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Fish assemblage patterns influenced by nutrient levels and thermal effluent from power plants in the lower reaches of Berung and Wadas Rivers, Serang Regency, Banten, Indonesia

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Abstract. The downstream of the Berung and Wadas Rivers in Serang Regency, Banten Province, Indonesia, possesses economically significant fishery resources. However, these waters face environmental threats, notably thermal effluent from a Steam Power Plant. This study aimed to analyze fish species diversity and habitat conditions by examining the relationship between fish assemblages and key physicochemical factors, specifically temperature and nutrient levels. The study was conducted in January 2020 at six sampling stations representing riverine, estuarine, and marine zones. Fish samples were collected using gillnets, while physicochemical parameters (including temperature, nutrients, DO, salinity, and pH) were measured concurrently. Fish diversity was evaluated using the Shannon index, and the relationship between fish assemblages and environmental variables was analyzed using Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA). A total of 63 individual fishes, comprising 11 species from 10 families, were recorded. The squaretail mullet (*Ellochelon vaigiensis*) was the dominant species (67%). Fish diversity varied significantly across stations. Stations 1, 2, and 6, located in productive estuarine areas, exhibited higher fish diversity. Conversely, Station 5, situated near the power plant's thermal discharge, recorded elevated temperatures (37.5°C) and low fish diversity, indicating negative impacts from thermal pollution. The findings confirm that the thermal effluent acts as a pollutant, creating environmental instability for the aquatic biota. Therefore, improved waste management strategies are necessary to mitigate the ecological impacts in this area.

1 Introduction

The waters surrounding Bojonegara, especially in the downstream area of Berung and Wadas Rivers, Serang Regency, Banten Province, Indonesia, possess economically significant fishery resources. These resources are exploited not only by local fishermen but also by the broader Banten community, as evidenced by the Karangantu Fish Auction Place. The sustainability of fish stocks in the downstream area of the Berung and Wadas River is inextricably linked to the environmental quality of the marine habitat.

An ecobiological approach can be employed to analyze the relationship between aquatic environmental conditions and the status of fishery resources. This approach examines the environmental interconnections (abiotic-biotic interactions) that can either support or hinder

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the sustainability of fish stocks. Currently, the sustainability of these fishery resources is under considerable pressure from anthropogenic activities. A demonstrated impact of such pressures is the decline of fish resources in Indonesia's coastal waters due to environmental degradation and pollution [1].

The coastal area is currently undergoing construction and development for a steam power plant, leading to its continuous transformation through new constructions, including land reclamation, port facilities, and jetty bridges. During electricity generation, the steam power plant utilizes water in its cooling system, subsequently discharging heated effluent into the marine environment. This process involves releasing large volumes of thermal effluent into the surrounding waters, leading to an increase in sea surface temperature [2]. Elevated water temperatures accelerate biological and chemical processes and reduce the solubility of dissolved oxygen in the water. These alterations can profoundly affect the fish resources at the downstream parts of the Wadas and Berung Rivers. This is shown by a study of the Tanjung Jati Coal Power Plant in Jepara, Central Java, which has been the subject of environmental monitoring since the early phases of its expansion. The research found a noticeable diversity decline in taxa and species abundance over the study period (January 2021 – December 2022), with species ranging from 79-197 species (19-23 per sample). Critically, the Shannon diversity index declined from 2.67 to 2.43, while dominance indices increased from 0.11 to 0.51, indicating ecological stress and a shift toward species dominance patterns typical of moderately polluted systems.

A study is therefore required to elucidate the diversity and distribution structure of the fish community at the Bojonegara coast, particularly in response to the increased sea surface temperatures caused by the steam power plant. Furthermore, the influence of organic pollution from various riverine inputs on these fish resources will also be assessed. This study aims to investigate the species composition and the relationship between fish assemblages, nutrients, and thermal effluents.

2 Methods

2.1 Time and location

The study was conducted in the downstream area of the Berung and Wadas Rivers, Serang Regency, Banten Province. A single sampling was carried out in January 2020. Samples were collected from six stations, selected based on their distinct aquatic characteristics (Fig. 1). Stations 1, 2 and 3 were for Wadas River, while 6, 5 and 4 were for Berung River. Stations 1 and 6 were located in the riverine zone, Stations 2 and 5 in the estuarine zone, and Stations 3 and 4 in the marine zone. Subsequent sample analysis was performed at the Bio-Macro Laboratory, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University.

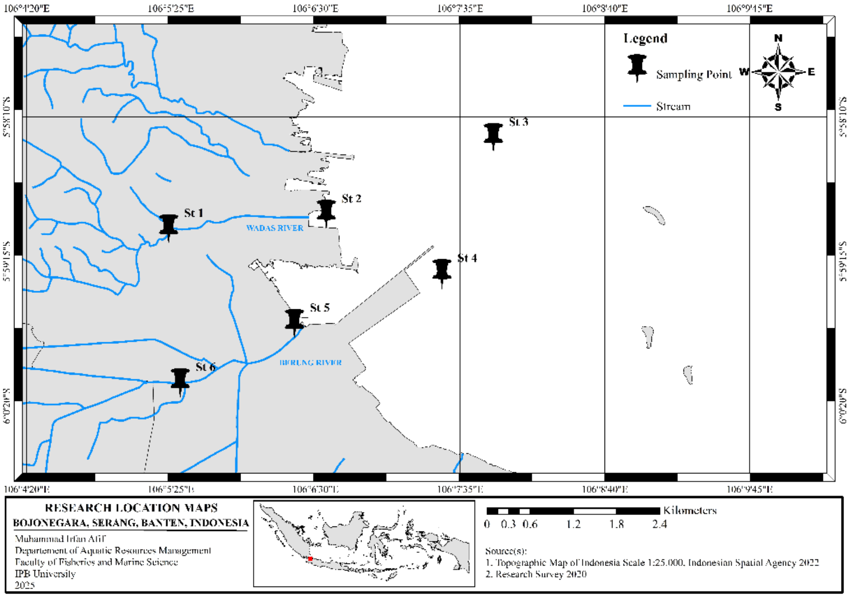

Fig. 1. Map showing the research sites in the Berung and Wadas Rivers and the Bojonegara coastal area.

2.2 Materials

The equipment used for sample collection included a gillnet (1-3 inches), field notebooks, a Global Positioning System (GPS) unit, DO meter, pH meter, refractometer, a measuring tape, bottles for nutrient samples, syringes, and a turbidity meter. A 10% formalin solution was used as a preservative for the collected samples.

2.3 Data collection

Fish samples were obtained from the gill net which was left to soak for about 30 minutes to 1 hour. Fish samples were sorted and preserved with 10% formalin and brought to the Bio-Macro Laboratory for identification. On the other hand, the measurement of water quality was obtained by collecting the physicochemical parameters as presented in Table 1.

Table 1. The physicochemical parameters that have been measured.

Parameters	Units	Principles of analysis
Temperature	°C	instrument
Turbidity	mg/L	laboratory analysis
Total suspended solid (TSS)	mg/L	laboratory analysis
pH		instrument
Salinity	‰	instrument
Dissolved oxygen (DO)	mg/L	instrument
Total Phosphate	mg/L	laboratory analysis
Nitrate	mg/L	laboratory analysis
Nitrite	mg/L	laboratory analysis

2.4 Data analysis

The frequency of occurrence illustrates the temporal distribution of fish throughout the research period and was calculated using the following formula [3]:

$$\left[Fk = \frac{P_i}{P} x\ 100\right] \quad (1)$$

where:

Fk: Frequency of occurrence (%)
Pi: Number of observations for species i
P: Total number of observations

The Shannon–Wiener Diversity Index (H′) was used to measure species diversity by considering both species richness (number of species) and evenness (relative abundance among species). The index is calculated as:

$$H' = -\sum_{i=1}^{S} p_i ln\ (p_i) \quad (2)$$

where:
S: total number of species
p_i: proportion of individuals belonging to the *i-th* species ($p_i = \frac{n_i}{N}$)
n_i: number of individuals of species i
N: total number of individuals across all species

The relationship between environmental factors and fish abundance was analyzed using Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA). The XLSTAT plugin was used in conjunction with Excel to examine the relationship of sampling stations, nutrient parameters, and fish assemblages. The results of these analyses were interpreted and discussed descriptively based on the relevant literature and additional environmental data, such as temperature, TSS, turbidity, and water productivity.

3 Results and discussion

3.1 Fish assemblages

During the sampling period, a total of 11 fish species from 10 families and 5 orders were identified across the six stations. The identified species are presented in Table 2. The lowest diversity was observed at stations 2 and 5. A total of 63 individuals were recorded, with the squaretail mullet (*Ellochelon vaigiensis*) from the family Mugilidae being the dominant species, accounting for 67% of the total individuals. The calculation results of the Shannon-Wiener index, classified according to Hashemi et al. [15], indicated that only station 4 possessed moderate diversity, while the other stations exhibited low diversity. These results reflected a situation where certain points contained a high abundance of fish, albeit belonging to only a single species.

The family Mugilidae was commonly found. This finding is consistent with Huang et al. [4], who stated that this family has one of the widest distributions in estuarine areas. Furthermore, these species tolerate a wide range of salinity, as they can inhabit brackish and marine environments. They are catadromous species that typically form large schools over sand or mud substrates.

Ellochelon vaigiensis and *Scomberoides commersonianus* exhibited the same frequency of occurrence, as both species were present at two of the sampling stations. Frequency of occurrence indicates the extent of a species' temporal distribution among stations, as observed from the frequency of fish caught during the observation period. Although they shared the same frequency of occurrence, their total abundance differed. This difference can be attributed to the schooling behavior of *E. vaigiensis*, whereas *S. commersonianus* tends to be more solitary [5].

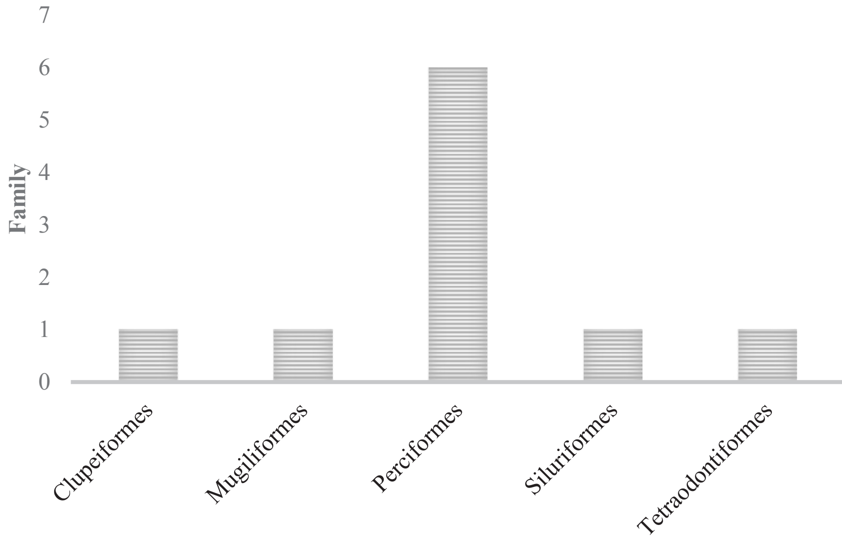

Fig. 2. This family-level classification in the downstream areas of the Wadas and Berung Rivers.

In addition to identifying the most abundant species, it is also necessary to examine the diversity of the catch. Grouping the species by family facilitates the interpretation of diversity and its relationship with environmental conditions. This family-level classification is illustrated in Fig. 2. A closer examination of the data reveals that the order Perciformes contained the highest number of families. The high representation of the order Perciformes aligns with its well-established status as the largest and most taxonomically diverse order of teleosts. This order is a dominant and characteristic feature of virtually all global marine ecosystems.

3.2 Physicochemical parameters of water

The measurement of water physicochemistry parameters yielded distinct results for each station (Table 3). Several parameters, specifically salinity, pH, and Dissolved Oxygen (DO), were sampled twice to assess potential differences between surface and bottom water layers. Additionally, nutrient levels were evaluated through the analysis of nitrate, nitrite, and total phosphate concentrations.

Table 2. Fish distribution in the downstream areas of the Berung and Wadas Rivers

No	Ordo	Family	Species	Station						Total	% Total	FK
				1	2	3	4	5	6			
1.	Clupeiformes	Engraulidae	*Thryssa hamiltoni*			3				3	5%	17%
2.	Mugiliformes	Mugilidae	*Ellochelon vaigiensis*	17					25	42	67%	33%
3.	Perciformes	Anabantidae	*Anabas testudineus*						7	7	11%	17%
4.	Perciformes	Carangidae	*Scomberoides commersonnianus*		1		1			2	3%	33%
5.	Perciformes	Cichlidae	*Oreochromis mossambicus*						3	3	5%	17%
6.	Perciformes	Cichlidae	*Oreochromis niloticus*						1	1	2%	17%
7.	Perciformes	Osphronemidae	*Trichopodus trichopterus*						1	1	2%	17%
8.	Perciformes	Polynemidae	*Eleutheronema tetradactylum*				1			1	2%	17%
9.	Perciformes	Sciaenidae	*Johnius trachycephalus*				1			1	2%	17%
10.	Siluriformes	Ariidae	*Arius arius*				1			1	2%	17%
11.	Tetraodontiformes	Tetraodontidae	*Lagocephalus lunaris*					1		1	2%	17%
Total				17	1	3	4	1	37	63	100%	
Shannon Wiener Index				0	0	0	1.4	0	1			

The chemical water quality varied depending on the sampling location. Compared to the seawater quality standards for marine biota established by the Government Regulation of Republic Indonesia No. 22 of 2021 (PP RI No. 22/2021), several parameters exceeded the permissible limits. These include the surface pH at station 5; surface DO at stations 3 and 5; bottom DO at stations 1, 2, and 3; nitrate concentrations at all stations; and total phosphate concentrations at stations 1, 2, and 6 (Table 3).

The pH value at station 5, which fell outside the standard range, is likely influenced by the thermal discharge from a nearby power plant. According to Menon et al. [6], elevated water temperatures can alter numerous physicochemical parameters, including causing a decrease in pH. Low DO levels were observed near the thermal discharge area and at the bottom of the river mouth. The reduced DO near the discharge area is attributable to the inverse relationship between water temperature and dissolved oxygen solubility. Meanwhile, the low DO at the river mouth bottom is likely due to high concentrations of suspended particles, which increase turbidity and reduce light penetration. This limited light availability inhibits photosynthesis by primary producers [7].

Table 3. The measurement of physicochemical parameters in the downstream area of the Wadas and Berung Rivers. Asteriks denote values exceeding the Indonesian national seawater quality standards for marine biota.

Parameters	**Units**	**Sample location**	**Station**					
			1	**2**	**3**	**4**	**5**	**6**
Salinity	‰	Surface	0	23	24	23	18	0
		Seabed	8	23	24	25	25	0
pH	-	Surface	7.17	7.87	7.88	7.65	6.63*	7.1
		Seabed	7.17	7.8	7.86	7.85	7.78	7.1
DO	mg/l	Surface	6.5	5.1	4*	5	4.3*	5.4
		Seabed	0.3*	4.1*	4.6*	5.6	5.2	5.4
Nitrate	mg/L	Surface	0.867*	0.794*	0.773*	0.762*	0.777*	0.873*
Nitrite	mg/L	Surface	0.128	0.064	0.062	0.065	0.067	0.064
Total phosphate	mg/L	Surface	0.094*	0.072*	< 0.001	< 0.001	< 0.001	0.321*
Temperature	^{o}C	Surface	28.4	30.4	30.4	34.5	37.5	29.5
Turbidity	NTU	Surface	111	28.0	8.6	5.5	10.6	380
TSS	mg/L	Surface	57.6	66.4	79.0	21.0	11.0	108

Nitrate concentrations were observed to be relatively low across the sampling sites, with all stations registering values below the 0.1 mg/L threshold typically associated with eutrophic waters [8]. However, spatial variations in nutrient loading were evident from the phosphate data. The highest phosphate concentrations were detected specifically in the river mouth areas (Stations 1 and 6). This finding aligns with Colborne et al. [9], who identified riverine input as a primary source of phosphate in marine environments. This pattern suggests a significant contribution of organic materials derived from terrestrial anthropogenic activities, such as domestic wastewater or agricultural runoff, entering the coastal ecosystem via the rivers.

3.3 Relationship between fish assemblages and water quality

The clustering of the sampling stations provides an overview of the defining parameters for each location. A Principal Component Analysis (PCA) revealed significant correlations between environmental parameters and the stations (Fig. 3), as well as between fish species and the stations (Fig. 4). The resulting PCA biplots clearly illustrate these groupings.

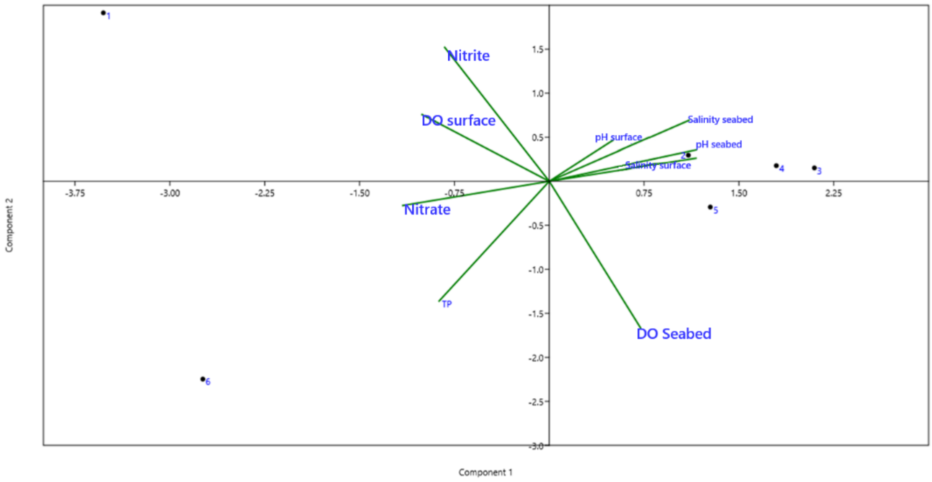

Fig. 3. Biplot diagram of PCA between sampling station points and water quality parameters.

The conditions at stations 2, 3, and 4 were predominantly influenced by salinity and pH (Fig. 3). This is attributed to their location at the confluence of freshwater and seawater, making salinity a dominant environmental factor. The pH of freshwater in an estuarine environment tends to be more acidic, an effect potentially exacerbated by the nearby power plant, which can alter the pH of the receiving waters [10]. In contrast, stations 1 and 6 were more strongly influenced by nutrient concentrations, characteristic of their riverine locations. Rivers typically exhibit high nutrient levels resulting from land erosion and anthropogenic waste discharge. Fig. 3 also suggests an inverse relationship between nutrient concentrations and salinity. This indicates that as the water body extends towards the sea, nutrient levels tend to decrease while salinity increases.

The distribution of fishes across the stations is illustrated in Fig. 4. The analysis shows that several freshwater species, namely *Oreochromis niloticus*, *Trichopodus trichopterus*, *Anabas testudineus*, and *Oreochromis mossambicus*, were primarily found at station 6. This distribution is consistent with the low salinity at this station (Table 3), which provides a suitable habitat for these species. The estuarine fish *Ellochelon vaigiensis* was also found within this group; this species typically inhabits near-shore areas and enters river mouths to forage [6]. A second distinct group consisted of strictly marine species, including *Arius arius*, *Scomberoides commersonnianus*, *Eleutheronema tetradactylum*, and *Johnius trachycephalus* [11]. As expected, these species were absent from the freshwater environments of stations 1 and 6.

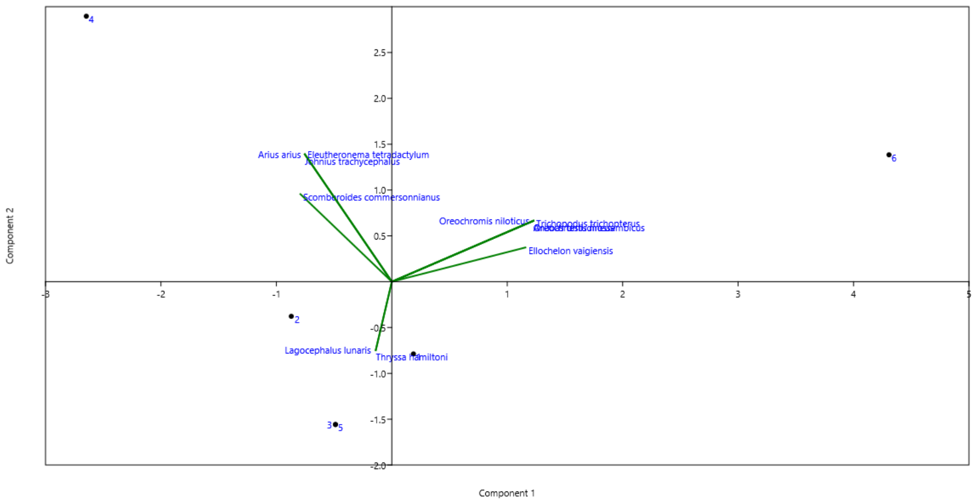

Fig. 4. Biplot diagram of PCA based on fish species and sampling station points.

Canonical Correspondence Analysis (CCA) was employed to visualize the relationships between stations, water chemistry parameters, and fish species. CCA is a direct gradient multivariate method used to explain the relationship between a species community and its environmental variables. It is particularly effective for assessing the influence of environmental parameters on fish abundance. Prior to the analysis, all water chemistry and fish abundance data were log-transformed (log(x+1)) to achieve normality.

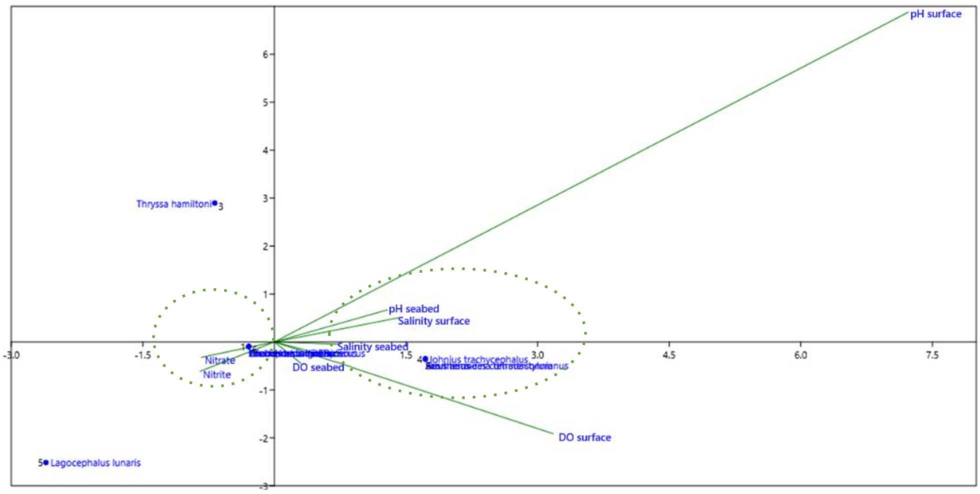

Fig. 5. Biplot diagram of CCA showing a relationship between fish species and water quality parameters.

The CCA biplot revealed two distinct clusters based on the relationships between stations, fish species, and water chemistry (Fig. 5). The first cluster was characterized by a strong association with nitrate and nitrite, which were the defining parameters for station 6. This station served as a congregation point for species such as *Ellochelon vaigiensis*, *Anabas testudineus*, *Oreochromis niloticus*, *Oreochromis mossambicus*, and *Trichopodus trichopterus*. These species likely gather at station 6 for foraging. As omnivores, *A. testudineus*, *O. niloticus*, *O. mossambicus*, and *T. trichopterus* can exploit the abundant food resources available in estuaries [12]. Similarly, *E. vaigiensis* probably utilizes this area to feed on detritus, which is highly available in river mouths.

In contrast, the second cluster was characterized by higher pH, salinity, and dissolved oxygen (DO), which were representative of station 2. This station was predominantly inhabited by *Johnius trachycephalus*, *Scomberoides commersonnianus*, and *Eleutheronema tetradactylum*. The area around station 2 features estuarine waters with extensive mangrove vegetation. Mangrove ecosystems are known for their high productivity and serve as crucial feeding grounds for numerous marine fish species.

Overall, in the downstream areas of both the Wadas and Berung river, the sampling stations are located within an estuarine region that is naturally expected to be highly productive. However, this ecosystem is highly susceptible to disturbances from various anthropogenic activities. This is particularly evident at station 5, the site of thermal effluent discharge from a power plant, which exhibited impoverished fish diversity. This low diversity strongly suggests that the thermal discharge has a significant negative impact on the aquatic biota. Such impacts are well-documented; for instance, research by Michie et al. [13] indicates that thermal effluent can lead to decreased primary productivity, fish recruitment failure, direct fish mortality, and alterations in fish migration patterns.

The results of this study are corroborated by findings from Ronauli et al. [14], which also indicate a relationship between nutrient dynamics, thermal effluent from power plants, and aquatic productivity. The discharge of heated water and high nutrient loads were found to cause phytoplankton blooms, particularly dominated by diatom groups such as *Chaetoceros* sp. and *Thalassiothrix* sp. This condition enhances primary productivity, which in turn supports a higher abundance of zooplankton, theoretically leading to a more active aquatic food web.

However, the dominance of specific phytoplankton species and the suppression of zooplankton diversity due to elevated temperatures suggest an ecosystem imbalance. This ecological pressure could potentially reduce the carrying capacity of the aquatic environment for higher trophic level organisms, including fish, which are highly dependent on a stable food chain. Therefore, although thermal effluent may locally increase primary and secondary productivity, the decline in habitat quality and the observed fluctuations in the plankton community indicate a significant risk of reduced fishery potential at stations located near the power plant's thermal discharge points.

4 Conclusion

The waters surrounding the Berung and Wadas river estuaries in Serang Regency, Banten Province, support high-value economic fishery resources. However, this environment faces threats, such as thermal waste from a steam power plant. In this study, fish diversity varied among the sampling stations, each possessing distinct characteristics. Stations 1, 2, and 6 exhibited high fish diversity, attributed to their locations within the estuary, which is rich in organic matter and high in productivity, serving as a critical feeding ground for fish. In contrast, Station 5 (Berung River), the site of the power plant's thermal waste discharge, recorded low fish diversity. The thermal effluent acts as a pollutant, causing environmental instability for the aquatic biota.

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