dominance. The computed indices were used to compare the two sampling areas and characterize the avifaunal community within the school campus [26].

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The Shannon–Wiener Diversity Index was calculated using:

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i)$$

where H' is the Shannon–Wiener diversity index, S is the number of species, and pi is the proportion of individuals belonging to species i.

The Simpson Diversity Index was expressed as:

$$D = 1 - \frac{\sum n_i(n_i - 1)}{N(N-1)}$$

where ni is the number of individuals of the i-th species and N is the total number of individuals in the community. The resulting values were used to describe the diversity of the recorded bird community [26].

2.6. Analysis of Environmental Factors and Bird Distribution

Mean bird population, temperature, and relative humidity were summarized for each sampling date to examine their observed relationship with bird abundance and distribution [13]. Locations with frequent bird observations were also identified and mapped for the two sampling areas. These spatial patterns were examined in relation to open spaces, vegetation, trees, buildings, and other observable habitat features within the campus [14, 7].

2.7. Comprehensive School Conservation Planning

The results of the biodiversity assessment and mathematical modeling were used as the basis for developing a comprehensive school conservation plan. The proposed plan focused on preserving mature trees, shrubs, and existing vegetation; planting native and fruit-bearing trees; increasing vegetative cover; protecting areas where bird populations were frequently observed; and establishing regular biodiversity monitoring. Environmental education, bird-watching activities, tree planting, and student participation were also incorporated to promote biodiversity awareness and environmental stewardship.

2.8. Ethics and Permissions

Permission to conduct the study was obtained from the administration of San Miguel National High School before data collection. The study used noninvasive observation techniques, and no birds were captured, handled, or disturbed. Field observations were conducted while minimizing disruption to wildlife, school activities, and the surrounding environment. Photographs and field records were used solely for species identification and research documentation.

VI. RESULTS AND DISCUSSIONS

The study assessed the avifaunal diversity of San Miguel National High School through line-transect observations conducted in two sampling areas: Area 1, the school oval or athletic grounds, and Area 2, the forested strip behind the Grade 11 building. The results provide quantitative information on species composition, abundance, diversity, spatial distribution, and the observed relationship between bird populations and environmental conditions.

3.1. Species Composition and Abundance

Six bird species representing five families were identified within the school campus: Eurasian Tree Sparrow (Passer montanus), Pacific Swallow (Hirundo javanica), Chestnut Munia (Lonchura atricapilla), Zebra Dove (Geopelia striata), Rock Pigeon (Columba livia), and Yellow-vented Bulbul (Pycnonotus goiavier). A total of 96 individuals were recorded. The Eurasian Tree Sparrow had the highest average population at 40 individuals, followed by the Pacific Swallow with 32, while the Chestnut Munia had the lowest average population with 2 individuals. The results indicate that the avifaunal community was composed of several species but was unevenly distributed, with a greater proportion of individuals belonging to a few species.

3.2. Biodiversity Indices

The Shannon–Wiener Diversity Index was calculated as H′=1.39, indicating moderate species diversity. The

Simpson Diversity Index, expressed as 1−D, was calculated as 0.70, indicating relatively high biodiversity. Together, these results show that the campus supports a moderately diverse bird community despite differences in species abundance, with the Eurasian Tree Sparrow and Pacific Swallow contributing substantially to the overall community structure [26].

3.3. Spatial Distribution of Bird Populations

Bird observations were not evenly distributed across the campus. In Area 1, the highest concentration occurred around the Track Oval and surrounding grassy areas, with different bird families also observed near buildings and other open or vegetated locations. In Area 2, bird observations were concentrated around vegetated and tree-covered portions of the forested strip. These locations represent areas where available vegetation, open spaces, and habitat features may support feeding, resting, and shelter for birds.This pattern is consistent with studies emphasizing the importance of vegetation and green spaces in supporting avian communities [6, 7, 9].

3.4. Temperature and Humidity

The recorded environmental conditions showed differences in bird population among sampling dates. The highest mean bird population, 146, was recorded on March 5, 2026, when temperature ranged from 32°C to 34°C and humidity ranged from 58% to 60%. The lowest mean population, 54, was recorded on March 3, 2026, when temperature ranged from 37°C to 39°C and humidity ranged from 53% to 55%. The observed pattern suggests that higher bird populations occurred under relatively cooler and more humid conditions; however, the manuscript notes that other factors, including food availability, vegetation, habitat characteristics, and observation time, may also have influenced the results. This observed pattern is consistent with research indicating that temperature and local environmental conditions can affect bird abundance and activity [13], while microclimatic conditions can also influence species–habitat associations [14].

3.5. Conservation Implications

Based on the computed diversity indices and observed distribution patterns, the study proposes a comprehensive school conservation plan focused on preserving existing mature trees, shrubs, and other vegetation; planting native and fruit-bearing trees; increasing vegetative cover; protecting areas with high bird concentrations. These measures are consistent with studies emphasizing the importance of vegetation and green spaces for maintaining avian diversity [6, 7, 9].

VII. FIGURES AND TABLES

Table 1: Species Composition and Average Population of Identified Birds

Name	Scientific Name	Family	Average Population
Eurasian Tree Sparrow	*Passer montanus*	Passeridae	40
Pacific Swallow	*Hirundo javanica*	Hirundinidae	32
Chestnut Munia	*Lonchura atricapilla*	Estrildidae	2
Zebra Dove	*Geopelia striata*	Columbidae	10
Rock Pigeon	*Columba livia*	Columbidae	7

Table 1 presents the species composition and average population of the identified birds within the San Miguel National High School campus. Six bird species representing five families were recorded during the survey. The Eurasian Tree Sparrow (Passer montanus) had the highest average population with 40 individuals, followed by the Pacific Swallow (Hirundo javanica) with 32 individuals. The Zebra Dove (Geopelia striata) and Rock Pigeon (Columba livia) had average populations of 10 and 7, respectively, while the Yellow-vented Bulbul (Pycnonotus goiavier) and Chestnut Munia (Lonchura atricapilla) had lower average populations of 5 and 2. The results indicate that the bird community was unevenly distributed, with the Eurasian Tree Sparrow and Pacific Swallow comprising the largest portions of the recorded avifaunal population.

Table 2: Bird Diversity in San Miguel National High School using Shannon-Wiener Diversity Index

Species (i)	Number (p)	pi	ln(pi)	Pi*ln(pi)
Passer montanus	40	0.41666667	-0.87546873	-0.36477864
Hirundo javanica	32	0.33333333	-1.0986123	-0.3662041
Lonchura atricapilla	2	0.020833333	-3.8712010	-0.08065002
Geopelia striata	10	0.10416667	-2.2617631	-0.23560033
Columba livia	7	0.072916667	-2.6184380	-0.19092777

Note: Total Individuals: 96; Shannon-Wiener Index (H'): 1.39206244

Table 2 shows the Shannon–Wiener Diversity Index calculation based on the abundance and relative proportion of the six recorded bird species. The Eurasian Tree Sparrow (Passer montanus) had the highest number of individuals (40), followed by the Pacific Swallow (Hirundo javanica) with 32 individuals, while the Chestnut Munia (Lonchura atricapilla) had the lowest abundance with 2 individuals. The resulting Shannon–Wiener Diversity Index of H′ = 1.39 indicates a moderate level of bird species diversity within the school campus. The result further shows that the bird community is not completely even because a large proportion of the recorded individuals belongs to the Eurasian Tree Sparrow and Pacific Swallow.

Table 3: Bird Diversity in San Miguel National High School using Simpson Diversity Index

Species (i)	Number (n_i)	$n_i - 1$	$n_i(n_i - 1)$
Passer montanus	40	39	1560
Hirundo javanica	32	31	992
Lonchura atricapilla	2	1	2
Geopelia striata	10	9	90
Columba livia	7	6	42
Pycnonotus goiavier	5	4	20

Note: Total Individuals (N): 96; N − 1: 95; Σ ni(ni−1): 2706; N(N−1): 9,120;
Simpson Diversity Index (1 − D): 0.70328948

Table 3 presents the calculation of the Simpson Diversity Index for the six bird species recorded within the San Miguel National High School campus. The Eurasian Tree Sparrow (Passer montanus) had the highest number of individuals with 40, resulting in the largest value of $n_i(n_i - 1)$ at 1,560, followed by the Pacific Swallow (Hirundo javanica) with 32 individuals and a value of 992. The Chestnut Munia (Lonchura atricapilla) had the lowest abundance, with only 2 individuals and a corresponding value of 2. The total number of individuals recorded was 96, while the sum of $n_i(n_i - 1)$ was 2,706. Using these values, the Simpson Diversity Index (1 − D) was calculated as 0.70, indicating a relatively high level of diversity within the bird community. The result also shows that although the community was dominated by a few abundant species, several other bird species were present and contributed to the overall diversity.

Table 4: Recorded Temperature and Humidity

Date	Temperature	Humidity	Bird Population (Mean)
March 3, 2026	37 °C to 39 °C	53% to 55%	54
March 5, 2026	32 °C to 34 °C	58% to 60%	146
March 7, 2026	33 °C to 35 °C	52% to 57%	93

Table 4 presents the recorded temperature, humidity, and mean bird population during the three sampling dates. On March 3, 2026, temperature ranged from 37°C to 39°C, humidity from 53% to 55%, and the mean bird population was 54. On March 5, temperature decreased to 32°C to 34°C, humidity increased to 58% to 60%, and the mean population reached the highest value of 146. On March 7, temperature ranged from 33°C to 35°C, humidity from 52% to 57%, and the mean population was 93.

The results indicate an observed association between environmental conditions and bird population, with the highest population recorded under cooler and more humid conditions and the lowest under hotter conditions. This pattern may suggest that birds were more active or easier to detect under relatively moderate temperatures and higher humidity. The findings are comparable to Ceresa et al. [7], which reported that temperature can affect bird abundance and activity [13]. However, because the study covered only three sampling dates, other factors such as food availability, vegetation, habitat characteristics, and observation time may also have influenced bird abundance.

Figure 1: Rank Abundance Distribution of Birds in San Miguel National High School

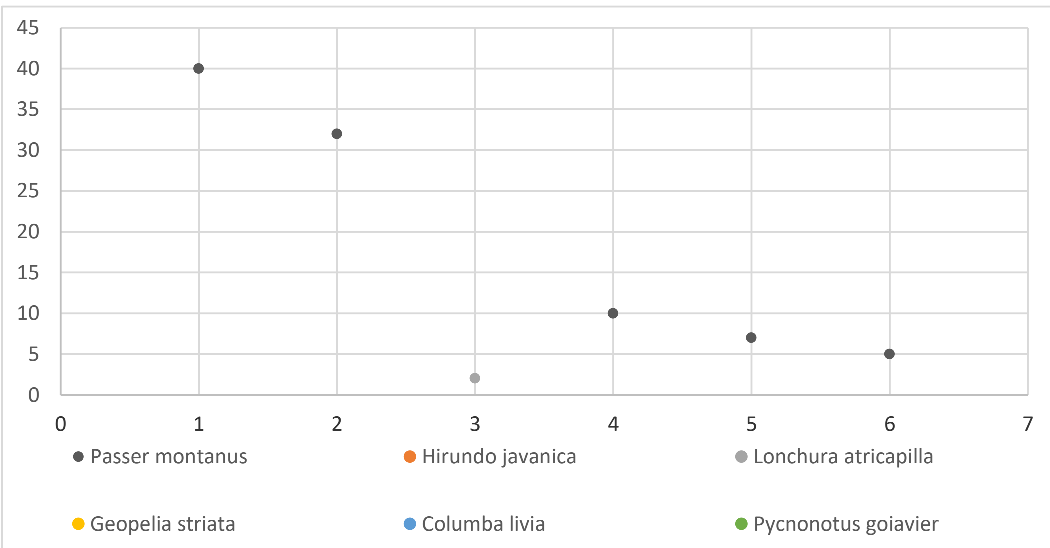

Figure 1 presents the rank abundance distribution of the bird species recorded within the San Miguel National High School campus. It is evident that the recorded species differed considerably in abundance, with the Eurasian Tree Sparrow (Passer montanus) having the highest average population of 40 individuals, followed by the Pacific Swallow (Hirundo javanica) with 32 individuals. The Zebra Dove (Geopelia striata), Rock Pigeon (Columba livia), Yellow-vented Bulbul (Pycnonotus goiavier), and Chestnut Munia (Lonchura atricapilla) had lower average populations of 10, 7, 5, and 2 individuals, respectively. This indicates that the observed bird community was unevenly distributed, with a small number of species accounting for a large proportion of the recorded individuals.

Furthermore, the rank abundance pattern is consistent with the calculated diversity indices. The higher abundance of the Eurasian Tree Sparrow and Pacific Swallow contributed substantially to the overall community structure, while the remaining species occurred at lower abundance. The Shannon–Wiener Diversity Index of H′ = 1.39 indicates moderate diversity, whereas the Simpson Diversity Index of 1 − D = 0.70 indicates relatively high diversity. These findings suggest that the school campus supports several bird species despite differences in their observed abundance.

VI. CONCLUSION

The study identified six bird species from five families within the San Miguel National High School campus, classified based on physical and behavioral characteristics such as plumage, body size, bill shape, flight behavior, feeding habits, and habitat preference. A total of 96 individuals were recorded, with the Eurasian Tree Sparrow (Passer montanus) being the most abundant and the Chestnut Munia (Lonchura atricapilla) the least abundant. The Shannon–Wiener Diversity Index (H′ = 1.39) indicated moderate species diversity, while the Simpson Diversity Index (1 − D =

0.70) indicated relatively high biodiversity. Higher bird concentrations were observed in specific areas with greater vegetation and suitable habitat features, including the school oval, grandstand, covered court, buildings, and forested strip. Higher bird populations were also observed under relatively cooler and more humid conditions. Based on these findings, a comprehensive school conservation plan is proposed focusing on preserving green spaces, planting native and fruit-bearing trees, conducting regular biodiversity monitoring, promoting environmental education, and encouraging student, teacher, and stakeholder participation to sustain avifaunal diversity and improve habitat quality.

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