**BIODIVERSITAS**
Volume 25, Number 10, October 2024
Pages: 3758-3767

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d251038

# Influencing the environmental factors on the abundance of puerulus *Panulirus homarus* in the Mentawai Islands, West Sumatra, Indonesia

**SUPARNO[1,♥], YUSRA[1], AMELIA SRIWAHYUNI LUBIS[2], AIDY FITRI YUSEN VIZA[1]**
[1]Department of Fishery Resources Utilization, Faculty of Fisheries and Marine Sciences, Universitas Bung Hatta. Jl. Sumatera Ulak Karang, Padang 25133, West Sumatra, Indonesia. Tel./fax.: +62-751-7055475, ♥email: suparnopranoto@bunghatta.ac.id
[2]Department of Aquaculture, Faculty of Fisheries and Marine Sciences, Universitas Bung Hatta. Jl. Sumatera Ulak Karang, Padang 25133, West Sumatra, Indonesia

Manuscript received: 26 August 2024. Revision accepted: 21 October 2024.

**Abstract.** *Suparno, Yusra, Lubis AS, Viza AFY. 2024. Influencing the environmental factors on the abundance of puerulus* Panulirus homarus *in the Mentawai Islands, West Sumatra, Indonesia. Biodiversitas 25: 3758-3767.* The lobster puerulus, the final larval stage of the spiny lobster, is significantly influenced by environmental factors, making it crucial for sustainable aquaculture development. This study aimed to analyze how these factors affect the abundance of puerulus *Panulirus homarus* (Linnaeus, 1758) in the Mentawai Islands, West Sumatra, Indonesia has practical implications for aquaculture. A one-way analysis of variance revealed that the temporal period significantly impacts the abundance of puerulus *P. homarus* ($P<0.05$). In February (west season), the abundance was not significantly different from April (transition season I), but both differed significantly from June (east season). The highest abundance occurred in June (33.8±4.21 ind/trip), followed by April (27.00±5.00 ind/trip) and February (23.20±2.22 ind/trip). Regression analysis showed that temperature ($R^2$=0.8111), salinity ($R^2$=0.5158), and phosphate ($R^2$=0.5492) strongly correlated with puerulus abundance. In contrast, chlorophyll-a ($R^2$=0.2236), nitrate ($R^2$=0.4136), and sea current velocity ($R^2$=0.0223) were less significant. These results emphasize the importance of temperature, salinity, and phosphate as key factors influencing puerulus distribution, providing valuable insights for sustainable aquaculture. Environmental parameters were observed using Aqua Modis satellite imagery. They included Sea Surface Temperature (SST), chlorophyll-a concentration, and current velocity, showing a good correlation with field measurements from the Copernicus Marine Environment Monitoring Service (CMEMs).

**Keywords:** Abundance, environmental factors, Mentawai Islands, puerulus

## INTRODUCTION

Indonesia, as the largest archipelagic country in the world, has very high marine biodiversity and plays an important role in the global marine ecosystem (Hasan and Islam 2020; Hasan et al. 2022; Deswati et al. 2023; Suparno et al. 2023; Lelono et al. 2024). One of the high-value marine commodities is lobster, especially the puerulus type, which is the final larval stage of lobster (Clark et al. 2015; Masithah et al. 2023; Kismiyati et al. 2024). Lobster puerulus has a crucial ecological role in the lobster life cycle because, at this stage, they act as indicators of the health of coral reef ecosystems and other coastal habitats (Groeneveld et al. 2003; McManus et al. 2021; Amin et al. 2022a). The presence of lobster puerulus reflects good environmental conditions, such as water quality and abundance of plankton as a food source (Selgrath et al. 2007; Amin et al. 2022b). Therefore, the management and utilization of lobster puerulus are not only important for the sustainability of lobster resources but also for maintaining the ecological balance and function of marine ecosystems in Indonesia (Goldstein et al. 2017; Larasati et al. 2018).

In Indonesia, there is potential to establish a lobster farming industry similar to Vietnam's, given the significant pueruli resources identified (Ye et al. 2005; Cavieres and Nicolis 2018). However, in 2015, the Indonesian spiny lobster aquaculture industry underwent a significant change when a new policy imposed a 200 g minimum legal size for spiny lobsters that could be caught and traded, effectively prohibiting the capture of pueruli for all species (Erlania et al. 2016; Setyagama et al. 2023). Furthermore, in 2016, another policy was announced, banning grow-out activities involving spiny lobsters (Lubis et al. 2023). By restricting access to pueruli and grow-out opportunities, these regulations have hindered the ability of Indonesian lobster farmers to develop a sustainable grow-out industry. Although the new policies were intended to increase the abundance of adult lobsters, there is no evidence (no increased fishery catch) that they have been successful (Clark et al. 2015; Priyambodo et al. 2020).

The Mentawai Islands, off the coast of West Sumatra, offer ideal conditions for marine conservation, known for their clear waters and diverse coral reefs, which serve as natural habitats for marine species like puerulus lobsters (Hedberg et al. 2018; Nizinski et al. 2023). These healthy coral reefs indicate a balanced and productive ecosystem, making the Mentawai Islands a key area for marine conservation research in Indonesia (Rizal and Dewanti 2017). However, information on the abundance and distribution of puerulus lobsters in this region remains limited. Accurate data on these populations are crucial for developing sustainable management strategies (Priyambodo et al. 2020; Filippi et al. 2024). Water quality, including physical, chemical, and biological parameters, plays a vital role in the survival and distribution of marine organisms like puerulus lobsters (Suparno et al. 2023). Variations in these parameters, influenced by both natural factors and human activities, can significantly impact marine populations. Therefore, understanding the relationship between water quality and puerulus lobster abundance is essential for effective conservation (Watson et al. 2016; Hutchinson et al. 2024). Furthermore, understanding the ecological and environmental drivers of puerulus lobster abundance in the Mentawai Islands is essential for informing both local and national marine policy (Priyambodo et al. 2020; Filippi et al. 2024).

Integrating scientific research on water quality parameters—such as salinity, temperature, dissolved oxygen, and nutrient levels—can provide a comprehensive assessment of habitat suitability for puerulus lobsters and help predict population fluctuations in response to environmental changes (Bright and Gueymard 2019; Purba et al. 2020). Sustainable conservation area development requires a holistic approach that considers various environmental and ecological factors. By knowing the relationship between water quality and the abundance of puerulus lobsters, cultivation practices can be developed that not only increase production but also maintain ecosystem balance (Priyambodo et al. 2020; Suparno et al. 2023). Environmentally friendly cultivation practices will ensure that aquaculture activities do not cause environmental degradation that can endanger marine ecosystems in the long term. Sustainable aquaculture development is also expected to provide economic benefits to the surrounding community, improving their welfare without sacrificing environmental sustainability (Rizal and Dewanti 2017). This study aimed to analyze the influence of environmental factors on the abundance of puerulus *P. homarus* in the Mentawai Islands, West Sumatra, Indonesia.

## MATERIALS AND METHODS

### Study area and data sources

The research was conducted in the waters of the Mentawai Islands, West Sumatra, specifically in Tapak 1 Bay, Tapak 2, and Bake Bay (Figure 1), from January to June 2024. Description of sampling stations, namely location and coordinates, is presented in Table 1. This study utilized daily Chl-a and semi-daily SST products from Aqua MODIS Level 3 (https://oceancolor.gsfc.nasa.gov/l3/), with a spatial resolution of 4 km. The data collected included monthly and 8-day intervals for each temporal period: the west season (2nd, 10th, 18th, and 26th of February), transition season I (5th, 13th, 21th, and 29th of April), and east season (3rd, 11th, 19th and 27th of June) (Ouzounov et al. 2004; Bright and Gueymard 2019). Additionally, data on currents, nitrate, phosphate, and salinity, with a spatial resolution of a quarter (¼) degree (27.83 km), were obtained using CMEMS (Copernicus Marine Environment Monitoring Service) (https://data.marine.copernicus.eu/) (Tama et al. 2007; Aulicino et al. 2021).

### Data collection

The research utilized spiny lobster puerulus larvae as the primary material for investigation. The equipment employed encompassed a variety of tools such as lobster seed collectors, fishing boats, cameras, life jackets, writing instruments, Global Positioning System (GPS) for geospatial positioning of observation stations, thermometers for temperature measurements, refractometer for salinity assessments, digital oxygen meter for dissolved oxygen quantification, secchi disk for brightness evaluations, current-meter for current speed determinations, pH Meter for pH level examinations, sample bottles, net plankton, microscope, and satellite data for comprehensive analysis. These tools were indispensable in facilitating the collection of data and ensuring the accuracy of the research findings.

**Table 1.** Description of sampling station

| Station | Location name | Coordinate |
|---|---|---|
| 1 | Tapak 1 Bay | 100°15'34"E; 3°03'41"S |
| 2 | Tapak 2 Bay | 100°15'19"E; 3°03'53"S |
| 3 | Bake Bay | 100°14'50"E; 3°03'28"S |

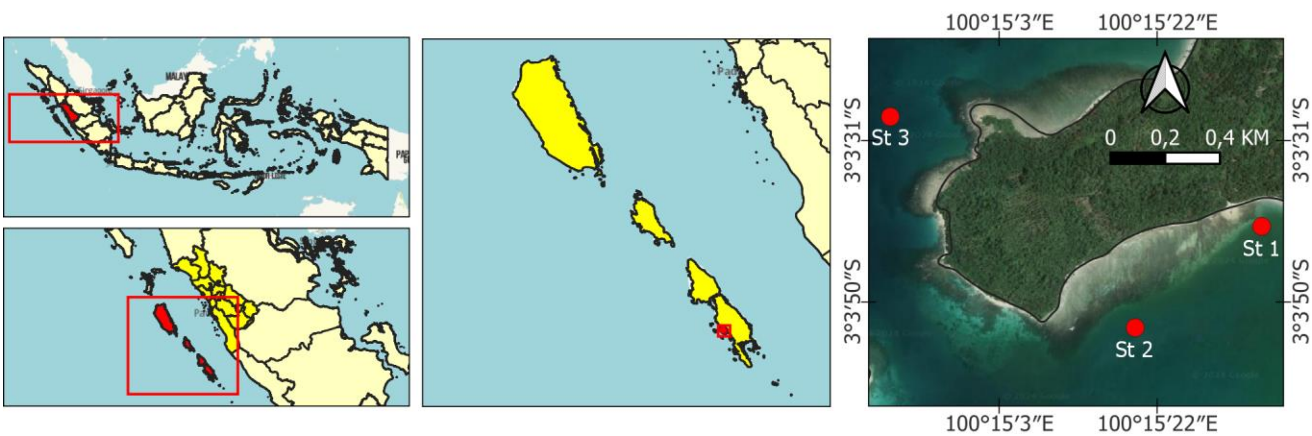


**Figure 1.** Research location in Mentawai Islands, West Sumatra, Indonesia. St 1: Tapak 1 Bay; St 2: Tapak 2 Bay; St 3: Bake Bay

The primary data gathered in this study pertains to the quantity of lobster seeds or puerulus obtained from fishermen's catches. At the same time, the supplementary data includes various physical and chemical characteristics of the aquatic environments under examination. Observing lobster larvae or seeds involves using a specialized collection tool called "pocong." The height of the pocong is 50 cm, the diameter is around 30 cm, and the mesh size is around 0.5 cm. Light is used to attract lobster larvae to the designated raft location, exploiting their phototaxis behavior. Then, to analyze monthly distribution patterns and abundance variations, the total count of lobster larvae or seeds at each monitoring site was recorded over three months. The seed data represents the combined total from all collectors at each specific station.

The evaluation of various physical, chemical, and biological aspects of water involves the measurement of parameters such as temperature, salinity, pH, dissolved oxygen levels, water flow rate, nitrate (NO3-N), phosphate (PO4-P), and chlorophyll-1 concentration. Field measurements were conducted for temperature, salinity, pH, dissolved oxygen, and water flow rate using tools such as a refractometer, pH meter, dissolved oxygen meter, Secchi disk, and current meter. In comparison, the analysis of nitrate (NO3-N) and phosphate (PO4-P) levels required water sample collection for laboratory testing. Furthermore, data on Sea Surface Temperature (SST) and chlorophyll-a concentration from satellite imagery were obtained from the NASA Ocean Color Web platform at https://oceancolor.gsfc.nasa.gov/l3/, while information on current velocities was obtained from the CMEMs (Copernicus Marine Environment Monitoring Service) in https://data.marine.copernicus.eu/.

**Satellite image data processing**

Sea Surface Temperature (SST) and chlorophyll-a data were acquired from Aqua-MODIS (Moderate Resolution Imaging Spectroradiometer) Level 3 composite satellite imagery, which had a spatial resolution of 4 km on a monthly basis spanning from August 2020 to October 2020 (Ciancia et al. 2018). The data was sourced from http://oceancolor.gsfc.nasa.gov/ in Network Common Data Form (NetCDF) format. Concurrently, measurements of current, nitrate, phosphate, and salinity were obtained with a spatial resolution of a quarter (¼) degree (equivalent to 27.83km) from the CMEMs (Copernicus Marine Environment Monitoring Service) portal (https://data.marine.copernicus.eu/) (Aznar et al. 2016). This dataset exhibits a strong correlation with argo measurements conducted in the field. Moreover, the data was meticulously arranged and scrutinized using Ocean Data View, employing DIVA gridding interpolation to assess the magnitude of each parameter.

**Data analysis**

To determine the effect of environmental factors on the abundance of puerulus *P. homarus* in the waters, a one way variance analysis was carried out. While analyzing the relationship between environmental factors in the waters and lobster puerulus settlements, a regression analysis was carried out. Analysis of variance and linear regression were carried out using SPSS 26.0 software. This study used puerulus settlements as dependent variables, with temperature, chlorophyll-a, salinity, phosphate, nitrate, and current speed as independent variables. The condition of the aquatic environment was analyzed using Ocean data view using DIVA gridding interpolation to view the values of all observed environmental parameters.

## RESULTS AND DISCUSSION

**Influence of temporal period on the abundance of puerulus lobsters**

This specimen is the puerulus stage of *P. homarus*, which is characterized by a body color that is still transparent and the morphology of the specimen's body does not have pigmentation. The antennae from the tip to the base have black dots (alternating) and the antennae do not light up when exposed to light. The figure of the puerulus is seen in Figure 2. Based on the results of a one-way analysis of variance, the temporal period significantly affects the abundance of puerulus *P. homarus* ($P<0.05$). The abundance of *P. homarus* puerulus in February (west season) was not significantly different from April (transition season I), but February and April were significantly different from June (east season). The highest abundance of *P. homarus* puerulus was in June or east season at 33.8±4.21 ind/Trip, followed by April (transition season I) at 27.00±5.00 ind/Trip and the last in February (west season) at 23.20±2.22 ind/Trip. Data on the effect of the period on the abundance of puerulus *P. homarus* is presented in Figure 3.

**Figure 2.** Puerulus of the *Panulirus homarus*

### The relationship between aquatic environment and *Panulirus homarus* puerulus

The results of the regression analysis revealed that the parameters of temperature ($R^2$=0.8111), salinity ($R^2$=0.5158), and phosphate ($R^2$=0.5492) had a strong relationship with the presence of lobster puerulus in the waters of the Mentawai Islands. In contrast, the parameters of chlorophyll-a ($R^2$=0.2236), nitrate ($R^2$=0.4136), and sea current velocity ($R^2$=0.0223) did not show a significant relationship with lobster puerulus at that location. The regression analysis of the aquatic environment and lobster puerulus is shown in Figure 4. The regression analysis (Figure 4) shows that temperature, salinity, and phosphate are key factors affecting the distribution of Puerulus lobsters in Mentawai Islands waters. These factors have a stronger and more significant impact on lobster distribution compared to chlorophyll-a, nitrate, and current velocities.

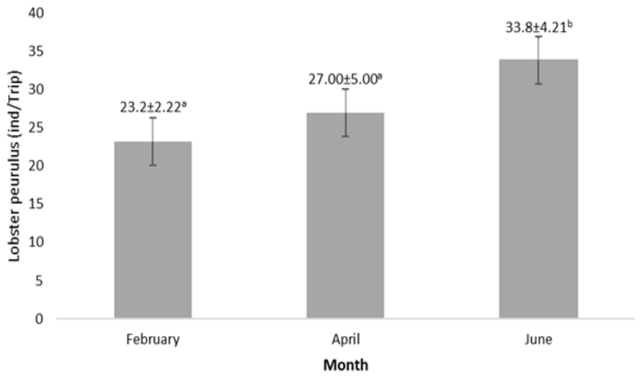


**Figure 3.** Influence of temporal period on the abundance of *Panulirus homarus* puerulus

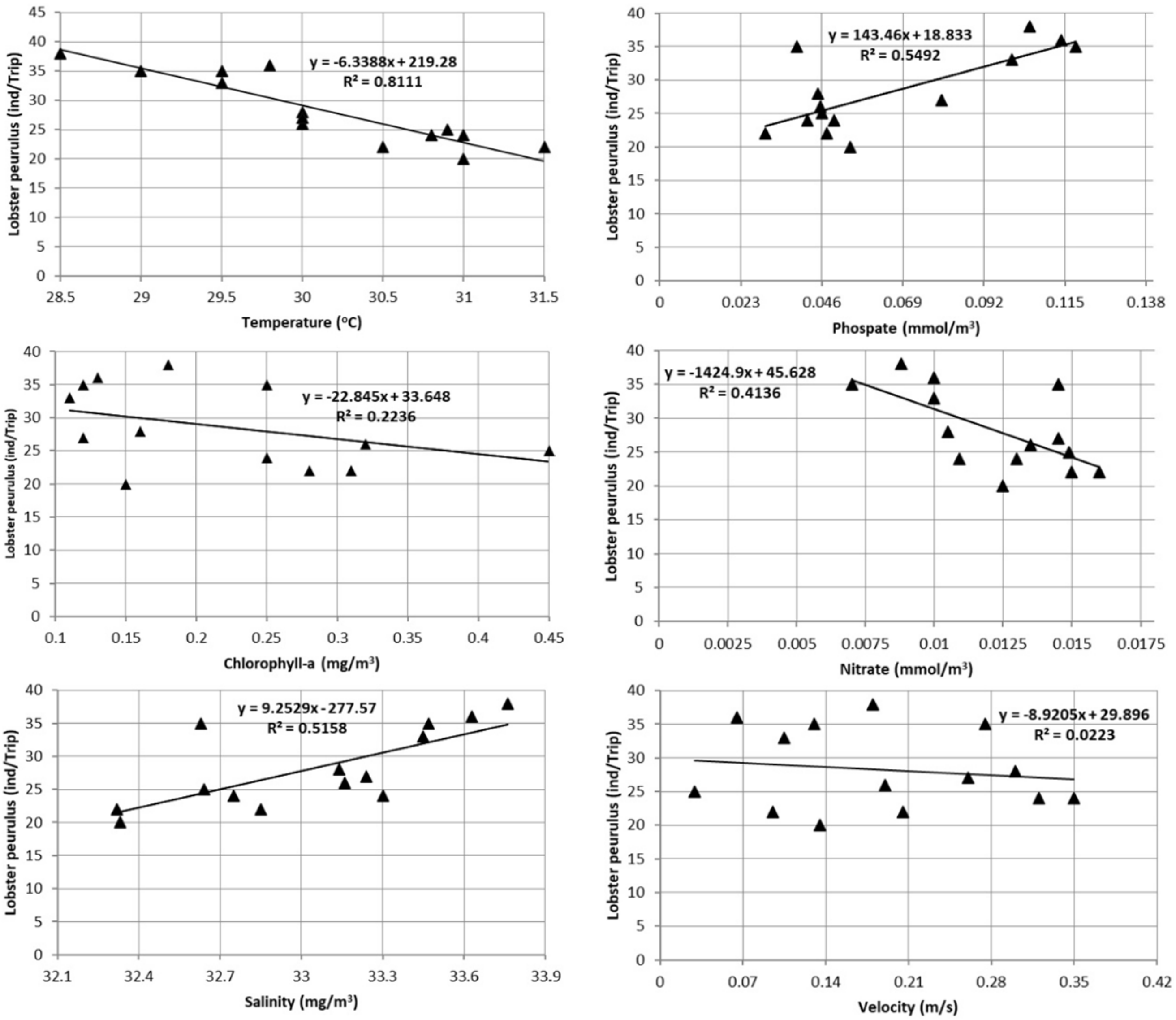


**Figure 4.** The regression analysis of the aquatic environment and lobster puerulus

**Condition of the aquatic environment**

The environmental parameters of the waters observed using Aqua Modis satellite imagery include Sea Surface Temperature (SST), chlorophyll-a concentration, and current velocity. The distribution of SST, chlorophyll-a, and current velocity in the waters of the Mentawai Islands is shown in Figure 5. Based on Aqua Modis satellite imagery, in February, April, and June, SST in the waters of the Mentawai Islands ranged from 28.5 to 31.5°C. Spatially, warm temperatures are generally found in coastal waters, especially in bays. Conversely, cold temperatures are spread in the offshore waters south of the sampling location. Sea Surface Temperature (SST) is greatly influenced by the amount of heat received from the sun, so tropical areas or around the equator, which receive the most heat from the sun, tend to have higher temperatures.

Based on the spatial distribution of Aqua Modis satellite imagery, the concentration of chlorophyll-a in the waters of the Mentawai Islands in February ranged from 0.15 to 0.45 $mg^{-1}m^3$, in April between 0.16 to 0.32 $mg^{-1}m^3$, and in June between 0.11 to 0.18 $mg^{-1}m^3$. Chlorophyll-a is more concentrated in coastal waters, and its concentration decreases as the season changes towards the east season. The highest concentration of chlorophyll-a was recorded in February, during the western season.

Environmental parameters observed at the research location include sea current velocity, salinity, phosphate, and nitrate. Spatial distribution data from the Copernicus Marine Environment Monitoring Service (CMEMs) showed a good correlation with argo measurements in the field (Figure 6). The results of current velocity measurements in the waters of the Mentawai Islands show significant variations throughout the year, with velocities ranging from 0.029 to 0.135 m/s in February, 0.190 to 0.350 m/s in April, and 0.065 to 0.260 m/s in June. The measurement results in the waters of the Mentawai Islands showed that the current speed ranged from 0.029 to 0.135 $m^{-1}s$ in February, between 0.190 to 0.350 $m^{-1}s$ in April, and between 0.065 to 0.260 $m^{-1}s$ in June. The salinity in these waters ranged from 32.33 to 33.85 $mg/m^3$ in February, April, and June. The spatial data shows that the salinity of the waters is relatively stable throughout the year; several environmental and hydrological factors can influence this stability.

Phosphate distribution spatial data from CMEMS shows a range of values between 0.0420 to 0.0540 $mg^{-1}m^3$ in February, between 0.0300 to 0.0495 $mg^{-1}m^3$ in April, and between 0.0800 to 0.1140 $mmol/m^3$ in June. Phosphate concentrations in the water tend to decrease towards the east season. For nitrate, data from CMEMS shows values of around 0.0125 to 0.0160 $mg^{-1}m^3$ in February, around 0.0109 to 0.0150 $mmol^{-1}m^3$ in April, and around 0.0070 to 0.0145 $mg^{-1}m^3$ in June. Like phosphate, nitrate concentrations also show a decrease towards the east season.

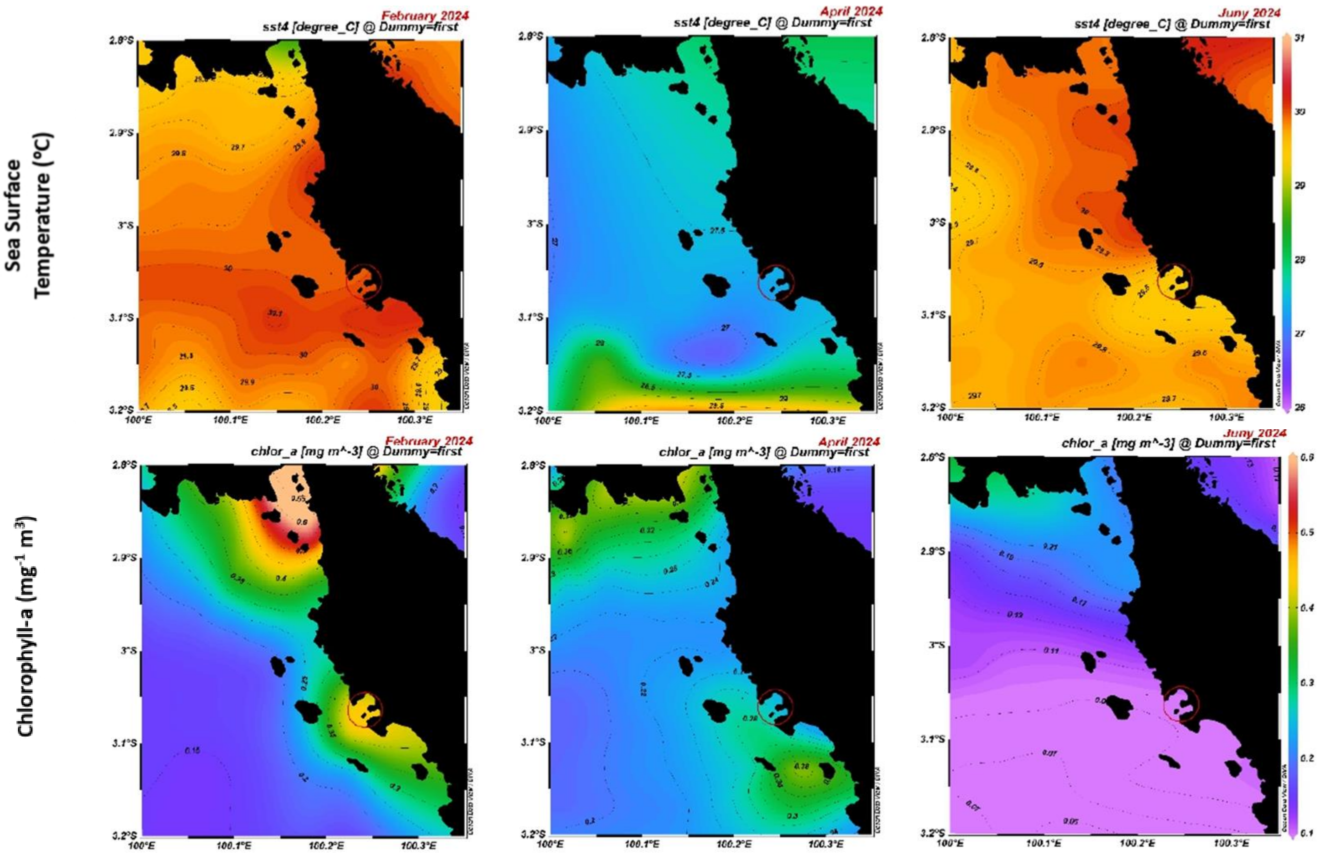


**Figure 5.** Spatial distribution of sea surface temperature, chlorophyll-a, and current speed in the waters of Mentawai Islands in February, April, and June 2024

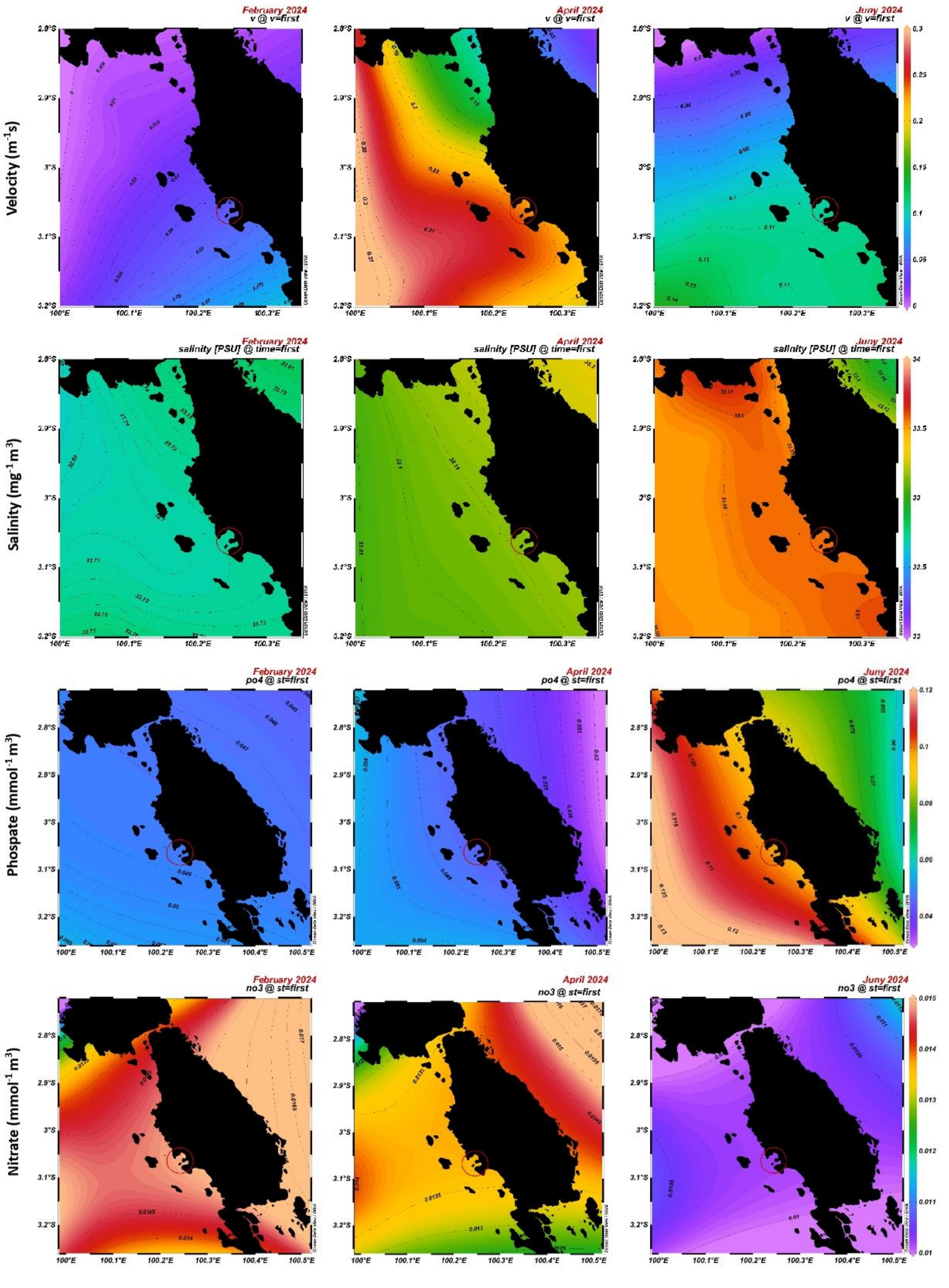


**Figure 6.** Spatial distribution of current speed, salinity, phosphate, and nitrate in the waters of Mentawai Islands in February, April, and June 2024

## Discussion

The findings of this research, which highlight the significant influence of environmental conditions in the east monsoon on the recruitment process of puerulus *P. homarus* (Masithah et al. 2023), pave the way for future studies. The highest lobster abundance is in the east season (June), which is 33.8±4.21 per trip; in April (transition season I), puerulus abundance decreased to 27.00±5.00 per trip (Figure 3). Finally, the lowest abundance occurred in February (west season), with an average of 23.20±2.22 per trip. The difference in puerulus abundance between the east season, transition season I, and the west season is believed to be a result of changes in environmental conditions such as currents, water temperatures, and food availability in each season. The east season appears to provide the most optimal conditions for puerulus recruitment, resulting in the highest abundance. Meanwhile, the west season, with its potentially extreme or unfavorable environmental conditions, shows lower puerulus abundance (Purba et al. 2021).

Differences in puerulus abundance observed between February, April, and June may provide insight into how the life cycle of *P. homarus* is affected by seasonal variation (Bell et al. 2008; Cavieres and Nicolis 2018). February, which is the west monsoon, is often characterized by less stable sea conditions and high rainfall, which may hinder puerulus mobility and capture. These conditions may lead to lower puerulus abundance compared to other months. In contrast, the east monsoon, which is characterized by calmer weather and more stable water temperatures, can enhance the success of puerulus in adapting and developing (Clark et al. 2015; Filippi et al. 2024). These data may also have implications for lobster resource management and conservation strategies. Understanding the period with high puerulus abundance can help in planning fishing or monitoring activities more efficiently. The peak period puerulus abundance period in June may be an optimal time for conservation efforts, such as the creation of protected areas or monitoring the species to ensure the successful development of hatching larvae before they enter the adult stage. Seasonal variation may affect not only puerulus abundance but also the overall health of the ecosystem (Purba et al. 2021; Hutchinson et al. 2024)

The $R^2$ value for temperature (0.8111) shows a strong influence on lobster Puerulus distribution. Temperature impacts lobster habitat suitability due to metabolic, growth, and survival effects (Sunder et al. 2020; Purba et al. 2021). Suitable temperature fluctuations affect species abundance and distribution. Salinity with an $R^2$ value of 0.5158 has a strong relationship affecting lobster presence moderately. Salinity influences osmoregulation, habitat adaptation, and migration patterns (Westermann et al. 2012; Sunder et al. 2020; Xing et al. 2021). Phosphate concentration's $R^2$ value of 0.5492 shows a significant relationship. Phosphate is vital in the marine food chain, impacting phytoplankton productivity (Suantika et al. 2018; Trinugroho et al. 2020). Changes in phosphate concentration affect food availability for lobster Puerulus (Aznar et al. 2016; Grifoll et al. 2022). Chlorophyll-a's $R^2$ value (0.2236) indicates a weak relationship with lobsters. Nitrate with an $R^2$ value of 0.4136 has a moderate relationship, not strong enough to explain lobster presence. Current velocities with an $R^2$ value of 0.0223 show no significant relationship with lobster Puerulus presence (Banihashemi et al. 2017; Khaled et al. 2023; Liu et al. 2024).

Sea surface temperatures in the tropical waters of Mentawai Islands show small fluctuations due to the tropical climate (Gao et al. 2010; Barnes et al. 2021). SST remains warm in February, April, and June. Local ocean currents and upwelling can affect SST, but their impact is minimal in tropical waters (García-Monteiro et al. 2022; Bousbaa et al. 2024). Stable temperatures of 27 to 30°C indicate insignificant influence of ocean currents. Solar radiation and weather patterns contribute to SST stability (Westermann et al. 2012; Sunder et al. 2020; Xing et al. 2021). Chlorophyll-a concentrations in Mentawai Islands waters are influenced by various factors (Tilstone et al. 2013; Montaghi et al. 2024). Nutrient flow from land runoff increases chlorophyll-a in rainy seasons, while dry seasons decrease it (Yang et al. 2020). Upwelling triggered by seasonal winds enhances phytoplankton production and chlorophyll-a. Ocean currents and SST fluctuations also affect chlorophyll-a concentrations (Zhang et al. 2020).

Fluctuations in current velocities are influenced by seasonal changes, with lower velocities in February and higher velocities in April, possibly due to river flows and tidal effects (Huang 2017; Grifoll et al. 2022). June sees decreased velocities due to reduced freshwater flows and wind changes, along with local ocean dynamics and seabed topography playing a role (Banihashemi et al. 2017). The complexity of current dynamics in Mentawai Islands can impact ecological and environmental processes (Kotarba 2015; Sreekanth and Kulkarni 2020). Salinity levels in the region remain stable throughout the year, with minimal impact from seasonal variations (Suantika et al. 2018; Trinugroho et al. 2020). The consistency in salinity levels is maintained by factors such as limited influence from seasonal changes, local ocean dynamics, and seabed topography (Imron et al. 2019). The stability in salinity levels reflects a balance between seasonal factors and ocean dynamics, keeping salinity within a consistent range (Purba et al. 2021; Iskandar and Suga 2022).

Phosphate concentrations decrease towards the east season due to environmental factors (Aznar et al. 2016; Grifoll et al. 2022). February shows higher levels of runoff, while April sees a decrease from reduced freshwater flow (Tama et al. 2007; Zhang and Ioannou 2016). June marks an increase, possibly due to ocean dynamics. Fluctuations reflect complex interactions in Mentawai Islands Waters (Purba et al. 2021). Nitrate concentrations also decrease towards the east monsoon (Xi et al. 2020; Aulicino et al. 2021). February has higher levels of land runoff, while April sees a decline from reduced input. June shows another decrease in sea surface temperatures and current changes. Fluctuations reflect interactions in Mentawai Islands Waters (Zhang and Ioannou 2016).

Data analysis shows the puerulus lobster population in Mentawai Islands increased due to favorable environmental factors like high sea surface temperature, supported by satellite imagery (Sunder et al. 2020; García-Monteiro et al.

2022). The specific temperature range boosts lobster recruitment and population growth. The optimal temperature for lobsters can be adjusted to geographical location. The ideal temperature for lobster cultivation in Indonesia ranges from 26 to 30°C. In this temperature range, tropical lobsters show optimal growth, good metabolism, and fewer health problems. Temperature can affect physiological responses, thermal tolerance, and bacterial communities in lobsters in water. Temperature factors also significantly affect lobster health, adaptability, and susceptibility to shell disease (Goncalves et al. 2021; Horricks et al. 2023; Watson et al. 2023). Stable salinity in Mentawai Islands waters is vital for lobster puerulus survival and growth, contributing significantly to successful larval development (Ihde et al. 2008; Lubis et al. 2023). Maintaining stable salinity levels is crucial for osmotic balance regulation in puerulus. The combination of appropriate salinity and temperature conditions creates a favorable environment for lobster larval recruitment (García-Monteiro et al. 2022; Barnes et al. 2021). Consistent temperature and salinity levels in Mentawai Islands likely contributed to the increase in puerulus captures, emphasizing the importance of considering multiple environmental factors for habitat suitability (Gao et al. 2010; Bousbaa et al. 2024). Salinity stability in the region directly affects puerulus lobster's ability to thrive and impacts overall population dynamics (Suantika et al. 2018; Trinugroho et al. 2020; Purba et al. 2021).

This study concludes the significant influence of environmental factors on the abundance of *P. homarus* puerulus in the waters of the Mentawai Islands, West Sumatra, Indonesia. Key findings indicate that water temperature, salinity, and phosphate concentrations have strong correlations with puerulus distribution, while chlorophyll-a, nitrate, and current velocity show weaker or negligible relationships. Seasonal variations also play an important role, with the highest abundance observed in June during the east monsoon, indicating that environmental conditions during this period are more conducive to puerulus recruitment. The results of this study demonstrate the importance of a comprehensive management strategy that considers both ecology and the environment, ensuring sustainable aquaculture practices and effective conservation efforts for puerulus *P. homarus.*

## ACKNOWLEDGEMENTS

We extend our heartfelt thanks to the Ministry of Education, Culture, Research and Technology and the Directorate General of Higher Education, Research and Technology for their generous support under Grant Regular Fundamental Research Scheme No. 112/E5/PG.02.00.PL/2024. We also acknowledge to Higher Education Service Institutions in Region X and Bung Hatta University Research and Community Service Institute provided under derivative contract No. 012/LL10/PG.AK/2024 and 029.7/LPPM-Penelitian/Hatta/VI-2024, which played a crucial role in enabling the successful completion of this research.

## REFERENCES

Amin M, Fitria A, Mukti AT, Manguntungi AB, Amrullah S, Alim S, Martin MB. 2022a. Evaluating the stomach content of Wild Scalloped Spiny Lobster (*Panulirus homarus*). Biodiversitas 23 (12): 6397-6403. DOI: 10.13057/biodiv/d231237.

Amin M, Harlyan LI, Achmad K, Diantari R. 2022b. Profiling the natural settlement habitat of spiny lobster, *Panulirus* spp. to determine potential diets and rearing conditions in a lobster hatchery. Biodiversitas 23 (6): 2893-2898. DOI: 10.13057/biodiv/d230615.

Aulicino G, Cesarano C, Zerrouki M, Ruiz S, Budillon G, Cotroneo Y. 2021. On the use of ABACUS high resolution glider observations for the assessment of phytoplankton ocean biomass from CMEMS model products. Ecol Modell 455: 109619. DOI: 10.1016/j.ecolmodel.2021.109669.

Aznar R, Sotillo MG, Cailleau S, Lorente P, Levier B, Amo-Baladrón A, Reffray G, Álvarez-Fanjul E. 2016. Strengths and weaknesses of the CMEMS forecasted and reanalyzed solutions for the Iberia–Biscay–Ireland (IBI) waters. J Mar Syst 159: 1-14. DOI: 10.1016/j.jmarsys.2016.02.007.

Banihashemi S, Kirby JT, Dong Z. 2017. Approximation of wave action flux velocity in strongly sheared mean flows. Ocean Model 116: 33-47. DOI: 10.1016/j.ocemod.2017.06.002.

Barnes BB, Hu C, Bailey SW, Pahlevan N, Franz BA. 2021. Cross-calibration of MODIS and VIIRS long near infrared bands for ocean color science and applications. Remote Sens Environ 260: 112439. DOI: 10.1016/j.rse.2021.112486.

Bell MC, Elson JM, Addison JT, Revill AS, Bevan D. 2008. Trawl catch composition in relation to Norway lobster (*Nephrops norvegicus* L.) abundance on the Farn Deeps grounds, NE England. Fish Res 90 (1-3): 128-137. DOI: 10.1016/j.fishres.2008.07.016.

Bousbaa M, Boudhar A, Kinnard C, Elyoussfi H, Karaoui I, Eljabiri Y, Bouamri H, Chehbouni A. 2024. An accurate snow cover product for the Moroccan Atlas Mountains: Optimization of the MODIS NDSI index threshold and development of snow fraction estimation models. Intl J Appl Earth Observation Geoinformation 129: 103851. DOI: 10.1016/j.jag.2023.103851.

Bright JM, Gueymard CA. 2019. Climate-specific and global validation of MODIS Aqua and Terra aerosol optical depth at 452 AERONET stations. Solar Energy 183: 594-605. DOI: 10.1016/j.solener.2019.03.043.

Cavieres J, Nicolis O. 2018. Using a spatio-temporal Bayesian approach to estimate the relative abundance index of yellow squat lobster (*Cervimunida johni*) off Chile. Fish Res 208: 97-104. DOI: 10.1016/j.fishres.2018.07.002.

Ciancia E, Coviello I, Di Polito C, Lacava T, Pergola N, Satriano V, Tramutoli V. 2018. Investigating the chlorophyll-a variability in the Gulf of Taranto (North-western Ionian Sea) by a multi-temporal analysis of MODIS-Aqua Level 3/ Level 2 data. Cont Shelf Res 155: 34-44. DOI: 10.1016/j.csr.2018.01.011.

Clark AS, Jury SH, Goldstein JS, Langley TG, Watson III WH. 2015. A comparison of American lobster size structure and abundance using standard and ventless traps. Fish Res 167: 243-251. DOI: 10.1016/j.fishres.2015.02.016.

Deswati D, Wisna ND, Zein R, Tetra ON, Suparno S, Pardi H, Suteja Y. 2023. Preliminary study on microplastic pollution in water and sediment at the Beaches of Pariaman City, West Sumatra, Indonesia. AACL Bioflux 16 (1): 381-397.

Erlania, Radiarta N, Haryadi J. 2016. Status of spiny lobster seeds resource management for aquaculture development: Case study Lombok Island Waters. Jurnal Kebijakan Perikanan Indonesia 8 (2): 85-96. DOI: 10.15578/jkpi.8.2.2016.85-96. [Indonesian]

Filippi JJ, Millot R, Bracconi J, Ligorini V, Gattacceca N, Crescioni A, Ronchi-Perfetti JB, Demolliens M, Pugliese S, Delmas A, Boussard A, Vela A, Bastien R, Pasqualini V, Aiello A. 2024. Effect of light intensity on the survival of European spiny lobster (*Palinurus elephas*) larvae reared in aquaculture system. Aquacult Rep 36: 102083. DOI: 10.1016/j.aqrep.2024.102083.

Gao Y, Xie H, Lu N, Yao T, Liang T. 2010. Toward advanced daily cloud-free snow cover and snow water equivalent products from Terra–Aqua MODIS and Aqua AMSR-E measurements. J Hydrol 385 (1-4): 23-25. DOI: 10.1016/j.jhydrol.2010.01.012.

García-Monteiro S, Sobrino JA, Julien Y, Sòria G, Skokovic D. 2022. Surface temperature trends in the Mediterranean Sea from MODIS

data during years 2003-2019. Reg Stud Mar Sci 49: 102086. DOI: 10.1016/j.rsma.2022.102086.
Goldstein JS, Morrissey EM, Moretti ED, Watson WH III. 2017. A comparison of the distribution and abundance of European green crabs and American lobsters in the Great Bay Estuary, New Hampshire, USA. Fish Res 189: 10-17. DOI: 10.1016/j.fishres.2017.01.002.
Goncalves R, Lund I, Gesto M. 2021. Interactions of temperature and dietary composition on juvenile European lobster (*Homarus gammarus*, L.) energy metabolism and performance. Comp Biochem Physiol Part A Mol Integr Physiol 260: 111019. DOI: 10.1016/j.cbpa.2021.111019.
Grifoll M, Borén C, Castells-Sanabra M. 2022. A comprehensive ship weather routing system using CMEMS products and A* algorithm. Ocean Eng 255: 111427. DOI: 10.1016/j.oceaneng.2022.111427.
Groeneveld JC, Butterworth DS, Glazer JP, Branch GM, Cockcroft AC. 2003. An experimental assessment of the impact of gear saturation on an abundance index for an exploited rock lobster resource. Fish Res 65 (1-3): 453-465. DOI: 10.1016/S0165-7836(03)00130-6.
Hasan V, Islam I. 2020. First inland record of Bull shark *Carcharhinus leucas* (Müller & Henle, 1839) (Carcharhiniformes: Carcharhinidae) in Celebes, Indonesia. Ecol Montenegrina 38: 12-17. DOI: 10.37828/em.2020.38.3.
Hasan V, South J, Katz AM, Ottoni FP. 2022. First record of the Small-eyed loter *Prionobutis microps* (Weber, 1907) (Teleostei: Eleotridae: Butinae) in Java, Indonesia. Cybium 46 (1): 49-51. DOI: 10.26028/CYBIUM/2022-461-008.
Hedberg N, Stenson I, Pettersson MN, Warshan D, Nguyen-Kim H, Tedengren M, Kautsky N. 2018. Antibiotic use in Vietnamese fish and lobster sea cage farms; implications for coral reefs and human health. Aquaculture 495: 366-375. DOI: 10.1016/j.aquaculture.2018.06.005.
Horricks RA, Clark KF, Watson KL, Lewis-McCrea LM, Reid GK. 2023. Effect of acclimation temperature on thermal tolerance between American lobster (*Homarus americanus*) collected in different lobster fishing areas in Atlantic Canada. FACETS 9 (1): 1-9. DOI: 10.1139/facets-2023-0177.
Huang H. 2017. Estimating random uncertainty of depth-averaged velocities measured by moving-boat acoustic Doppler current profilers. Flow Meas Instrum 57: 78-86. DOI: 10.1016/j.flowmeasinst.2017.09.001.
Hutchinson E, Matthews TR, Renchen GF. 2024. Relationships between postlarval settlement and commercial landings of Caribbean spiny lobster (*Panulirus argus*) in Florida (USA). Fish Res 279: 107137. DOI: 10.1016/j.fishres.2024.107137.
Ihde TF, Hoenig JM, Frusher SD. 2008. Evaluation of a multi-year index-removal abundance estimator, with application to a Tasmanian rock lobster fishery. Fish Res 89 (1): 26-36. DOI: 10.1016/j.fishres.2007.09.022.
Imron MF, Kurniawan SB, Soegianto A. 2019. Characterization of mercury-reducing potential bacteria isolated from Keputih non-active sanitary landfill leachate, Surabaya, Indonesia under different saline conditions. J Environ Manag 241: 113-122. DOI: 10.1016/j.jenvman.2019.04.017.
Iskandar MR, Suga T. 2022. Change in salinity of Indonesian upper water in the southeastern Indian Ocean during Argo period. Heliyon 8 (9): e10430. DOI: 10.1016/j.heliyon.2022.e10430.
Khaled MA, Al-Jamali FH, Said REM, Mohammad AS, Ahmed MH, Ahmed HO. 2023. Analysis of SST and Chl-a data from MODIS-Aqua in the major Egyptian fishing zones of the Red Sea. Egypt J Aquat Res 49 (4): 520-529. DOI: 10.1016/j.ejar.2023.08.006.
Kismiyati, Hidayat YT, Amin M. 2024. Morphological and molecular identifications of ectoparasites infesting the gills of scalloped spiny lobster *Panulirus homarus* Linnaeus, 1758. Biodiversitas 25 (1): 372-378. DOI: 10.13057/biodiv/d250143.
Kotarba AZ. 2015. Evaluation of ISCCP cloud amount with MODIS observations. Atmos Res 153: 310-317. DOI: 10.1016/j.atmosres.2014.09.006.
Larasati RF, Suadi, Setyobudi E. 2018. Short Communication: Population dynamics of double-spined rock lobster (*Panulirus penicillatus* Olivier, 1791) in Southern Coast of Yogyakarta. Biodiversitas 19 (1): 337-342. DOI: 10.13057/biodiv/d190146.
Lelono TD, Bintoro G, Setyanto A, Sutjipto DO, Tumulyadi A, Adhihapsari W, Sari WK, Rihmi MK, Aliviyanti D, Isdianto A, Putri ADR. 2024. Evaluating growth and exploitation dynamics of *Thunnus albacares* for sustainable fisheries in fishery landed in Bali's Benoa Harbor. Biodiversitas 25 (9): 2858-2869. DOI: 10.13057/biodiv/d250805.
Liu X, Warren M, Selmes N, Simis SGH. 2024. Quantifying decadal stability of lake reflectance and chlorophyll-a from medium-resolution ocean color sensors. Remote Sens Environ 306: 114120. DOI: 10.1016/j.rse.2024.114120.
Lubis AS, Efrizal, Syaifullah, Rusnam, Nurmiati, Puari AT. 2023. Growth performance and survival rate of spiny lobster *Panulirus homarus* (Linnaeus, 1758) with formulated feeding enriched by spinach extract. Biodiversitas 24 (11): 6010-6016. DOI: 10.13057/biodiv/d241121.
Masithah ED, Fadhilah MG, Amin M, Nur KU, Musdalifah L, Samara SH, Cahyoko Y, Alimuddin, Alim S, Setyono BDH. 2023. Diversity and abundance of plankton community in Prigi and Tawang Bays, natural settlement habitats of spiny lobster larvae in East Java, Indonesia. Biodiversitas 24 (3): 1642-1649. DOI: 10.13057/biodiv/d240337.
McManus MC, Kipp J, Shank B, Reardon K, Pugh TL, Carloni J, McKown K. 2021. A model-based approach to standardizing American lobster (*Homarus americanus*) ventless trap abundance indices. Fish Res 238: 105899. DOI: 10.1016/j.fishres.2021.105899.
Montaghi A, Bregaglio S, Bajocco S. 2024. An open-source cloud-based procedure for MODIS remote sensing products: The nasawebservicepython package. Ecol Inform 79: 102433. DOI: 10.1016/j.ecoinf.2023.102433.
Nizinski MS, McClain Counts J, Ross SW. 2023. Habitat utilization, demography, and behavioral observations of the squat lobster, *Eumunida picta* (Crustacea: Anomura: Eumunididae), on western North Atlantic deep-water coral habitats. Deep-Sea Res Part I: Trop Stud Oceanogr 193: 1-20. DOI: 10.1016/j.dsr.2022.103953.
Ouzounov D, Savtchenko A, Leptoukh G, Zhou B, Ostrenga D, Deroo C, Gonzalez L. 2004. GES DAAC tools for accessing Terra and Aqua MODIS data. Adv Space Res 33 (7): 1109-1113. DOI: 10.1016/S0273-1177(03)00738-5.
Priyambodo B, Jones CM, Sammut J. 2020. Assessment of the lobster puerulus (*Panulirus homarus* and *Panulirus ornatus*, Decapoda: Palinuridae) resource of Indonesia and its potential for sustainable harvest for aquaculture. Aquaculture 528: 735563. DOI: 10.1016/j.aquaculture.2020.735563.
Purba NP, Pranowo WS, Ndah AB, Nanlohy P. 2021. Seasonal variability of temperature, salinity, and surface currents at 0° latitude section of Indonesia seas. Reg Stud Mar Sci 44: 101772. DOI: 10.1016/j.rsma.2021.101772.
Rizal A, Dewanti LP. 2017. Using economic values to evaluate management options for fish biodiversity in the Sikakap Strait, Indonesia. Biodiversitas 18 (2): 575-581. DOI: 10.13057/biodiv/d180218.
Selgrath JC, Hovel KA, Wahle RA. 2007. Effects of habitat edges on American lobster abundance and survival. J Exp Mar Biol Ecol 353 (2): 253-264. DOI: 10.1016/j.jembe.2007.05.016.
Setyagama A, Susilo W, Su'ud M, Sulthon M, Harimurti YW. 2023. Indonesian government policy in maintaining environmental conservation of marine biota through the export prohibition of lobster shrimp seed. Russ Law J 11 (7S): 314-322. DOI: 10.52783/rlj.v11i7s.1169.
Sreekanth V, Kulkarni P. 2020. Comparison of V4 and V3 CALIOP (L3) aerosol products: A global perspective. Remote Sens Appl: Soc Environ 20: 100412. DOI: 10.1016/j.rsase.2020.100412.
Suantika G, Situmorang ML, Kurniawan JB, Pratiwi SA, Aditiawati P, Astuti DI, Azizah FFN, Djohan YA, Zuhri U, Simatupang TM. 2018. Development of a Zero Water Discharge (ZWD)—Recirculating Aquaculture System (RAS) hybrid system for super intensive white shrimp (*Litopenaeus vannamei*) culture under low salinity conditions and its industrial trial in commercial shrimp urban farming in Gresik, East Java, Indonesia. Aquac Eng 82: 12-24. DOI: 10.1016/j.aquaeng.2018.04.002.
Sunder S, Ramsankaran RAJJ, Ramakrishnan B. 2020. Machine learning techniques for regional scale estimation of high-resolution cloud-free daily sea surface temperatures from MODIS data. ISPRS J Photogrammetry Remote Sens 166: 228-240. DOI: 10.1016/j.isprsjprs.2020.06.008.
Suparno S, Deswati D, Pardi H. 2023. Water quality for grouper farming in Mandeh Bay waters, Pesisir Selatan, Indonesia. AACL Bioflux 16 (2): 1156-1165.
Tama VWY, Shen LY, Yaub RMY, Tam CM. 2007. On using a Communication-Mapping Model for Environmental Management

(CMEM) to improve environmental performance in project development processes. Build Environ 42 (8): 3093-3107. DOI: 10.1016/j.buildenv.2006.10.035.

Tilstone GH, Lotliker AA, Miller PI, Ashraf PM, Kumar TS, Suresh T, Ragavan BR, Menon HB. 2013. Assessment of MODIS-Aqua chlorophyll-a algorithms in coastal and shelf waters of the eastern Arabian Sea. Cont Shelf Res 65: 14-26. DOI: 10.1016/j.csr.2013.05.005.

Trinugroho MW, Bhatta B, Babur M. 2020. The seawater intrusion under dam failure in the Cimanuk River Estuary, Indonesia. Reg Stud Mar Sci 36: 101267. DOI: 10.1016/j.rsma.2020.101267.

Watson HV, McKeown NJ, Coscia I, Wootton E, Ironside JE. 2016. Population genetic structure of the European lobster (*Homarus gammarus*) in the Irish Sea and implications for the effectiveness of the first British marine protected area. Fish Res 183: 287-293. DOI: 10.1016/j.fishres.2016.06.015.

Watson WH, Gutzler BC, Goldstein JS, Jury SH. 2023. Impacts of increasing temperature on the metabolism of confined and freely moving American lobsters (*Homarus americanus*). Biol Bull 245 (2): 103-116. DOI: 10.1086/730687.

Westermann S, Langer M, Boike J. 2012. Systematic bias of average winter-time land surface temperatures inferred from MODIS at a site on Svalbard, Norway. Remote Sens Environ 118: 162-167. DOI: 10.1016/j.rse.2011.10.025.

Xi H, Losa SN, Mangin A, Soppa MA, Garnesson P, Demaria J, Liu Y, d'Andon OH, Bracher A. 2020. Global retrieval of phytoplankton functional types based on empirical orthogonal functions using CMEMS GlobColour merged products and further extension to OLCI data. Remote Sens Environ 240: 111704. DOI: 10.1016/j.rse.2020.111704.

Xing Z, Li ZL, Duan SB, Liu X, Zheng X, Leng P, Gao M, Zhang X, Shang G. 2021. Estimation of daily mean land surface temperature at global scale using pairs of daytime and nighttime MODIS instantaneous observations. ISPRS J Photogrammetry Remote Sens 178: 51-67. DOI: 10.1016/j.isprsjprs.2021.05.017.

Yang X, Zhao C, Luo N, Zhao W, Shi W, Yan X. 2020. Evaluation and comparison of Himawari-8 L2 V1.0, V2.1 and MODIS C6.1 aerosol products over Asia and the Oceania regions. Atmos Environ 220: 117068. DOI: 10.1016/j.atmosenv.2019.117068.

Ye Y, Pitcher P, Dennis D, Skewes T. 2005. Constructing abundance indices from scientific surveys of different designs for the Torres Strait ornate rock lobster (*Panulirus ornatus*) fishery, Australia. Fish Res 73 (1-2): 187-200. DOI: 10.1016/j.fishres.2005.01.008.

Zhang H, Zhang F, Che T, Wang S. 2020. Comparative evaluation of VIIRS daily snow cover product with MODIS for snow detection in China based on ground observations. Sci Total Environ 724: 138156. DOI: 10.1016/j.scitotenv.2020.138119.

Zhang Y, Ioannou PA. 2016. Environmental impact of combined variable speed limit and lane change control: A comparison of MOVES and CMEM model. IFAC-PapersOnLine 49 (3): 323-328. DOI: 10.1016/j.ifacol.2016.07.054.