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Estimated Population Abundance of a Bat (Chiroptera) Colony at the Batukoq Water Channel Cave, Senaru, North Lombok

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Abstract
Cave-roosting bats are highly exposed to disturbance because roost entrances are predictable and accessible, yet local management often lacks baseline population information. This study examines a cave-associated roost system in Batukoq, Senaru (North Lombok) and aims to provide a site-specific colony abundance estimate, describe emergence dynamics during the counting window, and identify the main sources of counting bias under field conditions relevant to low-resource monitoring. A Flight Line Census based on direct visual observation was implemented without thermal sensors or night-vision devices, conducted during critical movement periods (dusk and dawn) and restricted to a single large colony site to minimize cross-site variability. The colony's mean estimated abundance was approximately ±590 individuals per night, indicating that Batukoq functions as a key day roost. Visual observations suggested two major groups (Megachiroptera and Microchiroptera) using different flight corridors, and emergence was brief (about 30–45 minutes) with an early peak period that is most sensitive to counting error. The dominant limitation was flight-path overlap under high density and low light, which tends to produce underestimation; therefore, abundance values should be treated as conservative and supported by repeated counts across multiple nights and time windows. These results support the continued use of visual flight-line counts as a non-invasive baseline method, provided that procedural standardization is emphasized and roost disturbance is reduced as a practical conservation priority.

Keywords: Cave-roosting bats; Flight-line census; Population abundance; Emergence dynamics; Counting bias (overlap)

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INTRODUCTION

Bats are a major component of tropical biodiversity and, in many landscapes, they function less like "rare wildlife" and more like everyday ecological infrastructure. Their best-documented services fall into three categories: pollination, seed dispersal, and insect pest control. Nectar-feeding bats pollinate a wide range of plants, including species that support fruit production and broader plant community persistence in the tropics (Kunz et al., 2011; Kingston, 2015; Ramírez-Fráncel et al., 2021). Frugivorous bats disperse seeds across long distances, accelerating forest regeneration and influencing vegetation dynamics in fragmented habitats (García-Morales et al., 2016; Furey et al., 2018; Ramírez-Fráncel et al., 2021). Insectivorous bats contribute to pest suppression by consuming large quantities of nocturnal insects, a service that has measurable economic value in agricultural settings where pest outbreaks directly translate into yield losses (Frick et al., 2019; Kemp et al., 2019; Kingston, 2015). Despite this evidence, bats continue to be socially undervalued and frequently mischaracterized, with persistent misconceptions shaping policy responses and public attitudes (Kingston, 2008; Frick et al., 2019; Ramírez-Fráncel et al., 2021). This mismatch between ecological importance and social perception matters, because it influences whether roost sites are protected, tolerated, or actively disrupted.

The conservation challenge is especially acute for cave-roosting bats. Caves provide stable microclimates and physical protection that support roosting, maternity aggregations, and colony persistence, and they often host complex social structures and, at times, mixed-species assemblages (Leivers et al., 2019; Phelps et al., 2016). Yet cave systems are also unusually exposed to human disturbance because entrances are accessible, predictable, and often treated as recreational or extractive spaces. Across Southeast Asia, cave-roosting bats face pressure from habitat change, roost disturbance, direct exploitation, and climate-linked shifts that may alter cave microclimates and roost suitability (Furey et al., 2018; Shapiro et al., 2021; Sin et al., 2024). Disturbance associated with tourism is repeatedly identified as a practical risk pathway, particularly through light, noise, and repeated human presence that can disrupt roosting behavior and reproduction (Paksuz & Özkan, 2012; Debata, 2020). Hunting and targeted exploitation further compound decline risks, especially when combined with habitat loss and negative public perceptions that frame bats primarily as pests or threats (McKee et al., 2021; Pretorius et al., 2021). A related tension is that heightened awareness of zoonotic disease has sometimes encouraged reactive interventions that reduce tolerance for bats rather than supporting evidence-based management of human–wildlife interfaces (McKee et al., 2021; Pretorius et al., 2021). None of this implies bats should be treated as "untouchable"; it implies that management decisions should be guided by clear ecological objectives and reliable population information rather than fear or assumptions.

In Indonesia, these pressures interact with high bat diversity and rapid land-use change, making local conservation decisions unusually sensitive to gaps in baseline data. Roost sites are central to conservation because they anchor nightly foraging movements and can function as critical breeding sites; when a major roost is lost or repeatedly disturbed, local ecological services can drop in ways that are not immediately visible until pest pressure rises or forest regeneration slows (Paksuz, 2017; Phelps et al., 2016; Pretorius et al., 2021). At the same time, many communities derive tangible benefits from bats, including guano used as fertilizer and tourism value from cave visitation, so management must consider both ecological and livelihood dimensions rather than assuming conservation and local use are automatically in conflict (Frick et al., 2019; Shapiro et al., 2021; Kemp et al., 2019). Lombok, within the Wallacea biodiversity hotspot, is a useful example of why site-level evidence matters: cave habitats can support multiple bat taxa with different ecological roles. Work in southern Lombok has documented cave-dwelling bat diversity and underscored that caves are not interchangeable shelters but structured habitats with species-specific use patterns (Fajri et al., 2014). Functionally, this diversity likely translates into multiple services, from insect suppression by insectivorous bats (Aguiar et al., 2021; Nsengimana et al., 2023) to pollination and seed dispersal by Pteropodidae fruit bats (Yani & Yuliyantika, 2019). However, conservation planning in such contexts is often constrained by limited local monitoring, including uncertainty about which roosts are most important, how colony sizes fluctuate, and how sensitive particular sites are to disturbance (Phelps et al., 2016; Kingston, 2008).

Monitoring is therefore not a side task but a prerequisite for defensible management. Estimating colony size, tracking changes over time, and detecting early warning signals of decline allow conservationists to move beyond anecdote and respond proportionally to threats (Azmy et al., 2012; Leivers et al., 2019). There is also a methodological reality: monitoring approaches must fit local conditions. While technological methods can improve precision and reduce disturbance, many field settings still rely on non-intrusive, low-cost protocols that can be implemented repeatedly without specialized equipment (Azmy et al., 2012; Pretorius et al., 2021). Cave environments, in particular, invite non-invasive approaches because internal counts can disturb roosting bats and may be unsafe or impractical. For this reason, emergence-based counts, including flight-line census approaches conducted at dusk or dawn, remain widely used in roost monitoring because they estimate colony abundance without entering the roost (Azmy et al., 2012; Leivers et al., 2019). Still, this approach is not automatically "accurate." Visual emergence counts are sensitive to overlapping flight streams, low-light constraints, observer fatigue, and inconsistent interval timing. If these sources of error are ignored, emergence counts can produce numbers that look precise but are not reliably comparable across nights or sites. That is why robust monitoring is as much about standardization and transparency as it is about the counting technique itself (Henley et al., 2024; Phelps et al., 2016; Kingston, 2008).

A second challenge is the relationship between population monitoring and species identification. In Indonesia's multi-species roost contexts, colony-level abundance can be ecologically informative even when species-level identification is incomplete, but the limits must be stated clearly. Species identification may rely on morphological traits such as wing shape, body size, and cranial or facial characteristics, with additional inference possible through echolocation call structure for insectivorous taxa (Furey & Racey, 2016; Bolívar-Cimé et al., 2017; Deleva et al., 2023). These tools support improved field identification, but they also highlight why emergence-based visual counts often cannot guarantee species-level assignments unless paired with capture, acoustic monitoring, or other corroborating methods (Furey & Racey, 2016; Phelps et al., 2016). In that sense, a careful study should avoid inflating claims: a flight-line count can provide a defensible estimate of "bats exiting a roost" and a useful activity profile, but species composition and species-specific trends typically require additional methods.

Against this background, the present study focuses on a cave-associated roost system in Senaru, North Lombok (Batukoq water-canal/cave area), and uses a flight-line census approach to estimate colony abundance and describe emergence dynamics under field conditions relevant to low-resource monitoring. The objective is threefold: to provide a site-specific abundance estimate based on repeated emergence/return counts, to characterize temporal patterns of activity during the counting window (including the practical role of light conditions in shaping detectability and emergence timing), and to evaluate the main sources of counting bias that affect reliability when bats emerge in dense streams. By positioning these results within the broader conservation context of cave-roosting bats in Southeast Asia and Indonesia, this study aims to contribute local baseline data that can support management decisions, including practical monitoring protocols and disturbance-mitigation priorities for roost protection and surrounding habitats (Furey et al., 2018; Shapiro et al., 2021; Phelps et al., 2016; Kemp et al., 2019). Importantly, the contribution is not framed as a universal "solution" to bat monitoring; rather, it is offered as a transparent case study of what a standardized emergence-count approach can and cannot deliver in Lombok's cave-roost setting, and what methodological refinements are most defensible for future monitoring and conservation planning (Azmy et al., 2012; Leivers et al., 2019; Henley et al., 2024).

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METHODS

The Batukoq Cave/Water Channel in Senaru Village is located within a hilly landscape characterized by diverse vegetation and rich wildlife, including birds and primates. The area lies within the Senaru Resort zone of Mount Rinjani National Park and is surrounded by river systems and extensive green rice fields, contributing to a heterogeneous and ecologically dynamic environment.

Geographically, the study site is situated at Latitude: 8°18' S (–8.313657°) and Longitude: 116°24' E (116.402685°). In decimal degrees, the coordinates are –8.313657, 116.402685, while in degrees, minutes, and seconds (DMS) they correspond to 8°18'47" S and 116°24'10" E.

The census method applied in this study was the Flight Line Census, conducted through direct visual observation without the assistance of thermal sensors or automated nocturnal imaging equipment such as Night Vision Devices. This approach was intentionally selected to evaluate the pure contribution of human observer skill in estimating bat populations.

The research object was limited to bat species (Chiroptera) inhabiting a predetermined day roost at the study site. Observations were carried out during critical temporal windows, specifically at dawn and dusk, when peak colony movement occurs. Environmental factors considered in this study were restricted to weather-related visibility conditions (clear or cloudy), which directly influence natural lighting during the census process. To minimize variability associated with differing biotic conditions, data collection was confined to a single large colony location within the study area.

Table 1. Summary of Previous Studies Relevant to Bat Population Census

Researcher (Year)	Variable Focus	Key Findings	Relevance to This Study
Kloepper (2016)	Abundance & Acoustic Monitoring	Overlapping flight paths reduce visual counting accuracy by more than 25%.	Strengthens the background discussion on overlapping as a major source of counting error.
Jumail (2021)	Bat Census in Indonesia	Flight line observation is more effective than mist-netting for large colonies.	Supports the selection of the Flight Line Census method.
BatCount (2023)	Accuracy & Observer Skill	Human observers tend to underestimate population size in large colonies.	Reinforces the finding that observer skill strongly influences count accuracy.

Researcher (Year)	Variable Focus	Key Findings	Relevance to This Study
Eddington (2023)	High-Mobility Colonies	Thermal drone surveys are approximately 1.7 times more accurate than naked-eye observations.	Serves as a comparative benchmark for evaluating direct visual census effectiveness.

Geographic Scope Note: Data in the present study were collected from a single large colony site to minimize variability in biotic factors across different locations.

Figure 1. Geographic location of the study area at Batukoq Cave/Water Channel, Senaru Village, Mount Rinjani National Park, Indonesia.

Research Design

An observational research design was employed in this study to minimize the *observer effect*, ensuring that the abundance data obtained accurately reflected real field conditions without altering the natural flight behavior of the bat colony. By avoiding manipulative or intrusive techniques, the study preserved the integrity of emergence patterns and colony dynamics during data collection.

Research Materials

The primary research material consisted of a bat colony (Order: Chiroptera) inhabiting the designated day roost at the observation site. Supporting materials included topographic maps of the study area to determine optimal flight-line observation points, as well as secondary data records related to weather conditions and lunar phases, both of which are known to influence bat flight behavior and emergence timing.

Equipment

To support the direct census method, the following equipment was utilized:

1. Hand counter (tally counter): The primary tool for rapidly counting individual bats passing through the flight line.
2. Binoculars: Used to enhance visual clarity at longer viewing distances or under low-light conditions.
3. Stopwatch: Employed to measure emergence duration and flight time intervals.
4. Lux meter: Used to quantify light intensity at the onset of emergence (emergence time).
5. Data sheets and writing tools: Used for real-time recording and tabulation of census data.
6. Experiment, Sampling, and Analytical Procedures

Sampling Technique

Purposive sampling was applied, whereby observation locations were deliberately selected based on the densest and most clearly visible primary flight lines within open areas.

Experimental Procedure

1. Observers positioned themselves strategically beneath the identified flight line prior to sunset.
2. Counting commenced immediately after the first individual emerged from the roost.
3. Data were recorded at fixed time intervals (e.g., every 5 or 10 minutes) to capture fluctuations in flight density throughout the emergence period.

Data Analysis

Data were analyzed descriptively to estimate total population abundance and calculate the average number of individuals emerging per minute. Overlapping flight events were addressed using a group-estimation technique, in which individuals were counted in units of 10 when flight density became too high for individual-level counting.

Statistical Analysis

To validate data derived from direct observation, the following statistical analyses were conducted:

1. Descriptive statistics: Mean, standard deviation, and variance were calculated for daily population counts to assess central tendency and variability.
2. Comparative analysis (when multiple observers were involved): Independent *t*-tests or one-way ANOVA were applied to determine whether significant differences existed among observers' counts, thereby evaluating the influence of human error and observer skill on census accuracy.

RESULTS AND DISCUSSION

Estimated Population Abundance and Colony Structure

Based on the results of the Flight Line Census conducted at the bat colony site in the Batukoq Cave/Water Channel, Senaru Village, the estimated average population abundance was approximately ±590 individuals per night. This value indicates that the study site functions as a primary day roost capable of supporting a large and relatively stable Chiroptera population. The high abundance observed is consistent with the characteristics of open and flexible roosts, which allow bats to occupy a wide range of natural and artificial structures, including caves, water channels, rock crevices, and abandoned buildings (Kloepper et al., 2016).

Visual observations during the emergence process confirmed that the colony consisted of two major groups within the order Chiroptera, namely Megachiroptera and Microchiroptera. Megachiroptera are characterized by larger body sizes, with a weight range of approximately 25–900 grams, and are generally frugivorous and nectarivorous. In contrast, Microchiroptera are considerably smaller, with adult body weights ranging from 3.5 to 180 grams, and exhibit a more diverse feeding spectrum, including insectivory, small carnivory, nectarivory, and hematophagy.

These differences in body size were clearly reflected in the stratification of flight paths during emergence. Megachiroptera individuals tended to occupy higher and more open flight corridors, whereas Microchiroptera predominantly utilized lower and narrower flight paths. This pattern indicates the presence of morphological and ecological adaptations that minimize spatial competition and collision risk, while simultaneously enhancing flight efficiency in accordance with body mass and foraging strategies specific to each group.

Ecologically, these findings support the theory of niche differentiation, in which variations in body size, wing morphology, and flight behavior enable species from different groups to share the same roosting habitat without significant conflict. The coexistence of two major Chiroptera groups within a single roost highlights the Batukoq Cave/Water Channel as a multispecies habitat with high conservation value.

Activity Patterns and Duration of Colony Emergence

Census results showed that emergence activity began during early twilight, coinciding with a significant decline in natural light intensity. The reduction in light intensity acts as a primary zeitgeber that triggers nocturnal bat activity, as widely documented in previous studies (Hristov et al., 2008; Andrews & Andrews, 2016).

The total duration of emergence was relatively brief, lasting approximately 30–45 minutes, with peak flight density occurring between 15 and 25 minutes after the first individual exited the roost. This pattern formed a sharp emergence curve, indicating that the majority of individuals left the roost within a narrow temporal window.

This synchronization phenomenon reflects an adaptive colony strategy to minimize predation risk through the dilution effect, whereby the probability of an individual being targeted by predators decreases when bats emerge en masse (Kloepper et al., 2016; Yarbrough et al., 2023). In addition, synchronized emergence timing enables bats particularly insectivorous Microchiroptera to exploit peak insect availability, which typically occurs shortly after sunset (Cryan et al., 2014). However, the extremely high flight density over a short period also posed a significant methodological challenge for visual censusing, as it increased the likelihood of overlapping individuals and counting errors.

Analysis of Overlapping Constraints and Human Error

The data indicated that individual overlap constituted the primary source of error in visual counting, particularly during peak emergence. Under these conditions, multiple individuals often flew parallel to one another from the observer's perspective, leading to frequent miscounts where several bats were recorded as a single individual. Analysis revealed a tendency toward underestimation, which increased as light intensity decreased and flight speed increased.

This phenomenon can be theoretically explained by limitations in human cognitive processing of fast-moving objects under low-contrast conditions. Eddington et al. (2023) emphasized that the accuracy of visual censuses is strongly dependent on observer skill and experience. The findings of this study reinforce this conclusion, as experienced observers demonstrated greater consistency by applying grouped counting strategies (e.g., counting in sets of 10 or 20 individuals) compared to novice observers.

These results align with those of Kloepper et al. (2016), who reported that overlapping along primary flight paths represents a universal challenge in Flight Line Census methodologies. Consequently, visual census results should be interpreted as conservative estimates that require repeated validation or the application of correction factors.

Effectiveness of the Flight Line Census Method

Methodological evaluation indicates that the Flight Line Census is a highly effective non-invasive technique for monitoring large bat colonies. Compared with capture–release methods, this approach does not disturb natural bat behavior and allows population estimates to be obtained within a relatively short time frame. Proper placement of observation points along primary flight paths proved effective in capturing the majority of individuals exiting the day roost.

The use of simple equipment such as hand counters significantly enhanced counting consistency, as also reported by Huzzen et al. (2020). Although automated technologies such as BatCount systems and thermal imaging are increasingly being developed, manual methods remain relevant due to their cost efficiency and ease of implementation in field settings, particularly in regions with limited access to advanced technology.

Previous studies have demonstrated that thermal imaging can improve counting accuracy by detecting individuals based on heat signatures, even under complete darkness (Hristov et al., 2008; Betke et al., 2008). However, Betke et al. (2008) also reported that thermal-based estimates can differ substantially from those obtained using conventional methods, underscoring the growing recommendation for multi-method integration to enhance accuracy and data validity (Huzzen et al., 2020).

Morphology, Species Identification, and Roost Ecology

Bats are widely recognized as mammals that are difficult to identify from a distance. Consequently, definitive species identification generally requires examination of skull morphology and dental structures (Anonim, 1989). At the study site, several species were successfully identified or documented, including *Tadarida plicata*, *Hipposideros larvatus*, and *Murina suilla*.

Figure 2. Species of Chiroptera at the Study Site

(a) *Tadarida plicata* (Wrinkle-lipped Bat); (b) *Hipposideros larvatus* (ventral view); (c) *Murina suilla* (dorsal view); individuals incidentally trapped in community nets in the Batukoq Cave/Water Channel area, Senaru.

Morphologically, bats possess a lightweight and fragile skeletal structure, with forelimbs highly modified into wings. The wing membrane consists of flexible connective tissue and fine muscle fibers, allowing complex aerial maneuverability. Variations in tail morphology and uropatagium structure reflect differences in ecological strategies and habitat use, as described by Anonim (1989).

Quantitative Counting Results and Emergence Complexity

The results of individual counts across multiple observation days are presented in Table 3, illustrating daily variation in individual numbers as well as differences in counting complexity based on time intervals.

Table 3. Complexity Coverage, Values, and Average Time of Chiroptera Individuals

Exam	Number of Individuals Day 1	Numberof Individuals Day 2	∑ Individuals / 3 Seconds	∑ Individuals / 1 Second
1	5842	1875	1827	1780
2	5461	1830	1831	1820

These variations reflect the dynamic nature of emergence, which is influenced by environmental factors such as light conditions, weather, and colony density. Average Number of Chiroptera Individuals Graph.

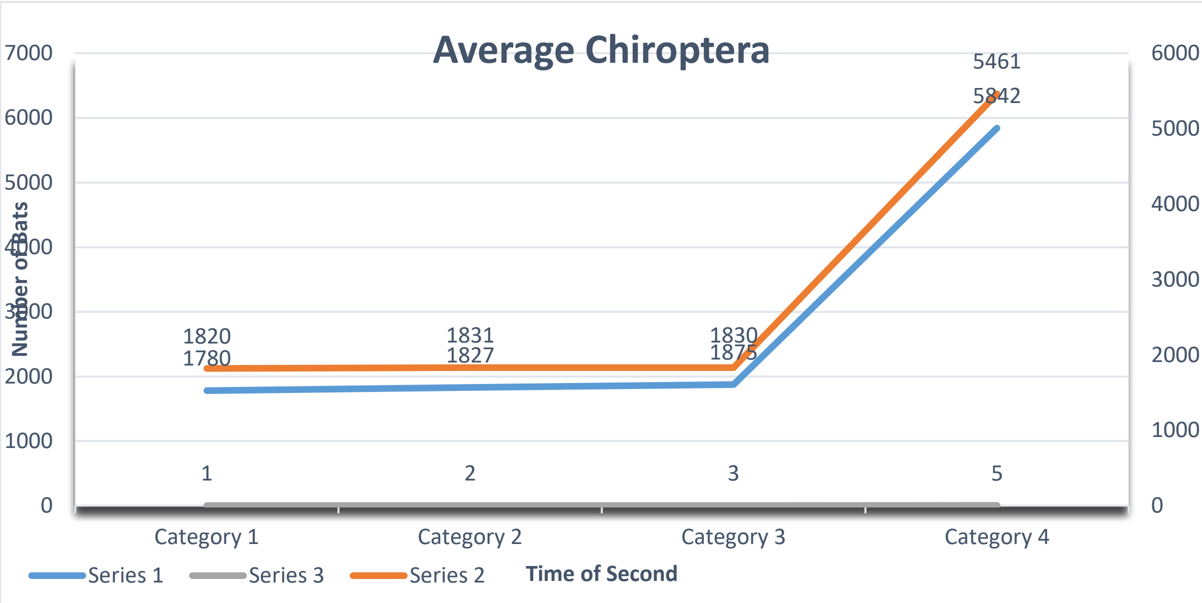

Figure 3. Average Number of Chiroptera Individuals Graph

Jaccard Index Analysis and Emergence–Return Patterns

The analysis of bat emergence and return activities using the Jaccard Index (JI) is presented in Table 4, which summarizes the degree of similarity in individual activity patterns across multiple observation periods. The Jaccard Index serves as an effective metric for quantifying temporal overlap in emergence behavior, thereby allowing a more refined assessment of behavioral consistency and variability within the colony.

Table 4. Bat Individual Count Data Based on Jaccard Indices

Observation	Emergence Time	Return Time	JI	Normality
Experimental	17.30–18.31	11.45	0.200	Yes
Control	17.40–18.45	–	0.250	Yes
Control	17.55–18.47	–	0.188	Yes
Control	17.57–18.51	15.45	0.038	No
Control	18.52–18.53	–	0.273	Yes
Control	18.53–19.00	–	0.067	No

As shown in Table 4, JI values varied considerably across observation sessions, ranging from very low similarity (0.038) to moderate similarity (0.273). These variations indicate that emergence patterns were not entirely uniform across different time intervals. Observation periods with JI values above 0.180 suggest moderate overlap in individual activity, implying relatively stable emergence dynamics during those sessions. This pattern was particularly evident in several control observations that met normality assumptions.

Conversely, observation periods characterized by low JI values especially those failing normality tests indicate minimal overlap in emergence behavior. Such results reflect higher temporal heterogeneity in bat activity, which may be influenced by environmental variability such as changes in light intensity, weather conditions, or fluctuations in prey availability. Additionally, internal colony factors, including differences in species composition, age classes, or energetic demands, may further contribute to this variability.

The inclusion of return-time data also appeared to affect similarity outcomes. Observations that recorded both emergence and return times tended to yield lower JI values, suggesting that individuals returning to the roost may not represent the same subset that emerged earlier. This asymmetry highlights the complexity of bat foraging behavior, where return timing can differ substantially among individuals based on foraging success or spatial range.

The fluctuating Jaccard Index values presented in Table 4 underscore the dynamic nature of bat emergence return patterns. These findings emphasize the importance of repeated observations across multiple time windows to adequately capture behavioral variability. Relying on a single observation period may therefore result in incomplete or biased interpretations of population activity. Repeated and temporally distributed monitoring is essential for enhancing the robustness and ecological validity of bat population studies.

Synthesis and Conservation Implications

Overall, the findings of this study confirm that the Flight Line Census continues to be a practical, cost-effective, and informative approach for assessing Chiroptera populations, particularly when applied through standardized procedures and conducted by well-trained observers. The method offers a non-invasive means of monitoring large colonies while preserving natural bat behavior, making it especially suitable for long-term population assessments and routine monitoring programs.

The results also highlight the potential benefits of integrating conventional visual census techniques with emerging technologies, such as thermal imaging and video-based monitoring systems. The incorporation of these technologies can substantially improve counting precision, reduce observer bias, and enhance data reliability, particularly under conditions of low light intensity and high flight density. Such methodological integration is therefore recommended for future studies seeking to improve the accuracy and robustness of bat population estimates.

From a conservation perspective, the study underscores the critical role of roost sites as fundamental ecological assets for sustaining bat populations. The Batukoq Cave/Water Channel area functions not only as a primary day roost but also as a key habitat supporting multispecies Chiroptera assemblages. Consequently, the protection and proper management of roosting sites should be prioritized within broader conservation planning frameworks.

Furthermore, these findings carry important implications for the development of sustainable ecotourism in the Senaru region. Conservation-oriented management of bat roosts can serve dual purposes by safeguarding biodiversity while simultaneously providing educational and ecotourism opportunities for local communities. Ensuring minimal disturbance to roosting habitats, regulating human access, and raising public awareness are essential measures to balance conservation objectives with socioeconomic benefits.The continued application of the Flight Line Census, complemented by technological advancements and supported by strong roost protection policies, represents a strategic pathway for enhancing Chiroptera conservation and promoting sustainable ecosystem management in the study area.

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CONCLUSION

Based on the Flight Line Census conducted at the Batukoq Cave/Drainage corridor in Senaru Village, the colony's mean estimated abundance is around ±590 individuals per night, indicating that this site functions as an important and relatively stable day roost for local Chiroptera. Observations also point to the presence of two main groups, Megachiroptera and Microchiroptera, which appear to use different flight corridors (higher, more open paths versus lower, narrower paths). This pattern supports the interpretation that the roost enables coexistence through spatial or niche differentiation. Emergence from the roost begins as twilight light levels decline and typically lasts about 30–45 minutes, with peak density occurring roughly 15–25 minutes after the first individuals exit; this peak period is therefore the most critical window for accurate visual counts. A key limitation of visual counting is the overlap of individuals along the flight line during high-density moments and low-light conditions, which tends to bias estimates downward and means the reported abundance should be treated as conservative. Variation in emergence patterns, reflected by fluctuating Jaccard Index values, further suggests that activity dynamics are not fully uniform across sessions, so relying on a single night of observation risks producing only a partial picture of colony behavior

RECOMMENDATIONS

For long-term monitoring, Flight Line Census remains appropriate as a non-invasive approach, but it should be strengthened through stricter standardization of observer positions, consistent counting intervals, and improved observer training (including group-counting strategies), supported by simple tools such as hand counters to enhance between-session consistency. Because overlap-related bias increases during peak emergence, repeated observations across multiple nights and multiple time windows should be treated as a minimum requirement rather than an optional enhancement, so that behavioral variability is adequately captured. To improve the validity of abundance estimates, follow-up work should consider combining visual counts with methods that perform better under darkness and high density (for example, thermal imaging or video-based monitoring), and integrating additional approaches if the objective expands to species-specific trend analysis. From a management perspective, the Batukoq roost should be treated as a high-value conservation habitat, making disturbance reduction a priority through access control and ecotourism practices that minimize light, noise, and visit frequency, accompanied by public education to reduce negative perceptions while maintaining socio-economic benefits without compromising colony stability.

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