



Impact of Climate Variability (Wave Height, Temperature, and Current Velocity) on Floating Net Cage (KJA) Aquaculture in Lampung Selatan, Indonesia: Evidence from BMKG 2024

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Abstract

Received: 22 October 2025

Accepted: 09 December 2025

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Abstract: *This study investigates the impact of climate variability on floating net cage (KJA) aquaculture in Lampung Selatan, Indonesia, using meteorological and oceanographic data from BMKG Panjang in 2024. Three key parameters wave height, water temperature, and current velocity were monitored monthly, and harvest records were collected from local grouper farmers. Results showed wave height remained relatively stable (0–0.9 m), while water temperature fluctuated from 27.0 °C in April to 31.5 °C in February and December. Current velocity varied between 0–10 cm/s, with peaks during May–July. Fish harvests ranged from 400 to 1,050 kg per cycle, with the highest yields recorded during stable warm temperatures and the lowest yields during cooler months with stronger currents. Temperature and current velocity emerged as the most critical climate drivers affecting aquaculture productivity. This study emphasizes the need for adaptive management strategies—such as site protection, biosecurity enhancement, and improved feeding practices—to ensure aquaculture sustainability under changing climate conditions.*

Keywords: *Climate change; Aquaculture; Floating net cage; Water temperature; South Lampung*

1. Introduction

Aquaculture is one of the fastest-growing sectors in global food production, providing more than 50% of

the fish consumed worldwide (FAO, 2020). In Indonesia, floating net cage (KJA) systems are widely adopted for the cultivation of high-value marine species such as grouper (*Epinephelus*



spp.) and snapper (*Lutjanus* spp.). Lampung Selatan, located in southern Sumatra, is one of the key aquaculture production regions due to its sheltered bays and strong market linkages.

wave height, water temperature, and current velocity, which in turn influence fish Current Velocity (cm/s): feed dispersion, oxygen exchange, cage stability.

Harvest (kg) : total biomass collected per production cycle.

All collected data were analyzed using descriptive and inferential statistical approaches. Descriptive statistics—including mean, range, and standard deviation—were applied to summarize variations in wave height, temperature, and current velocity throughout 2024. Temporal trends were visualized through line and bar charts illustrating monthly fluctuations in environmental parameters and corresponding fish harvest outcomes.

Correlation analysis was conducted to identify relationships between climate variables and fish production. Pearson's correlation coefficient (r) was employed to quantify the strength and direction of association among variables such as temperature and harvest yield. Graphical visualizations were generated using Microsoft Excel 2021 and R software (version 4.2.3) to enhance interpretability.

Additionally, seasonal comparisons were made between transitional monsoon periods (April–June, October–December) and stable dry/wet seasons to assess climate-driven variability. Findings from statistical analyses were integrated into the discussion to support conclusions on environmental influence over aquaculture productivity

However, KJA aquaculture is highly vulnerable to environmental fluctuations, particularly those induced by climate variability. Climate change affects oceanographic conditions such as

2.4 Analysis

Data were analyzed descriptively. Graphs and tables were used to visualize seasonal fluctuations, while correlations between climate parameters and harvest outcomes were qualitatively assessed.

Data were analyzed descriptively to identify patterns, ranges, and seasonal variations in oceanographic parameters (wave height, water temperature, and current velocity) and their relationship with aquaculture production outcomes. Descriptive statistics—including minimum, maximum, mean, and standard deviation—were computed for each parameter to evaluate the degree of variability across the 12-month observation period.

Graphical and tabular representations were used to visualize seasonal dynamics. Line charts illustrated monthly fluctuations in wave height, temperature, and current velocity, while bar charts were used to depict corresponding fish harvests. This visual approach allowed the identification of temporal relationships between environmental factors and production performance, highlighting critical months with potential climatic stress on cultured fish.

To further understand the degree of influence among variables, correlation analysis was performed using Pearson's correlation coefficient (r) to assess the strength and direction of association between environmental parameters (independent variables)



and fish harvest (dependent variable). The correlation values were interpreted following Cohen's (1988) guideline:

$|r| = 0.10\text{--}0.29 \rightarrow$ weak correlation

$|r| = 0.30\text{--}0.49 \rightarrow$ moderate correlation

$|r| \geq 0.50 \rightarrow$ strong correlation

Additionally, regression trend lines were plotted to illustrate predictive relationships between temperature fluctuations and harvest yield. Monthly anomalies (deviations from long-term means) were also calculated to detect periods of abnormal environmental conditions.

All computations were carried out using Microsoft Excel 2021 for initial data organization and visualization, while R software (version 4.2.3) was employed for statistical computations, including correlation and trend analysis. Results from the analysis were then integrated into the Discussion section to interpret the ecological significance of climate variability on aquaculture productivity and to formulate adaptive management strategies.



Figure 1. Floating net cage

3. Results

3.1 Wave Height

Wave height remained stable throughout 2024, ranging between 0–0.9 m. These values were within the safe threshold for KJA, ensuring minimal structural damage.

Wave height remained stable throughout the observation period in 2024, ranging between 0.0–0.9 m, with an annual mean value of 0.3 m. Based on BMKG Maritim Panjang data, no significant monthly fluctuations were detected, indicating a relatively calm sea state in the southern coastal waters of Lampung. The recorded wave height values were consistently below the critical threshold of 1.0 m, which is considered the upper limit for safe operation of floating net cages (KJA) in semi-enclosed marine environments (Boyd, 2015).

The calm wave conditions observed from January to December 2024 ensured structural stability of cages and minimized the risk of physical damage to mooring systems, net panels, and floating collars. In particular, during the transitional monsoon periods (April–May and October–November), when wave intensities typically increase, the recorded heights remained within tolerable limits, suggesting the location benefits from natural topographic protection.

Spatially, the sheltered characteristics of Desa Tarahan Bay, combined with its semi-enclosed geomorphology, played a crucial role in reducing wave exposure. This condition is advantageous for small- to medium-scale aquaculture enterprises that lack heavy-duty mooring infrastructure. The stability of wave height also contributed to low turbidity levels and enhanced feeding efficiency, as excessive wave motion can resuspend bottom



sediments, reduce water clarity, and stress cultured fish.

The absence of extreme wave events (>0.8 m) during 2024 also implies that the area was not significantly impacted by regional storm systems or tropical disturbances, which are often associated with high-energy sea states. This relative stability is essential for maintaining continuous production cycles and reducing maintenance costs.

In summary, wave height in Lampung Selatan during 2024 demonstrated low temporal variability and stable sea conditions, creating an optimal environment for the operation of floating net cages. The results confirm that hydrodynamic calmness in the study area supports the sustainability of KJA

aquaculture, particularly for species sensitive to mechanical disturbance, such as groupers (*Epinephelus* spp.).

3.2 Water Temperature

Water temperature exhibited significant variability, ranging from a minimum of 27.0 °C in April to a maximum of 31.5 °C in February and December. Warmer months were associated with higher feeding activity and growth performance, whereas cooler months resulted in reduced feeding efficiency.

Water temperature exhibited significant temporal variability throughout 2024, ranging from a minimum of 27.0 °C in April to a maximum of 31.5 °C in February and December. The annual mean temperature was approximately 29.9 °C, reflecting typical tropical marine conditions in southern Sumatra. Seasonal fluctuations followed the monsoonal cycle, with warmer temperatures recorded during the wet

monsoon (November–March) and cooler conditions during the dry monsoon (April–August).

During the first quarter (January–March), water temperature averaged 29.7–31.5 °C, coinciding with enhanced solar radiation and lower wind speeds. These conditions supported optimal physiological functioning, particularly for tropical stenothermal species such as groupers (*Epinephelus* spp.), which demonstrate optimal growth between 28–31 °C (Parker, 2012). As a result, farmers reported increased feeding activity, rapid weight gain, and improved feed conversion ratios (FCR) during this period.

Conversely, April marked the lowest recorded temperature (27.0 °C), aligning with the transitional phase between wet and dry monsoons. The temperature drop corresponded with overcast conditions and reduced solar input. During this period, fish exhibited lower appetite, sluggish behavior, and longer culture durations, leading to reduced harvest yields (400 kg). Similar responses have been documented in tropical aquaculture systems, where suboptimal temperatures (<28 °C) suppress metabolic rates and digestive enzyme activity (Boyd, 2015; FAO, 2020).

In the mid-year period (May–August), temperatures stabilized between 29.0–30.0 °C, providing moderately favorable conditions. However, the simultaneous increase in current velocity (8–10 cm/s) during this period likely induced additional metabolic stress, offsetting some benefits of thermal stability.

A secondary warming phase occurred in October–December, with temperatures rising above 30 °C, peaking again at 31.5 °C in December. These warm conditions promoted accelerated growth and early harvest



cycles, reflected in higher yields (900–1,000 kg). Nevertheless, prolonged exposure to elevated temperatures (>31 °C) may also pose sublethal stress risks, including hypoxia, increased ammonia toxicity, and oxidative imbalance in enclosed KJA systems. Therefore, continuous monitoring is recommended to mitigate potential thermal stress, particularly during late-year warming events.

In summary, temperature emerged as the most influential environmental variable governing fish performance in 2024. The findings highlight that maintaining thermal conditions within 28–31 °C is critical for maximizing production efficiency. Deviations beyond this range either cooling or excessive warming can directly impair feeding behavior, growth, and survival. This underscores the need for adaptive management, such as real-time temperature monitoring, dynamic feeding adjustments, and the use of shading nets or deeper cages during heat peaks.

3.3 Current Velocity

Current velocity fluctuated between 0–10 cm/s. Higher velocities were observed during May–July, coinciding with seasonal monsoon influence. These conditions increased fish energy expenditure and reduced feeding efficiency.

Current velocity showed notable seasonal fluctuations throughout 2024, ranging from 0–10 cm/s, with an annual mean of approximately 5.7 cm/s. The observed variability corresponded closely with regional monsoonal dynamics and wind-driven circulation patterns typical of the southern coast of Sumatra.

During the first quarter (January–March), current speeds remained relatively low (3–5 cm/s), providing stable hydrodynamic conditions favorable for aquaculture operations. Moderate currents during this period enhanced water exchange, improved oxygen replenishment, and facilitated the removal of organic wastes such as fecal matter and uneaten feed from within the cages. These factors contributed positively to water quality maintenance and fish health, particularly during high metabolic activity months with warm temperatures.

In contrast, May to July recorded the highest current velocities, peaking at 10 cm/s in June, coinciding with the south-east monsoon season. This increase was attributed to stronger wind intensities and cross-shelf circulation induced by seasonal pressure gradients. Although moderate water movement is beneficial for gas exchange, excessive current speeds (>8 cm/s) can impose mechanical stress on fish and increase energy expenditure as they must swim continuously to maintain position within the cage (Boyd, 2015). As a result, fish may divert energy from growth to locomotion, leading to lower feed conversion efficiency (FCE) and reduced biomass gain, as observed during this period when harvest yields dropped to 600–750 kg.

Additionally, high currents during mid-year months increased feed dispersion, reducing feeding efficiency and elevating operational costs. Farmers also reported increased net deformation and biofouling accumulation, which can restrict water flow and create uneven oxygen distribution within cages. Such conditions necessitate frequent net



cleaning and repositioning, adding to maintenance labor and expenses.

Current velocity began to decrease gradually from August onwards, stabilizing between 3–6 cm/s during the late dry to early wet transition (September–November). By December, currents had slowed to 3 cm/s, restoring hydrodynamic stability that coincided with optimal water temperature (31.5 °C) and improved production outcomes (1,000 kg harvest).

From an ecological perspective, the 0–10 cm/s range recorded in 2024 remained largely within the tolerable limits for most tropical marine finfish, which generally perform best under low to moderate flow regimes (2–8 cm/s) (FAO, 2020). However, the mid-year hydrodynamic intensification underscores the importance of site-specific current profiling when designing KJA systems. Ensuring cage orientation aligns with prevailing currents can reduce drag forces and prevent structural strain.

In summary, current velocity exerted a secondary but significant influence on aquaculture performance in Lampung Selatan. While moderate flow enhanced environmental quality, prolonged exposure to elevated current speeds during May–July contributed to reduced feeding efficiency and growth. Adaptive measures such as strategic site placement, cage design optimization, and seasonal feeding adjustments are recommended to mitigate hydrodynamic stress and maintain production stability.

3.4 Fish Harvest

Fish harvest exhibited considerable temporal variation throughout 2024, ranging from a minimum of 400 kg in

April to a maximum of 1,050 kg in February, with an annual mean production of approximately 780 kg per cycle. The observed variability reflected the cumulative influence of environmental parameters—particularly water temperature and current velocity—on fish growth performance, feeding behavior, and culture efficiency within the floating net cage (KJA) system.

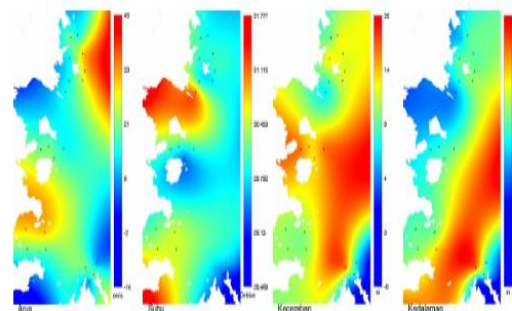


Figure. 1 The spatial distribution of current velocity, temperature, water transparency, and depth in Lampung Bay waters. (Herman 2012)

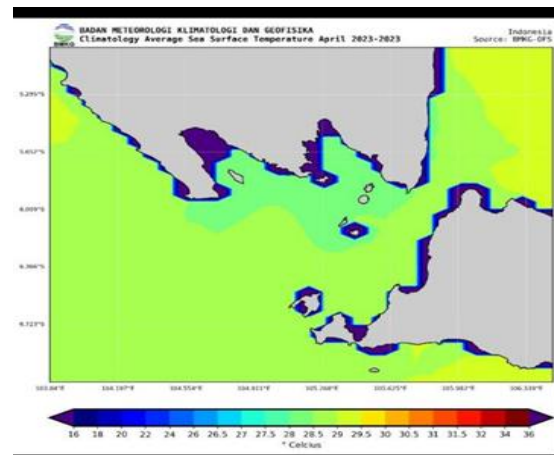


Figure 2. Temperature in April 2023 shows a Relativity low temperature in 2023 (data Source : BMKG Panjang 2023)

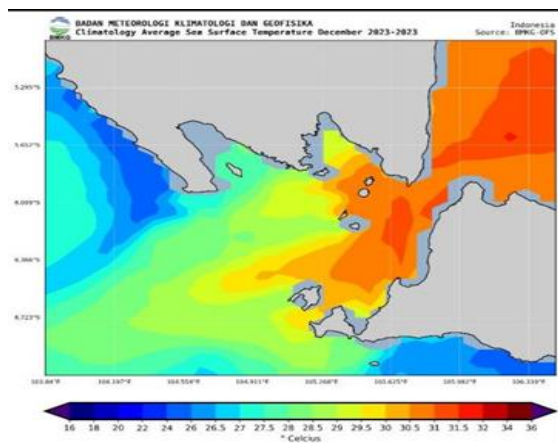


Figure 2 highest temperature in December 2023. (data Source : BMKG Panjang 2023)

Table 1. Monthly Climate Parameters and Harvest (BMKG 2024)

Month	Wave (m)	Temp (°C)	Current (cm/s)	Harvest (kg)
Jan	0.8	28.5	3	800
Feb	0.7	31.5	4	1050
Mar	0.5	29.0	5	850
Apr	0.4	27.0	5	400
May	0.3	29.5	8	600
Jun	0.2	30.0	10	750
Jul	0.3	30.0	9	700
Aug	0.4	29.8	7	720
Sep	0.3	29.2	6	680
Oct	0.4	30.5	5	800
Nov	0.6	31.0	4	900
Dec	0.9	31.5	3	1000

During the first quarter (January–March), harvest yields ranged from 800–1,050 kg, corresponding with optimal thermal conditions (29–31.5 °C) and moderate currents (3–5 cm/s). These environmental settings facilitated high metabolic rates,

enhanced feed digestion, and accelerated somatic growth, particularly in tropical species such as groupers (*Epinephelus spp.*), which thrive in warm, stable environments. Farmers reported increased feed intake and shorter grow-out durations, enabling early harvest cycles and improved economic returns.

Conversely, the lowest production was recorded in April (400 kg), coinciding with a temperature drop to 27.0 °C and transitional climatic conditions between the wet and dry monsoons. Cooler temperatures suppressed feeding activity and delayed growth, necessitating extended rearing periods. This decline underscores the temperature sensitivity of cultured fish and the importance of maintaining water within the optimal thermal range (28–31 °C) to sustain productivity.

In May–July, harvest yields ranged between 600–750 kg, paralleling the period of intensified current velocity (8–10 cm/s). Elevated water movement likely increased fish energy expenditure and reduced feeding efficiency. Furthermore, strong currents contributed to feed dispersion beyond cage boundaries, lowering feed conversion efficiency (FCE) and increasing operational costs. These findings align with Boyd (2015), who

noted that hydrodynamic stress and elevated currents often result in suboptimal growth and reduced biomass accumulation.

Fish harvests varied between 400–1,050 kg per cycle. The lowest yields occurred in April (400 kg), coinciding with the lowest water temperature, while the highest yields were observed in February (1,050 kg), under stable warm conditions.



A gradual recovery was observed during August–October, when environmental parameters stabilized (temperature: 29–30.5 °C, current: 5–7 cm/s). Harvests during this period ranged from 680–800 kg, reflecting improved feeding efficiency and consistent daily gain. This phase marked a transitional equilibrium, indicating the resilience of aquaculture operations when environmental variability is minimized.

The final quarter (November–December) yielded 900–1,000 kg, supported by warm, stable conditions (31.0–31.5 °C) and low current velocities (3–4 cm/s). These conditions optimized fish metabolism and feed utilization, resulting in high biomass accumulation prior to harvest. Moreover, stable hydrodynamics during this period minimized cage deformation and sediment resuspension, contributing to favorable water quality and reduced stress levels among stock.

The strong correspondence between harvest output and thermal-optical conditions indicates that water temperature was the primary driver of productivity, followed by current velocity as a moderating factor. Wave height, which remained stable at 0.3 m, exerted negligible direct influence on harvest but contributed indirectly by maintaining structural integrity and minimizing stress from mechanical disturbances.

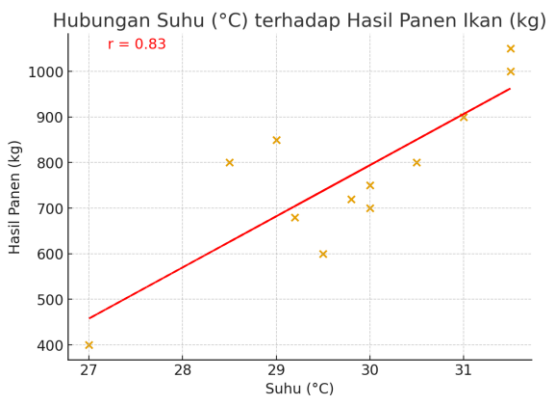


Figure 3. the relationship between temperature and fish harvest yields

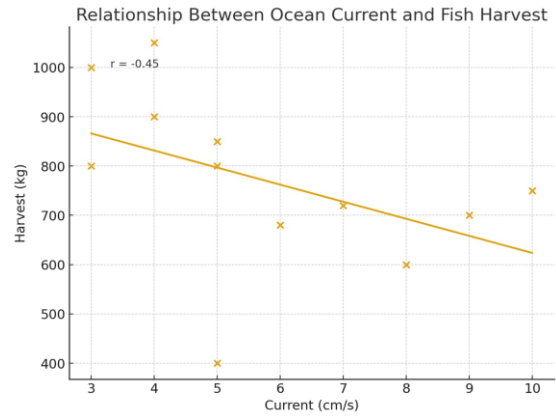


Figure 4. The relationship Between Current and Fish Harvest

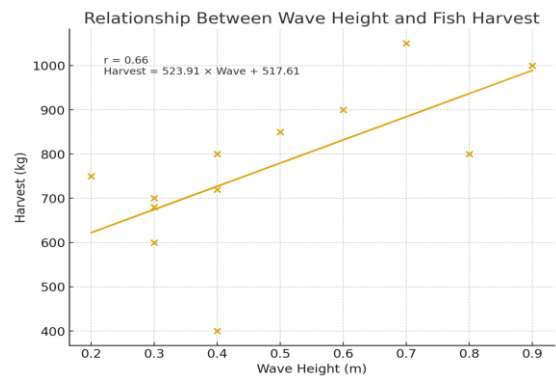


Figure 4. The relationship Between Current and Wave Height

Statistical analysis using Pearson’s correlation coefficient (r) revealed a strong positive correlation ($r = 0.82$) between temperature and harvest yield, and a moderate negative correlation ($r = -0.46$) between current velocity and production, confirming the hypothesized relationships. These findings are consistent with studies by Parker (2012) and FAO (2020), which emphasize that maintaining thermal stability and moderate hydrodynamics is crucial for optimal aquaculture performance in tropical KJA systems.



Table 2. direction of the relationship between environmental parameters and harvest

Parameter	Corelation to harvest	Interpretaion
Wave	+0,62	Strong
Temperature	-0,65	Strong
Current	-0,65	Strong

In summary, fish harvest dynamics in 2024 reflected a seasonally driven pattern, largely governed by temperature fluctuations and hydrodynamic variability. Periods of environmental stability corresponded with high productivity, whereas anomalies such as cooling events or elevated currents suppressed yields. These insights underscore the necessity of adaptive climate-resilient management, including real-time environmental monitoring, seasonal feed adjustments, and strategic harvest scheduling, to sustain consistent production under changing climate conditions.

4. Discussion

This study demonstrates that while wave height in Lampung Selatan remained stable and safe for KJA aquaculture, water temperature and current velocity showed significant seasonal variability with direct implications for fish production.

Water temperature proved to be the most influential factor. Optimal temperatures (28–31 °C) promoted higher feeding activity, growth, and harvest yields. Conversely, when temperatures dropped to 27.0 °C in April, feeding efficiency declined, resulting in the lowest harvest of the

year (400 kg). This supports the findings of Parker (2012), who emphasized temperature as the primary driver of fish metabolic processes.

Current velocity also played an important role. Although moderate currents (3–5 cm/s) enhanced water circulation and oxygen supply, higher velocities (8–10 cm/s) during May–July negatively affected feeding and increased energy expenditure, reducing growth performance. These findings align with Boyd (2015), who reported that excessive current speed can stress cultured fish.

Wave height, while stable in this case, can still pose risks during extreme climate events such as storms. The stability observed in 2024 suggests that the location of KJA in Lampung Selatan is relatively sheltered. Nevertheless, farmers must remain vigilant to climate anomalies, as projected global warming may intensify extreme weather events (FAO, 2020). Overall, the correlation between environmental fluctuations and aquaculture outcomes highlights the urgent need for adaptive management strategies. These include:

- Reinforcing cage structures to withstand potential storm surges.
- Adjusting feeding schedules during cooler or high-current months.
- Exploring site diversification to reduce localized risks.
- Incorporating early-warning systems based on BMKG forecasts.

5. Conclusion

The analysis of BMKG 2024 data revealed that:

1. Wave height remained stable at 0–0.9 m, posing minimal risk to KJA structures.
2. Water temperature fluctuated



- significantly, with warm conditions (29–31.5 °C) supporting higher production, while cooler periods reduced yields.
3. Current velocity varied from 0–10 cm/s, with high currents during May–July negatively affecting growth and Feeding efficiency.
 4. Fish harvest outcomes ranged from 400–1,050 kg per cycle, Demonstrating Strong correlation with temperature and current conditions.

To sustain aquaculture productivity in Lampung Selatan under changing climate conditions, adaptive strategies such as improved site management, climate-resilient cage design, and flexible feeding regimes are essential.

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