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The abundance and association of zooplankton and phytoplankton in silvofishery ponds of Maros, Indonesia

Kelimpahan dan asosiasi zooplankton dan fitoplankton di tambak silvofishery di Maros, Indonesia

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ABSTRACT

This study examines plankton abundance, site characteristics, and plankton associations in silvofishery ponds at the Research Center for Brackish Water Aquaculture and Fisheries Extension in Maros Regency. The water quality and plankton samples were collected from December 2022 to January 2023. The study sites are located in rivers (1), polyculture ponds (2), mangrove reservoirs (3), bait ponds (4), pond canals (5), and fishery loading and unloading sites (6). Sampling locations were determined using the purposive sampling method. A randomized group design with ANOVA analysis was used to compare plankton abundance between locations and observation times. Site characterization was analyzed using principal component analysis (PCA) and the associations between plankton genus and observation time were analyzed using correspondence analysis (CA). The results showed the highest total phytoplankton abundance in week 4 at site 1 (3124 ind/L). In the initial observation, the highest total zooplankton abundance was found at site 1 (508 ind/L). This study also showed that phytoplankton abundance was partially influenced by salinity and NO_3, while zooplankton abundance was not affected by all water quality variables. Based on PCA, sites 4 and 2 are characterized by water temperature, pH, and PO_4 parameters. Sites 1 and 6 are characterized by salinity, brightness, and NO_3 parameters. PO_4 poorly characterizes site 5. showed no deviations in any water quality parameters. Chaetoceros has the highest mass value in the line profile (0.279). The largest mass value of zooplankton (0.501) was from subclass Copepoda.

Keywords: correspondence analysis, plankton abundance, principal component analysis, silvofishery, water quality

ABSTRAK

Penelitian ini mengkaji kelimpahan plankton, karakteristik lokasi dan asosiasi plankton pada tambak *silvofishery* di Balai Riset Perikanan Budidaya Air Payau dan Penyuluhan Perikanan Kabupaten Maros. Sampel kualitas air dan plankton dikumpulkan dari bulan Desember 2022 hingga Januari 2023. Lokasi penelitian terletak di sungai (1), kolam polikultur (2), waduk bakau (3), kolam umpan (4), kanal tambak (5), dan lokasi bongkar muat perikanan (6). Rancangan acak kelompok dengan analisis ANOVA digunakan untuk membandingkan kelimpahan plankton antara lokasi dan waktu pengamatan. Analisis karakterisasi situs dilakukan menggunakan *principal component analysis* (PCA) dan hubungan antara genus plankton dan waktu pengamatan dianalisis menggunakan *correspondence analysis* (CA). Hasil penelitian menunjukkan kelimpahan total fitoplankton tertinggi pada minggu ke-4 di lokasi 1 (3,124 individu/L). Pada pengamatan awal, kelimpahan total zooplankton tertinggi ditemukan di lokasi 1 (508 individu/L). Penelitian ini juga menunjukkan bahwa kelimpahan fitoplankton secara parsial dipengaruhi oleh salinitas dan NO_3, sedangkan kelimpahan zooplankton tidak dipengaruhi oleh semua variabel kualitas air. Berdasarkan *principal component analysis* (PCA), Lokasi 4 dan 2 dicirikan oleh parameter suhu air, pH, dan PO_4. Lokasi 1 dan 6 dicirikan oleh parameter salinitas, kecerahan, dan NO_3. Lokasi 5 dikarakterisasi secara lemah oleh PO_4. Lokasi 3 tidak ditandai oleh parameter kualitas air apa pun. *Chaetoceros* adalah fitoplankton dengan nilai massa tertinggi dalam profil garis (0,279). Nilai massa zooplankton terbesar (0,501) berasal dari subkelas Copepoda.

Kata kunci: analisis komponen utama, analisis korespondensi, kelimpahan plankton, kualitas air, *silvofishery*

INTRODUCTION

Coastal areas are often utilized used for aquaculture activities to increase the income of the local community income (Aheto *et al.,* 2019). However, this condition can cause ecosystem degradation, especially through mangrove deforestation (Aslan *et al.,* 2021; Lukman *et al.,* 2021). An environmentally friendly aquaculture system, including silvofishery, has been implemented in Indonesia (Putra *et al.,* 2025). Silvofishery integrates brackish water aquaculture with mangrove conservation efforts (De-León-Herrera *et al.,* 2015; Musa *et al.,* 2020). The Research Center for Brackishwater Aquaculture and Fisheries Extension (BRPBAPPP) in Maros Regency has developed an innovative symbiotic relationship that combines aquaculture with environmental conservation through a silvofishery pond system. By adopting this system, local people can enhance their income through aquaculture while minimizing negative impacts on the natural ecosystem in the area (Rahman & Mahmud, 2018).

The composition of plankton in aquatic ecosystems can reflect the overall productivity of these ecosystems (El Gammal *et al.,* 2017). Plankton contributes up to 90% of the primary food supply in aquatic ecosystems (Kyewalyanga *et al.,* 2020). Phytoplankton and zooplankton play a central role in driving fish productivity as they are the primary producers of the trophic structure of aquatic food webs (Kyewalyanga & Malesa, 2024; Ren *et al.,* 2024). In addition, they are essential for enhancing water quality, preserving the natural environment, and diluting toxic substances in aquatic ecosystems (Lu *et al.,* 2022).

Recent studies indicate that various water quality factors strongly influence plankton abundance (Escalas *et al.,* 2022; Kyewalyanga *et al.,* 2020; Lubis *et al.,* 2024). The main factors are physico-chemical, such as water temperature, brightness, dissolved oxygen (DO), salinity, pH, nitrate (NO_3), and phosphate (PO_4) (Gogoi *et al.,* 2019; Kyewalyanga *et al.,* 2020). Nutrient availability for photosynthesis can also affect the plankton life cycle, subsequently affecting its abundance (Escalas *et al.,* 2022; Painter *et al.,* 2021; Volynkin & László, 2020). Plankton abundance can vary significantly among aquatic ecosystems, especially in coastal areas, where a combination of marine runoff, riverine inflow, and settlement activities affects plankton dynamics (Kyewalyanga *et al.,* 2020; Sekadende *et al.,* 2021).

BRPBAPPP's silvofishery ponds in Maros Regency are located near the Marana River, agricultural areas, and mariculture activities, creating a high diversity of aquatic biota in this area. However, information on plankton abundance and associations in this area remains to be explored. Therefore, this study aims to examine zooplankton and phytoplankton abundance, site characteristics, and associations between zooplankton and phytoplankton in silvofishery ponds at BRPBAPPP Maros Regency. The results of this study provide insights into the dynamics of relationships between zooplankton and phytoplankton species in habitats with specific characteristics and their implications for aquaculture productivity.

MATERIALS AND METHODS

Study area

This study was conducted from December 2022 to February 2023 at the silvofishery pond installation area of the Brackish Water Aquaculture Research and Fisheries Extension Center (BRPBAPPP), Maros Regency, South Sulawesi Province. Water and plankton sampling sites in the silvofishery Pond Installation area are shown in Figure 1, and the profile of each site is presented in Table 1.

Sampling procedure

This study uses a purposive sampling method for each site. The selection of these sites was based on their representative features, such as varying water quality conditions and their relevance to silvofishery systems in Maros Regency. These locations were selected due to their ecological and environmental diversity, which is crucial for understanding plankton dynamics in relation to varying water quality parameters. Water sampling was conducted twice weekly (5 rounds of observation), which was chosen to calculate temporal variations, notably coinciding with dry season tides and significant water volume changes (Sekadende *et al.,* 2021). This time was chosen to align with the routine water replacement practices commonly used by pond farmers and often relies on this tidal cycle for water management. The water samples then used for water quality analysis (physicochemical) and plankton analysis. Plankton samples were collected by filtering 100 L of water using a plankton net with a mesh size of 25 µm, concentrated to 30 mL, and preserved with 1% Lugol's solution in a plankton bottle.

Water quality analysis

These water samples were used for in situ water quality measurements, including physicochemical tests. The water quality parameters and data collection tools used in this study are provided in Table 2.

Plankton analysis

Plankton samples were identified to the genus level at the BRPBAPPP Laboratory based on identification guides (Newell & Newell, 1970; Yamaji, 1979). Identification and abundance counting were performed with the Sedgwick Rafler Counter Cell chamber under an Olympus U-PMTVC electric microscope (Lundgreen *et al.,* 2019). Plankton abundance was quantified

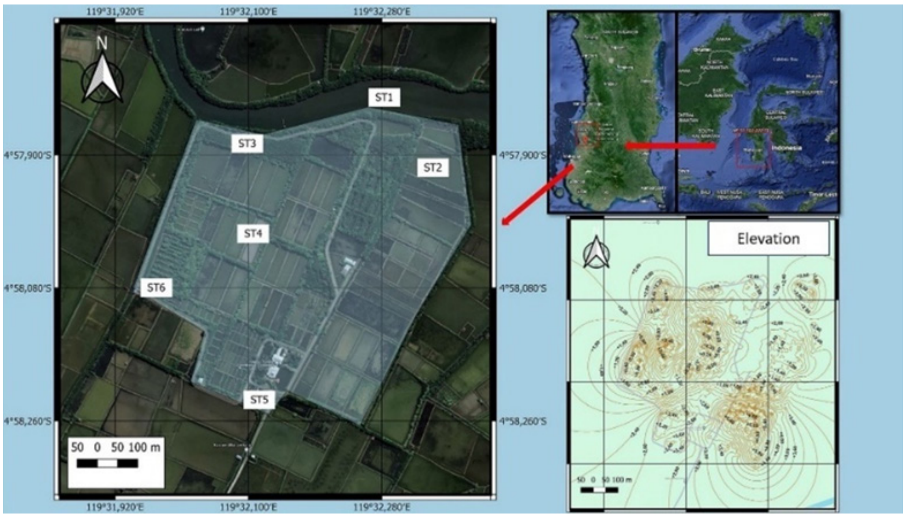

Figure 1. Study sites for water sampling and plankton at Silvofishery pond installation area of Brackish Water Aquaculture Research and Fisheries Extension Center (BRPBAPP), Maros Regency, South Sulawesi.

Table 1. Site study characteristic at Silvofishery pond installation area of Brackish Water Aquaculture Research and Fisheries Extension Center (BRPBAPP), Maros Regency, South Sulawesi.

Site	Profile
1	Marana River (source of raw water for aquaculture activities).
2	Polyculture pond of *Gracilaria* and milkfish.
3	Mangrove reservoir/biofilter of Marana River water before its distribution to the pond plots.
4	Milkfish bait production pond.
5	A pond inlet/outlet canal connected to a farm irrigation disposal canal.
6	A loading and unloading point for fishery products and pond production facilities (pier).

Table 2. Water quality parameters and tools used at Brackish Water Aquaculture Research and Fisheries Extension Center (BRPBAPP) Laboratory, Maros Regency, South Sulawesi.

Parameter	Tool	Description
	Physical	
Temperature (°C)	DO meter YSI	In-situ
Brightness (m)	*Secchi disk*	In-situ
	Chemistry	
Dissolved oxygen (mg/L)	DO meter YSI	In-situ
Salinity (ppt)	DO meter YSI	In-situ
pH	DO meter YSI	In-situ
NO_3 (mg/L)	UV-Vis spectrophotometer UV2401PC	BRPBAPPP Laboratory
PO_4 (mg/L)	UV-Vis spectrophotometer UV2401PC	BRPBAPPP Laboratory

as the number of cells per liter using the formula provided by Malik and Halima (2019).

$$N = n \times \left[\frac{Vr}{Vo}\right] \times \left[\frac{1}{Vs}\right]$$

Note:
N = Total cell count per liter
n = Total cell count observed (individuals)
Vr = Filtered water volume (mL)
Vo = Volume of observed water (mL)
Vs = Volume of water before filtering (l)

Data analysis

Comparative analysis of plankton abundance between sites and observation times was conducted using ANOVA with a Randomized Group Design (RGD), using sites as a considered factor and time as a grouping variable. This data was analyzed using SPSS version 26. Principal component analysis (PCA) was used to characterize the site based on water quality parameters, and correspondence analysis (CA) was used to examine the association between plankton genera and observation time (Lu *et al.*, 2022).

RESULTS AND DISCUSSION

Result

Water quality

The results of water quality measurements at each site and observation time during the observation are shown in Table 3. Water temperature at each site, ranging from 25.1–36.2°C, is still within the limits that can be tolerated by zooplankton and phytoplankton. The optimum temperature range for plankton growth ranges from 28–32°C (Kyewalyanga & Malesa, 2024; Tambaru & Massinai, 2020). Additionally, brightness levels at each site were within tolerable limits. Plankton cannot perform photosynthesis when the brightness is less than 25 cm. High turbidity blocks the penetration of sunlight in phytoplankton photosynthesis and potentially causes siltation, although there was no significant siltation found at the study site (Lu *et al.,* 2022; Nahiduzzaman *et al.,* 2023; Wan *et al.,* 2023).

According to the chemical variable, dissolved oxygen content throughout the study site ranged from 2.58–8.1 mg/L. Based on these results, dissolved oxygen levels are still relatively suitable to maintain the aquatic ecosystem, especially for zooplankton and phytoplankton. This result is in accordance with the research of Kyewalyanga *et al.* (2020), which states that the optimal dissolved oxygen level for plankton growth is 6.70–6.77 mg/L. Salinity levels at all sites ranged from 0.15–18.87 ppt. According to a study by Hendrajat and Sahrijanna (2019**),** phytoplankton can survive, reproduce, and perform frequent photosynthesis at salinity levels of more than 20 ppt. Nevertheless, the results of this study show that phytoplankton can still survive even in salinities <20 ppt.

For all sites, the pH of the water indicates relatively high biodiversity, which is characterized as a productive condition. A pH between 6 and 9 can encourage the mineralization of organic substances that can be assimilated by phytoplankton (Buana *et al.,* 2021). The NO_3 levels at each site are still suitable for phytoplankton growth. The ideal NO_3 level to support phytoplankton life

Table 3. Water quality at each site and observation time at silvofishery pond installation area of Brackish Water Aquaculture Research and Fisheries Extension Center (BRPBAPP), Maros Regency, South Sulawesi.

Parameter	Site					
	1	**2**	**3**	**4**	**5**	**6**
Physical						
Temperature (°C)	25.1–35.5	26.5–33	26.9–32.1	26.8–36.2	25.3–31.6	25.1–33.1
Brightness (m)	43-107	48-62	54-68	50-64	37-56	37-116
Chemistry						
Dissolved oxygen (mg/L)	4.06–6.49	4.26–5.77	2.58–4.5	4.96–8.10	4.13–5.61	4.48–5.96
Salinity (ppt)	0.34 –23.4	0.95–16.68	1.36–10.65	1.36–11.86	0.15–8.64	0.24–18.87
pH	7.02–8.07	7.27–7.90	7.03–7.57	7.84–8.12	7.32–7.96	7.36–7.85
NO_3 (mg/L)	0.08–0.78	0.04–0.38	0.04–0.21	0.05–0.10	0.12–0.41	0.21–0.41
PO_4 (mg/L)	0.08–0.78	0.04–0.38	0.04–0.21	0.05–0.10	0.12–0.41	0.21–0.41

is 0.01-1 mg/L (Patty & Akbar, 2019). From the result, PO_4 concentrations are classified as low to high fertility levels, sufficient to support phytoplankton life.

Phytoplankton identification and abundance

The total phytoplankton counts recorded at each sampling site and during each observation week are shown in Table 4. These data provide an overview of the temporal and spatial variations in phytoplankton abundance throughout the silvofishery pond system. This study found 31 phytoplankton genera from all observation sites, as shown in Appendix 1. The highest total phytoplankton abundance was observed in week 4 at site 1 (3,124 ind/L). The lowest total phytoplankton abundance was observed in week 6 at site 4 (33 ind/L) as shown in Table 4. The comparative analysis of phytoplankton abundance between sites and observation times showed significant differences (P<0.05) by observation time, but no significant differences (P>0.05) were found between sites (Table 5). This result suggests that variations in phytoplankton abundance at all sites are more influenced by the observation time than by site characteristics.

Although the observation period was two weeks, the rainfall and environmental fluctuations in the short period were significant enough to affect plankton abundance. Therefore, the influence of seasonality is still observed. These results align with Gogoi *et al.* (2019) and Kyewalyanga *et al.* (2020), state that nutrient fluctuation is influenced by the seasonal changes, affecting the abundance of plankton. The Tukey HSD BNT test showed that the highest average abundance of phytoplankton was obtained in week 4, which was not significantly different (P>0.05) from the average phytoplankton abundance in the initial observation (week 0). However, it is significantly different (P<0.05) from the abundance of phytoplankton in week 8 and week 2 of observation.

Phytoplankton abundance between the initial, week 8, and week 2 was not significantly different (P>0.05). The lowest mean phytoplankton abundance found in the week 6 was not significantly different (P>0.05) with week 2 and week 8, but significantly different (P<0.05) from the initial observation. The phytoplankton abundance results showed that the highest abundance was in the week 4, as shown in Figure 2. This condition, caused by no rain during that week, resulted in optimal water temperatures for phytoplankton growth, averaging 28-32°C (Tambaru & Massinai, 2020). In contrast, phytoplankton abundance decreased in the week 2 of observation because a few days before and until the observation was conducted, rain persisted throughout the day.

Table 4. Total phytoplankton abundance each site and observation time at silvofishery pond installation area of Brackish Water Aquaculture Research and Fisheries Extension Center (BRPBAPP), Maros Regency, South Sulawesi.

Observation (week)	Abundance (ind/L)					
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
0	1.467	1.043	1.108	341	893	1.034
2	117	75	67	50	750	541
4	3.124	625	1.799	800	1.175	2.657
6	133	58	71	33	87	108
8	1.374	533	383	491	1.000	541

Table 5. Analysis of variance (ANOVA) comparison of phytoplankton abundance between sites and observation times.

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	12510039.600[a]	9	1390004.400	6.398	.000
Intercept	16842016.133	1	16842016.133	77.516	.000
Site	2725859.067	5	545171.813	2.509	.064
Time	9784180.533	4	2446045.133	11.258	.000
Error	4345424.267	20	217271.213		
Total	33697480.000	30			
Corrected total	16855463.867	29			

Note: Dependent variable = Abundance. R Square = .742 (Adjusted R squared = .626).

The rain can cause a decrease in temperature, salinity, and brightness (25°C; 1.3 ppt; 49 cm) (Cutajar *et al.*, 2024). Decreased water brightness will reduce the level of sunlight penetration, impacting the low photosynthesis process carried out by phytoplankton (Li *et al.*, 2023). The decrease in plankton abundance is caused by several factors, such as decreased water pH, mineral concentrations, micronutrients, and low sunlight intensity (Greco *et al.*, 2023; Karavoltsos *et al.*, 2022; Slater *et al.*, 2022). Increased rainfall causes seawater salinity to be low and vice versa (Wang *et al.*, 2018). Low phytoplankton abundance was also found in week 6 and week 8 because a flood drained the plankton in the study site to the sea.

Zooplankton identification and abundance

This study found 12 zooplankton genera from all observation sites, as shown in Appendix 2. The highest total zooplankton abundance was found in site 1 at the initial observation (508 ind/L). The lowest total zooplankton abundance was found in site 3 at week 8 and site 4 at week 2 observation (8 ind/L). The total zooplankton abundance at each site is provided in Table 6. The results of the

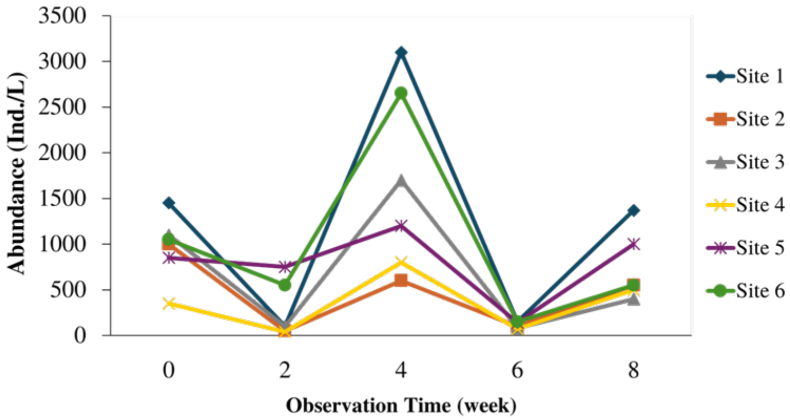

Figure 2. Phytoplankton abundance during observation.

Table 6. Total zooplankton abundance at each site and observation time at silvofishery pond installation area of Brackish Water Aquaculture Research and Fisheries Extension Center (BRPBAPP), Maros Regency, South Sulawesi.

Observation (week)	Abundance (ind/L)					
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
0	508	58	25	158	34	441
2	559	25	108	8	34	250
4	258	25	33	50	75	42
6	233	100	25	17	450	450
8	342	25	8	150	233	42

Table 7. Analysis of variance (ANOVA) comparison of zooplankton abundance between sites and observation times.

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	12510039.600[a]	9	1390004.400	6.398	.000
Intercept	16842016.133	1	16842016.133	77.516	.000
Site	2725859.067	5	545171.813	2.509	.064
Time	9784180.533	4	2446045.133	11.258	.000
Error	4345424.267	20	217271.213		
Total	33697480.000	30			
Corrected total	16855463.867	29			

ANOVA comparison of zooplankton abundance between site and observation time showed that zooplankton abundance was significantly different ($P<0.05$) by site but not significantly different ($P>0.05$) by observation time (Table 7). This result indicates that site characteristics significantly determine zooplankton abundance and type (Zhao *et al.,* 2018).

The changes in zooplankton abundance found at site 1 were not significantly different ($P>0.05$) from the average abundance of zooplankton at sites 5 and 6, but significantly different ($P<0.05$) from the abundance of zooplankton at sites 4, 2, and 3. The lowest average zooplankton abundance at site 3 was not significantly different ($P>0.05$) from that at sites 2, 4, 5, and 6. The graph of zooplankton abundance at sites 1, 5, and 6 fluctuates relatively high compared to sites 2, 3, and 4, as shown in Figure 3. This condition is suspected because sites 1, 5, and 6 are connected to the river estuary/beach and are accessible by the tides.

During high tide, stirring strongly influences temperature (lowest 25°C and highest 36°C), NO_3 (lowest 0.08 mg/L and highest 0.4 mg/L), and PO_4 (lowest 0.006 mg/L and highest 0.08 mg/L), all of which are crucial to plankton abundance. The results of this study are consistent with the research of *Sekadende et al.* (2021) and Kyewalyanga *et al.* (2020), which found that tidal movements influence water characteristics. However, sites 2, 3, and 4 are located in the aquaculture area and thus not directly influenced by the tides. The fluctuations are relatively low enough to carry zooplankton to these three sites.

Based on Table 6, the zooplankton abundance at site 1 was higher than at the other sites. Site 1 also had a higher NO_3 concentration, which could explain the higher zooplankton abundance at this location. This condition is caused by its location in the Marana River, which automatically receives marine water input that carries plankton and nutrients at high tide. In addition, there are agricultural lands, residential areas (upstream on the river), and aquaculture areas on both sides of the Marana River.

Domestic waste, overflow from rivers, and many human activities around the sites will impact the presence of nutrients (Zhao *et al.,* 2021). The presence of human activities, such as organic waste disposal (e.g., food waste), increases the amount of organic matter in water bodies (Lai *et al.,* 2022). Organic waste that enters the water will be decomposed by aerobic bacteria into nitrite (NO_2) or nitrate (NO_3), becoming a source of nutrients for phytoplankton. Phytoplankton are prey for zooplankton, which automatically increases the food source of phytoplankton, which will increase zooplankton in the waters (Han *et al.,* 2024).

In comparison to the zooplankton and phytoplankton abundance data, there is a positive correlation between them. The higher the abundance of phytoplankton in the water, the higher the abundance of zooplankton at that location. In this condition, the abundance of phytoplankton is higher, which can also be seen in the results of phytoplankton and zooplankton abundance at site 1.

Relationship between phytoplankton abundance and water quality

The partial significance test (t-test) results indicate that water temperature, dissolved oxygen, pH, brightness, and PO_4 have a significance value >0.05. These results indicate that water

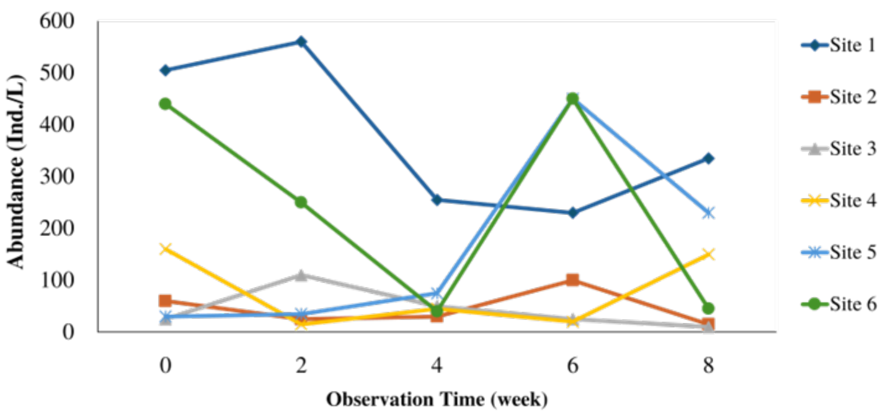

Figure 3. Zooplankton abundance during observation.

temperature, dissolved oxygen, pH, brightness, and PO_4 have no significant influence on phytoplankton abundance. On the other hand, salinity and NO_3 have a significant value <0.05, indicating that they partially influence phytoplankton abundance. The simultaneous significance test (f-test) between environmental parameters and phytoplankton abundance has a significant value of 0.000, less than 0.05 (0.000<0.05). This result indicates that water temperature, dissolved oxygen, pH, salinity, brightness, NO_3, and PO_4 simultaneously significantly influence phytoplankton abundance. From the SPSS output, the adjusted R^2 is 0.699. This result indicates that 69.9% of the variation in phytoplankton abundance values can be explained by all independent variables (water temperature, dissolved oxygen, pH, salinity, brightness, NO_3, and PO_4). Other causes outside the model explain the others studied.

Relationship between zooplankton abundance and water quality

The results of the partial significance test (t-test) on water quality variables have a significance >0.05. This result indicates that the variables of water temperature, dissolved oxygen, salinity, pH, brightness, NO_3, and PO_4 do not have a significant effect on zooplankton abundance. Similarly, from the simultaneous significance test (F-test) the significant value of 0.168 is greater than 0.05 (0.168>0.05), which indicates all water quality variables simultaneously have no significant influence on zooplankton abundance.

Sites characteristics

The linear combination of the variables is shown in Figure 4. The value of axes F1 and F2 is 84.49%, indicating that the characteristics of environmental parameters influence all observation sites by 84.49%. This value is representative of explaining the existing data. The red axis is the water quality parameter, and the blue point is the observation site. The angle of the red axis that forms a small angle means a relatively strong relationship between the variables of the water quality parameters. Conversely, axes forming a large angle have a weaker relationship and may not be correlated.

Figure 4 shows that different water quality parameters characterize some sites. Sites 4 and 2 are characterized by three parameters: dissolved oxygen, water pH, and temperature. Although these three parameters are dominant, there is a possibility of overlap, which is explained in the PCA analysis and can be seen at the site 2 position in Figure 4. Sites 1 and 6 are characterized by salinity, brightness, and NO_3. Salinity dominates due to the presence of the Marana River at site 1 and the boat dock at site 6, which is reached by the tides. Site 5 was characterized by PO_4 content, but not strongly enough, while any water quality parameters or nutrient distribution in the water did not characterize site 3. This condition is caused by site 3, which has lower nutrient concentrations compared to the other sites.

Table 3 shows that site 3 has the lowest concentration of water quality parameters. This nutrient deficiency is because this site is not heavily influenced by tides or river flow. Sites 1

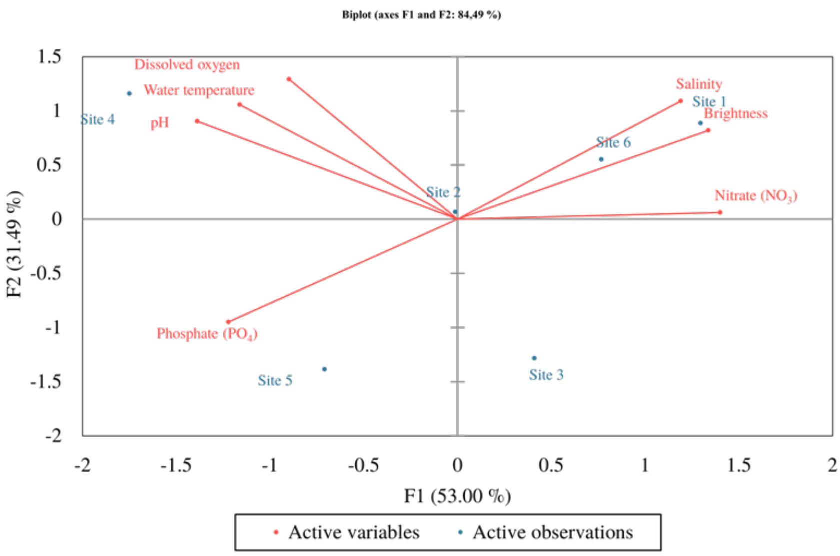

Figure 4. Site characteristics based on PCA analysis of water quality.

and 6 have a higher abundance of phytoplankton and zooplankton than the others. This condition is due to the brightness and nutrients being relatively good at the site. Thus, phytoplankton can perform the process of photosynthesis well.

The high phytoplankton in the waters will automatically be followed by high zooplankton. This condition is due to phytoplankton being predators of zooplankton. Sites 2 and 4 had low plankton abundance because phytoplankton abundance is not influenced by water quality but by nutrients and the abundance of zooplankton as their prey. Site 5 had slightly higher plankton abundance because the PO_4 content was quite good. Some species of phytoplankton need PO_4 as their nutrient (Kyewalyanga *et al.,* 2020).

Association between phytoplankton and observation time

Based on the *chi-square* test in Table 8, the p-value >α (1,000>0.05) indicates that there is no significant association between phytoplankton species and observation time. In the row profile, the genus *Chaetoceros* has the largest mass value of 0.279 (Appendix 1). *Chaetoceros* is shown in Figure 5. In the column profile, the largest mass value of 0.337 was found at week 4 (Appendix 2). These results indicate that the highest phytoplankton species association occurred in week 4 of observation.

Table 9 shows the number of dimensions, where the dimensions we use are based on the *accounted-for* value *in* the *proportion of the inertia* section with a value above 0.2. In Table 8, there are four dimensions, but only two dimensions are used, specifically the first and the second dimensions. The first dimension›s value is 57.9%, and the second dimension›s value is 23.2%, giving an accumulative value of 81.1%. The accumulative value is relatively high and indicates that the *Correspondence Analysis* (CA) is valid.

Figure 6 shows that when viewed parallel to the horizontal axis, *Amphora* and *Chaetoceros* have a relatively close distance, indicating that these two species were associated in the early observations. Similarly, *Asterionellopsis*, *Crucigenia*, *Tetraselmis*, *Petalomonas*, *Ceratium*, and *Protoperidinium* were intensely associated in the week 2 of observation. The association of the

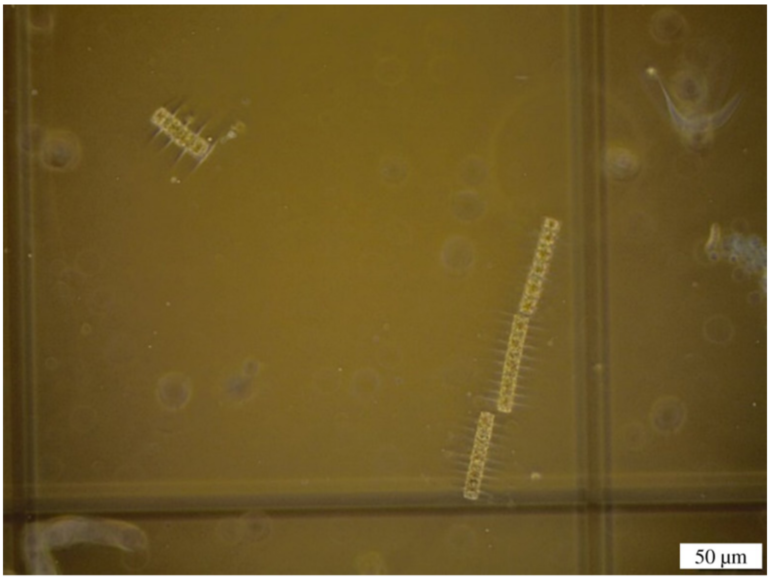

Figure 5. *Chaetoceros* under an electric microscope at magnification 16×10.

Table 8. Correspondence analysis (CA) for the association between phytoplankton species and observation time.

Value	df	Asymptotic Significance (2-sided)
.000[a]	120	1.000
.000	120	1.000
.000	1	1.000
155		

[a]155 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

phytoplankton genus in the week 4 of observation occurred between *Ditylum*, *Eucampia*, *Guinardia*, *Dinophysis*, *Noctiluca*, and *Biddulphia*. Furthermore, the association in the *Gymnodinium*, *Amphora*, and *Nitzschia* occurred in week 6. *Podolampas*, *Anabaena*, *Spirulina*, *Closterium*, *Gyrosigma*, and *Thalassionema* were associated in the eighth week of observation. These results were also proven in the first stage through the column profiles analysis, where the phytoplankton genus with the most significant value in the profile of each row and each observation time indicates a close association.

Association between zooplankton and observation time

Based on the chi-square test in Table 10, the Pearson Chi-Square p-value is 0.000. This value is smaller than the alpha of 0.05 (0.000<0.05), indicating an association between zooplankton

Table 9. Phytoplankton summary at silvofishery pond installation area of BRPBAPP, Maros Regency, South Sulawesi.

Dimension	Singular value	Inertia	Chi square	Sig.	Proportion of inertia		Confidence singular value	
					Accounted for	Cumulative	Standard deviation	Correlation
1	.539	.290			.579	.579	.020	.406
2	.341	.117			.232	.811	.014	
3	.261	.068			.136	.947		
4	.164	.027			.053	1.000		
Total		.502	2523.571	.000[a]	1.000	1.000		

Note: [a]120 degrees of freedom.

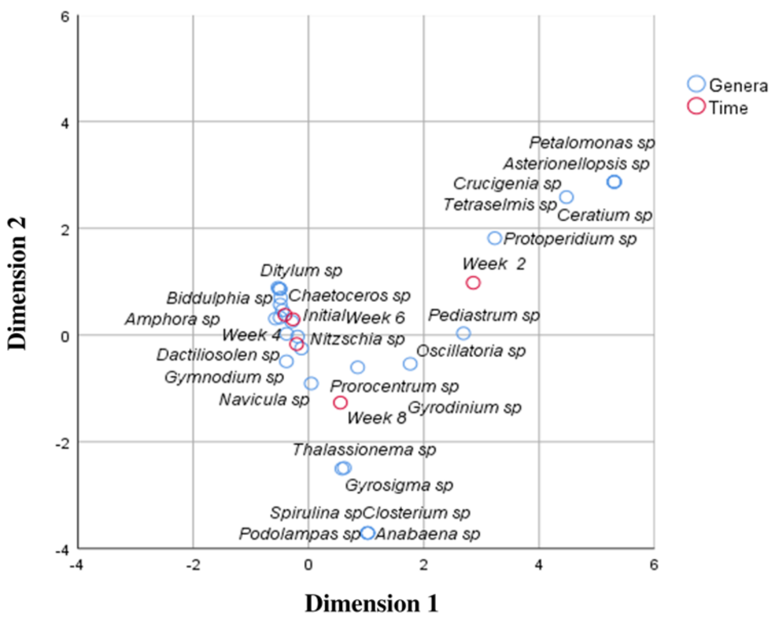

Figure 6. Correspondence graph of the association between phytoplankton species and observation time.

Table 10. Correspondence of association between zooplankton and observation time.

	Value	df	Asymptotic significance (2-sided)
Pearson Chi-Square	790.034[a]	40	.000
Likelihood Ratio	735.654	40	.000
Linear-by-Linear Association	22.929	1	.000
N of Valid Cases	795		

Note: [a]38 cells (69,1%) have expected count less than 5. The minimum expected count is 10.

species and observation time. Therefore, the association between zooplankton species and observation time is significant. The zooplankton with the most significant mass value in the row profile is from subclass Copepoda, which has a value of 0.501 (Appendix 3). Copepods are shown in Figure 7. It also has the most significant mass value in the column profile, which is 0.268, found at the observation time of week 6 (Appendix 4). These results indicate that the highest association between the zooplankton genus occurred during week 6 of observation.

Table 11 shows the summary of zooplankton with four dimensions, but only two dimensions, specifically the first and second dimensions, are used. In the first dimension, the value is 61.4%, and the second dimension has a value of 27.3%, causing the cumulative value to be 88.7%. This value is relatively high, which indicates that the CA is valid. In Figure 8, it can be seen that Copepoda is close to the initial observation. *Strombidium,* Amphipoda, and *Lecane*, when viewed parallel to the horizontal axis, are at a relatively close distance.

This result indicates that these three genera are associated in week 2 of observation. Copepoda, *Euplotes,* *Favella*, and *Apocyclops* were strongly associated in week 4 of observation.

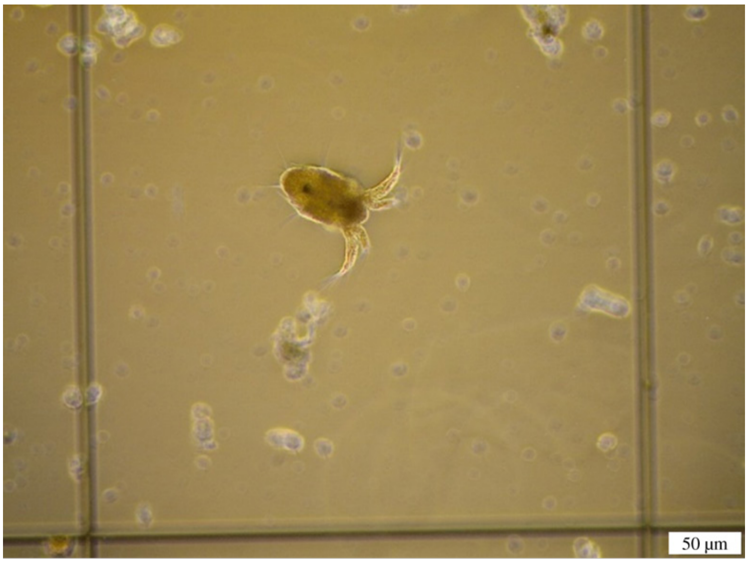

Figure 7. Copepoda under an electric microscope at magnification 10×16.

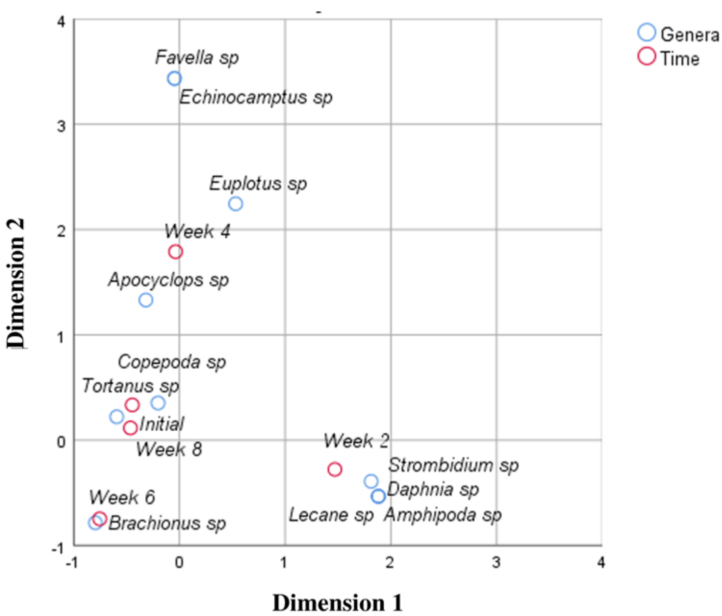

Figure 8. Correspondence graph of the association between zooplankton and observation time.

The association of *Branchiounus,* and Copepoda occurred during week 6 of observation. Furthermore, the association of Copepoda, *Brachiounus* and *Tortanus* occurred in week 8 of observation. The analysis results in the column profiles table also demonstrate that the most significant zooplankton genera in the profile, shown for each observation time, indicate a close relationship.

Discussion

This study found that salinity and nitrate (NO_3) levels had a significant effect on phytoplankton abundance at six study sites in the silvofishery ponds at the Center for Brackish Water Aquaculture Research and Fisheries Extension (BRPBAPPP). It is because the balance between salinity and nitrate levels is crucial for phytoplankton growth. The results of this study are consistent with those of Sarker *et al.* (2023), who found that water salinity significantly influences phytoplankton abundance. Salinity is significant to maintain the osmosis pressure between the body and the water. Thus, salinity can affect the abundance and distribution of plankton.

High salinity will cause the body's osmosis pressure, resulting in increased energy to adapt to the environment (Li *et al.,* 2023). In addition, the results of this study are also in line with the research by Khairy *et al.* (2024), which used CCA analysis to prove that nitrate concentration is a significant factor in phytoplankton abundance. Nitrate (NO_3) is a form of nitrogen that plankton, especially phytoplankton, can absorb. It is then processed into protein and may be a dietary source for another biota. Organisms use nitrates in the process of photosynthesis and protein synthesis and as a component of genes and growth (Li *et al.,* 2020).

This study shows that all water quality variables had no effect on zooplankton abundance. Various factors influence zooplankton abundance, including food availability, predation pressure, and habitat conditions. However, there are some cases where these factors do not influence zooplankton. For example, some zooplankton genetic variations have a high tolerance or adaptability to environmental conditions or water quality changes (Imant & Novoselov, 2021). In addition, the interaction of these water quality variables can neutralize their impact on zooplankton abundance (Vera-Mendoza & Salas-de-León, 2014).

This study also shows that there is no significant relationship between phytoplankton species and observation time. These results indicate that an observation period of eight weeks cannot yet be considered a primary factor determining phytoplankton community composition. The study by Demir and Turkoglu (2022) shows that variations in phytoplankton communities occur in tandem with changes in hydrographic conditions throughout the observation period. Additionally, Sarker *et al.* (2023) also confirms that phytoplankton communities along the coast of Bangladesh are more influenced by a combination of oceanographic parameters and nutrients. Therefore, with an 8-week observation period, the study only captures a segment of the community dynamics currently underway. The changes in phytoplankton composition observed between weeks are more accurately described as an ecological response to changing water conditions rather than a direct effect of the observation period itself.

Furthermore, this study also indicates that zooplankton species exhibit a significant relationship with the observation period. Although conducted over a short timeframe (December–February), these findings confirm that the zooplankton community during the observation period is dynamic, as indicated by

Table 11. Zooplankton summary.

Dimension	Singular value	Inertia	Chi square	Sig.	Proportion of inertia		Confidence singular value	
					Accounted for	Cumulative	Standard deviation	Correlation
1	.781	.610			.614	.614	.020	.204
nm[2]	.521	.272			.273	.888	.029	
3	.299	.090			.090	.978		
4	.149	.022			.022	1.000		
Total		.994	790.034	.000[a]	1.000	1.000		

the composition of zooplankton, which is not constant but shifts from week to week. In this study, the most dominant genus detected was Copepoda, with the highest abundance in week 6. This study aligns with Kim *et al.* (2024), which showed that Copepoda is the group most strongly driving changes in zooplankton community patterns despite seasonal variations. Thus, both on a seasonal and weekly scale, the Copepoda group appears to continue playing a major role in the temporal dynamics of the zooplankton community.

CONCLUSION

This study found the highest total phytoplankton abundance in week 4 of observation at site 1 (3,124 ind/L). However, the lowest total phytoplankton abundance was found in week 6 of observation at site 4 (33 ind/L). In the initial observation, the highest total zooplankton abundance was found at site 1 (508 ind/L). The lowest total zooplankton abundance was found at site 3 in week 8 of observation and site 4 in week 2 of observation (8 ind/L). Phytoplankton abundance varied significantly ($P<0.05$) according to observation times but showed no significant difference ($P>0.05$) across different sites. On the other hand, zooplankton abundance varied significantly ($P<0.05$) across sites, but no significant difference ($P>0.05$) was observed across observation times.

Principal Component Analysis (PCA) revealed that site 4 is primarily characterized by water temperature, pH, and phosphate (PO_4) parameters. In contrast, sites 1 and 6 are primarily characterized by salinity, brightness, and nitrate (NO_3) parameters, with salinity being the dominant factor in these sites (indicated by the longer axis). No water quality parameters were found to characterize sites 3 and 5 significantly. *Chaetoceros* exhibited the highest mass value among phytoplankton in the row profile, and the highest association between phytoplankton genera occurred during week 4. The highest zooplankton abundance was found in Copepoda, and the highest association with zooplankton genera was observed during week 6 of observation.

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REFERENCES

Aheto DW, Acheampon E, Odo JO. 2019. Are small-scale freshwater aquaculture farms in coastal areas of Ghana economically profitable?. Aquaculture International 27: 785–805.

Aslan A, Rahman AF, Robeson SM, Ilman M. 2021. Land-use dynamics associated with mangrove deforestation for aquaculture and the subsequent abandonment of ponds. Science of The Total Environment 791: 148320.

Buana S, Tambaru R, Selamat MB, Lanuru M, Massinai A. 2021. The role of salinity and total suspended solids (TSS) to abundance and structure of phytoplankton communities in Estuary Saddang Pinrang. In: IOP Conference Series: Earth and Environmental Science. IOP Conference Series: Earth and Environmental Science 860: 012081.

Cutajar J, Sterba-Boatwright B, Wetz MS. 2024. Coastal residential canals harbor distinct water quality conditions and phytoplankton community composition. Estuarine, Coast and Shelf Science 296: 108595.

De-León-Herrera R, Flores-Verdugo F, Flores-de-Santiago F, González-Farías F. 2015. Nutrient removal in a closed silvofishery system using three mangrove species (*Avicennia germinans*, *Laguncularia racemosa*, and *Rhizophora mangle*). Marine Pollution Bulletin 91: 243–248.

Demir EI & Turkoglu M. 2022. Temporal variations of phytoplankton community and their correlation with environmental factors in the coastal waters of the Çanakkale Strait in 2018. Oceanologia, 64: 176–197.

El Gammal MAM, Nageeb M, Al-Sabeb S. 2017. Phytoplankton abundance in relation to the quality of the coastal water – Arabian Gulf, Saudi Arabia. Egypt Journal Aquatic Research 43: 275–282.

Escalas A, Avouac A, Belmaker J, Bouvier T, Clédassou V, Ferraton F, Rieuvilleneuve F, Rilov G, Rovirosa Mulet A, Shapiro Goldberg D, Villéger S. 2022. An invasive herbivorous fish (*Siganus rivulatus*) influences both benthic and planktonic microbes through defecation and nutrient excretion. Science of The Total Environment 838: 156207.

Gogoi P, Sinha A, Das Sarkar S, Chanu TN, Yadav AK, Koushlesh SK, Borah S, Das SK, Das BK. 2019. Seasonal influence of physicochemical parameters on phytoplankton diversity and assemblage pattern in *Kailash Khal*, a tropical wetland, Sundarbans, India. Applied Water Science 9: 156.

Greco DA, Arnott SE, Fournier IB, Schamp BS. 2023. Effects of chloride and nutrients on freshwater plankton communities. Limnology Oceanography Letters 8: 48–55.

Han Q, Wang X, Peng S. 2024. Distribution pattern of zooplankton assemblages in the Eutrophic Hangzhou Bay, China. Regional Studies in Marine Science 70: 103368.

Hendrajat EA, Sahrijanna A. 2019. Kondisi plankton pada tambak udang windu (*Penaeus monodon* Fabricius) dengan substrat berbeda. Berita Biologi 18: 47–57. (In Indonesian).

Imant EN, Novoselov AP, 2021. Dynamics of zooplankton composition in the Lower Northern Dvina River and some factors determining zooplankton abundance. Russian Journal Ecology 52: 59–69.

Karavoltsos S, Sakellari A, Plavšić M, Bekiaris G, Tagkouli D, Triantafyllidis A, Giannakourou A, Zervoudaki S, Gkikopoulos I, Kalogeropoulos N. 2022. Metal complexation, FT-IR characterization, and plankton abundance in the marine surface microlayer of coastal areas in the Eastern Mediterranean. Fronties in Marine Science 9: 932446.

Khairy HM, Senousy HH, Faragallah HM, Keshta, A.E, Elshobary, M. E. 2024. Dynamics of phytoplankton community in the Eastern Harbor and Qaitbay Bay, Alexandria, Egypt: Seasonal abundance and ecological insights. *Egyptian Journal of Aquatic Research*, *50*(3), 309–317. https://doi.org/10.1016/J.EJAR.2024.06.006

Kim G, Park W, Choi DH, & Kang, H. K. 2024. Seasonal variation in the mesozooplankton community structure and indicator species of the Yellow Sea. Regional Studies in Marine Science, 73: 103454.

Kyewalyanga MS, Malesa FM. 2024. Seasonal variation in plankton abundance and diversity of Tanga coastal waters, Tanzania. Regional Studies in Marine Science 69: 103298.

Kyewalyanga MS, Peter N, Semba M, Mahongo SB. 2020. Coastal upwelling and seasonal variation in phytoplankton biomass in the Pemba Channel. Western Indian Ocean Journal of Marine Science 1: 19–32.

Lai Q, Shui J, Ma J, He F, Wang L, Peng, F, Zhu X, Pang Q, Wang Y. 2022. Effects of dissolved organic matter (DOM) on perfluorooctanoic acid (PFOA) in a Seagoing River—A Case Study of the Wanggang River Flowing into the East China Sea. Water (Switzerland) 14: 3580.

Li L, Song X, Wang Z, Wan M, Ni G, Tan Y, Li G. 2023. Nitrogen enrichment ameliorates the stimulatory effects of reduced salinity on photosynthesis and growth of phytoplankton assemblages in the Northern South China Sea. Marine Environmental Research 192: 106249.

Li Y, Nwankwegu AS, Huang Y, Norgbey E, Paerl HW, Acharya K. 2020. Evaluating the phytoplankton, nitrate, and ammonium interactions during summer bloom in Tributary of a Subtropical Reservoir. Journal Environmental Management 271: 110971.

Lu X, Zhang Y, Liu Y, Fan Y. 2022. Differences in planktonic and benthic diatoms reflect water quality during a rainstorm event in the Songhua River Basin of northeast China. Ecological Indicators 144: 109547.

Lubis VIS, Nirmala K, Supriyono E, Hastuti YP. 2024. Monitoring the water quality of Belawan Sea for rearing asian seabass Lates calcarifer in a floating net cage system. Jurnal Akuakultur Indonesia 23: 269–280.

Lukman KM, Uchiyama Y, Kohsaka R. 2021. Sustainable aquaculture to ensure coexistence: Perceptions of aquaculture farmers in East Kalimantan, Indonesia. Ocean & Coastal Management 213: 105839.

Lundgreen K, Eckford-Soper L, Pedersen KL, Holbech H. 2019. Development of a novel automated analytical method for viability assessment of phytoplankton used for validation of ballast water treatment systems. Journal of Applied Phycology 31: 2941–2955.

Malik AA, Halima AS, 2019. The Type and biodiversity of plankton in an integrated fishery activity in Waters of the Bay Awerange. IOSR Journal of Biotechnology and Biochemistry 5: 23–30.

Musa M, Mahmudi M, Arsad S, Buwono NR. 2020. Feasibility study and potential of pond as silvofishery in coastal area: Local case study in Situbondo Indonesia. Regional Studies Marine Science 33: 100971.

Nahiduzzaman M, Karim E, Nisheeth NN, Bhadra A, Mahmud Y. 2023. Temporal distribution of plankton and fish species at Mithamoin

Haor: Abundance, composition, biomass and ecosystem based management approach. Heliyon 9: e22770.

Newell GE, Newell RC. 1970. Marine Plankton: A Practical Guide. London: Anchor Press, and bound by Wm. Brendon. pp. 244.

Painter SC, Sekadende B, Michael A, Noyon M, Shayo S, Godfrey B, Mwadini M, Kyewalyanga M. 2021. Evidence of localised upwelling in Pemba Channel (Tanzania) during the southeast monsoon. Ocean & Coastal Management 200: 105462.

Patty SI, Akbar N. 2019. Sebaran horizontal fosfat, nitrat dan oksigen terlarut di perairan Pantai Bolaang Mongondow, Sulawesi Utara. Jurnal Ilmu Kelautan Kepulauan 2: 13–21. (In Indonesian).

Putra RS, Ernawita E, Iswahyudi. 2025. Prospects for Mangrove Reforestation Using the Silvofishery Method in Aquaculture Areas in Bireuen Regency, Aceh. Jurnal Akuakultur Indonesia 24: 244–257.

Rahman MM, Mahmud MA. 2018. Economic feasibility of mangrove restoration in the Southeastern Coast of Bangladesh. Ocean & Coastal Management 161: 211–221.

Ren Y, Shi W, Chen J, Li J. 2024. Water quality drives the reconfiguration of riverine planktonic microbial food webs. Environmental Research 249: 118379.

Sarker S, Riya SC, Rahman MJ, Huda ANMS, Hossain MS, & Das N. 2023. Spatial and temporal variability of phytoplankton dynamics in-relation to essential oceanographic variables in the south east coast of Bangladesh. Journal of Sea Research 195: 102438.

Sekadende BC, Michael A, Painter SC, Shayo S, Noyon M, Kyewalyanga, MS. 2021. Spatial variation in the phytoplankton community of the Pemba Channel, Tanzania, during the south-east monsoon. Ocean & Coastal Management 212: 105799.

Slater SM, Bown P, Twitchett RJ, Danise S, Vajda V. 2022. Global record of “ghost” nannofossils reveals plankton resilience to high CO_2 and warming. Fossil record 376: 853–856.

Tambaru R, Massinai A. 2020. Detection of HABs in the coastal Waters of Maros, South Sulawesi, Indonesia. International Journal of Advanced Science and Technology 29: 1672–1679.

Vera-Mendoza RR, Salas-de-León DA. 2014. Effect of environmental factors on zooplankton abundance and distribution in river discharge influence areas in the Southern Gulf of Mexico. In: Amezcua F, Bellgraph B. Fisheries Management of Mexican and Central American Estuaries. United States: Springer Dordrecht. pp. 93–112.

Volynkin AV, László GM. 2020. Revision of the genus *Palaeugoa* Durante, 2012, with descriptions of seven new species (Lepidoptera: Erebidae: Arctiinae: Lithosiini). Ecologica Montenegrina 36: 53–77.

Wan Y, Huang G, Du H, Yang S, Yang W, Li W. 2023. Effects of waterway regulation structures on the planktonic community in the upper Yangtze River. Ecological Indicators 155: 111049.

Wang Jin, Zhang J, Wang Jing. 2018. Sea surface salinity retrieval under rain based on aquarius combined active/passive observations. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 11: 367–374.

Yamaji I. 1979. Illustration of marine plankton of Japan. Japan: Hoikusha Publishing Company.

Zhao K, Cao Y, Pang W, Wang L, Song K, You Q, Wang Q. 2021. Long-term plankton community dynamics and influencing factors in a man-made shallow lake, Lake Dishui, China. Aquatics Sciences 83.

Zhao K, Wang L, Riseng C, Wehrly K, Pan Y, Song K, Da L, Pang W, You Q, Tian H, Liu S, Wang Q. 2018. Factors determining zooplankton assemblage difference among a man-made lake, connecting canals, and the water-origin river. Ecological Indicator 84: 488–496.