Research Article

Population Dynamics of Sakub Sheep Production System in Village Breeding Center

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Abstract | Population dynamics are essential for understanding livestock production by analyzing changes in population size, structure, growth, and viability. The Sakub sheep Village Breeding Center (VBC) manages over 14,000 heads with a production target of 500 heads per month, but demand exceeding supply may pose risks to long-term population sustainability. This study aims to analyze the population dynamics of Sakub sheep in order to evaluate their reproductive capacity, replacement stock availability, and the risk of population decline. A retrospective study with a quantitative descriptive approach was conducted using secondary data from the Brebes Regency Livestock and Animal Health Service and BPS–Statistics Indonesia. Observed variables included births, deaths, animal inflow and outflow, the number of productive ewes and the number of replacement stock, and population structure based on physiological status and sex. Data were analyzed using the Natural Increase (NI), Net Replacement Rate (NRR), population output, and time-series analysis. The results indicated that the Sakub sheep population within the VBC had a relatively strong biological foundation, characterized by the dominance of productive ewes (54% of the total population), an NI of 19.52%, and an NRR of 121.23%. Nevertheless, the off-take rate (34.45%) exceeded sustainable limits, resulting in an estimated annual population deficit of 14.93%, thereby increasing the risk to long-term sustainability.Despite this pressure, the VBC population exhibited a positive growth trend (+3.69), in contrast to the declining regional sheep population (−5.62%). These findings highlight the importance of strengthening reproductive and health management and regulating animal outflow to support the sustainability of Sakub sheep as a superior local breed.

Keywords | Sakub sheep, Natural increase, Net replacement rate, Population output, Time series, Sustainability

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INTRODUCTION

Livestock production systems are vital to global food security, providing approximately 33% of human protein intake, supporting the livelihoods of more than half of rural households, and enhancing nutrient cycling in agricultural landscapes (FAO, 2018). In many developing countries, including Indonesia, sheep

production is predominantly characterized by traditional smallholder systems, typically keeping 5–15 heads per household (Sujarwanta *et al*., 2024). Within these systems, sheep primarily function as household savings and a readily accessible financial buffer to meet urgent needs. Beyond their economic role, sheep also hold socio-cultural significance, being used in traditional livestock competitions and religious practices such as aqiqah and qurban. Furthermore, sheep contribute to integrated crop–livestock systems through manure provision for crop production. Under these conditions, management decisions are driven more by household security and multifunctionality than by production efficiency (Udo and Budisatria, 2011; Ririmase *et al*., 2022).

According to Statistics Indonesia (2024), the national sheep population exceeded 9.2 million head in 2024, underscoring its important contribution to meat production and smallholder income. Indonesia maintains various local sheep breeds that possess distinct genetic characteristics and serve as valuable germplasm resources. Indigenous livestock constitute important assets for livestock development and generally exhibit comparative advantages over imported breeds, including superior adaptation to tropical environments and relatively high reproductive performance shaped by natural selection (Widi *et al*., 2014). However, The World Watch List of Domestic Animal Diversity reports that one to two livestock breeds are lost globally each week (FAO, 2015). Breed loss is driven by global economic and environmental pressures, but the Sakub sheep faces more localized threats within the Village Breeding Center (VBC) system. A notable risk is the popular sire effect, where the overuse of a few high-performing rams narrows the gene pool and increases inbreeding depression. Furthermore, the high demand for large-bodied males during religious festivals often leads to negative selection, as farmers sell their best stock for immediate profit rather than retaining them for breeding replacement (FAO, 2012). The case of the Gembrong goat in Bali illustrates this trend, where low productivity, limited socio-cultural value, and declining farmer interest have led to a drastic population decline, placing the breed at risk of extinction (Atmoko, 2020).

In response to the risk of local genetic resource loss, the Government of Indonesia, via Law No. 18/2009 concerning Animal Husbandry and Animal Health, mandates the protection, conservation, and development of local livestock genetic resources as national assets (Government of Indonesia, 2009). A key outcome of this policy was the official recognition of the Sakub sheep as a distinct local breed by the Ministry of Agriculture (2022) via Decree No. 882/KPTS/PK.010/M/12/2022. Classified as a meat-type breed, the Sakub sheep is characterized by a predominantly white coat, compact body conformation, and rapid growth performance. Its mature body weight approximately 90 kg for males and 60 kg for females represents a superior productivity profile compared to other Indonesian breeds such as the Garut (57.74/36.89 kg), Priyangan (38.9/25.5 kg), Sapudi (44.6/25.8 kg), Palu (30.3/28.0kg), and Kisar (29.43/21.74 kg). While its growth potential is closely rivaled by the Batur and Wonosobo sheep (which can reach 108/82 kg), the Sakub sheep remains a premier genetic resource, particularly for intensive meat production and the high-demand religious festival markets (Ministry of Agriculture, 2011a, b, c, d, 2012, 2013, 2017).

To promote the development of Sakub sheep, the The Brebes Regency Agriculture and Food Security Office (2022a, 2022b) adopted a community-based breeding framework by designating Pandansari (Paguyangan District) and Wanareja (Sirampog District) as official Village Breeding Centers (VBC). Within this organizational structure, the VBC functions not only as a geographic location but also as a coordinated management system where local farmers serve as the primary actors responsible for maintaining the nucleus breeding stock (Subiharta *et al*., 2024). However, increasing demand for Sakub sheep and the introduction of production targets create significant challenges for farmers. The Brebes Regency Agriculture and Food Security Office targets a monthly production of 500 head to stabilize regional meat supplies and meet seasonal Qurban demand. However, the Sakub sheep's high market value has triggered an unplanned outflow of breeding stock to other regions, driving a negative selection process. This trend is not merely a result of poverty; rather, farmers treat high-quality livestock as flexible savings or liquid assets to meet urgent social or household obligations. Combined with infrastructure constraints and the high maintenance costs of superior rams, these socioeconomic pressures lead farmers to prioritize immediate liquidation over the long-term, riskier investment of genetic conservation.

Population dynamics analysis provides a framework for evaluating these conditions by describing changes in population size, structure, and replacement over time (Krebs, 2014). This approach facilitates the assessment of reproductive capacity, mortality rates, and management patterns affecting breeding stock availability and breed continuity (Gebre *et al*., 2016). Such understanding is essential to determine whether production targets can be achieved without reducing the availability of breeding animals. Therefore, this study aims to analyse the population dynamics of Sakub sheep in Brebes Regency to provide a strategic basis for optimizing breeding stock availability and ensuring a stable supply for the regional meat market within a farmer-based breeding system.

MATERIALS AND METHODS

Study location

The study was conducted in the VBC areas for Sakub sheep located in Pandansari Village, Paguyangan District, and Wanareja Village, Sirampog District, Brebes Regency, Central Java, Indonesia (Figure 1). Both districts are highland regions situated on the slopes of Mount Slamet, with an average elevation of 1,342 ± 61.51 m above sea level, and are recognized as important horticultural production areas. The Sakub sheep population in these districts accounted for 92.56% of the total Sakub sheep population in Brebes Regency. The agroclimatic conditions of the VBC were characterized by an average temperature of 23.80 ± 3.00 °C, relative humidity of 76.40 ± 15.07%, light intensity of 2,838.67 ± 554.94 lux, and low wind speed of 0.03 ± 0.03 m/s. Annual rainfall in Paguyangan and Sirampog districts was 3,678 mm and 4,850 mm, respectively.

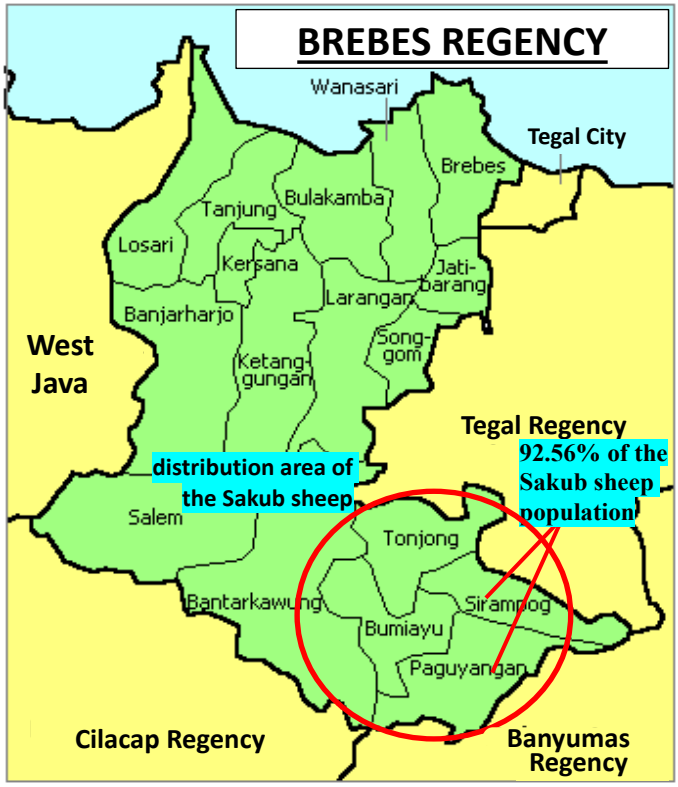

Figure 1: Distribution of the Sakub sheep population in Brebes Regency, 2019-2024.

Data sources

The data used in this study came from two sources: The Brebes Regency Livestock and Animal Health Service (DPKH Brebes) and Statistics Indonesia (2024), each serving distinct analytical purposes. Time-series population data from (unpublished data) Statistics Indonesia (2024) were used to develop the dynamic population model, as they provide multi-year information necessary to capture population trends and minimize short-term variability. In contrast, DPKH Brebes data were derived from a one-year census conducted between September 2023 and September 2024 and were used exclusively to characterize the current population structure of Sakub sheep at the VBC. These data supported the estimation of population strength indicators, including natural increase, population output, and net replacement rate. The census variables included annual births, mortality, migration, the number of productive ewes, replacement stock, population outflow (sale or slaughter), and population structure based on physiological status and sex.

Data analysis

The population dynamics of Sakub sheep were analyzed using Natural Increase (NI), Net Replacement Rate (NRR), population output, and time-series analysis. Analyses were conducted at multiple levels, including the Sakub sheep population at the Village Breeding Center (VBC), the total Sakub sheep population, and the overall sheep population in Brebes Regency for time-series evaluation. All calculations refer to Widyaningrum *et al.* (2021) and are described as follows.

Natural Increase (NI) is defined as the difference between births and deaths within the observation period and expressed as a percentage of the total population:

$$\%\ Birth = \frac{Number\ of\ births}{Total\ population} \times 100\%$$

$$\%\ Deaths = \frac{Number\ of\ deaths}{Total\ population} \times 100\%$$

$$NI\ (\%) = \%\ Births - \%\ Deaths$$

Net Replacement Rate (NRR) was defined as the proportion of available replacement stock relative to the replacement requirement. In this study, the replacement requirement was defined as the proportion of animals removed from the breeding population (culled animals, including sales and slaughter) during the observation period. Thus, the replacement requirement reflects the number of animals that must be replaced to maintain population stability. The equations used are as follows:

$$Culled\ animals\ (\%) = Replacement\ requirement\ (\%)$$

$$\text{Remaining replacement stock } (\%) = \text{NI}(\%) - \text{Replacement requirement}(\%)$$

$$\text{Population output} = Culled\ animal\ (\%) + Replacement\ stock\ (\%) - Target\ population\ increase\ (\%)$$

Population output is calculated to reflect the effective population surplus after meeting replacement needs and accounting for the targeted population increase. The target population increase used in this study refers to the regional livestock development target established by the local government of Brebes Regency. Population dynamics were further analyzed using time-series analysis with the least

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squares method to estimate population trends over time. The following equation was applied to estimate population dynamics:

$$Y = aX + b$$

Where Y represents the population size, X is the time variable (year deviation from the reference year), a is the intercept, and b is the regression coefficient indicating the direction and magnitude of population change.

RESULTS AND DISCUSSION

Population structure

The population structure of Sakub sheep in the VBC (Figure 2) indicated a strong foundation for the sustainability of the breeding program. The population was dominated by adults (63.13%), followed by young sheep (25.14%) and lambs (11.73%). This condition is consistent with the concept that a balanced age distribution particularly the dominance of the adult group provides an essential basis for reproductive performance and breeding sustainability (Paterson *et al.*, 2021; Abdel-Moneim *et al.*, 2009). A key strength of this population is the high proportion of productive ewes (54.20% of the total population), which provides strong potential to support long-term production sustainability (Chapman *et al.*, 2023). A balanced age structure, together with sufficient replacement stock availability, is a prerequisite for sustainable breeding systems. The substantially higher proportion of females compared with males (79.89% vs. 20.11%) reflects reproductive efficiency in small ruminant production systems. In terms of active breeding stock, the ratio of mature rams to ewes was approximately 1:6 (8.93% vs. 54.20%). This ratio is very conservative compared with the recommended breeding standard of between 1:20 and 1:30 for sheep in tropical environments (Kenyon *et al.*, 2010; Asrullah *et al.*, 2025). Such a low ewe-to-ram ratio ensures that all reproductive females are adequately covered, suggesting that the suboptimal birth rates observed in this population are likely driven by non-mating factors such as nutritional status or environmental stressors rather than a shortage of rams or breeding fatigue. This pattern aligns with the biological principle that only a small number of males are required to mate with a large number of females, a common practice used to maximize reproductive potential (Lindström *et al.*, 2002).

Natural increase

The analysis indicated that the natural increase (NI) of Sakub sheep in the VBC was 19.52% (Table 1), which falls within the moderate category (Samberi *et al.*, 2010; Hendrawan *et al.*, 2025). The birth rate was 20.54% of the total population (Table 3), which appears lower than the rates reported for Garut sheep (56.63%) (Astuti *et al.*, 2022) and Palu sheep (32.48%) (Mangun *et al.*, 2024). However, this comparison requires nuance; Garut sheep and Palu sheep are renowned for their high reproductive efficiency (Inounu *et al.*, 1999). This is reflected in the relatively high litter size of Garut sheep (1.77 ± 0.18), indicating frequent twin births, and their common management under intensive systems (Wijayanti *et al.*, 2025; Jannah *et al.*, 2025). Similarly, Palu sheep exhibit high prolificacy, with a litter size of 1.83 (Mangun *et al.*, 2022). In contrast, Sakub sheep in this VBC show moderate prolificacy (litter size 1.50 ± 0.63) and are typically managed under semi-intensive village conditions (Jannah *et al.*, 2024).

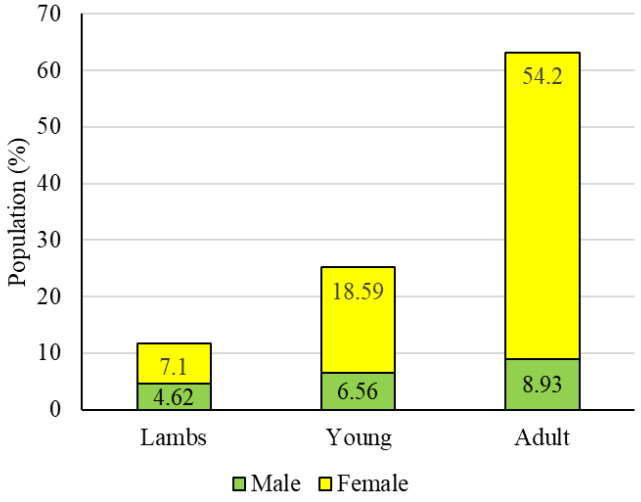

Figure 2: Population structure of Sakub sheep in the VBC. **Note:** Total population is 14.108 heads; Lamb: 0-6 months, Young: 6-12 months, Adult: >12 months.

Table 1: Natural increase of the Sakub sheep population in the Village Breeding Center during the period September 2023–September 2024.

Variables	Male	Female	Total
Births (head)	954	1944	2898
Births (% of total populations)	6.76	13.78	20.54
Births (% of total ewes)	-	-	32.54
Sex ratio (%)	32.92	67.08	100
Deaths (head)	54	90	144
Death rate (% of total populations)	0.38	0.64	1.02
Natural Increase (%)	6.38	13.14	19.52

Note: Percentages (%) are calculated relative to the total population (14,108 animals); Births (% of total ewes) are calculated using 8,906 ewes (all breeding-age females).

Although the birth rate relative to total ewes (32.54%) is regarded as suboptimal for a one-year cycle, the sustainability of the population was effectively supported by an exceptionally low mortality rate of 1.02% (Table 3). This indicates that while the reproductive 'input' is modest, the 'retention' of animals within the system is high. This

suggests a population strategy focused on survival and stability rather than rapid expansion. The gap between the actual birth rate and the biological potential (1.4–2.2 lambs/ewe/year) (Tron et al., 2009) is likely not due to a shortage of rams given the sufficient 1:6 ram-to-ewe ratio but is rather a reflection of the breed's specific biological traits and potential management constraints in estrus synchronization. Despite these reproductive inefficiencies overall herd productivity was largely maintained by a very low mortality rate of 1.02% per year, which is substantially lower than mortality reported for Palu sheep (5.76%) and Garut sheep (26.09%) (Astuti *et al.*, 2022; Mangun *et al.*, 2024). Furthermore, Astuti *et al.* (2022) reported that the highest NI values are achieved when all ewes produce lambs with zero mortality. Therefore, although a birth rate of population 20.54% and birth rate of ewes 37.90% may be considered acceptable, substantial improvement remains possible through enhanced reproductive management, health control, and maternal nutrition. Furthermore, the sex ratio indicates that female Sakub sheep births (67%) exceeded male births (33%), thereby supporting the availability of replacement breeding stock in the Sakub Sheep Village Breeding Center (VBC).

Net replacement rate

Table 2 shows that the female NRR reached 121.23%, with 1,854 replacement females available to meet the requirement for 1,529 ewes. In contrast, the male NRR reached a substantial 500%, with 900 males available to replace only 180 rams, resulting in a surplus of 720 replacement males. While these surplus males are technically available as replacement stock, in smallholder systems, they are primarily managed as high-value offtake for commercial purposes, such as the Qurban market or local consumption. This massive surplus (400%) indicates that only a fraction of the young males are retained for genetic continuity, while the remainder contribute significantly to the economic output of the VBC. To avoid overestimating the breeding stock, these surplus males are categorized as part of the offtake in the subsequent productivity analysis, reflecting the dual role of VBCs in both genetic conservation and meat production (Susanti *et al.*, 2015; Widyaningrum *et al.*, 2021).

Table 2: Net replacement rate of the Sakub sheep population in the Village Breeding Center during the period September 2023–September 2024

Variables	Male		Female	
	Head	%	Head	%
Replacement requirement	180	1.28	1529	10.84
Replacement stock	900	6.38	1854	13.14
Net replacement rate (%)	500		121.23	
Surplus replacement stock	720	400	325	21.23

Note: % values are based on the total population of 14,108 heads.

Population output

The magnitude of population output depends largely on NI and NRR. Accordingly, population output represents the surplus of NI after replacement needs (NRR) have been fulfilled. Higher NI values and adequate reproductive efficiency allow greater sustainable output without reducing population size (Sumadi *et al.*, 2015). The Sakub sheep population in the VBC was theoretically capable of producing a sustainable output of 19.52%, equivalent to 2,754 heads per year (Table 3). However, the actual offtake reached 34.45% (4,860 heads), substantially exceeding sustainable capacity and generating a population deficit of −14.93% (2,106 heads per year). This deficit directly explains the projected population decline from 14,108 in 2024 to 12,002 in 2025, which implies that, to sustain this offtake level, the population must shrink. This deficit corresponds directly to the projected population decline from 14,108 in 2024 to 12,002 in 2025, indicating that the current level of off-take is being achieved at the expense of population reduction. In practical terms, this suggests that the deficit is likely covered by the under-retention of replacement stock, particularly young females that should enter the breeding population. Instead of being retained as future ewes, a proportion of these animals are sold to meet immediate economic needs, thereby weakening the regenerative capacity of the system (Udo and Budisatria, 2011).

Table 3: Population output of Sakub sheep in the Village Breeding Center, 2024 (September 2023–September 2024)

Variables	Male		Female		Total	
	Head	%	Head	%	Head	%
Population output of Sakub sheep (2024)						
Culled sheep	180	1.28	1529	10.84	1709	12.00
Remaining replacement stock	720	5.10	325	2.30	1045	7.40
Population output	900	6.38	1854	13.14	2754	19.52
Actual off-take (2024)						
Actual removal	1728	12.25	3132	22.20	4860	34.45
Surplus/deficit	-828	-5.87	-1278	-9.06	-2106	-14.93
Population comparison before and after actual off-take						
Population 2024 (before off-take)	2,838	20.11	11,271	79.89	14,108	100.00
Population 2025 (after off-take)	2,010	14.24	9,993	70.83	12,002	85.07
Government target vs. output capacity (2024)						
Government target					6000	42.53
Deficit					−3246	−23.01

Furthermore, while the realized off-take (4,860 heads) remains below the government production target of 6,000 heads per year, this target appears to function more as an aspirational benchmark rather than a strictly enforced

quota. Nevertheless, the existence of such targets may create implicit pressure for increased sales. Given that the current off-take already exceeds the biological regenerative capacity of the population, any attempt to further increase offtake toward the 6,000-head target approximately 43% higher than the sustainable level could accelerate population decline and exacerbate the structural deficit. Similar findings by Ie Roex and Ferreira (2020) demonstrate that off-take rates not balanced by regenerative capacity (NI and NRR) lead to a structural mismatch that threatens long-term sustainability. Consequently, the Sakub sheep production system in the VBC has not yet achieved an optimal balance between population regeneration and extraction levels, risking a terminal decline if current off-take pressures persist.

Time-series analysis

Table 4 and Figure 3 present the population growth trend of Sakub sheep in the VBC for 2019–2030. While the time-series projection shows a positive growth of 2.04% per year for 2025–2030, this statistical model primarily reflects the historical growth trajectory of 2019–2023 and tends to smooth over the unsustainable 'shock' observed in 2024. Consequently, the projection may be overly optimistic; if the 2024 offtake level persists, the actual population trend will deviate significantly from the regression-based forecast, leading to an accelerated decline rather than the predicted growth. The statistical prediction of 14,075 heads by 2030 would only be achievable through major external interventions, such as restocking (Pica-Ciamarra *et al*., 2005). However, restocking poses a significant challenge for the VBC. Currently, there is no evidence of large-scale restocking from external sources. Furthermore, introducing animals from outside the VBC risks compromising the genetic integrity of the Sakub sheep, unless the stock is sourced from verified purebred satellite flocks. Without a shift toward sustainable offtake management or a strictly controlled purebred restocking program, the VBC faces a critical risk of genetic dilution and long-term depopulation.

CONCLUSION

This study demonstrates that the Sakub sheep population in Brebes Regency possesses a relatively strong biological foundation, as reflected in its favorable population structure and positive growth trend. However, an off-take rate exceeding sustainable capacity poses a serious threat to long-term population sustainability. Therefore, the Village Breeding Center plays a crucial role as a genetic conservation hub in maintaining population stability amid the regional decline in sheep populations. To ensure sustainability and enhance productivity, several strategic measures are required. These include controlling the off-take rate to align with sustainable population capacity (approximately 19.52% per year), optimizing reproductive management through improved mating programs, nutrition, and reproductive health monitoring, and reassessing government production targets to establish more realistic and gradually achievable goals without compromising the core breeding population.

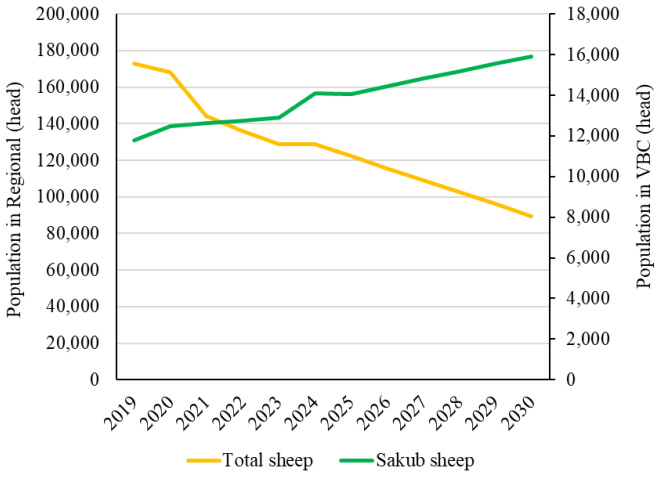

Figure 3: Comparative trends of Sakub sheep population at VBCs and the total sheep population in regional.
Note: Total sheep: represents the total population of sheep across all breeds; Sakub sheep: the total population of Sakub sheep maintained in the Village Breeding Center (VBC) within the same region.

Table 4: Predicted population growth of Sakub sheep in the Village Breeding Center and the overall sheep population in Brebes Regency, Central Java

Year	Sakub sheep in VBC		Sheep in Brebes	
	Population (Head)	Growth (%)	Population (Head)	Growth (%)
2019	11800		173021	
2020	12484	5.80	168203	-2.78
2021	12624	1.12	144356	-14.18
2022	12763	1.11	136110	-5.71
2023	12904	1.10	128979	-5.24
2024	14108	9.34	128735	-0.88
2025	14075	-0.24	122206	-5.07
2026	14444	2.63	115676	-5.34
2027	14814	2.56	109147	-5.64
2028	15184	2.50	102617	-5.98
2029	15554	2.44	96087	-6.36
2030	15923	2.38	89558	-6.80
Average population growth (2019 – 2030)		2.79		-5.75
Average observed population growth (2019 – 2024)		3.69		-5.62
Projected population growth (2025 – 2030)		2.04		-5.87

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NOVELTY STATEMENT

This study integrates key population parameters (NI, NRR, population output, and time-series analysis) to evaluate the sustainability of Sakub sheep in a Village Breeding Center system. It reveals a critical imbalance between strong reproductive potential and high off-take pressure, highlighting the risk of population decline despite a positive growth trend.

AUTHOR'S CONTRIBUTION

Conceptualization: ZNJ, TSMW, SB, P. Methodology: ZNJ, TSMW. Investigation: ZNJ. Data curation: ZNJ. Formal analysis: ZNJ. Supervision: TSMW, SB, P. Writing original draft: ZNJ, BAA, AI. Writing review and editing: TSMW, SB, P, Validation: TSMW, SB, P.

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Statement of conflict of interest

The authors have declared no conflict of interest.

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