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ECOLOGICAL FOOTPRINT ASSESSMENT OF AGRICULTURAL AND FISHERIES LAND IN CIREBON REGENCY, INDONESIA: IMPLICATIONS FOR ENVIRONMENTAL CARRYING CAPACITY

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ABSTRACT

This study evaluates the ecological balance in Cirebon Regency in 2023 through an Ecological Footprint approach to mitigate the impact of population growth and land conversion on natural resources. The main findings show that this region has an ecological surplus of 0.06485 gha/capita, indicating that the current regional environmental carrying capacity is still in the sustainable category. This positive condition is strongly driven by the agricultural sector, where the biocapacity value of 0.09218 gha/capita significantly exceeds the community's consumption footprint of 0.03015 gha/capita. Although the fisheries sector still records a surplus, its capacity is becoming limited and highly vulnerable to future anthropogenic pressures. Given the vital role of agriculture in local food security, this study recommends strategic interventions in the form of land protection from conversion, implementation of sustainable cultivation systems, and optimization of efficient aquaculture. Further prospective analysis is strongly recommended to integrate spatial variables, temporal trends, and energy dimensions to produce a much more comprehensive, holistic, and accurate assessment of regional sustainability for policymakers.
***Keywords**: Agriculture; biocapacity fisheries; carrying capacity; Cirebon; ecological footprint*

A. INTRODUCTION

Global environmental change and population growth have significantly increased pressure on natural resources, particularly land and water. According to the Food and Agriculture Organization (FAO), the world will need to produce 50% - 70% more food by 2050 to meet demand, yet arable land per capita is declining due to urban expansion, industrial development, and environmental degradation (Diaz-Ambrona & Maletta, 2014). Similarly, aquaculture, while offering potential to meet global protein needs, has raised sustainability concerns related to water use, land competition, and ecological balance (da Silva Morales et al., 2022; Jegatheesan et al., 2011; Mitra & Barua, 2022). These challenges highlight the urgent need for robust tools or framework to evaluate the balance between human consumption and ecological supply.

In Indonesia, agricultural land conversion remains a critical national issue. The Central Bureau of Statistics (BPS) reported that between 2010 and 2019, approximately 1.122.027 hectares of rice fields were converted with average rate conversion 5,68 % per year into

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non-agricultural uses, threatening national food security (Yafi & Rondhi, 2024). In parallel, aquaculture activities, especially in coastal regions such as Java, are expanding rapidly, but often without adequate environmental safeguards, leading to habitat loss and reduced carrying capacity of ecosystems (Hidayati et al., 2021). Cirebon Regency, located in West Java, is a strategic agricultural hub with fertile rice fields and aquaculture potential. However, with a population exceeding 2.36 million people and an annual growth rate of 1.42%, the region faces significant challenges in balancing food production, land use, and ecological sustainability (BPS, 2024)

The concepts of carrying capacity and assimilative capacity critical in understanding the limits of ecological systems to support human activities. Carrying capacity refers to the he maximum number, density, or biomass of a population that a specific area can support sustainably without degrading the ability of that space to generate and regenerate supporting resources (Hartvigsen, 2013, 2024). One of the most widely used operational tools to measure this is the ecological footprint (EF). The concept of the ecological footprint, developed by Mathis Wackernagel and William Rees in the early 1990s, is a measure of the environmental impact of human activities. It quantifies the amount of biologically productive land and water area required to produce the resources consumed and to absorb the waste generated by a population, expressed in hectares per person (Vanderheiden, 2008; Yang & Wang, 2007). When compared to biocapacity (BC) the available supply of such productive area—the EF provides a direct measure of ecological balance. A surplus indicates that an area is operating within its ecological limits, while a deficit suggests unsustainable resource use (Ministry of Public Works, 2010).

Previous studies in Indonesia have applied the EF approach mostly at the national or provincial scale. Apriyeni et al.,(2017). demonstrated that Lombok Island, has experienced ecological deficits in the categories of agricultural land, livestock, fisheries, forestry, built-up land and carbon sequestration. Rahman et al., (2020). further highlighted the growing balance between food demand and ecological supply, particularly in the Province of East Kalimantan. However, research at the regency level remains limited, even though land-use planning and agricultural policies are largely implemented at this administrative scale. To date, there has been no comprehensive ecological footprint analysis of agricultural and fisheries land in Cirebon Regency, despite its strategic importance as a food producer and aquaculture center in West Java.

This study seeks to fill this gap by quantifying the ecological footprint and biocapacity of agricultural and fisheries land in Cirebon Regency. Using the Global Footprint Network methodology and secondary data from the Central Bureau of Statistics (BPS, 2024). the study evaluates the ecological balance between local consumption and production capacity. By focusing on Cirebon, this research contributes novelty in two aspects: (i) providing empirical evidence at the regency level, which is crucial for spatial planning and regional sustainability policies, and (ii) integrating both agriculture and fisheries sectors into the ecological balance framework. The objective is to determine whether Cirebon is currently in ecological surplus or deficit, and to propose recommendations for sustainable land-use management at the local scale.

B. MATERIALS AND METHODS

Study Area

Cirebon Regency is located in West Java Province, Indonesia, covering 1,076.76 km² and administratively divided into 40 districts and 424 villages (Figure 1). The region lies between 0–130 m above sea level, with a mix of lowland rice fields and coastal aquaculture areas. In 2023, the population reached 2,360,441 with an annual growth rate of 1.42% (BPS, 2024).

Data Source

This study used secondary data obtained from:

- Central Bureau of Statistics (BPS, 2024). population, agricultural production, harvested area, and aquaculture production.
- Local Government Reports: land use and productivity statistics.\
- Market price data: average prices of staple commodities (Rp/kg) in Cirebon Regency in 2023.

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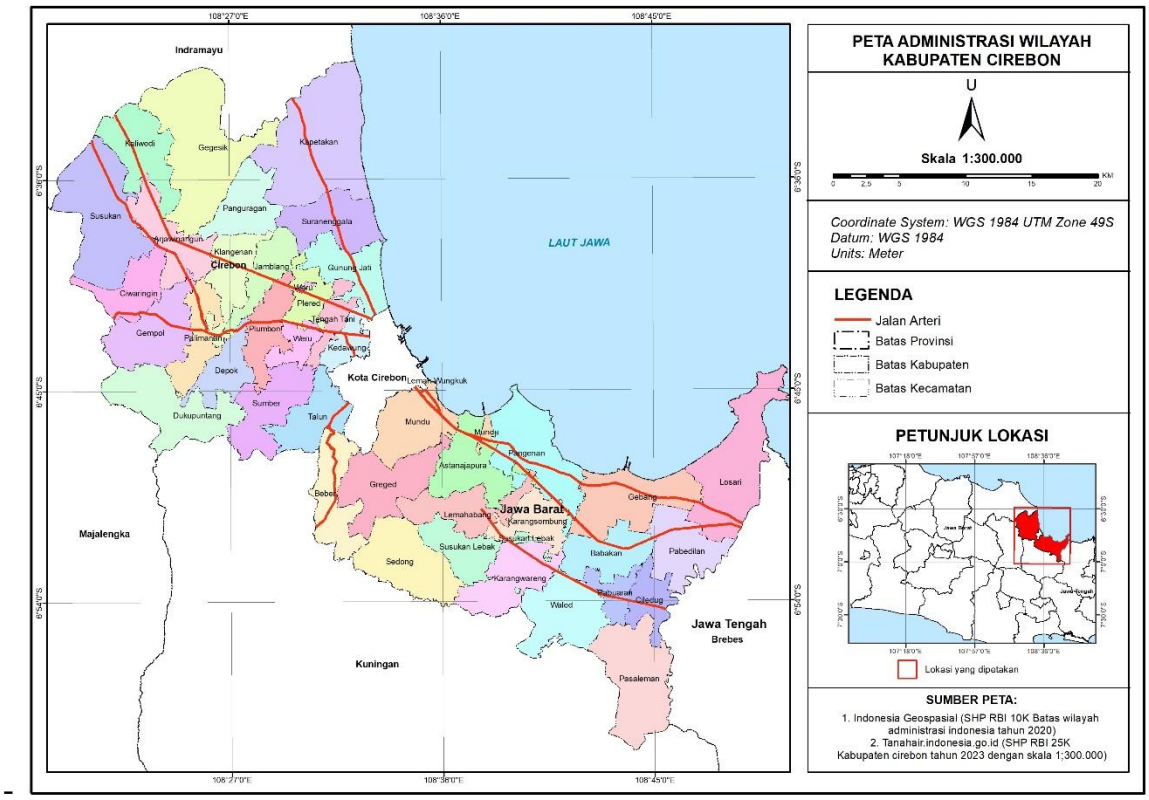


Figure 1. Location of study areas

Data on consumption were derived from household expenditure on food commodities, converted into physical quantities (kg) by dividing the total expenditure by average prices. Data on food consumption were derived from household consumption statistics published by the Central Bureau of Statistics (BPS) of Cirebon Regency. Consumption values (Rp/year) were converted into physical quantities (kg/year) by dividing total consumption by the average annual market prices of each commodity at the regency level. Average prices were obtained from official local market statistics to minimize price distortion. This approach is commonly applied in ecological footprint studies, where direct consumption-quantity data are unavailable, and it allows consistent estimation of consumption-based ecological demand.

Ecological Footprint and Biocapacity

The Global Footprint Network (GFN) methodology was applied. Biocapacity (BC) represents the ecological supply, calculated as:

$$BC = A \; x \; YF \; x \; EqF \qquad 1$$

where:

A = area (ha)

YF = yield factor (relative productivity of local land compared to global average)

EqF = equivalence factor (conversion factor to global hectares, gha).

Ecological footprint (EF) represents the ecological demand, calculated as:

$$EF = \frac{P}{YK} \; x \; YF \; x \; EqF \qquad 2$$

where:

P = consumption (tons)

YK = land productivity (tons/ha)

YF and EqF as defined above

Ecological Footprint Deficit (ED)

The ED was determined as the difference between per capita BC and EF:

$$ED = EFtotal - BC\ total \qquad 3$$

where:

ED = Ecological deficit

EFtotal = Ecological footprint total

BCtotal = Biocapacity total

The criteria and the resultfor determining ED can be seen in **Table 1.**

Table 1. Ecological Footprint Deficit (ED) Level

Deficit Region	Reserve or Balanced Region
Very severe deficit (ED>2.0)	Balance regions (-0.1<ED≤0.1)
Severe deficit (1.0<ED≤2.0)	
Moderate deficit (0.5<ED≤1.0)	Reserve regions (ED≤-0.1)

Source:(Ministry of Public Works, 2010)**.**

C. RESULTS AND DISCUSSION

Biocapacity of Agricultural and Fisheries Land

The results show that agricultural land provides the largest ecological supply in Cirebon Regency. As presented in Table 2, the biocapacity of agricultural land reached 217,605.36 gha, equivalent to 0.09218 gha per capita. By contrast, fisheries contributed a much smaller biocapacity of 7,036.82 gha or 0.00298 gha per capita. The total biocapacity of the regency therefore amounted to 224,642.18 gha, equivalent to 0.09516 gha per capita. These results

indicate that agriculture is the main contributor to ecological supply, while fisheries play a relatively minor role.

Table 2. Biocapacity of agricultural and fisheries land in Cirebon Regency

Category	Land Area (ha)	Yield Factor	Eq. Factor	Biocapacity (gha)	Biocapacity per capita (gha capita-1)
Agriculture	101,391	0.98	2.19	217,605.36	0.09218
Fisheries	5,776	3.39	0.36	7,036.82	0.00298
Total	–	–	–	224,642.18	0.09516

These findings suggest that the biological supply is strongly dependent on agricultural land, indicating that any large-scale loss of agricultural land as a result of land conversion might significantly impair the ecological balance in the area.

Ecological Footprint of Consumption

The ecological footprint (EF) reflects the ecological demand of the population. As shown in Table 3, agricultural consumption in Cirebon Regency generated an EF of 71,174.90 gha or 0.03015 gha per capita, while fisheries consumption contributed only 387.71 gha or 0.00016 gha per capita. The total ecological footprint of the regency was 71,562.61 gha, equivalent to 0.03031 gha per capita. These findings suggest that the population's ecological demand is dominated by agriculture, while fisheries contribute only marginally to total demand. The ecological footprint values of agricultural and fishery consumption in Cirebon Regency are presented in detail in **Table 3.**

Table 3. Ecological footprint of agricultural and fisheries consumption in Cirebon Regency

Category	Consumption (tons)	Productivity (ton/ha)	Yield Factor	Eq. Factor	EF (gha)	EF per capita (gha capita-1)
Agriculture	361,147.47	10.89	0.98	2.19	71,174.90	0.03015
Fisheries	7,036.82	7.43	3.39	0.36	387.71	0.00016
Total	–	–	–	–	71,562.61	0.03031

The dominance of agricultural consumption in the total ecological footprint reflects the central role of staple food demand in shaping regional ecological pressure**Ecological Footprint Deficit (ED)**

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The ED was obtained by subtracting EFtotal from BCtotal. As shown in Table 4, both agriculture and fisheries currently have an ecological reserve. The agricultural sector shows a surplus of –0.06203 gha per capita, while fisheries provide a smaller surplus of –0.00282 gha per capita. Overall, the total ecological balance in Cirebon Regency is –0.06485 gha per capita, which indicates that the regency is in a condition of ecological surplus. The following **Table 2** shows the detailed values of the biological capacity of agricultural and fishery land in Cirebon Regency. Based on the values in the previous table, **Table 4** shows the final results of the Ecological Deficit Level in agricultural and fishery areas in Cirebon Regency.

Table 4. ED level of agricultural and fisheries land in Cirebon Regency

Category	EF per capita (gha capita-1)	BC per capita (gha capita-1)	Ecological Balance (gha capita-1)	Status
Agriculture	0.03015	0.09218	–0.06203	Reserve
Fisheries	0.00016	0.00298	–0.00282	Reserve
Total	0.03031	0.09516	–0.06485	Surplus

Although the current ecological balance reflects a surplus condition, the strong dependence on agricultural land implies limited system resilience, where future pressures from land conversion, population growth, or climate variability may quickly erode this ecological reserve.

Discussion

The results indicate that Cirebon Regency is currently in an ecological surplus, particularly in the agricultural sector. This finding confirms that agricultural production is more than sufficient to meet local consumption needs. It also aligns with previous studies that identified agricultural regions in Java as still maintaining ecological reserves, especially in rice production areas (Giwangkoro et al., 2023). The carrying capacity of agricultural land in West Java Province is 0.74, indicating that the region is under high population pressure. Despite this, the province maintains a high agricultural productivity level (Ade Maya Dian et al., 2023).

From an environmental carrying capacity perspective, the observed rice surplus suggests that the biophysical capacity of agricultural land remains capable of supporting population consumption demands and even contributes to regional food supply. However, this surplus should be regarded as dynamic and vulnerable, as it is highly dependent on climatic stability

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and the intensity of land-use conversion pressures. Climate-related changes, including rainfall variability, rising temperatures, and the increasing frequency of extreme weather events in Java, are projected to reduce rice productivity between 2020 and 2049 (Nazarudin, 2024). Empirical evidence further underscores the role of demographic growth in accelerating land-use change. Indrianawati and Mahdiyyah, (2019). reported that population growth contributed approximately 12% to agricultural land conversion in Cirebon Regency during the period 2010–2016. Such demographic pressures have already reduced agricultural land availability and may intensify in the future, posing additional challenges to maintaining ecological balance.

While the agricultural sector demonstrates a relatively substantial ecological surplus, the fisheries sector provides only a limited ecological reserve. This condition indicates heightened vulnerability, as even marginal increases in consumption or declines in production could push the fisheries sector into an ecological deficit. Similar findings have been reported in coastal areas of Java, including Cirebon, where aquaculture systems are constrained by multiple environmental stressors such as sedimentation, nutrient imbalance, pollution, coastal abrasion and flooding, land-use change, and increasing exposure to climate variability (Asaf & Faizal, 2019; Bosman et al., 2021; Elfitasari et al., 2019; Prakoso et al., 2020; Qurani et al., 2021; Sumarga et al., 2022).

Climate change and coastal pollution in Cirebon have also emerged as significant drivers of livelihood transformation. These environmental pressures have contributed to a gradual shift in coastal communities' livelihoods from capture fisheries toward manufacturing and service sectors (Mulyadi, 2024). Such adaptive responses reflect both economic resilience and ecological stress, and they warrant careful attention given the already limited ecological surplus of the fisheries sector. Over the long term, continued degradation of coastal ecosystems may further weaken the ecological foundation supporting fisheries-based livelihoods.

Despite the overall positive ecological balance, the sustainability of Cirebon Regency remains subject to considerable risk. Climate change, agricultural land conversion, and broader environmental degradation may collectively reduce the ecological surplus of both agricultural and fisheries sectors in the future. Therefore, effective protection of agricultural land and the implementation of sustainable aquaculture practices are critical to maintaining long-term ecological stability (da Silva Morales et al., 2022; Qurani et al., 2021; Wicaksono et al., 2023).

From a policy perspective, integrating ecological footprint and biocapacity analyses into regional spatial planning (RTRW) can serve as an early warning tool for sustainable resource management. The current ecological surplus provides an opportunity for Cirebon Regency not only to safeguard local food security but also to support surrounding regions. However, without proactive and adaptive management, continued demographic growth and land-use change may rapidly erode this surplus, undermining long-term ecological sustainability.

D. CONCLUSION

This study demonstrates that Cirebon Regency is currently characterized by an ecological surplus, largely supported by agricultural land biocapacity, while the fisheries sector shows a limited ecological reserve and higher susceptibility to deficit conditions. These findings indicate that, under current conditions, the regional ecological system remains capable of meeting local consumption demands; however, sectoral disparities reveal uneven ecological resilience across land-based and coastal systems. From a policy perspective, integrating ecological footprint and biocapacity indicators into regional spatial planning (RTRW) can serve as an early-warning tool to safeguard food security and prevent future ecological deficits.

Despite the existing surplus, long-term sustainability remains uncertain due to population growth, land-use conversion, climate variability, and declining sectoral productivity. This study is limited by its reliance on secondary data and a static ecological footprint framework, which does not fully capture dynamic climate and policy interactions. Future research should incorporate climate projections, land-use change modeling, and scenario-based policy analysis to better anticipate potential transitions from ecological surplus to deficit and to support adaptive environmental governance.

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