



Avian Diversity as a basis for developing Birdwatching Ecotourism in the Industrial Landscape of PT Indonesia Asahan Aluminium (PT Inalum), North Sumatra, Indonesia

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ABSTRACT

Industrial landscapes are often perceived as degraded environments with limited ecological value. However, when managed responsibly, such areas can contribute to biodiversity conservation and environmental education. This study investigated the diversity, conservation status, and ecotourism potential of birds in the operational areas of PT Indonesia Asahan Aluminium (PT Inalum), located in Batu Bara Regency, North Sumatra. Bird surveys were conducted from August 2023 to May 2024 across three habitat types: residential green areas, plantation and shrub habitats, and coastal–mudflat zones. Data were collected through direct visual observations, supported by photographic documentation and sound recordings. Species identification followed Eaton *et al.* (2021), and conservation status was assessed using the IUCN Red List and Indonesian national protection regulations. A total of 103 bird species belonging to 41 families were recorded. Of these, 22 species are legally protected in Indonesia, and one species is listed as Endangered globally, the Milky Stork *Mycteria cinerea*. The study also documented 31 migratory species and several breeding records, including *Nisaetus limnaeetus*, *Pycnonotus analis*, *Treron vernans*, *Ploceus philippinus*, and *Merops philippinus*, indicating the site's importance for both resident and migratory populations. The diversity and breeding activity suggest that PT Inalum's managed habitats provide suitable ecological conditions for birds despite industrial operations. These findings demonstrate that corporate-managed lands can serve as complementary conservation habitats and highlight their potential for birdwatching-based ecotourism and environmental education. Establishing a continuous monitoring program, strengthening wildlife management capacity, and developing interpretive facilities are recommended to enhance conservation outcomes and promote sustainable industry biodiversity integration.

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Introduction

Birds represent one of the most diverse and widely distributed groups of vertebrates, exhibiting remarkable ecological adaptability across a broad range of habitats. Through their roles as pollinators, seed dispersers, and insect predators, birds play a crucial part in maintaining ecosystem balance and functioning (Şekercioglu, 2006; Whelan *et al.*, 2008). Owing to their sensitivity to environmental change, they are widely recognized as reliable bioindicators of habitat quality and ecosystem health. Variations in bird community composition often mirror ecological degradation or recovery processes (Gregory & van Strien, 2010).

Beyond their ecological value, birds hold substantial potential for nature-based tourism, particularly birdwatching ecotourism, which combines recreation, education, and conservation objectives. Ecotourism is defined as responsible travel to natural areas that conserves the environment, supports the well-being of local people, and fosters environmental awareness (Honey, 2008; Fennell, 2020). Among its many forms, birdwatching has emerged as one of the most rapidly expanding ecotourism sectors worldwide, offering significant ecological and socio-economic benefits. Birdwatching tourism contributes not only to biodiversity conservation through habitat protection but also to local livelihoods by generating employment in guiding, hospitality, and transport services (Steven *et al.*, 2014).

Indonesia, with more than 1,800 bird species and over 500 endemics, ranks among the most avifaunally rich nations on Earth (Eaton *et al.*, 2021). This exceptional diversity provides vast potential for the development of birdwatching ecotourism as a sustainable alternative that integrates conservation with community-based economic development. However, much of Indonesia's birdwatching potential remains

concentrated in protected or remote areas, whereas industrial and urbanized landscapes are often overlooked despite their latent ecological value.

Recent studies suggest that industrial areas, commonly associated with environmental degradation, can still harbor considerable biodiversity when managed under principles of sustainability. Post-mining landscapes, reclaimed industrial zones, and corporate greenbelts have been found to support secondary vegetation and a diversity of avian species (Al-Reza *et al.*, 2016). Initiatives under Indonesia's corporate social responsibility (CSR) and green industry programs increasingly integrate biodiversity conservation through mangrove rehabilitation, tree planting, and the development of vegetated buffer zones. These "transitional ecosystems" can function as secondary habitats for both resident and migratory birds. Consequently, assessing avian diversity in such areas provides valuable insight into their ecological function and management effectiveness.

PT Indonesia Asahan Aluminium (INALUM), a state-owned aluminum industry located in the coastal zone of Batu Bara Regency, North Sumatra, represents a compelling example of such a landscape. The area encompasses a mosaic of mangrove forests, shrublands, sedimentation ponds, landscaped green areas, and coastal ecosystems that may support diverse bird communities. Despite this potential, scientific documentation of bird diversity within the INALUM area remains limited. Therefore, this study aims to (1) identify and analyze the diversity of bird species in the PT INALUM area, and (2) assess its potential for birdwatching-based ecotourism development. The findings are expected to contribute to the understanding of avian diversity in industrial landscapes and provide a scientific basis for integrating conservation, education, and sustainable tourism within corporate environmental management frameworks.

Materials and Methods

Study Area

The study was conducted within the operational zones of PT Indonesia Asahan Aluminium (INALUM), located in Batu Bara Regency, North Sumatra, Indonesia (**Figure 1**). Observations covered three main sites:

(1) the Tanjung Gading Residential Area (200 ha); consists of urban green spaces, gardens, and artificial ponds.

(2) the Aluminium Smelter Complex (181 ha); dominated by oil palm plantations, shrubs, and grasslands interspersed with small wetlands and drainage channels.

(3) the Kuala Tanjung Port (15.5 ha); represents coastal mudflat habitats with minimal vegetation cover, functioning as a feeding and roosting site for waterbirds and shorebirds. These sites represent different habitat types ranging from terrestrial to aquatic environments. A summary of habitat characteristics for the three locations is presented in Table 1.

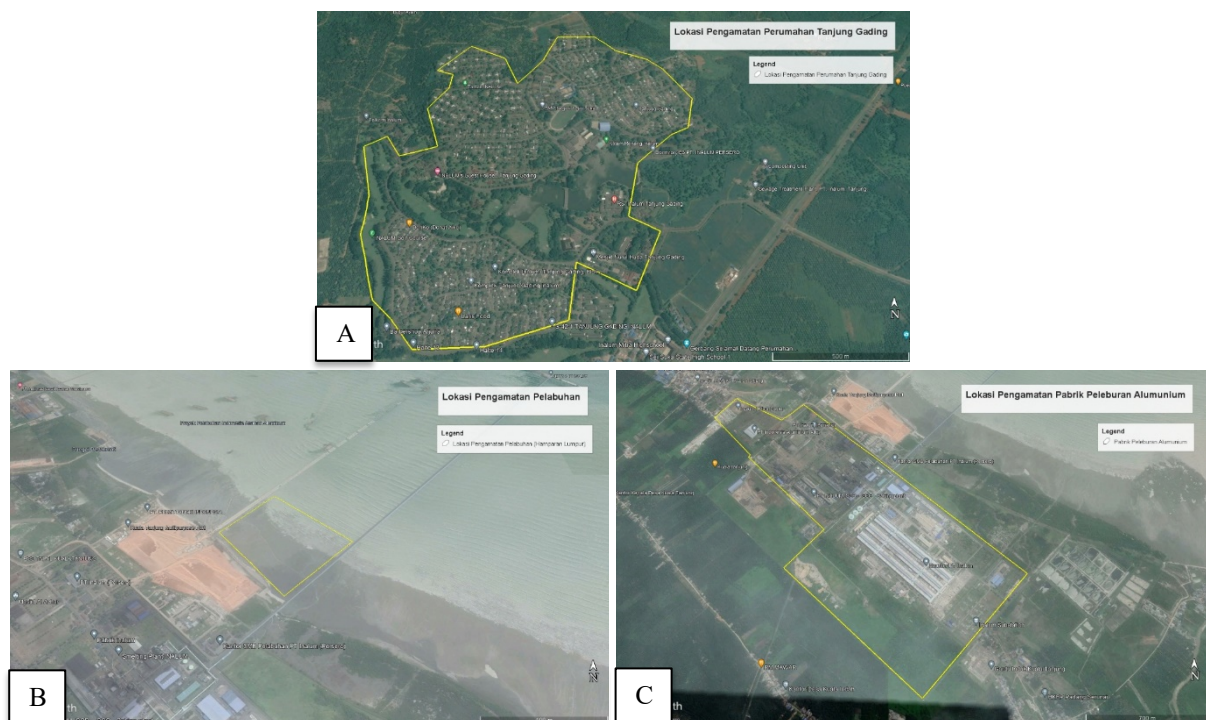


Figure 1. Map of observation sites: A) Tanjung Gading Residential Area, B) Aluminium Smelter Complex, C) Kuala Tanjung Port

Bird Survey

Bird observations were conducted between April 2023 and July 2024, encompassing both the dry-wet and migratory seasons to capture temporal variations in species occurrence. Surveys were carried out for 2–3 days each month, totaling 10 months of field observations. Each survey day included two observation sessions, early morning (06:00–10:00 WIB) and late afternoon (15:30–18:00 WIB)

corresponding to the periods of peak bird activity. Bird observations were conducted using the MacKinnon List method (MacKinnon & Phillipps 1993), which provides an efficient and standardized approach to estimate avian species richness. Each list consisted of the first 20 distinct species encountered during a survey session, irrespective of the number of individuals. Once a list was completed, a new list was initiated immediately. All lists

were treated as independent sampling units, ensuring equal sampling effort across sessions. Data were compiled into a presence–absence matrix, with each sampling unit representing one replicate for species accumulation analysis.

Observations were carried out along accessible routes within the three major habitat types: urban green zones (Taman Gajah and golf course) with total number of sampling units is 21. Therefore, due to lack of access/prohibited zone for shrubland and wetland areas behind the smelting plant and the coastal mudflats near Kuala Tanjung Port accessible via the port bridge, the total number of sampling is only one. A total of 23 MacKinnon lists were compiled over ten

months of observation between April 2023 and July 2024. A reconnaissance and exploratory survey approach was employed. The bird data were analyzed descriptively to summarize species composition and spatial distribution among the three sites. Community composition was evaluated by comparing species presence across habitat types (terrestrial vs. aquatic). Field equipment comprised binoculars, monoculars, digital cameras, and tripods for visual detection and photographic documentation. Particular attention was devoted to breeding and nesting species, with camera traps deployed strategically to record nesting behavior, parental care, and breeding success.

Table 1. Characteristics of the three bird observation sites within PT INALUM operational areas

Location	Area (ha)	Dominant Vegetation	Habitat Type
Tanjung Gading Residential Area	200	Fruit trees (<i>Mangifera indica</i> , <i>Nephelium lappaceum</i> , <i>Musa sp.</i> , etc.), shade trees (<i>Ficus sp.</i> , <i>Casuarina equisetifolia</i> , <i>Roystonea regia</i>), and ornamental plants (<i>Bougainvillea sp.</i> , <i>Plumeria sp.</i>)	Terrestrial and aquatic (urban habitats, including artificial ponds)
Aluminium Smelter Complex	181	Oil palm (<i>Elaeis guineensis</i>), shrubs, and grasses	Terrestrial and aquatic (secondary vegetation, wetlands, and drainage zones)
Kuala Tanjung Port	15.5	Sparse vegetation	Aquatic (coastal mudflat)

Data Analysis

Species identification followed the field guide Birds of the Indonesian Archipelago: Greater Sundas and Wallacea (Second Edition) by Eaton *et al.* (2021). Bird calls were recorded using a Zoom H6n sound recorder and cross-checked with verified vocalizations from the Xeno-canto online database (<https://www.xeno-canto.org>). All recorded species were tabulated according to their family, scientific name, Indonesian/local name, english name and site occurrence across the three observation areas. Each species was also classified based on its conservation

status following the IUCN Red List (2024) and its legal protection status under Indonesian regulation (Permen LHK No. P.106/2018).

Ecotourism Potential Assessment

Ecotourism potential was qualitatively assessed based on the bird diversity, habitat accessibility, aesthetic and educational value and environmental integrity of each site. Factors considered included the presence of attractive or flagship bird species (e.g., migratory waterbirds, colorful frugivores, the conservation or protection status of birds,

nesting event), visual landscape quality, and existing infrastructure such as walking trails, observation platforms, or educational facilities. The assessment aimed to identify opportunities for birdwatching-based ecotourism development compatible with PT INALUM's Corporate Social Responsibility (CSR) and environmental sustainability programs, emphasizing low-impact tourism and local community engagement.

Results and Discussion

Species Composition and Distribution

A total of 103 bird species belonging to 40 families were recorded across the three study sites within the operational areas of PT Indonesia Asahan Aluminium (INALUM): the Tanjung Gading Residential Complex, the Smelting Plant Area, and the Kuala Tanjung Port (**Appendix 1**). These species were categorized into two major ecological groups: aquatic birds/waterbirds and terrestrial birds. Aquatic species, those associated with wetland or coastal habitats, were represented by eight families, including Ardeidae, Phalacrocoracidae, Ciconiidae, Charadriidae, Laridae, Rostratulidae, Scolopacidae, and Rallidae. Terrestrial birds, on the other hand, comprised 32 families such as Accipitridae, Falconidae, Columbidae, Pycnonotidae, Apodidae, Picidae, Meropidae, Artamidae, Cuculidae, Laniidae, Sturnidae, Motacillidae, Dicaeidae, Nectarinidae, and

Estrildidae (Documentation of the birds provide on **Appendix 2**).

The highest species richness was recorded in the Smelting Plant Area with 60 species, followed by 57 species in the Residential Area, and 24 species in the Port Area. The relatively high diversity in the first two locations reflects the coexistence of both terrestrial and aquatic microhabitats, including vegetation-rich patches, artificial ponds, and semi-natural wetlands. In contrast, the Kuala Tanjung Port dominated by open mudflats and coastal areas, harbored fewer species, though it supported a number of specialized aquatic and migratory birds.

The species accumulation curve for the area shows a rapid increase in bird species richness during the initial observation samples, followed by a gradual stabilization as sampling effort increased (**Figure 2**). The curve rises steeply from the first to about the sixth sampling effort, indicating the discovery of many new species in the early phase of data collection. After approximately the 10th to 12th observation, the curve begins to level off, suggesting that most of the species present within the area had been detected. By the 22nd to 24th observation samples, the curve approaches an asymptote near 103 species, indicating sampling completeness and a relatively comprehensive documentation of avian diversity across the study sites. This pattern reflects an adequate survey effort and a high level of species richness within the heterogeneous industrial landscape of PT INALUM.

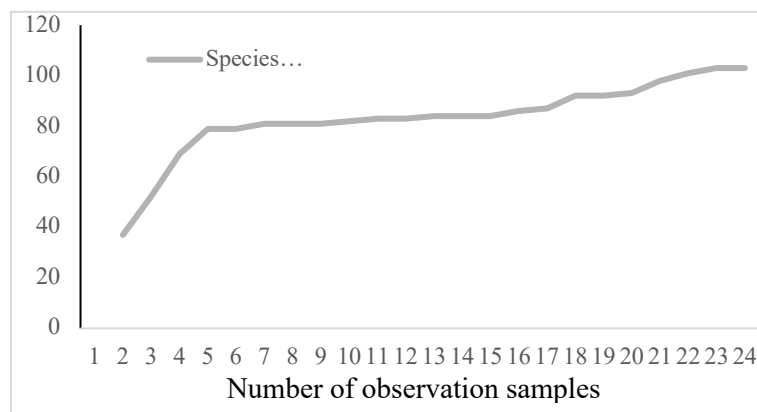


Figure 2. Species accumulation curve showing the relationship between sampling effort (number of observation samples) and cumulative bird species richness recorded in the industrial landscape of PT Indonesia Asahan Aluminium, North Sumatra.

Three families exhibited notably high species richness: Ardeidae (10 species), Accipitridae (9 species), and Scolopacidae (9 species) (**Figure 3**). The Ardeidae, including egrets, herons, and bitterns, are ecologically dependent on wetlands, both natural (lakes, rivers) and artificial (ponds, ditches, paddy fields). Their presence in both the Residential and Smelting Plant areas indicates the availability of semi-aquatic foraging habitats within INALUM's landscape. The Accipitridae represent diurnal raptors such as kites, eagles, sparrowhawks, and honey-buzzards. As apex predators, they play an

important role in maintaining ecological balance by controlling populations of small mammals and other prey species. For example, the Black-winged Kite (*Elanus caeruleus*) is known to effectively reduce rodent populations in plantation landscapes. The Scolopacidae, comprising sandpipers, curlews, and godwits, are predominantly migratory shorebirds that utilize the Kuala Tanjung mudflats during their non-breeding season. These species undertake long-distance migrations between northern breeding grounds (e.g., Mongolia, China, Russia and Alaska) and southern wintering areas in Southeast Asia and Australasia.

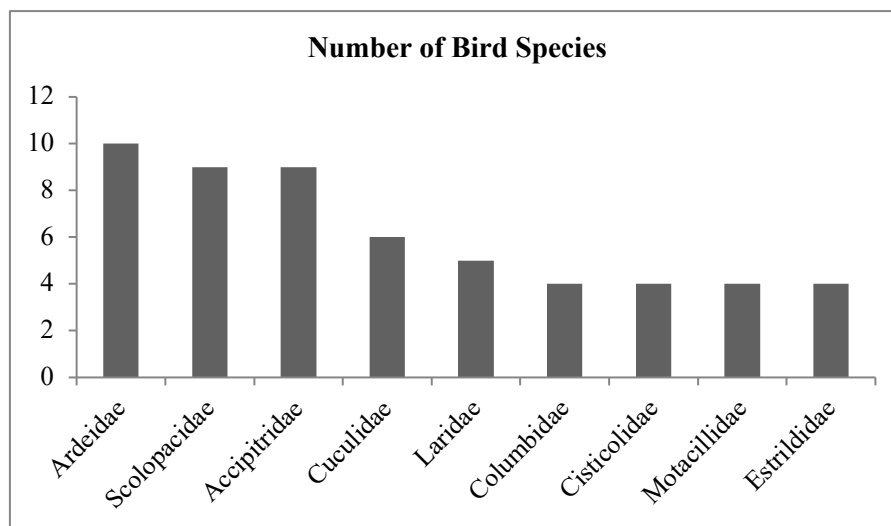


Figure 3. Number of bird species recorded by family, showing the families with the highest species richness

Habitat-Specific Observations

At the Smelting Plant Area, semi-aquatic vegetation and shrublands supported diverse bird communities, including the Common Moorhen (*Gallinula chloropus*), Cinnamon Bittern (*Ixobrychus cinnamomeus*), and White-breasted Waterhen (*Amaurornis phoenicurus*). Tree-dwelling species such as Sunda Pygmy Woodpecker (*Picoides moluccensis*), Rufous Woodpecker (*Micropternus brachyurus*), and White-breasted Kingfisher (*Halcyon smyrnensis*) were also

common, reflecting structural habitat heterogeneity. Grasslands near the entrance supported large congregations of Blue-tailed Bee-eater (*Merops philippinus*), some of which were observed breeding. The Tanjung Gading Residential Area hosted a variety of urban-tolerant species due to abundant green spaces such as gardens and golf courses with large shade trees (e.g., *Ficus* spp., *Casuarina* spp.). Common species included Pink-necked Green-pigeon (*Treron vernans*), Asian Glossy Starling (*Aplonis panayensis*), Sooty-headed Bulbul

(*Pycnonotus aurigaster*), and White-breasted Woodswallow (*Artamus leucorhynchus*). Artificial ponds within this area provided habitat for Little Egret (*Egretta garzetta*), Cattle Egret (*Ardea ibis*), and Collared Kingfisher (*Todirhamphus chloris*).

The Kuala Tanjung Port, characterized by open coastal mudflats, was dominated by aquatic and migratory species, including Milky Stork (*Mycteria cinerea*), Lesser Adjutant (*Leptoptilos javanicus*), Pacific Golden Plover (*Pluvialis fulva*), Common Redshank (*Tringa totanus*), and several tern species (e.g., *Chlidonias* spp., *Sterna* spp., *Thalasseus* spp.). During high tide, many individuals were observed roosting on nearby cables and port structures.

Conservation and Migration Status

Of the 103 species recorded (Figure 4), 22 species are legally protected under Indonesian law (Regulation of the Minister of Forestry No. P.106/2018). These include several raptors such as Brahminy Kite (*Haliastur indus*), White-bellied Sea-eagle (*Ichthyophaga leucogaster*), and Changeable Hawk-eagle (*Nisaetus limnaetus*), as well as large waterbirds such as Great Egret (*Ardea alba*), Milky Stork (*Mycteria cinerea*), and Lesser Adjutant (*Leptoptilos javanicus*). According to the IUCN Red List, *Mycteria cinerea* is classified as Endangered, with an estimated global population of only 1,200–1,500 individuals (Birdlife International 2024), approximately 80% of which occur in Sumatra. This highlights the significance of INALUM's mudflat and wetland habitats as potential foraging or roosting areas for this globally threatened species.

A total of 31 migratory species were identified, mainly from Scolopacidae and Charadriidae, as well as a few raptors (Accipitridae) and passerines (Muscicapidae, Phylloscopidae). These include Pacific Golden Plover (*Pluvialis fulva*), Whimbrel (*Numenius phaeopus*), Curlew Sandpiper (*Calidris ferruginea*),

Asian Brown Flycatcher (*Muscicapa dauurica*), and Arctic Warbler (*Phylloscopus borealis*). The presence of these species underscores the regional importance of INALUM's coastal zone as part of the East Asian–Australasian Flyway (EAAF).

The regular occurrence of these species demonstrates that INALUM's semi-natural habitats, including mangrove fragments, sediment ponds, and vegetated wetlands, still provide suitable foraging and roosting grounds for waterbirds. The presence of species with restricted distributions or declining global populations emphasizes the conservation significance of maintaining habitat heterogeneity within industrial landscapes. This finding supports previous studies showing that managed green spaces and rehabilitated zones in industrial areas can act as important refuges for birds (Al-Reza *et al.*, 2021). Integrating biodiversity conservation into corporate environmental management offers a dual benefit supporting national conservation targets while enhancing the company's sustainability profile. Measures such as maintaining riparian vegetation, managing water levels in sediment ponds, and creating buffer zones around key wetland patches can further improve the habitat quality and ensure long-term viability of these species.

Nesting Records and Breeding Observations

Several bird species were recorded breeding within the study area, providing strong evidence that portions of the INALUM landscape support essential life-history stages, not merely transient foraging use. Breeding activity was confirmed through direct observation and camera-trap monitoring of nesting sites across residential green zones and semi-natural habitats. Nesting species included Changeable Hawk-Eagle (*Nisaetus limnaetus*), Sunda Yellow-vented Bulbul (*Pycnonotus analis*), Pink-necked Green Pigeon (*Treron vernans*), White-headed

Munia (*Lonchura maja*), Chestnut Munia (*Lonchura malacca*), Pied Thriller (*Lalage nigra*), Baya Weaver (*Ploceus manyar*),

Blue-tailed Bee-eater (*Merops philippinus*) and Zebra Dove (*Geopelia striata*).

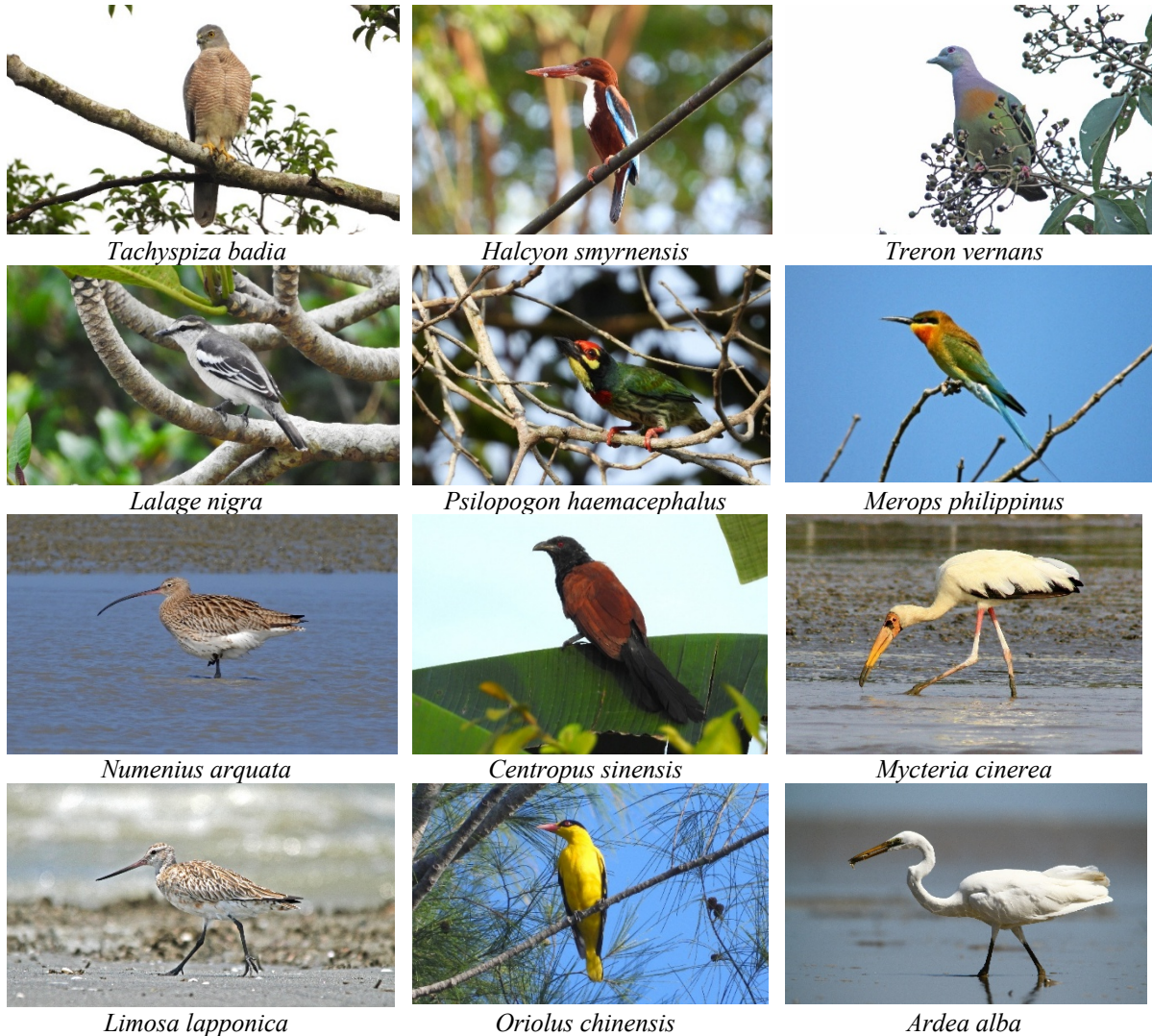


Figure 4. Birds recorded within the industrial landscape of PT Indonesia Asahan Aluminium (PT INALUM), North Sumatra, Indonesia. All photos copyright by Chairunas Adha Putra

These nesting observations occurred predominantly in areas with mature trees, flowering shrubs, and semi-open habitats, particularly around the Tanjung Gading residential complex and adjacent green corridors. Camera-trap images captured courtship, incubation, and chick-feeding behaviors of several species, notably the Sunda Yellow-vented Bulbul (Figure 5), further confirming the ecological suitability of these habitats for successful reproduction. The presence of breeding

populations of both common and protected species underscores the ecological resilience of the area. Industrial green zones with tree cover, gardens, and artificial wetlands appear to provide microhabitats comparable to semi-natural ecosystems. Such evidence positions INALUM as an example of how industrial and ecological functions can coexist when managed with sustainability principles.

Implications for Birdwatching Ecotourism

From an ecotourism perspective, the combination of high bird diversity, the presence of threatened species, and observable breeding behavior presents a valuable opportunity to develop guided birdwatching activities. The sighting of large, charismatic, and easily observable species such as the Milky Stork, Lesser Adjutant, and Changeable Hawk-Eagle offers strong visual appeal for both amateur and professional birdwatchers. Moreover, the occurrence of nesting events provides opportunities for interpretive and educational ecotourism, allowing visitors to appreciate avian life cycles and ecosystem dynamics. However, birdwatching development must be carefully planned to avoid disturbance to breeding birds. Visitor

management strategies, such as controlled access, seasonal restrictions during nesting periods, and designated viewing points are essential to balance tourism and conservation. Educational signage and trained local guides can further enhance environmental awareness among visitors and contribute to community engagement in biodiversity protection. If appropriately managed, the INALUM landscape could become a model for “industrial-based bird ecotourism,” demonstrating how corporate green zones and rehabilitated habitats can serve not only as biodiversity refuges but also as platforms for public education and sustainable recreation. This integration of ecological monitoring and low-impact tourism aligns with both national biodiversity strategies and the global vision of nature-positive industry practices.



Figure 5. A Sunda Yellow-vented Bulbul (*Pycnonotus analis*) feeding its chick at the nest during the breeding period

Discussion

Avian Richness in Industrial and Semi-Natural Landscapes: Comparative Insights from North Sumatra and Beyond

A total of 103 bird species representing 40 families were recorded across the three study sites within PT Indonesia Asahan Aluminium's

(INALUM) operational area; the Tanjung Gading Residential Complex, the Smelting Plant Area, and the Kuala Tanjung Port. This level of species richness is notably high for an industrial landscape, indicating that the site retains considerable ecological heterogeneity. When compared with other studies across Sumatra and neighboring regions, INALUM's bird diversity exceeds

or matches findings from similar modified environments. For instance, Dewita *et al.* (2016) recorded only 19 bird species from 14 families within the green open spaces of the Petrochemical Industrial Area in Palembang, South Sumatra. In contrast, Azman *et al.* (2011) reported 132 species from 46 families in a mixed-use landscape of secondary forests, paddy fields, and oil palm plantations in the Kerian River Basin, Malaysia an area characterized by higher habitat complexity and broader landscape connectivity. Meanwhile, Husna *et al.* (2024) recorded 87 species from 32 families across residential zones, plantations, and forest edges in Bukit Mas Village, North Sumatra, which similarly represents a semi-natural mosaic of habitats.

The comparatively high bird richness observed at INALUM suggests that its heterogeneous land-use composition comprising forest patches, landscaped gardens, wetlands, and coastal mudflats supports diverse ecological guilds and trophic interactions. Such habitat diversity allows the coexistence of both resident and migratory species, underscoring the site's potential role as a local biodiversity refuge within an increasingly industrialized coastal zone of North Sumatra. This finding reinforces the growing recognition that well-managed industrial landscapes, particularly those maintaining semi-natural vegetation and aquatic habitats, can contribute meaningfully to regional biodiversity conservation.

Ecological Indicators and Conservation Significance of Key Bird Groups

The Accipitridae, comprising diurnal raptors such as kites, eagles, hawks, and honey-buzzards, serve as valuable indicators of ecosystem health (Donázar *et al.*, 2016). Their presence reflects a relatively intact trophic structure and adequate prey availability, conditions that often deteriorate under high anthropogenic pressure. The consistent occurrence of species such as the Crested Serpent Eagle (*Spilornis cheela*) and Brahminy Kite

(*Haliastur indus*) within the INALUM area suggests that, despite ongoing industrial operations, portions of the landscape retain sufficient ecological integrity to sustain top predators. This finding aligns with studies emphasizing the sensitivity of raptors to habitat quality and their role as bioindicators of environmental health in modified ecosystems.

Equally significant is the presence of Scolopacidae, a family of migratory shorebirds including sandpipers, curlews, and godwits, which utilize the Kuala Tanjung mudflats during the non-breeding season. These long-distance migrants travel thousands of kilometers from breeding grounds in Siberia, Mongolia, and Alaska to wintering sites across Southeast Asia and Australasia (Bamford *et al.*, 2008). The records of Eurasian Curlew (*Numenius arquata*), Bar-tailed Godwit (*Limosa lapponica*) and Curlew Sandpiper (*Calidris ferruginea*) highlight the regional importance of INALUM's coastal habitats as feeding and stopover sites along the East Asian–Australasian Flyway. Comparable shorebird assemblages reported from other areas along the east coast of North Sumatra (Putra *et al.*, 2015; Putra *et al.*, 2020) reinforce the continuity and ecological value of this coastline for migratory waterbirds.

The observation of the Milky Stork (*Mycteria cinerea*), a globally endangered species (BirdLife International, 2024), further elevates the conservation value of the site. This species is now largely restricted to a few remnant wetlands in western Indonesia, notably in South Sumatra and Java (Iqbal *et al.*, 2012; Baveja *et al.*, 2019). Its presence within the INALUM landscape suggests that the area still supports the ecological functions required by sensitive wetland specialists. However, it also underscores the need for sustained monitoring to prevent habitat degradation and potential hybridization with Painted Storks (*Mycteria leucocephala*), a growing concern in nearby regions (Baveja *et al.*, 2019). Additionally,

the breeding activity of several resident bird species confirms that the INALUM landscape provides not only foraging grounds but also suitable nesting habitats. Species such as the Changeable Hawk-eagle (*Nisaetus limnaeetus*), Sunda Yellow-vented Bulbul (*Pycnonotus analis*), Pink-necked Green Pigeon (*Treron vernans*), White-headed Munia (*Lonchura maja*), Chestnut Munia (*Lonchura atricapilla*), Pied Triller (*Lalage nigra*), Baya Weaver (*Ploceus philippinus*), Blue-tailed Bee-eater (*Merops philippinus*), and Zebra Dove (*Geopelia striata*) were all observed exhibiting nesting behavior. The occurrence of these breeding populations within an industrial and residential matrix highlights the adaptive capacity of certain species to modified environments, consistent with findings from other parts of Sumatra.

Collectively, these observations indicate that INALUM's heterogeneous mosaic of forest patches, landscaped gardens, wetlands, and coastal mudflats maintains essential ecological processes that support a broad spectrum of avian guilds from apex predators and resident breeders to long-distance migrants. Beyond its ecological value, this bird diversity also presents a strong foundation for birdwatching-based ecotourism and environmental education. Given the site's proximity to Medan (approximately one hour by toll road), the INALUM residential and surrounding green areas could be developed as a corporate biodiversity learning site, integrating citizen science, guided interpretation trails, and community-based monitoring to strengthen local engagement and corporate environmental stewardship.

Implications for Corporate Biodiversity Management

Beyond its biological implications, the results of this study offer practical guidance for corporate biodiversity management. The establishment of a Wildlife Management Team within INALUM could institutionalize long-term

biodiversity monitoring, aligning with global frameworks such as the Business and Biodiversity Pledge and the Post-2020 Global Biodiversity Framework. Such programs have been shown to improve species outcomes in industrial zones when combined with local community engagement. Regular monitoring can also function as an early-warning system for environmental changes, providing both ecological and compliance benefits under Indonesia's Environmental Management regulations. Continuous monitoring will not only help detect ecological trends but also provide a platform for corporate reporting on Sustainability and ESG (Environmental, Social, and Governance) goals.

The potential for environmental education and ecotourism, especially birdwatching activities, further enhances the social value of INALUM's biodiversity assets. Given its proximity to Medan (approximately one hour by toll road), the area could serve as a living laboratory for schools, universities, and visitors, integrating conservation education with local economic benefits. That initiatives can be benefit where employee and community participation strengthened both conservation outcomes and corporate reputation. Overall, the findings highlight that even within industrial landscapes, biodiversity persistence is achievable through habitat retention, ecological design, and active monitoring. PT INALUM's operational area, by supporting over a hundred bird species including migratory and threatened taxa demonstrates the potential coexistence of industrial development and biodiversity conservation, provided that management actions remain evidence-based and adaptive to ongoing environmental changes.

Conclusions

This study recorded a total of 103 bird species from 40 families within the operational areas of PT Indonesia Asahan Aluminium (INALUM), demonstrating that

even industrial landscapes can sustain high levels of biodiversity when managed with ecological awareness. The presence of raptors, migratory shorebirds, and breeding resident species indicates that INALUM's mosaic of green spaces, wetlands, and coastal habitats still provides essential ecological functions and supports multiple avian guilds. The record of the endangered Milky Stork (*Mycteria cinerea*) further emphasizes the site's conservation importance at both national and regional scales. To enhance biodiversity management and public awareness, it is recommended that INALUM:

- 1) Integrate bird monitoring as part of its long-term environmental management and CSR programs, with regular surveys covering both breeding and migratory seasons.
- 2) Develop birdwatching-based ecotourism and environmental education programs, leveraging existing green zones and coastal habitats as learning sites for employees, students, and local communities.
- 3) Strengthen habitat protection and restoration, particularly in mangrove and wetland areas, to maintain ecological connectivity and minimize disturbance to sensitive species.
- 4) Collaborate with local conservation groups, conservation NGO's and research institutions to promote data sharing, capacity building, and awareness of industrial biodiversity conservation.
- 5) To reinforce conservation awareness, PT Inalum should invest in interpretive and educational infrastructure such as biodiversity information boards, videotron displays, posters, and other outreach materials. These should highlight the ecological significance of the area and the species it supports. Such communication efforts would not only promote public understanding of biodiversity conservation but also position PT Inalum as a model for industry conservation collaboration in

Indonesia. Integrating biodiversity information into public spaces, staff areas, and educational tours will further strengthen the company's commitment to sustainable environmental management.

This study demonstrates that PT Inalum's operational landscape, despite being an industrial zone, possesses substantial conservation value and ecotourism potential. Through continuous biodiversity monitoring, habitat protection, and public engagement, PT Inalum can play a pivotal role in promoting industrial sustainability integrated with biodiversity conservation, contributing to both national conservation targets and local community empowerment.

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