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Beef Cattle Dynamic Projection Model: Forced Sell vs Capacity Expansion, Muara Enim

Kautsar Muhakku Ramadhan[1]*, Lucia Cyrilla[2], Bramada Winiar Putra[2]

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ABSTRACT

This study aimed to simulate the population dynamics projection of beef cattle in smallholder farms by comparing the forced sale and capacity expansion scenarios over a 10-year period. The research was conducted through a survey involving 60 cattle farmers (30 semi-intensive and 30 intensive systems) in Gelumbang District, Muara Enim Regency. Population dynamic modeling was analyzed using the Dynamics System approach with the Cohort Component Method to project the population from 2025 to 2034. The results showed that semi-intensive farmers were oriented towards breeding for asset accumulation, while intensive farmers focused on rapid capital turnover. Projection simulations proved that the existing scenario (forced sell) led to a stagnation in business scale, where the semi-intensive population was constrained to 11 to 12 heads and the intensive to 5 to 6 heads over the 10 years (Figure 1). In contrast, implementing the capacity expansion scenario through delayed sales, capital reinvestment, and partnership schemes triggered a progressive organic population surge, reaching 151 heads in the semi-intensive system and 22 heads in the intensive system by the 10th year (Figure 2). It can be concluded that the traditional mindset of treating cattle as reactive savings is the main cause of stagnation. Population growth strategies require a sociocultural transformation through capacity planning, education, and the institutionalization of partnership systems.

Keywords: barn capacity planning, beef cattle, cohort component method, forced sell, population projection

INTRODUCTION

Indonesia is projected to face a beef deficit of 271.82 thousand tons in 2026, driven by continuous human population growth and an increase in national per capita consumption to 2.77 kg/year. Because high population density and land conversion in Java restrict livestock development, the national supply strategy must shift to South Sumatra. Spanning 91,592 km² and producing 13,665 tons of beef, this province serves as a crucial distribution hub to cover Java's deficit (BPS 2026). Within this region, Muara Enim Regency offers highly strategic potential for livestock integration with 148,377 ha of rubber and 24,450 ha of oil palm plantations (BPS Muara Enim 2025), further enhanced by the prospective utilization of reclaimed mining lands owned by PT Bukit Asam Tbk. This potential is supported by toll road infrastructure that improves market access and reduces body weight shrinkage during transport by up to 16.67% (Meidayanti 2023; Pantur *et al.* 2023).

[1] Animal Production and Technology Study Program, Graduate School IPB University, IPB Darmaga Campus, Bogor 166680, Indonesia
[2] Department of Animal Production and Technology, Faculty of Animal Science, IPB University, IPB Darmaga Campus, Bogor 166680, Indonesia
* Corresponding Author:
Email: kautsarmuhakku@apps.ipb.ac.id

Gelumbang District, the largest cattle center in Muara Enim, experiences a fundamental economic dualism in smallholder farming. The semi-intensive system prioritizes asset accumulation ("living bank") but struggles with severe land conflicts, feed scarcity, and low genetic quality due to inbreeding (Zakiah *et al.* 2017; Oktavia 2018). Conversely, the intensive system focuses on capital turnover but faces a rigid growth ceiling of 5–6 heads per farmer due to manual forage collection limits. Despite prevalent resistance to innovation, a specific local outlier successfully transitioned from an intensive smallholder into a business-scale operation with dozens of cattle.

Previous livestock population dynamic models often treat traditional farming management as a static variable (Yulastari *et al.* 2018; Mangun *et al.* 2024; Yendraliza *et al.* 2020). There remains a lack of simulation models explicitly quantifying the impact of the traditional "forced sell" mechanism against business-oriented capacity expansion scenarios. By cautiously adapting the success parameters of the local intensive outlier to avoid socio-economic marginalization (Hajar 2025; Prayoga *et al.* 2019), we hypothesize that the existing forced-sell behavior causes capacity stagnation, whereas a reinvestment-based expansion scenario will exponentially multiply growth. Therefore, this study aims to develop a simulation model using the Cohort Component Method to project beef cattle population dynamics over the next

10 years, comparing the "forced sell" scenario with a capacity expansion model inspired by localized evidence of success.

METHODS

Time and Location

This research was conducted from December 2024 to March 2025 in Muara Enim Regency, specifically in Talang Taling, Segayam, and Putak Villages. The location was purposively selected as a center for smallholder beef cattle farming.

Materials and Instruments

Instruments used included structured questionnaires and Microsoft Office 2021. Research materials consisted of primary data from direct interviews and secondary data from the Central Bureau of Statistics (BPS) and the local Livestock Agency.

Sampling and Research Procedures

This study employed field surveys and structured interviews with 60 respondents (30 semi-intensive and 30 intensive system practitioners). The intensive group included 29 smallholders for baseline data and one business-scale farmer as a benchmark for the expansion phase.

Modeling Approach and Simulation Scenarios

The population was divided into cohorts based on age and sex. Technical parameters used in the calculation, including reproduction and mortality rates, are summarized in Table 1. In the simulation, the Calving Interval (CI) is standardized to 12 months for both systems to maintain consistency in the annual time-step and minimize fractional calculation errors. The technical parameters used in the projection calculation were calculated using the following formulas and approaches (Mangun *et al*. 2024):

- Calving Interval

While field data indicated a variation in birth intervals (11 to 12 months), the simulation model standardizes the Calving Interval (CI) to 12 months for both systems. This standardization is applied to ensure a uniform annual time step in the system dynamics approach and to minimize fractional calculation errors in the 10-year projection. The 12-month CI serves as a biological gold standard for local beef cattle, assuming one birth per cow per year under optimized management.

- Calving Rate

The birth calculation was based on the percentage of fertility performance and livestock availability (Kutsiyah 2017; Yendraliza *et al*. 2020).

$$\text{Calving Percentage} = \frac{\textit{Number of births per year}}{\textit{Number of productive cows}} \text{ x } 100\%$$

The mating capacity of fertile cows was set at an ideal ratio of 1:15, where one bull can mate with 15 cows (Syaiful *et al*. 2024). This ratio was then adapted as a limiting factor within the dynamic system modeling framework (Yulastari *et al*. 2018).

- Mortality Rate

$$\text{Mortality Percentage} = \frac{\textit{Number of deaths per year}}{\textit{Total population per year}} \text{ x } 100\%$$

Assessing livestock health and environmental management is reflected in the mortality percentage. Good management correlates with a low mortality percentage, whereas high mortality indicates poor management practices.

Table 1 Biological parameters of beef cattle for population projection

Parameters	Unit	Semi-intensive	Intensive
Reproduction performance			
Natural mating	%	100	97
Artificial insemination	%	0	3
Calving interval			
<12	%	60	93
12	%	7	0
12 - 14	%	23	3
15 - 18	%	10	3
Average (CI)	Month	12	11
Calving rate	%	69	58
Productive age of cows	Year	9	11
Number of births per cow	Head	7	9
Age at first mating	Year	2	2
Post-partum mating	Month	2	2
Mortality rate			
Bulls	%	2	2
Cows	%	3	0
Feeder cattle	%	0	0
Heifers	%	0	1
Calves	%	7	9

Table 2 Livestock management dynamics and simulation assumptions

Livestock category	Semi-intensive (n=30)		Intensive (n=30)	
	Buy	Sell	Buy	Sell
Actual sales data				
Bulls (%)	3	62	92	96
Cows (%)	14	19	3	2
Feeder cattle (%)	45	10	5	1
Heifers (%)	10	9	1	1
Male calves (%)	7	0	0	0
Female calves (%)	21	0	0	0
Simulation assumption				
Bulls sale rate (%)	100		100	
Culling rate decision	Full capacity/Urgent need		Full capacity/Urgent need	

Note: Simulation based on field interviews regarding farmers' intentions for liquidity.

- Livestock Inflow and Outflow Management

Management decisions regarding purchasing and selling, as summarized in Table 2 were used to measure the inflow and outflow rates of livestock. This is aimed at controlling the livestock population according to production goals through the replacement of unproductive livestock and the avoidance of *inbreeding*. Projections were made by considering the calculation of livestock growth rates based on population structure data grouped by age and sex, as well as how farmers make decisions in beef cattle business management. The population projection simulation was conducted under two managerial scenarios:

a) **Forced Sell Scenario (Existing Pattern):** Simulates current actual behavior where excess population above barn capacity is sold immediately.

b) **Capacity Expansion Scenario (Business Expansion):** Simulates a model where farmers respond to overcapacity by expanding barns through reinvestment and partnership (titip gaduh).

The population projection was constructed using the fundamental mathematical model of the Cohort Component Method within a dynamic system framework. The population for the subsequent year was mathematically projected using the following demographic balancing equation:

$$\mathrm{P}_{(t+1)} = \mathrm{P}_{(t)} + \mathrm{B}_{(t)} - \mathrm{D}_{(t)} + \mathrm{I}_{(t)} - \mathrm{O}_{(t)}$$

Where:

$P_{(t+1)}$ = Total projected population at year *t* +1

$P_{(t)}$ = Base population at year *t*

$B_{(t)}$ = Total births during year *t* (derived from the number of productive cows × calving rate)

$D_{(t)}$ = Total deaths during year *t* (derived from the population × mortality rate)

$I_{(t)}$ = Livestock inflow or purchases during year *t*

$O_{(t)}$ = Livestock outflow, including sales and culling during year *t*

This mathematical formulation allows the simulation to process the annual inflow and outflow across different age and sex cohorts based on the two behavioral scenarios. The cohort data were subsequently processed and projected annually using Microsoft Excel.

RESULTS AND DISCUSSION

Basic Characteristics and Initial Population Structure

Analysis of the farmer profiles and initial population structure (Table 3) reveals a fundamental dualism in economic orientation. Semi-intensive farmers prioritize asset accumulation with an average ownership of 5.7 AU (8 heads), dominated by productive cows (60%) for long-term breeding. Conversely, intensive farmers focus on rapid capital turnover with 4.4 AU (4 heads), dominated by bulls (46%). This behavior is driven by the fact that 83% of semi-intensive practitioners treat cattle as a "living bank" to meet urgent cash needs (Utama 2020), while 37% of intensive farmers have transitioned toward a primary business focus.

The demographic profile shows farmers are in their productive years (avg. 46–53 years) but possess limited formal education, with 57–60% only completing elementary school. This leads to a reliance on 12–15 years of field experience and traditional "old methods" rather than modern technical adoption (Vinogradova *et al.* 2016). Labor constraints are the primary bottleneck; intensive systems require more labor (1.5 persons) for fewer cattle compared to semi-intensive systems (1.1 persons). This is due to the "searching for grass" (*ngarit*) activity, which creates a physical capacity ceiling of 5–6 heads per person in intensive management.

Technical Management and Reproductive Performance

Natural mating remains the sole method used (97–100%) due to a negative perception of Artificial Insemination (AI) success rates and high costs (Suharyati *et al.* 2016). Despite this, intensive systems

Table 3 Initial population structure and farmer profiles

Profile and Business Scale	Semi-Intensive (n=30)		Intensive (n=30)	
	n	%	n	%
Age (years)				
20-34	7	23	0	0
35-49	7	23	10	33
50-64	16	53	15	50
>64	0	0	5	17
Average (years)	46		53	
Educational level				
No formal education	0	0	4	13
Elementary school	17	57	18	60
Junior high school	8	27	4	13
Senior high school	5	17	3	10
Bachelor/diploma	0	0	1	3
Farming experience				
< 5 years (beginner)	5	17	9	30
6–10 years (intermediate)	9	30	8	27
> 10 years (experienced)	16	53	13	43
Average (years)	15		12	
Main occupation				
Livestock farmer	5	17	11	37
Food crop farmer	7	23	10	33
Agricultural laborer	13	43	9	30
Employee/pensioner	5	17	0	0
Farmer ownership (au)				
<5	14	47	20	67
5 - 10	11	37	8	27
11 - 15	3	10	1	3
>15	2	7	1	3
Average barn capacity (m^2)	41		25	
Average livestock (au)	5.7		4.4	
Average labor (person)	1.1		1.5	
Initial population baseline (head)	8		4	
Bulls	1	15	2	46
Cows	3	60	2	40
Feeder cattle	1	9	0	5
Heifers	1	7	0	4
Male calves	1	4	0	2
Female calves	1	6	0	2

show superior reproductive efficiency with a Calving Interval (CI) of <12 months (93%), compared to only 60% in semi-intensive systems. Reproductive gaps stem from poor estrus detection and nutritional deficiencies under 100% field-grass reliance, triggering "silent heat" (Budiawan *et al.* 2015). Furthermore, farmers' reluctance to own bulls relying instead on communal grazing mates leads to erratic breeding cycles and prolonged calving intervals. Nevertheless, local cattle exhibit high adaptability and disease resistance, as shown by low adult mortality rates (0–3%).

Forced Sell Scenario Simulation: Business Scale Stagnation

Simulation results over the ten-year period (2025–2034) under the existing "forced sell" pattern show a clear stagnation in business scale. The population fails to grow, merely fluctuating at the limit of the farmers' independent barn capacity (Figure 1). In the semi-intensive system, the initial population of 8 heads remains locked between 11 and 12 heads, while the intensive system fluctuates between only 5 and 6 heads.

This stagnation is not caused by low reproductive performance, but by capacity constraints and limited managerial skills. Approximately 83% of respondents treat cattle farming as a side business, leading to minimal labor allocation (averaging 1.1 persons). This labor constraint is a widespread characteristic where up to 96.12% of smallholders treat livestock as a secondary activity (Afriani *et al.* 2019). Furthermore, with 60% of farmers having only a primary school education, there is a significant challenge in transferring complex managerial knowledge. Farmers rely heavily on 12–15 years of visual experience rather than theoretical extension. The absence of "local success stories" in the semi-intensive sector causes farmers to operate without long-term capacity planning. Consequently, any population increase is managed through a forced sell mechanism, with the management dynamics and culling decisions detailed in Table 3, a practice deeply rooted in the sociocultural view of cattle as a "living bank" triggered by urgent household cash needs (Widiati & Widi 2016).

Capacity Expansion Scenario Simulation: Organic Growth Surge

The capacity expansion scenario yields a contrasting, progressive growth trend. By 2034, the semi-intensive system reaches a dramatic organic surge of 151 heads, while the intensive system reaches 22 heads (Figure 2). The initial phase (2025–2029) serves as a payback period. Transitioning from traditional passive savings to early financial management accelerates the break-even point to 2029, two years earlier than the existing pattern. This rapid capital recovery is achieved by structuring income from bull fattening, male calf rearing, and capacity-driven forced sales prior to full expansion. This surge is primarily driven by a high calving rate (69%) and the local wisdom of semi-intensive farmers who retain female cattle for asset accumulation. Although this 69% calving rate is higher than the 40.98%–56.75% reported in other local cattle centers (Suranjaya *et al.* 2019), it remains biologically realistic as it aligns with the 68.63% rate achieved in optimized local breeding programs (Nubatonis & Dethan 2021). Analysis using the cohort component method (Haloho & Legiran 2023) confirms the cow cohort is the primary growth driver.

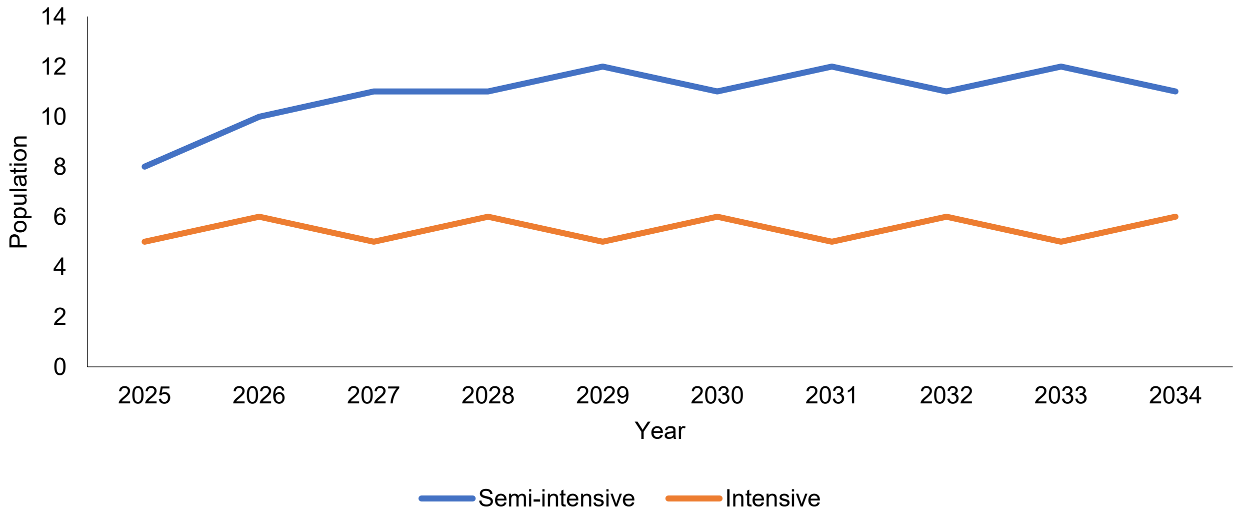

Figure 1 Beef cattle population trend under the existing pattern (forced sell) scenario.

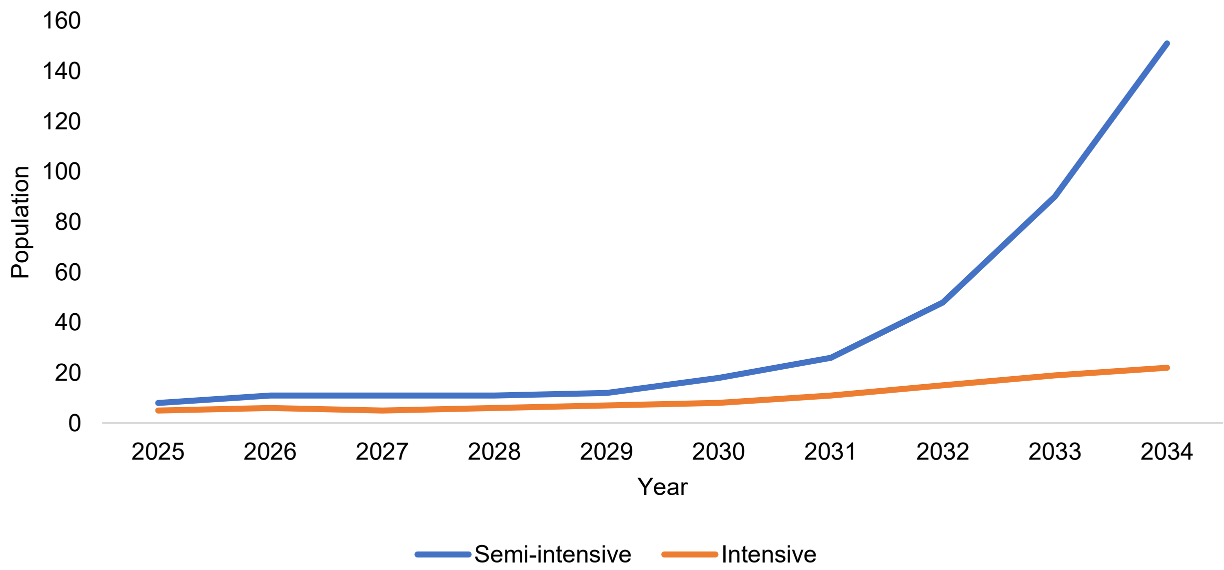

Figure 2 Beef cattle population trend under the capacity expansion scenario.

These data confirm that the biological potential is already available; the primary bottleneck is not fertility, but the management of overcapacity (Romjali 2018). The semi-intensive strategy leverages farmers' wisdom in retaining females for asset accumulation while reinvesting in bulls to mitigate inbreeding.

Conversely, the intensive system grows moderately as farmers prioritize liquidity and rapid capital turnover by selling marketable bulls. Ultimately, unleashing the multiplier effect requires transforming the "living bank" mindset toward capacity planning and partnership schemes. Under such schemes, investors provide long-term capital while farmers utilize family labor for future savings without massive initial costs (Sutia & Susilawati 2022).

CONCLUSION

The 10-year beef cattle population projection simulation under the forced-sell scenario demonstrates a population stagnation at 11–12 heads, driven by constraints in barn capacity, labor, and a management pattern oriented toward short-term liquidity needs. Conversely, the capacity expansion scenario through reinvestment and partnership schemes significantly increases the population, reaching 151 heads in the semi-intensive system and 22 heads in the intensive system. These findings demonstrate that capacity management is the main constraint in smallholder farms, making business transformation integrated with local wisdom an essential strategy for sustainable beef cattle population growth.

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