JPPIPA 10(8) (2024)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Estimating the Inbreeding Rate in Natural Populations of The Black-Naped Fruit Dove (*Ptilinopus melanasphila*)

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Received: May 16, 2024
Revised: July 10, 2024
Accepted: August 25, 2024
Published: August 31, 2024

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DOI: 10.29303/jppipa.v10i8.7666

Abstract: This research aimed to determine the population of the Black-Naped Fruit Dove (*Ptilinopus melanasphila*) by estimating population size, sex ratio, effective population, and inbreeding rate, providing a basis for ex-situ design considerations. Data collection employed survey techniques such as the line transect and concentration count point methods. Data analysis focused on determining population size, sex ratio, effective population, and inbreeding rate. The research was conducted in the Sula Islands, North Maluku. Observations and discussions were conducted separately for each location to obtain empirical and comprehensive data serving as a reference for further research. Results revealed the inbreeding rates at the research locations were observed as follows: Soamole village (1.42%), Wai Ipa village (1.56%), and Bega village (1.60%). Sex ratios were observed as follows: Soamole village (male : female ratio of 22.17 : 85.38), Wai Ipa village (male : female ratio of 19.48 : 73.78), and Bega village (male : female ratio of 19.61:80.39). Effective populations were observed as follows: Soamole village (22.39 heads), Wai Ipa village (16.48 heads), and Bega village (16.08 heads). The inbreeding rate is in the good category, while the population number, sex ratio and effective population are in the medium category, however habitat destruction and continuous excessive hunting can result in decline and extinction.

Keywords: Inbreeding rate; Population; *Ptilinopus melanosphila*

Introduction

The fauna within the Wallacea area is notably diverse, with approximately 249 species residing in the region of North Maluku alone, constituting 36% of the 698 species found in this area, including 27 endemic species (Tabba & Nurrani, 2016). The Black-Naped Fruit Dove is an arboreal species, predominantly inhabiting trees and subsisting on fruit (Fatmona et al., 2020). This species is categorized as endangered on the IUCN Red List (IUCN, 2015) and listed in Appendix 2 of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2014).

It is imperative to accurately characterize the estimated population within its natural habitat to assess the status of the Black-Naped Fruit Dove and delineate subsequent conservation measures. This understanding is imperative to ensure the ongoing preservation of the Sula Black-Naped Fruit Dove in alignment with conservation principles, potentially leveraging its meat as a premium culinary delicacy for Sula's culinary tourism sector. Acquiring knowledge about the estimated population of birds in their natural habitat is essential for assessing their status and guiding future conservation efforts (Beyer & Manica, 2020).

The spatial occupancy of a population, ranging from small to expansive areas, varies depending on the species and the carrying capacity of its habitat. Understanding population size is imperative for balancing trade-offs between populations and their

How to Cite:
Fatmona, S., Utami, S., & Sahil, J. (2024). Estimating the Inbreeding Rate in Natural Populations of The Black-Naped Fruit Dove (Ptilinopus melanasphila). *Jurnal Penelitian Pendidikan IPA*, *10*(8), 6142–6153. https://doi.org/10.29303/jppipa.v10i8.7666

habitats and for tracking population dynamics over extended periods (Mace et al., 2010). Birds confer significant ecological and economic benefits, serving as a valuable protein source and contributing to ecosystem stability and resilience (Saputra et al., 2020). Determining conservation status is important for bird conservation (Masykur et al., 2023). They are commonly employed as bioindicators to assess ecological damage extent and nature (Ridwan, 2015). Birds have distinctive sound frequencies (Hujatulatif et al., 2022).

Influence vegetation structure and composition (Salahuddin et al., 2021), and fulfill essential ecological functions such as seed dispersal and pollination (Mariyappan et al., 2013). Furthermore, birds aid in regulating populations of pestilent invertebrates and vertebrates through their foraging activities, thereby maintaining ecological balance (Tela et al., 2021). Birds also contribute significantly to human livelihoods by providing various natural resources such as game meat for sustenance, feathers for crafting clothing, and fertilizer for composting (Nirmal & Pokharel, 2017). Given their sensitivity to environmental changes and the ease of monitoring their distribution, birds serve as valuable indicators of environmental quality (Adams et al., 2021).

The Black-Naped Fruit Dove (*Ptilinopus melanospila*), an endemic bird species of North Maluku found within the Sula Islands, warrants conservation attention. This arboreal bird primarily feeds on leaves within tree canopies (Fatmona et al., 2020). Alongside the Common Emerald Dove (*Chalcophaps indica*), another dove species belonging to the Columbidae family, they are collectively referred to as Punai birds and are frequently hunted for their delectable meat. Doves hold considerable economic significance in numerous countries due to the high demand for their meat (Wang et al., 2023). Notably, they are among the most widespread bird species in mainland Europe, belonging to the Columbidae family (Hanane & Yassin, 2017).

The peril of the Black-Naped Fruit Dove facing extinction in its natural habitat is primarily attributed to uncontrolled hunting. Unregulated hunting poses a significant threat to avian extinction (Tilker et al., 2019). Additionally, habitat degradation on the Sula Islands, including illegal logging and the conversion of forested areas into plantations and agricultural land without regard for existing wildlife habitats, exacerbates the decline in population. Consequently, there is a looming threat of the species disappearing or becoming extinct in the near future. The existence of a stable habitat is a source of food (Febriyanda et al., 2022; Hadinata et al., 2023). Habitat degradation can lead to population decline (Lismarita et al., 2022). To conserve and protect animals, it is also necessary to map out clear areas between animal habitats and human presence (Abdullah et al., 2023). Indigenous norm systems can also be involved in regulating forest protection (Mei & Suryadarma, 2023).

Indeed, one of the leading causes of declining bird populations is environmental mismanagement, including illegal logging and the conversion of forested areas into plantations and agricultural land without consideration for the natural habitats of resident animals (Bell and Molloy, 2023). Knowing the population, density, sex ratio, growth pattern and reproductive system is very important for conservation (Sinaga et al., 2023). Understanding and estimating inbreeding is crucial for the management of wildlife populations threatened with near extinction (Miller et al., 2017).

This research aimed to determine the population of the Black-Naped Fruit Dove by estimating population size, sex ratio, effective population, and inbreeding rate, providing a basis for ex-situ design considerations. The novelty of this research lies in the acquisition of data pertaining to the population size, sex ratio, effective population, and inbreeding rate of the Black-Naped Fruit Dove (*Ptilinopus melanospila*), which has not been previously researched. The empirical and comprehensive data generated by this research serve as the foundation for ex-situ conservation efforts. It is hoped that this research will serve as a reference for future research endeavors aimed at preserving the biodiversity of our planet.

Method

Within the habitat of the Black-Naped Fruit Dove. Sample locations were deliberately selected across three villages: Soamole Village, Wai Ipa Village, and Bega Village, situated in the Sula Islands, North Maluku. These selections were made based on information from the local community, indicating frequent hunting of Black-Naped Fruit Dove for sustenance within these villages. Each location was equipped with three observation points.

Preliminary Observations

Preliminary research observations were conducted to assess field conditions and identify the research target area. The focus in the field was directed towards the gathering places of the Black-Naped Fruit Dove and its food trees. This preliminary observation period spanned fifteen days.

Population Observation:

Information was collected using a survey technique known as the line transect method (Khotimah et al., 2023). Involving direct measurements in the field within

a designated area of 1,000 x 100 m², with a focal point in the bird foraging area. Line transect observations were conducted within a focus area of 50 m², positioned along three distinct lines: left, middle, and right within the observation area. Each concentration point was deliberately selected on specific trees that were focal points for the Black-Naped Fruit Doves' foraging behavior. Observation techniques involved recording the population size and sex ratio of the Black-Naped Fruit Dove at the beginning and end of each day, conducted over a period of fifteen days. In addition to field observations, interviews were conducted with local residents to gather information about bird breeding in their natural habitat. The interview method involved utilizing a structured questionnaire comprising a list of pertinent questions.

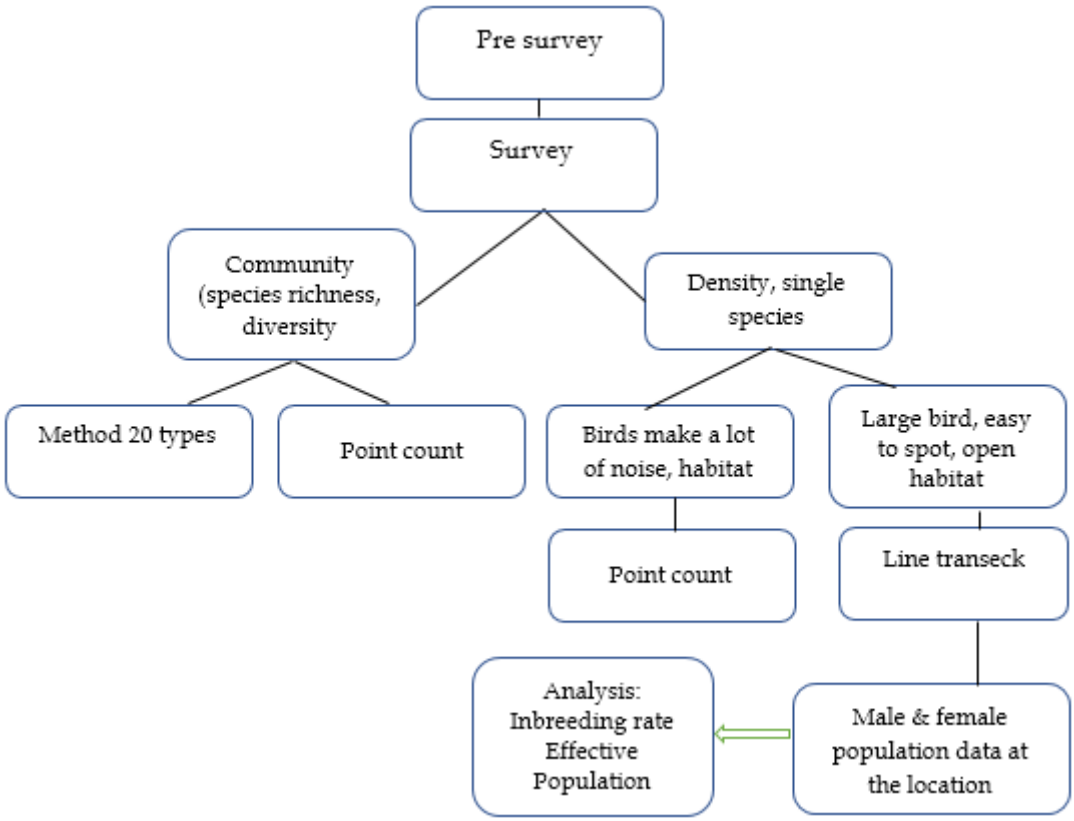

Figure 1. Flow chart of research data collection and analysis methods (specifically for single species and line transect methods)

Materials and Tools

The material utilized as a variable in this research is the Black-Naped Fruit Dove (*Ptilinopus mangoliensis*) in the area of Sula Besi Island, the Sula Islands, North Maluku. The tools utilized in this research includes: Binoculars (7 x 35): Utilized for observing Black-Naped Fruit Dove; Computerized cameras: Utilized for recording field activities; Writing tools (pen/pencil and notebook): Utilized for documenting significant data; Field Manual for Birds in the Wallacea Area (Qiptiyah et al., 2013): Referenced for identifying bird and plant species; Stopwatch: Utilized for recording encounter times with animals and plants; Count sheets: Utilized for recording acquired information; Raffia rope: Utilized for setting up observation points.

Research Area

The Sula Islands is situated within North Maluku, Indonesia. The Sula Islands, with its capital Sanana, is positioned in the southernmost of North Maluku. It is approximately 284 km away from Sofifi, the capital of North Maluku, accessible via air travel and sea transportation.

Geographics

The Sula Islands encompass an area of 13,732.7 km². This region encompasses two large islands, namely Sula Besi Island and Mangole Island, along with 17 medium and small islands. It is divided into 12 sub-areas, encompassing six authoritative sub-regions and 13 development sub-regions, as stipulated in PERDA Number 2 of 2006, and encompasses 124 cities. Geographically, the region is situated between 125°19'42-126°29'11 East Longitude and 01°45'08-02°28'39 South Latitude.

Territorial Boundaries

The territorial boundaries of the Sula Islands are: to the North: Maluku Sea; to the East: South Halmahera Government; to the South: Seram Ocean, Maluku Province; to the West: Taliabu Island.

Topography

From a ground-level perspective, the Sula Islands is typically situated at altitudes ranging from 0 to 100 meters above sea level. The forest environment remains largely intact, characterized by highly fertile forests encompassing swamp rainforests and mountain rainforests. Across approximately 150,000 hectares of coastal plains within the Sula Islands, ample red and yellow Podzolic soils are present, suitable for plantation purposes. Additionally, lands with slopes exceeding 15-25% exhibit Podzolic and Alluvial soil types.

Climate

The Sula Islands features a tropical climate characterized by humidity and two distinct seasons: the rainy season and the dry season. Unlike other regions in Indonesia, where the rainy season typically occurs towards the end or beginning of the year, the Sula Islands and other regencies in North Maluku and Maluku experience the rainy season around the middle of the year, coinciding with the peak of the dry season in other parts of Indonesia. Annual rainfall in this region ranges from 1500 to 1900 mm, with over 120 windy days annually. May registers as the wettest month, with rainfall exceeding 250 mm, whereas October registers as the driest month, with rainfall below 90 mm. The average humidity level in this region is approximately 72%. Air temperatures fluctuate between 22°C and 31°C. The research location map is illustrated in Figure 2.

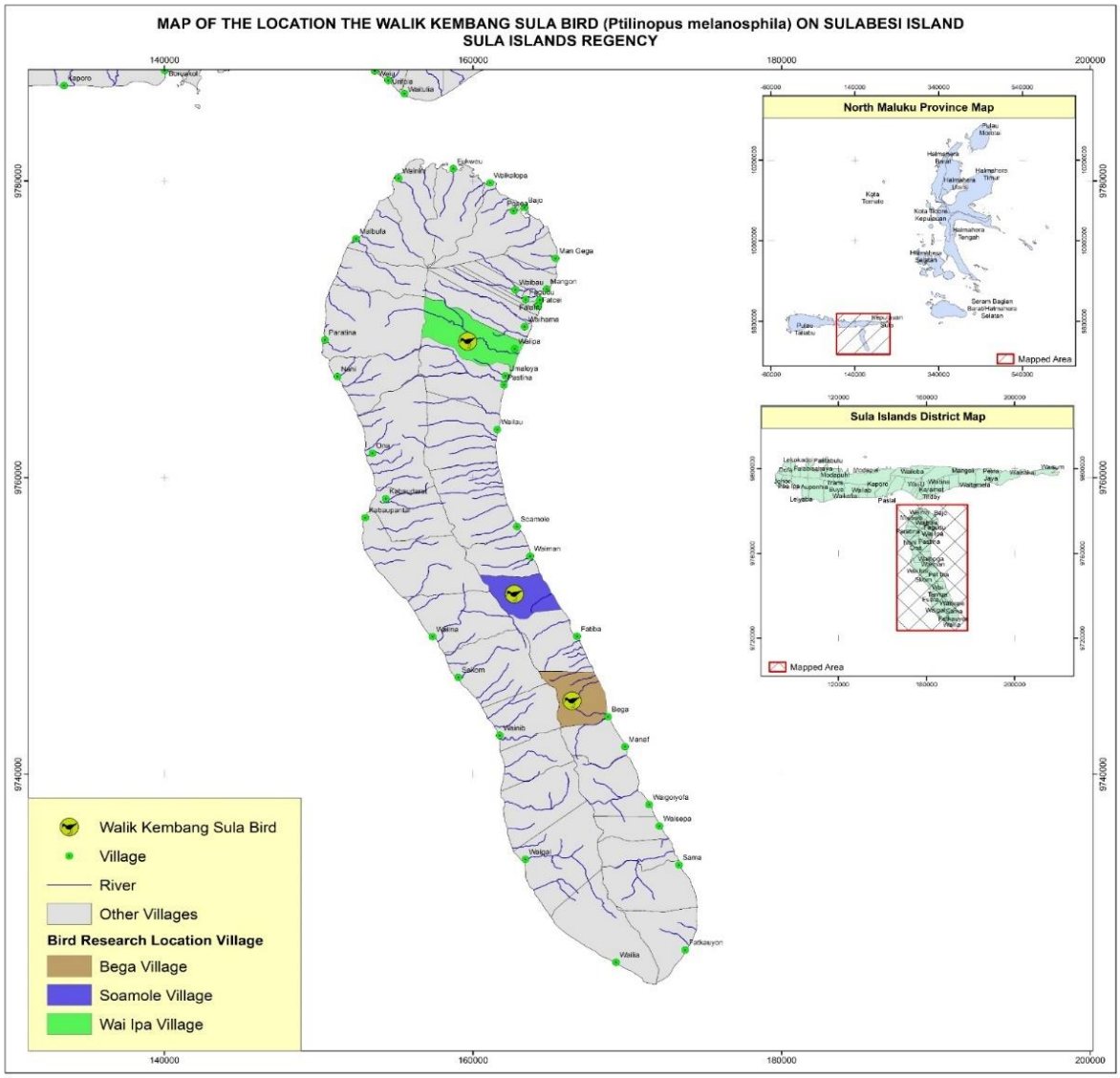

Figure 2. Research Locations: Wai Ipa Village, Soamole Village and Bega Village, Sula Besi Island, Sula Islands, North Maluku (Private collection map)

Data analysis

The formula utilized for estimating the population of the Black-Naped Fruit Dove involves the calculation of effective population analysis and the population inbreeding coefficient (Stansfield, 1982), as outlined in the article by (Rusfidra et al., 2012).

Formula of Effective Population (N):

$$N = \frac{4Nm \times Nt}{Nm + Nt} \quad (1)$$

Information:
N = Effective population
Nm = Number of males
Nt = Number of females

$$\text{Formula of Inbreeding rate} = 1/8\ Nm + 1/8\ Nf \quad (2)$$

Information:
Nm = Number of males and future males
Nf = Number of females that can be mated

The formula utilized for calculating the average is the formula from Sudjana (2005) in Milas et al. (2020):

$$\overline{X} = \frac{\sum x_i}{n} \quad (3)$$

Information:
$\overline{X}$ = Average value of observations or sample average
$\sum$ = Total (Sum up)
x_i = Value of the nth observation
n = Number of samples

The sex ratio can be determined based on age groups. The sex ratio (SR) within each age group can be calculated using the following formula (Setiati et al., 2020).

$$SRi = Mi / Fi \times K \quad (4)$$

Where SRi = Sex Ratio; Mi = number of male populations; Fi = number of female populations; K = constant (value 100). Figures of male and female *Ptilinopus melanospila* are illustrated in Figure 3 (Fatmona et al., 2018).

Figure 3. Black-Naped Fruit Doves (*Ptilinopus mangoliensis*) male left, female right

Result and Discussion

The Population of the Black-Naped Fruit Dove in Soamole Village Based on Total Number, Average, and Sex Ratio

Observations using the concentration count point method are recognized as a valid data collection technique commonly employed in research (Rusfidra et al., 2012). A population is defined as a group of organisms of the same species inhabiting a specific area over a given period (United Nations Department of Economic and Social Affairs, 2023). Populations exhibit distinct characteristics distinguishing them from individual organisms. For instance, populations have a certain density, representing the number of animals occupying a specific area, such as 20 deer per 100 hectares (World Organisation for Animal Health, 2009).

Additionally, populations possess an age structure, which refers to the distribution of individuals across different age classes (Trask et al., 2021). Moreover, populations exhibit sex ratios, which significantly influence the reproductive potential of animals (Schacht et al., 2022). The extinction risk of a species can be inferred if only one sex is present within a population (Mustari, 2020). Hence, a natural population consists of both adult male and female animals engaged in a mating system conducive to offspring production (Li et al., 2023).

Observations using the line transect method were conducted in Soamole village, revealing an average population of 21.2 Black-Naped Fruit Doves. Among these, the average number of adult males and sub-adult males was 4.7, while the average number of females was 18.1, resulting in a sex ratio of 2 : 8 (males : females) or 27.17% males and 85.38% females. The effective population size in Soamole village was determined to be 17.24.

During these observations, some birds were directly observed without binoculars, while others were observed through binoculars or identified by their vocalizations. The population size, sex ratio, and effective population of Black-Naped Fruit Doves in Soamole village indicate a balanced and sufficiently available population. These aspects of population dynamics encompass fertility, survivability, genetic diversity, and effective population size (Facy et al., 2023), which, in turn, influence changes in various aspects, including the sex ratio (Furlan et al., 2012).

Observations using the concentration count point method of the Black-Naped Fruit Dove (*Ptilinopus mangoliensis*) were conducted at nine observation points across three villages, focusing on population size, sex ratio, effective population, and inbreeding rate. Table 1 summarizes the total number, average, and sex ratio of Black-Naped Fruit Doves in Soamole village.

Table 1. Amount number, average, and sex ratio of Black-Naped Fruit Doves in Soamole village

Observation (day)	Amount (head)	Average males in the morning and afternoon (head)	Average females in the morning and afternoon (head)
1	21	4	17
2	22	5	17
3	19	6	20.5
4	20	4	16
5	24	5	20
Amount	106	24	90.50
Average	21.20	4.80	18.10
Sex ratio		22.17	85.38

The average total of male and female Black-Naped Fruit Doves observed in the morning and afternoon (data processed from field observations)

Inbreeding Rate of the Black-Naped Fruit Dove in Soamole Village

A small population size can lead to reduced genetic diversity, hindering the population's ability to adapt to changes in natural conditions (Kumar, 2023). This can result in random deviations in offspring, an increase in inbreeding rate, and a decrease in effective population size (Klimova et al., 2022). The inbreeding rate is employed to estimate the number of males and females that have mated, as well as the number of offspring expected to join the population as adults in the following year (Bercovitch, 2023). Inbreeding can also lead to deviations that result in mortality at various life stages, birth abandonment, or metabolic failure (OECD, 2008). Moreover, inbreeding results in reduced genetic variation and diminished diversity and productivity (Nichols, 2017).

Inbreeding can be mitigated if the coefficient and rate of inbreeding per generation remain below 2% (Kruuk et al., 2002). A population can persist if the rate of increase in inbreeding per generation is equal to or below 1% (Salamena et al., 2007). A 1% increase in inbreeding per generation will reduce animal performance and lead to decreased productivity (Praharani et al., 2018). The average inbreeding rate for the Black-Naped Fruit Dove in Soamole village was determined to be 1.42%, indicating a relatively favorable level. These data are presented in Table 2.

Table 2. Value of inbreeding rate for Black-Naped Fruit Doves in Soamole Village

Gender	Average Number of Black-Naped Fruit Doves (head)	Inbreeding rate (%)
Adult males and sub-adult males	4.80	0.59
Adult females	18.10	2.26
Amount	22.80	2.85
Average	11.40	1.42

The Population of the Black-Naped Fruit Dove in Wai Ipa Village Based on Total Number, Average, and Sex Ratio

By understanding the heredity status of a population, conservation programs aimed at preventing species extinction can be planned by introducing new individuals for genetic enhancement (Torres et al., 2023). This can involve both in situ and ex situ breeding, transferring individuals from populations with high genetic diversity to those with low genetic diversity, thus forming the basis for further management strategies (Aliaga-Samanez et al., 2023). Therefore, proper management is paramount to balance the population's existence through phylogenetic reproduction (Oli & Dobson, 2003).

Observations using the line transect method were conducted in Wai Ipa village, revealing an average population of 19.1 Black-Naped Fruit Doves. Among these, the average number of adult males and sub-adult males was 4.3, while the average number of females was 14.8, resulting in a sex ratio of 2 : 8 (males : females) or 22.51% males and 77.49% females. The effective population size in Wai Ipa village was determined to be 13.33. These data are presented in Table 3.

Table 3. Total number, average, and sex ratio of Black-Naped Fruit Doves in Wai Ipa village

Observation (day)	Amount (head)	Average males in the morning and afternoon (head)	Average females in the morning and afternoon (head)
1	19	4	15
2	21	5	16
3	18	3.50	14.5
4	17	4	13
5	20.5	5	15.5
Amount	95.5	21.50	74
Average	19.1	4.30	14.80
Sex ratio		22.51	77.49

The average total of male and female Black-Naped Fruit Doves observed in the morning and afternoon (data processed from field observations)

Inbreeding Rate of the Black-Naped Fruit Dove in Wai Ipa Village

Inbreeding can lead to deviations that result in mortality at various life stages, birth defects, or metabolic failure (Trask et al., 2021). It results in a loss of genetic variation and a decrease in diversity and productivity (Sawitri & Takandjandji, 2016). Inbreeding can be mitigated if the coefficient and rate of inbreeding per generation remain below 2% (Kruuk et al., 2002). A population can persist if the rate of increase in inbreeding per generation is equal to or below 1% (Salamena et al., 2007). However, a 1% increase in inbreeding per generation will reduce animal performance and lead to decreased productivity (Praharani et al., 2018).

The average inbreeding rate for the Black-Naped Fruit Dove in Wai Ipa village was determined to be 1.56%, indicating a relatively favorable level. These data are presented in Table 4.

Table 4. Value of inbreeding rate for Black-Naped Fruit Doves in Wai Ipa Village

Gender	Average number of Black-Naped Fruit Doves (head)	Inbreeding rate (%)
Adult males and sub-adult males	5.20	0.65
Adult females	19.70	2.46
Amount	24.90	3.11
Average	12.45	1.56

The Population of the Black-Naped Fruit Dove in Bega Village Based on Total Number, Average, and Sex Ratio

Bird populations possess average growth, birth rates, and mortality rates per hectare per year per individual (Sæther et al., 2016). They also possess an age structure, which refers to the distribution of individuals across different age classes (Sonerud et al., 2021). Additionally, bird populations exhibit sex ratios which significantly influence their breeding potential (Payevsky, 2021). This implies that a population can be considered extinct if only one sex is present, rendering reproduction impossible (Turnhout & Purvis, 2020).

Observations using the line transect method were conducted in Bega village, revealing an average population of 25.5 Black-Naped Fruit Doves. Among these, the average number of adult males and sub-adult males was 5, while the average number of females was 20.5, resulting in a sex ratio of 2 : 8 (males : females) or 22.51% males and 77.49% females. The effective population size in Bega village was determined to be 16.8. These data are presented in Table 5.

Table 5. Total number, average, and sex ratio of Black-Naped Fruit Doves in Bega village

Observation (day)	Total (head/%)	Average males in the morning and afternoon (head)	Average females in the morning and afternoon (head)
1	30.50	7	23.50
2	26.50	5	21.50
3	26	5.50	21
4	25	4	21
5	19.50	3.50	15.50
Amount	106.50	30	76.50
Average	25.50	5	20.50
Sex ratio		19.61	80.39

The average total of male and female Black-Naped Fruit Doves observed in the morning and afternoon (data processed from field observations)

Inbreeding Rate of the Black-Naped Fruit Dove in Bega Village

An assessment of the inbreeding rate is necessary to determine the impact of inbreeding pressure (Misztal et al., 2022). Factors greatly influencing genetic diversity in a population include natural selection, genetic transformation or mutation, and non-random mating (Okazaki et al., 2021). Birds are fascinating wild animals to observe due to their remarkable feather colors, behaviors, and morphological structures. They inhabit various habitats ranging from open areas to dense forests (Benton, 2014). The diversity of land cover types in a biological system contributes to a diversity of bird species, which can serve as ecotourism attractions (Dias et al., 2023).

Inbreeding pressure often leads to an increase in male offspring, while female offspring generally decrease (Hutu et al., 2020). However, this phenomenon was not observed in the Black-Naped Fruit Dove at any

of the research locations. The consequences of severe inbreeding can lead to extinction if the number of offspring falls below one individual (Kempenaers, 2022). High inbreeding values in birds can result in inbreeding pressure, leading to reduced productivity and reproductive performance (Harrisson et al., 2019).

Inbreeding can be mitigated if the coefficient and rate of inbreeding per generation remain below 2%. A population can persist if the rate of increase in inbreeding per generation is equal to or below 1%. However, a 1% increase in inbreeding per generation will reduce animal performance and lead to decreased productivity. The average inbreeding rate for the Black-Naped Fruit Dove in Bega village was determined to be 1.60%, indicating a relatively favorable level. These data are presented in Table 6.

Table 6. Value of inbreeding rate for Black-Naped Fruit Doves in Bega Village

Gender	Average Number of Black-Naped Fruit Doves (head)	Inbreeding rate (%)
Adult males and sub-adult males	5	0.62
Adult females	20.50	2.52
Amount	25.50	3.19
Average	12.75	1.60

Conclusion

Based on the results of this research, it can be concluded that the Black-Naped Fruit Dove, based on the inbreeding rate, falls within the good category. However, based on the population size, sex ratio, and effective population, the Black-Naped Fruit Dove at the three research locations, falls within the medium category. Nonetheless, habitat destruction and excessive hunting persist, which could lead to the decline and eventual extinction of this species. Therefore, the potential for the Black-Naped Fruit Dove to be developed ex-situ is important. Additionally, the utilization of its meat as a regional specialty for culinary tourism presents an intriguing opportunity. To achieve the goal of identifying the Black-Naped Fruit Dove (*Ptilinopus mangoliensis*) in terms of estimating population size, sex ratio, and effective population as a basis for ex-situ design considerations, support from the government, community, and academia is crucial. These stakeholders must take steps to implement conservation principles, namely the protection, preservation, and sustainable utilization of the Black-Naped Fruit Dove (*Ptlinopus mangoliensis*). The novelty of this research lies in the acquisition of data pertaining to the population size, sex ratio, effective population, and inbreeding rate of the Black-Naped Fruit Dove (*Ptilinopus melanospila*), which has not been previously researched. Consequently, this research serves as the foundation for ex-situ conservation efforts and provides empirical and comprehensive data to serve as a reference for future research endeavors and application in other regions.

Acknowledgment

The authors would like to express their gratitude to various parties, including the Dean and Head of LPPM at Universitas Khairun, as well as the Head of the Animal Husbandry Study Program, Faculty of Agriculture, Universitas Khairun, for their contributions to this research. Special thanks are extended to the team of authors who contributed to this paper, and to Prof. Rudi Priyanto and Prof. Asnath M Fuah for their assistance in language editing.

Authors Contribution

Sariffudin Fatmona: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Writing – Original Draft. Sri Utami: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Writing – Original Draft, Writing – Review & Editing. Jailan Sahil: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Writing – Original Draft, Writing – Review & Editing.

Funding

This research received no external funding.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work described in this paper.

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