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Life stages, growth, and habitat suitability of Clupeiformes in Biru Bay, Bali Strait
Stadia hidup, pertumbuhan, dan kesesuaian habitat Clupeiformes di Teluk Biru, Selat Bali

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ABSTRACT

Biru Bay, a lift-net fishing ground in the Bali Strait, plays a key role in supporting Clupeiformes fishery production in Muncar and the surrounding Bali Strait region. This study aims to evaluate the species composition and growth patterns of Clupeiformes caught in Biru Bay and their relationship with environmental parameters. Sampling was conducted during the northwest monsoon (December 2023, February 2024) and the first transitional season (March–April 2024). Data analyses included assessments of species composition, length-weight relationships, condition factors, spatiotemporal variability of oceanographic parameters, and Canonical Correspondence Analysis. Clupeiformes catches during both seasons consisted of six species, with monthly variation in predominant species. Most of the individuals were juvenile fish, with the exception of *Spratelloides delicatulus*, which was frequently found in both juvenile and adult stages. The majority of species exhibited positive allometric growth and were in good condition (CF > 1.00). Physicochemical parameters varied over time, supporting the presence of fish in this area. Chlorophyll-a levels decreased during the northwest monsoon but increased before the transitional season, showing an inverse pattern to sea surface temperature. Four key environmental parameters—temperature, salinity, dissolved oxygen, and chlorophyll-a—were significantly associated with the composition of Clupeiformes.

Keywords: Chlorophyll-a, Clupeiformes, floating lift nets, juvenile, nursery, positive allometric

1. Introduction

The order Clupeiformes, which includes anchovies, sardines, and herrings, is a group of small pelagic fish that plays a vital role in marine ecosystems, both ecologically and economically (Peck *et al.* 2021). This group acts as a key trophic intermediary in marine food webs, providing a vital prey base for organisms at higher trophic levels (Somarakis *et al.* 2019; Peck *et al.* 2024). A notable characteristic of Clupeiformes is their tendency to form large aggregations, which makes them particularly vulnerable to overexploitation as both forage fish and targets for commercial fisheries. Overfishing has become a significant threat to Clupeiformes populations, especially in the archipelagic regions of Indonesia, Malaysia, and the Philippines, where many threatened and data-deficient species are concentrated (Birge *et al.* 2021). Intensive harvesting has been particularly evident in Indonesian waters, including the areas off Java and the Bali Strait, which are among the primary fishing grounds for small pelagic species.

The Bali Strait, located within Indonesia's Fisheries Management Area (FMA) 573, is recognized as a key center for small pelagic

fisheries, particularly for Clupeiformes. Fishery landings are predominantly composed of Bali sardinella (*Sardinella lemuru*), which accounts for 80–90% of total catches, alongside other Clupeiformes species such as sardines (*Sardinella gibbosa* and *Sardinella fimbriata*) and anchovies (*Stolephorus* spp.) along the eastern coast of Java (Sartimbul *et al.* 2018; Harlyan *et al.* 2022). Bali sardinella, belonging to the family Dorosomatidae (Clupeidae), has historically served as the key indicator species for the Bali Strait fishery since the 1980s, primarily harvested using purse seine gears (Pet *et al.* 1997; Ihsan *et al.* 2020). In addition to active gears, passive fishing gears are also utilized in the Bali Strait, particularly lift nets (*bagan*), which are operated exclusively in the eastern Java region. including stationary lift nets in Pangpang Bay and floating lift nets in Biru Bay (Himelda *et al.* 2012; Setyohadi and Wiadnya 2018).

Biru Bay, also known as Senggrong Bay, serves as a principal fishing ground for floating lift net operations in Banyuwangi and the Bali Strait. The catch composition from floating lift nets in Biru Bay consists of Bali sardinella, anchovies, ponyfish, ribbonfish, and squid (Aliyubi *et al.* 2015; Syahputra *et al.* 2016). The floating lift net fishery in Biru Bay constitutes an important contributor to the annual Clupeiformes fishery production in Muncar and the Bali Strait.

Small pelagic fisheries in the Bali Strait are influenced by variability in marine environmental conditions. Oceanographic parameters such as sea surface temperature (SST) and chlorophyll-a (chl-a) concentration serve as key indicators, affecting seasonal fish catches (Puspasari *et al.* 2018). Variability in chl-a is closely correlated with SST and differs significantly across seasons, both in the Bali Strait and Biru Bay (Sukresno *et al.* 2019; Wijaya *et al.* 2020). Oceanographic and climatic phenomena, such as upwelling and the Indian Ocean Dipole (IOD), drive the dynamics and fluctuations of these environmental parameters, subsequently impacting fishery resource production (Lumban-Gaol *et al.* 2021; Setyohadi *et al.* 2021). Clupeiformes fishes, which are planktivorous (Hunnam 2021), are closely linked to oceanographic conditions due to their reliance on planktonic prey. In the Clupeoid fishery of the Bali Strait, chl-a concentration is positively correlated with Bali sardine catch and is statistically significant with a certain time lag (Lumban-Gaol *et al.* 2004; Puspasari *et al.* 2019).

However, the fishery appears to exhibit fluctuations in both catch production and the number of operating gears, with a high proportion of the catch reportedly comprising individuals that have not yet reached gonadal maturity (Sukresno *et al.* 2021). These conditions underline the necessity for comprehensive assessments of the floating lift net fishery in Biru Bay. To date, previous studies have primarily focused on the oceanographic characteristics (Sukresno *et al.* 2019) and the spatial distribution of floating lift nets (Sukresno *et al.* 2021), leaving a gap in knowledge regarding the status of Clupeiformes resources and their relationship with environmental conditions. Therefore, this study aims to evaluate the condition of Clupeiformes fishery resources, in terms of species composition and growth patterns, and to examine their associations with environmental parameters in Biru Bay.

2. Methods

2.1. Time and Location Research

Sampling of Clupeiformes fish was conducted to represent two seasons, namely the northwest monsoon season (December 2023 and February 2024) and the first transitional season (March and April 2024). Fish samples were collected at night following the operational time of the lift net, from sunset until before sunrise. Sampling locations were situated in the coastal waters of eastern Banyuwangi, specifically in Biru Bay and its surrounding waters (Figure 1). These coastal waters are part of the fishing grounds for lift net operations in the Bali Strait. Subsequent analyses of the fish samples were carried out at the Macro Biology Laboratory, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University.
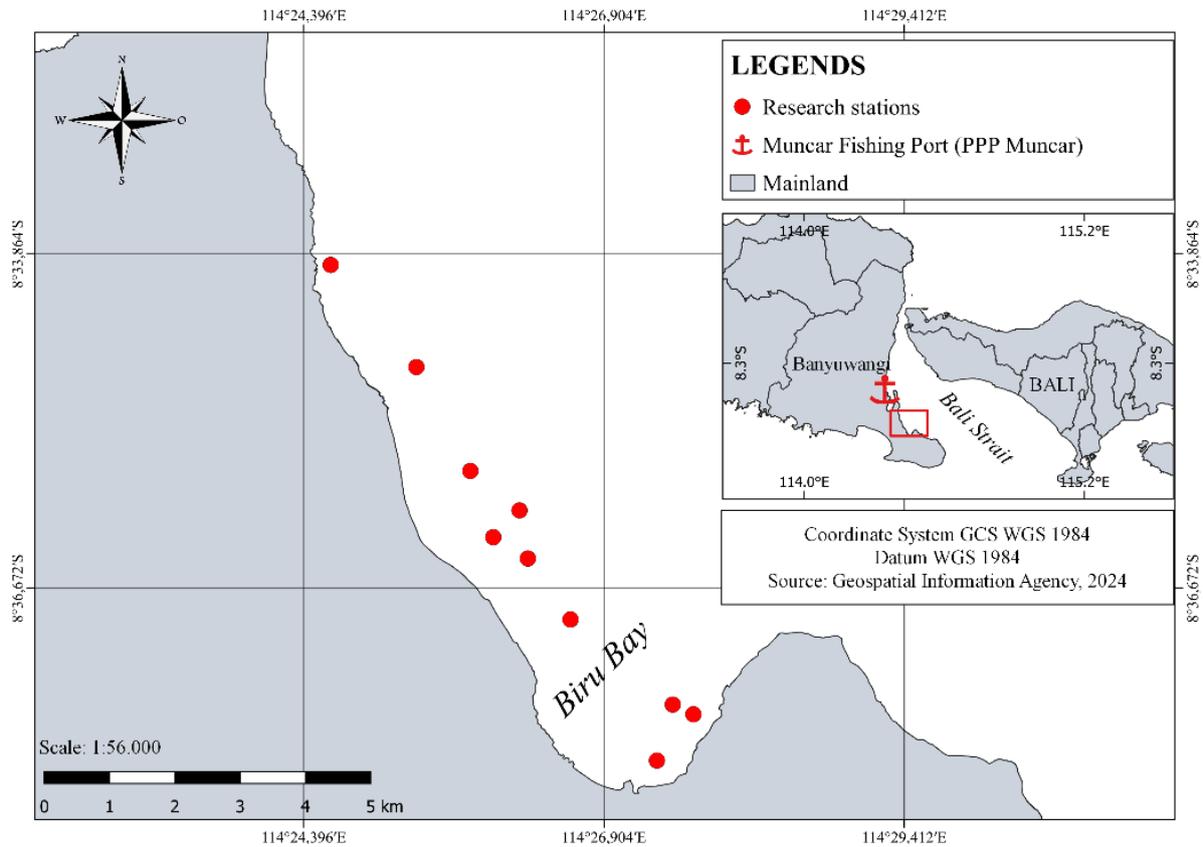
Figure 1. Sampling locations in Biru Bay, East Java.

2.2. Materials and Tools

Clupeiformes fish samples were obtained using lift nets operating in Biru Bay. The lift nets used had frame dimensions of 10×10 m², with a net frame size of 7×7 m². The nets were made of polypropylene material with a mesh size of approximately 3–5 mm and had a cube-shaped configuration. In-situ measurements of water physicochemical parameters were carried out, including water temperature, salinity, and dissolved oxygen (DO). Temperature measurements were conducted using a thermometer, while salinity and DO were measured using a refractometer and a DO meter, respectively. Morphometric measurements (length-weight) of the captured fish were performed using a ruler with 0.05 cm precision and a digital analytical balance with 0.001 g precision. The materials used during the research included 10% formalin and 80% ethanol for fish sample preservation, and 1-liter HDPE bottles for sample storage.

2.3. Research Methods and Data Collections

The research procedures involved measuring water physicochemical parameters and collecting Clupeiformes fish samples. In-situ measurements included water temperature, salinity, and dissolved oxygen, conducted simultaneously with fish sampling at lift net sites. Additionally, oceanographic parameters such as sea surface temperature (SST) and chlorophyll-a concentration were obtained from Aqua-MODIS satellite imagery available through the official Ocean Color website (https://oceancolor.gsfc.nasa.gov). Fish samples were collected from lift nets concentrated in the waters of Biru Bay. Sampling followed an observational method by accompanying lift net fishing operations.

Captured fish samples were randomly collected (random sampling) from the lift nets. A total of 2,292 individuals representing six species were obtained during the study period. Fish preservation was initiated immediately after sampling by placing the fish in sample containers with 10% formalin. After approximately 3–4 hours of immersion in formalin, the fish samples were rinsed with running water and then preserved with 80%

ethanol (Simanjuntak *et al.* 2020). Preserved fish were subsequently transported to the Macro Biology Laboratory 1, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, IPB University for identification using taxonomic references including Allen (1997), Carpenter and Niem (1999), Carpenter and Niem (2001), and White *et al.* 2013).

2.4. Data Analysis

The identified Clupeiformes specimens were counted for each species to calculate species composition. The species composition analysis of the catch was used to determine the proportion of Clupeiformes assemblages captured at the sampling stations each month. Species composition was calculated using the following formula (Odum 1971).

$$\text{Composition (\%)} = \frac{n_i}{N} \times 100$$

While the n_i = number of individuals of species (i), and N = total number of individuals across all species.

The growth patterns of the captured fish were analyzed through length-weight relationship (LWR) analysis. The formula used for LWR analysis was as follows (Keys 1928; Froese 2006).

$$W = aL^b$$

While the W = individual weight (g), L = total length (mm), a = intercept, and b = slope

The fish growth pattern was interpreted based on the value of b, the slope of the linear regression in the logarithmic form of the LWR equation. Growth was considered isometric if b=3, positive allometric if b>3, and negative allometric if b<3. A t-test was conducted on the b value to assess whether growth was isometric (b=3) or allometric (b≠3) at a 95% confidence level.

The condition factor of the fish was used to describe their nutritional condition or "plumpness", where a higher value indicated a better condition (Froese 2006; Froese *et al.* 2011). Condition factor calculations were

based on the growth pattern. For fish exhibiting isometric growth, the Fulton's condition factor (Fulton 1904) was calculated as:

$$K = 10^5 \frac{W}{L^3}$$

For fish showing allometric growth, the relative condition factor was determined according to Le Cren (1951).

$$K_{rel} = \frac{W}{aL^b}$$

While the K = Fulton's factor condition, K_{rel} = relative factor condition, W = individual weight (g), L = total length (mm), a = intercept, b = slope.

The physicochemical parameters of the water were described temporally for each month and season. Oceanographic parameters, namely SST and chlorophyll-a concentrations, were visualized to provide a spatial and temporal distribution overview for each month (season). Monthly data were downloaded from https://oceancolor.gsfc.nasa.gov using Aqua MODIS SMI (Standard Mapped Image) level 3 products with a spatial resolution of 4 km. The downloaded SST and chlorophyll-a images were extracted using the SeaDAS 8.4.1 software, and the study area was cropped accordingly. The processed data were saved in Tab-Delimited Text (txt) format. Maps illustrating the spatial distribution of SST and chlorophyll-a concentrations were subsequently generated using QGIS software with Inverse Distance Weighting (IDW) interpolation processing.

The relationship between fish abundance and environmental parameters, including temperature, salinity, dissolved oxygen, and chlorophyll-a concentration, was analysed using Canonical Correspondence Analysis (CCA). CCA is a multivariate method used to explain the relationship between environmental variables and species abundance (ter Braak and Verdonschot 1995). Data processing for CCA was performed using the Paleontological Statistics (PAST) software version 5.02.

3. Result and Discussion

3.1. Result

3.1.1. Fish Composition

A total of 2,292 individuals, representing three families and six species, were collected during the study period. The family Dorosomatidae (Clupeidae) dominated the composition, represented by four species: *Amblygaster sirm*, *Herklotsichthys quadrimaculatus*, *Sardinella gibbosa, and Sardinella lemuru*. The other two families were each represented by a single species, namely *Encrasicholina heteroloba* (Engraulidae) and *Spratelloides delicatulus* (Spratelloididae).

In terms of individual abundance, *Spratelloides delicatulus* was the most dominant species in December 2023 and March 2024, while *Herklotsichthys quadrimaculatus* had the highest proportion (67.21%) in February 2024 (Figure 2). In April 2024, the composition appeared relatively balanced among four species from the three families. Biomass composition exhibited a similar pattern, although, in February 2024, *Amblygaster sirm* contributed the largest biomass. Overall, three species (*Spratelloides delicatulus, Herklotsichthys quadrimaculatus,*

and *Amblygaster sirm*) were consistently dominant and present in all sampling months. Notably, *Sardinella lemuru,* one of the most economically valuable species in the Bali Strait and Biru Bay, was only captured in April 2024, contributing a relatively balanced proportion alongside other Clupeiformes species.

The composition of Clupeiformes fish based on life stages showed that juvenile stages were generally more dominant than adult stage. Juveniles of all species were more abundant in February and April 2024, while adult fish were more frequently observed in December 2023 and March 2024 (Figure 3). The high proportion of adults among Clupeiformes was primarily due to the abundance of mature individuals of *Spratelloides delicatulus,* which corresponded with the dominance of this species during December 2023 and March 2024. This also indicates that *S. delicatulus* exhibited the presence of both juvenile and adult stages throughout all months. In contrast, the other five species showed a significantly higher proportion of juveniles, particularly *Sardinella lemuru, Sardinella gibbosa,* and *Herklotsichthys quadrimaculatus,* which were found to be entirely in the juvenile phase.
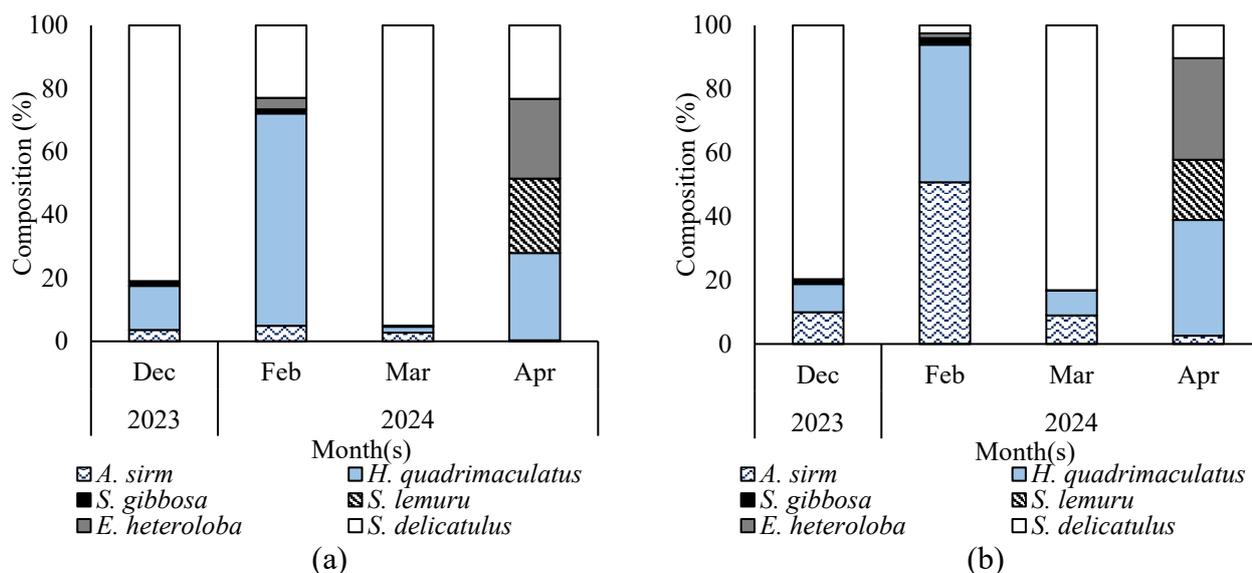

Figure 2. Species composition of Clupeiformes in Biru Bay based on (a) Individuals; (b) Biomass.
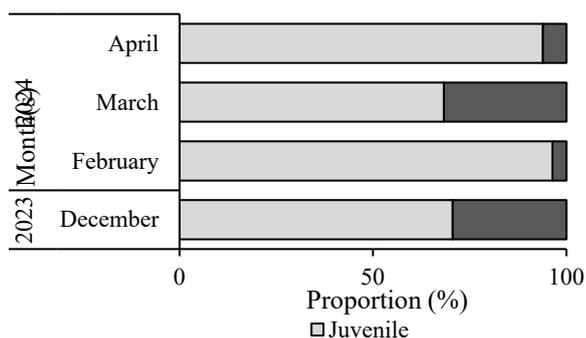
Figure 3. Monthly proportion of Clupeiformes life stages in Biru Bay, East Java.

3.1.2. Length-Weight Relationship and Condition Factor

The growth aspects of Clupeiformes species in Biru Bay were analysed based on their length-weight relationship and condition factor. Overall, Clupeiformes in this area exhibited both positive allometric and isometric growth patterns (Tables 1–4). These two growth types were relatively balanced across all months, except in March 2024, when all species displayed positive allometric growth. *Herklotsichthys quadrimaculatus* consistently showed positive allometric growth throughout the study. *Amblygaster sirm* tended to exhibit positive allometric growth in all months except February 2024 (Table 2), whereas *Spratelloides delicatulus* showed mostly isometric growth, except in March 2024 (Table 3).

Condition factor (CF) values of Clupeiformes varied monthly (Tables 1–4). Several species in each month exhibited mean CF values greater than 1.00, indicating good condition. Species from the family Dorosomatidae—*Amblygaster sirm*, *Herklotsichthys quadrimaculatus*, and *Sardinella lemuru*—tended to have the consistently good condition (CF > 1.00). In contrast, *Spratelloides delicatulus* (Spratelloididae) and *Sardinella gibbosa* (Dorosomatidae) generally had lower condition factors (CF < 1.00), except in March 2024 (Table 3). *Encrasicholina heteroloba* showed good condition in February 2024 but recorded a lower CF (<1.00) in April 2024 (Table 4).

Table 1. Length-weight relationship and condition factor of Clupeiformes in December 2023.

No	Species	Growth Types	Condition Factor	
			Range	Mean±SD
1	*Amblygaster sirm*	Allometric +	0.8405–1.1935	1.0019±0.0626
2	*Herklotsichthys quadrimaculatus*	Allometric +	0.7190–1.8298	1.0085±0.1342
3	*Sardinella gibbosa*	Isometric	0.5231–0.8171	0.6248±0.0705
4	*Spratelloides delicatulus*	Isometric	0.5611–1.1739	0.6889±0.0674

Table 2. Length-weight relationship and condition factor of Clupeiformes in February 2024.

No	Species	Growth Types	Condition Factor	
			Range	Mean±SD
1	*Amblygaster sirm*	Isometric	0.7889–0.9483	0.8602±0.0497
2	*Herklotsichthys quadrimaculatus*	Allometric +	0.6832–1.5502	1.0089±0.1373
3	*Encrasicholina heteroloba*	Allometric +	0.8499–1.0875	1.0019±0.0634
4	*Spratelloides delicatulus*	Isometric	0.4811–1.0574	0.6427±0.0824

Table 3. Length-weight relationship and condition factor of Clupeiformes in March 2024.

No	Species	Growth Types	Condition Factor	
			Range	Mean±SD
1	*Amblygaster sirm*	Allometric +	0.8835–1.1323	1.0015±0.0570
2	*Herklotsichthys quadrimaculatus*	Allometric +	0.8818–1.1287	1.0029±0.0801
3	*Spratelloides delicatulus*	Allometric +	0.6126–3.4237	1.0121±0.1724

Table 4. Length-weight relationship and condition factor of Clupeiformes in April 2024.

No	Species	Growth Types	Condition Factor	
			Range	Mean±SD
1	*Herklotsichthys quadrimaculatus*	Isometric	0.8305–1.1217	0.8621±0.0631
2	*Sardinella lemuru*	Allometric +	0.8772–1.1246	1.0016±0.0567
3	*Encrasicholina heteroloba*	Isometric	0.7874–1.1909	0.5555±0.0419
4	*Spratelloides delicatulus*	Allometric +	0.8954–1.2385	1.0012±0.0511

Table 5. Physicochemical parameters in Biru Bay, East Java.

No	Parameters	West Season		Transitional-1 Season	
		December 2023	February 2024	March 2024	April 2024
1	Temperature (°C)	29.07±0.21	31.14±0.59	30.77±0.21	29.02±0.77
2	Salinity (PSU)	34.52±0.53	33.34±0.58	33.01±0.03	33.11±0.85
3	Dissolved Oxygen (mg/L)	7.51±0.06	6.30±0.37	5.40±0.1	7.01±0.44

3.1.3. Relationship of Clupeiformes' Abundance and Their Environmental Parameters

Water quality in the Biru Bay, Bali Strait, was assessed in situ through physicochemical parameters: temperature, salinity, and dissolved oxygen (DO). Water temperatures varied monthly (Table 5), with the highest mean temperature recorded in February 2024 (the west monsoon season) at 31.13 ± 0.59 °C. Temperatures declined entering the transitional season (seasonal shift to east monsoon) and reached the lowest mean value in April 2024 at 29.02 ± 0.77 °C.

Salinity exhibited narrow temporal variations, ranging between 33 and 34.5 psu (Table 5). The lowest mean salinity occurred in March 2024 (33.01 ± 0.03 psu), while the highest was in December 2023 (34.52 ± 0.53 psu). Salinity levels in February–April 2024 remained relatively stable around 33 psu.

Dissolved oxygen levels showed more fluctuation over time (Table 5). The lowest mean DO concentration was recorded in March 2024 at 5.40 ± 0.10 mg/L, whereas the highest was in December 2023 at 7.51 ± 0.05 mg/L.

Sea surface temperature (SST) in Biru Bay followed a similar trend to the in-situ measurements. SST reached its lowest mean value in April 2024 at 27.85 ± 0.61 °C (range: 26.60–29.24 °C) and peaked in February 2024 (west monsoon) at 30.00 ± 0.16 °C (range: 29.60–30.22 °C). The highest SST variability was observed between February and March 2024 (transition period). Spatially, SST values inside Biru Bay tended to be lower than those outside the bay, except in April 2024 when the opposite pattern was observed (Figure 4). In February–March 2024, SST was relatively uniform inside and outside the bay.

Chlorophyll-a concentrations in and around Biru Bay ranged from 0.44 to 0.83 mg/m³. The highest mean chlorophyll-a value was recorded in April 2024 at 0.83 ± 0.37 mg/m³ (range: 0.44–1.95 mg/m³). Chlorophyll-a concentrations were lower during the west monsoon season, reaching the lowest mean value in February 2024 at 0.25 ± 0.09 mg/m³ (range: 0.18–0.61 mg/m³). Spatially, chlorophyll-a concentrations in Biru Bay and adjacent coastal waters were generally lower compared to the eastern Java coast, particularly in Muncar waters. However, in April 2024, chlorophyll-a concentrations increased substantially in both Biru Bay and the nearby coastal areas (Figure 5).
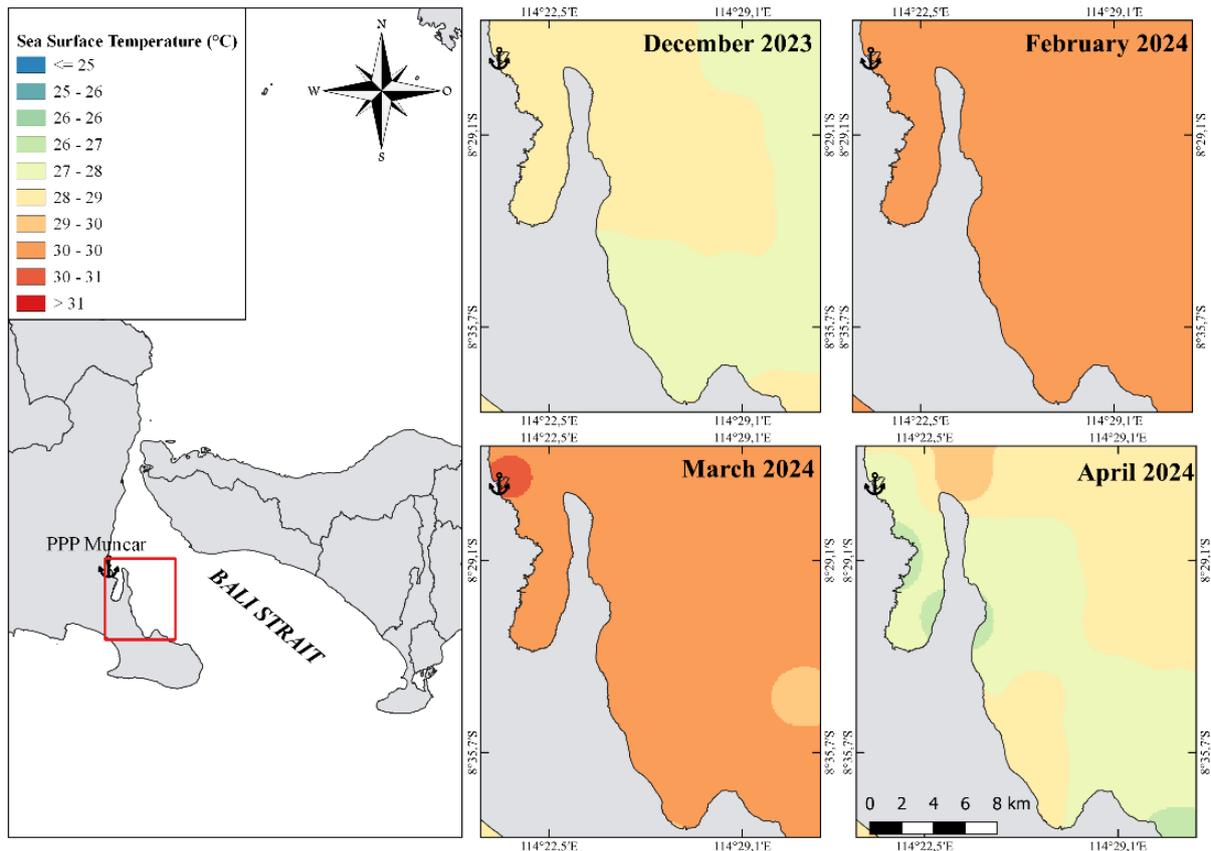
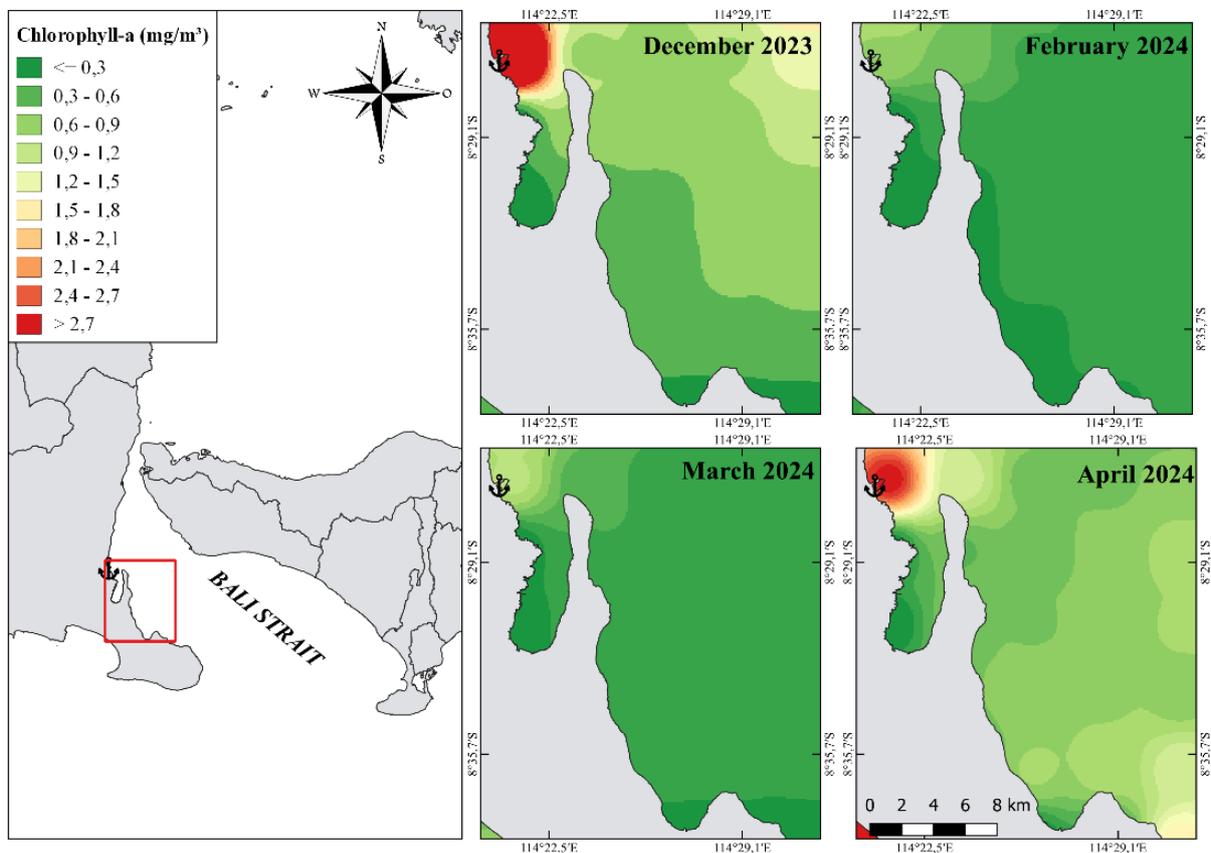Figure 4. Spatial distribution of sea surface temperature in Biru Bay, East Java.

Figure 5. Spatial distribution of chlorophyll-a concentration in Biru Bay, East Java.

Temporal variability in chlorophyll-a concentration was inversely related to sea surface temperature (Figure 6). Changes in SST over time were closely associated with fluctuations in chlorophyll-a concentration in opposite directions. The peak SST during the northwest monsoon coincided with the lowest chlorophyll-a concentration. Conversely, the highest chlorophyll-a values in April 2024 occurred during the lowest SST.

Based on CCA ordination, the abundance of Clupeiformes species in the northwest monsoon season was associated with specific environmental parameters. *Spratelloides*

delicatulus was positively associated with higher dissolved oxygen, salinity, and chlorophyll-a, and negatively associated with temperature. In contrast, *Amblygaster sirm* showed a preference for higher temperatures. *Sardinella gibbosa* was positively associated with high dissolved oxygen and chlorophyll-a, although the relationship was relatively weak (Figure 7). Meanwhile, *Herklotsichthys quadrimaculatus and Encrasicholina heteroloba* showed minimal association with the negative value from all environmental parameters.
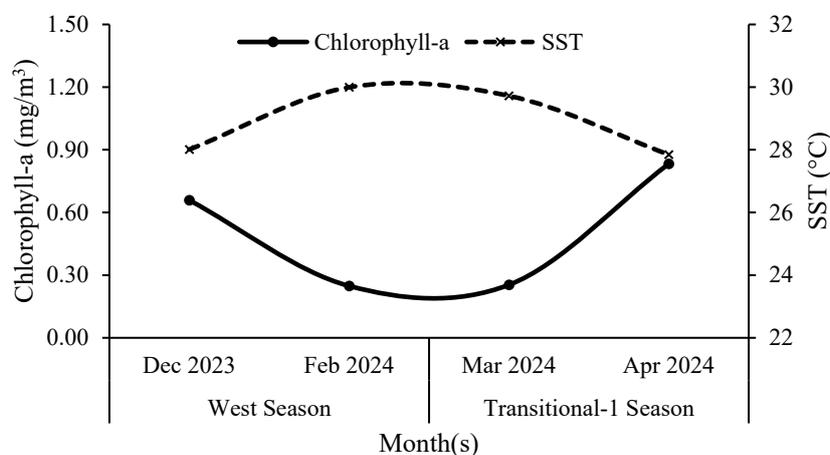

Figure 6. Temporal variability of chlorophyll-a and sea surface temperature in Biru Bay, East Java.
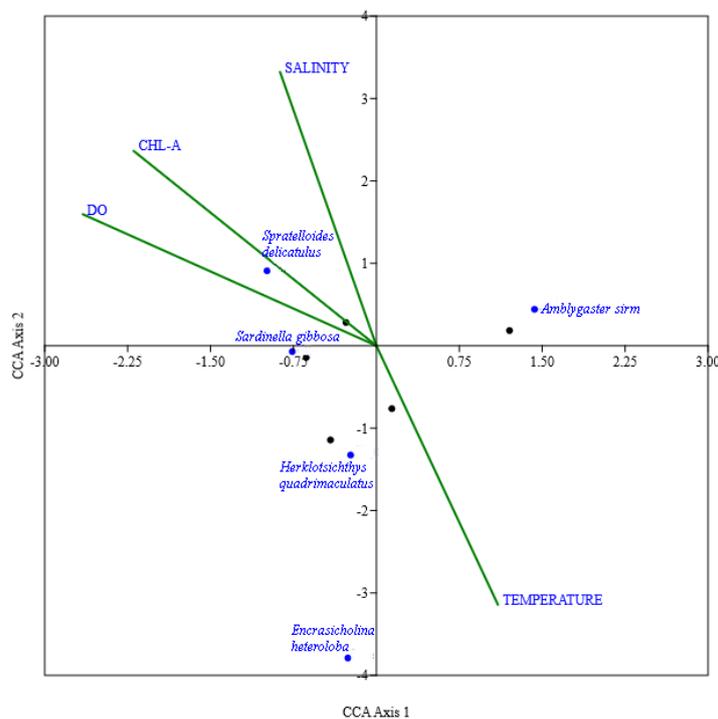

Figure 7. CCA ordination diagram illustrating the relationships between fish species and environmental variables during northwest monsoon season in Biru Bay, East Java.
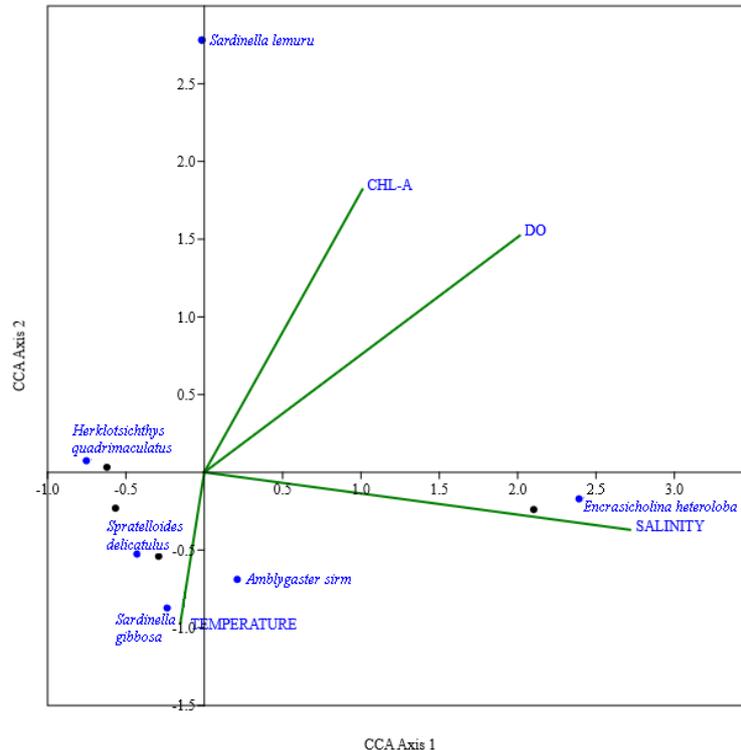
Figure 8. CCA ordination diagram illustrating the relationships between fish species and environmental variables during the transitional-1 season in Biru Bay, East Java.

In the transitional season (transition-1), the associations between Clupeiformes species and environmental parameters differed from those observed in the northwest monsoon. *Encrasicholina heteroloba* was strongly associated with higher salinity. *Spratelloides delicatulus*, *Sardinella gibbosa*, and *Amblygaster sirm* showed positive associations with warmer temperatures, lower oxygen level, and relatively low chlorophyll-a concentration. Conversely, *Sardinella lemuru* was associated with higher levels of chlorophyll-a and dissolved oxygen, as well as lower temperatures (Figure 8). *Herklotsichthys quadrimaculatus* exhibited weak or no clear associations with all environmental parameters.

3.2. Discussion

The order Clupeiformes constitutes one of the dominant fish groups in lift net catches from Biru Bay and in other fisheries across the Bali Strait. In this study, the species composition of Clupeiformes in Biru Bay was dominated by the delicate round herring (*Spratelloides delicatulus*) and the bluestripe herring (*Herklotsichthys quadrimaculatus*),

both of which were consistently recorded across all months and seasons. Pham *et al.* (2020) reported that *S. delicatulus* is widely distributed in tropical marine habitats and is characterized by a high biomass. This species plays a pivotal role in the trophic structure of marine ecosystems by serving as prey for higher trophic level fishes, owing to its large population size and rapid growth (Kingsford *et al.* 2022).

The family Dorosomatidae (formerly Clupeidae) also contributes significantly to the fish assemblage structure in Biru Bay. Dominant species from this family include *H. quadrimaculatus*, *Amblygaster sirm*, *Sardinella gibbosa*, and *Sardinella lemuru*. Among these, *H. quadrimaculatus* exhibited the highest abundance, which aligns with its broad distribution in Indo-Pacific and seasonal population increases approaching the spawning season during the western monsoon when sea temperatures are relatively warm (Oka and Miyamoto 2015). Bali sardinella (*S. lemuru*) was recorded only during the first transitional season in this study. This species is economically important in the Bali Strait, with its population concentrated in Fisheries

Management Area (FMA) 573, particularly along the Bali Strait waters (Hendiari *et al.* 2020; Pertami *et al.* 2020).

Research on fish species composition in Biru Bay remains limited. A study by Syahputra *et al.* (2016) reported that *S. lemuru* was the dominant Clupeiformes species in lift net catches during the southeast monsoon of 2016. In contrast, Aliyubi *et al.* (2015) observed that anchovies (Engraulidae) were the most abundant during the first transitional season in May 2014. Additionally, Sukresno *et al.* (2021) identified both Bali sardinella and anchovies as the main Clupeiformes caught in Biru Bay between 2013 and 2017.

The composition of Clupeiformes in Biru Bay varied depending on species-specific life stages. Most species—such as *S. lemuru*, *S. gibbosa*, and *H. quadrimaculatus*—were predominantly found in the juvenile stage, indicating immature gonadal development. Juvenile of Bali sardinella were particularly concentrated in Biru Bay, as inferred from their frequent capture by lift nets compared to other fishing gears operating in the Bali Strait (Wudianto and Wujdi 2014; Sukresno *et al.* 2021). In contrast, adult-stage individuals were primarily observed in *S. delicatulus*, a species that spawns in warmer waters and is characterized by rapid population growth and a short life cycle (Pham *et al.* 2020; Kingsford *et al.* 2022). As such, all life stages of *S. delicatulus* were observed during the northwest monsoon and first transitional season.

Juvenile Clupeiformes in Biru Bay were generally abundant throughout this study. This pattern can be linked to previous reports on their life cycles and spawning periods. *Heklotsichthys quadrimaculatus* is known to spawn near the southeast monsoon season, from March to October (Oka and Miyamoto 2015; Hunnam 2021). The goldstripe sardine (*Sardinella gibbosa*) is capable of spawning year-round across the Indo–West Pacific region, while *Amblygaster sirm* tends to spawn closer to the eastern monsoon (Hunnam 2021). The spawning season of Bali sardinella in the Bali Strait occurs during the southeast monsoon, with a peak between September and November (Wujdi *et al.* 2013). Meanwhile, *Spratelloides delicatulus* exhibits a life cycle similar to *S. gibbosa*, spawning continuously throughout the year with a minor peak in April (Milton *et al.* 1990). Shorthead anchovy, *Encrasicholina heteroloba*, in the Java Sea is known as a partial spawner, with all life stages present almost every month (Wright 1990). Altogether, these Clupeiformes species display relatively similar reproductive patterns and life-stage cycles, generally spawning around the southeast monsoon. Consequently, the presence of immature populations tends to be abundant during both the northwest and transitional seasons.

Clupeiformes in Biru Bay exhibited both positive allometric and isometric growth patterns. Positive allometric growth reflects a greater increase in body weight relative to length and is considered an indicator of optimal growth (Jisr *et al.* 2018). Some species, such as *S. delicatulus*, displayed isometric growth during certain months (e.g., December 2023 and February 2024), which indicates proportional increases in length and weight, representing ideal growth conditions (Froese *et al.* 2011). Changes in growth patterns were also observed in a few species across different months. For example, *A. sirm* and *S. delicatulus*, which had isometric growth patterns in February 2024, turned to positive allometric growth in March 2024. This is related to differences in average body size across different months and variation in environmental factors. The length-weight relationship in each species can differ substantially because the weight of fish varies spatially (region) and temporally (month, season) as a result of feeding history and the allocation of energy to growth and reproduction (Kimmerer *et al.* 2005). It is supported by an increase in chlorophyll-a concentration during transitional season-1 (March-April 2024). Temporal changes in growth patterns suggest physiological adaptations, body dimensional changes, and maturity development (Possamai *et al.* 2020).

Condition factor values also varied among species and over time. Several species showed good growth conditions in certain months,

particularly in March 2024, when all recorded species were in favourable condition. These differences may be attributed to the suitability of environmental factors (Vuić *et al.* 2024) and food availability, including prey abundance and predation pressure (Azrita *et al.* 2024). For instance, *Spratelloides delicatulus* exhibited a condition factor below 1.00 during the northwest monsoon, but above 1.00 in the first transitional season (March–April 2024), indicating improved growth conditions. This improvement may be associated with increased chlorophyll-a concentrations, which enhance plankton availability as its primary food source. Although not directly and significantly related, chlorophyll-a, a bioindicator of phytoplankton, is linked to zooplankton presence (Baihaqi *et al.* 2020).

Environmental parameters during the northwest monsoon and first transitional season in Biru Bay appeared suitable for Clupeiformes populations. Dissolved oxygen concentrations exceeded 5 mg/L, which is sufficient to meet the respiratory demands of fish. Waters with dissolved oxygen levels above 4 mg/L support metabolic activities such as respiration and growth (Ali *et al.* 2022; Marium *et al.* 2023). Salinity conditions in Biru Bay during the northwest monsoon and transition-1 season were quite stable, ranging from 33 to 34 psu. The oceanographic characteristics of salinity in Biru Bay and the Bali Strait were also in line with the findings of this study, where salinity was lower than during the southeast monsoon season (Sukresno *et al.* 2019; Sartimbul *et al.* 2023).

Water temperatures during these seasons ranged between 29.02 to 31.13°C, favoring tropical pelagic fish. These values, derived from both in-situ measurements and satellite imagery, are consistent with prior findings from Sukresno *et al.* (2019), who reported higher sea surface temperatures (SST) during the northwest monsoon (28.1–31.6°C) compared to the southeast monsoon (24.9–30.7°C). Temperature directly affects physiological processes in fish, influencing growth rate, metabolism, reproduction, and feeding behavior (Hanks and Secor 2011; Marium *et al.* 2023). Thus, the

physicochemical parameters of the aquatic environment are critical to the survival of Clupeiformes. Abiotic factors such as temperature and dissolved oxygen are known to influence productivity and the spatial distribution of small pelagic fish (Peck *et al.* 2021). Physicochemical parameters, such as temperature, dissolved oxygen concentration, and salinity, are also intrinsically linked to plankton distribution as a prey source due to their variability (Nunn *et al.* 2012).

Chlorophyll-a concentrations in Biru Bay during the western monsoon and first transitional season were generally low. Historical data also show that chlorophyll-a levels are lower in the western monsoon compared to the eastern monsoon across the Bali Strait and Biru Bay (Susilo 2015; Sukresno *et al.* 2019; Wijaya *et al.* 2020). Variations in chlorophyll-a levels directly impact Clupeiformes resources, as this pigment indicates phytoplankton biomass and thus the primary productivity of waters. An increase in chlorophyll-a implies higher phytoplankton and zooplankton abundance, which supports greater productivity and catch rates of small pelagic fish, as explained through food web dynamics (Lumban-Gaol *et al.* 2021). The presence of phytoplankton and zooplankton is essential to Clupeiformes diets. However, chlorophyll-a influences fish production indirectly, as there is often a time lag between phytoplankton proliferation, zooplankton consumption, and fish predation (Suprianto *et al.* 2021).

In this study, fish abundance was positively correlated with chlorophyll-a concentrations. Members of the families Spratelloididae (*S. delicatulus*) and Dorosomatidae (*S. lemuru, S. gibbosa*) were associated with higher chlorophyll-a levels in the water reflecting their reliance on planktonic food sources. Garrido *et al.* (2008) stated that the remotely sensed chlorophyll-a data, which serves as indicator of phytoplankton in the waters, matched the temporal variability in the dietary contribution by plankton, meaning that satellite-derived chlorophyll-a data could potentially be used as as a proxy for sardine distribution and feeding

intensity. Variability in chlorophyll-a concentrations may therefore influence the distribution and abundance of certain Clupeiformes species in Biru Bay. Furthermore, chlorophyll-a concentration and sardine catch data in the Bali Strait are positively correlated with a certain time lag (Lumban-Gaol *et al.* 2004). The delayed effect of chl-a on sardine production, which seems to be related to the time needed for material transfer between trophic levels, from phytoplankton to zooplankton, and ended up in Clupeoid fish as a secondary consumer (Puspasari *et al.* 2019).

Overall, environmental conditions in Biru Bay during the northwest monsoon and first transitional season were supportive of Clupeiformes populations. This was evidenced by generally favorable condition factors, particularly in the first transitional season. Most Clupeiformes were juveniles, except for *S. delicatulus* which has a moderately balanced juvenile-adult phase. Despite their vulnerability, juveniles exhibited good growth, indicating that the habitat provided adequate environmental conditions. The supportive and convenient aquatic environmental conditions for the juvenile fish population can potentially act as a suitable habitat or nursery area (Mattone *et al.* 2022). These findings suggest that Biru Bay serves as a suitable habitat and potential nursery ground for Clupeiformes in the Bali Strait.

However, favorable environmental and growth conditions in Biru Bay are accompanied by significant fishing pressure. Daily lift net operations are highly concentrated in the bay, yielding fluctuating catch volumes and a high proportion of juvenile fish (Sukresno *et al.* 2021). The mesh size of floating lift net gear is small (approximately 3–5 mm), enabling the capture of immature fish at high percentages. Historical catch data from previous research indicate that Clupeiformes comprise a substantial proportion of lift net landings, suggesting their status as main target species. Globally, Clupeiformes are also recognized as essential fishery and ecological resources, playing a central role in marine food webs

(Hunnam 2021). The overlap between fishing activity and nursery habitats in Biru Bay underscores the need for integrated management that considers both ecological and economic perspectives. This highlights the importance of Clupeiformes as key resources in the Bali Strait fisheries.

4. Conclusion

The species composition of Clupeiformes changes over time, predominated by *Spratelloides delicatulus*, *Herklotsichthys quadrimaculatus*, and *Amblygaster sirm*. The juvenile phase represents most of the fish composition with positive allometric growth patterns and good growth conditions, supported by favorable environmental parameters during the northwest and first transitional seasons. The management of Clupeiformes resources requires attention to ecosystem dynamics and the lift-net fishery operating in Biru Bay.

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