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Seasonality in Phytoplankton Species Composition and their Influence on Small Pelagic Fish along the Western Pemba Channel

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Abstract

The influence of phytoplankton biomass on small pelagic fish groups was studied at three sites along the Western Pemba Channel, to assess the contribution of seasonality. Sampling took place at the three sites in the coastal waters of Tanga, Tanzania. The study used *in-situ* data from July 2016 to January 2017, remotely-sensed chlorophyll-*a* data from August 2016 to August 2017 and 2019–2020, and small pelagic fish catch data from the same periods as the remotely-sensed data. The dominant groups at all the three sites were diatoms, dinoflagellates, and cyanobacteria, with diatoms having the highest number of species compared to the other two. In comparison to the southeast monsoon season, phytoplankton species and biomass were significantly higher during the northeast monsoon season. The most plentiful fish were anchovies, which had high peaks in both seasons, followed by sardinella, while mackerel had the lowest catch. Chlorophyll-*a* and anchovy catches showed a positive correlation; however, the relationship was not significant (r = 0.47, df = 11, p = 0.12). Both variables showed the highest peaks in October, while other fish groups showed very weak and insignificant positive or negative correlations. These findings suggest that factors other than phytoplankton biomass contribute to controlling small pelagic fish availability.

Keywords: Phytoplankton, monsoon seasons, chlorophyll-*a*, Pemba Channel, small pelagic fish.

Introduction

Phytoplankton are the foundation of the aquatic food webs (both freshwater and marine). They are highly effective primary producers. They play an important role in biogeochemical circles and sustain the marine biodiversity and fisheries of the world's oceans (Passow and Carlson 2012). Many marine animals' planktonic phases have been directly supported by phytoplankton, the second most important food source for small pelagic fish after zooplankton (Bachiller and Irigoien 2015, Abdellaoui et al. 2017). In Tanzania, phytoplankton and small pelagic fish abundances are mainly controlled by different predominant oceanic processes (Sekadende et al. 2020a, Painter et al. 2021), which are influenced by two seasonal monsoon wind systems, the northeast (NE) monsoon which runs from November to March, and the southeast (SE) monsoon season from May to September (Mahongo and Shaghude 2014). Phytoplankton and small pelagic fish composition, abundance and distribution vary greatly between the two seasons (Kizenga 2020).

Some studies along the Tanzanian coastal waters (Peter et al. 2018, Kyewalyanga et al. 2020, Peter et al. 2021) have shown that phytoplankton abundance is higher during the NE seasons especially around Tanga and Dar es Salaam. This has been linked to localized upwelling (Kyewalyanga et al. 2020) or nutrients input due to surface runoff.

However, in the deeper waters, phytoplankton abundance and productivity have been observed to be higher during the SE monsoon season (Barlow et al. 2011, Painter et al. 2021, Peter et al. 2021). Upwelling processes and mixing are the main drivers for phytoplankton abundance and productivity offshore and along the Pemba Channel, especially the eastern part of the channel (Semba et al. 2019, Kizenga et al. 2021, Painter et al. 2021).

Small pelagic fish in Tanzania include species from families Clupeidae (sardines and herring), Eungraulidae (anchovy) (Sekadende et al. 2020a) and Scombridae (mackerel). These fish groups are abundant on the whole coast of Tanzania and they constitute a major catch in many regions (Bidiguel and Breuil 2015). In most cases, the catches of these fish groups peak in different seasons and areas. The Tanzanian channels (Pemba, Zanzibar and Mafia) are the major fishing grounds for small pelagic fish (Mayala 2018, Kamukuru et al. 2020, Kizenga 2020). As foraging and highly migratory fish, they are found in large groups especially in areas with high food abundance nearshore and near the upwelling regions. Recently, Kizenga (2020) showed that the link between phytoplankton productivity and some small pelagic fish exhibits a positive trend along the eastern Pemba Channel. This, however, might not be the case for all small pelagic fish species, as other environmental conditions may influence their abundance (Bidiguel and Breuil 2015). Kizenga (2020) found a positive correlation between phytoplankton biomass as chlorophyll-*a* (Chl-*a*) concentration and mackerel and sardines in the eastern Pemba Channel, but a negative relationship with anchovies. Interestingly, anchovies showed a positive relationship with sea surface temperature, implying that phytoplankton abundance is not the only controlling factor for these fish groups. Since the animal component of the plankton group plays a bigger role as food for small pelagic fish (zooplankton consume phytoplankton, and the small pelagic fish feed mostly on zooplankton; Bachiller and Irigoien 2015, Sekadende et al. 2020b), the contribution by phytoplankton could be limited as its linkage is indirect for most species of small pelagic fish. Therefore, the current study aimed to determine the seasonal distribution of phytoplankton species and the extent to which their biomass (as Chl-*a* concentrations) contributes to the abundance of small pelagic fish in Tanga coastal waters.

Materials and Methods

Study area

The study area is located on the western side of the Pemba Channel, in Tanga coastal waters. It stretches from longitude 39.10° to 39.70° E and latitude 4.60° to 5.10° S (Figure 1). The area is known for the high productivity of small pelagic fishes (Kamukuru et al. 2020, Mwaipopo and Mahongo 2020). Three villages, representing fish landing sites (Mwaboza, Vyeru and Sahare) were chosen as sampling locations (Figure 1). The area is under the influence of seasonal reversals of monsoon winds (Mahongo and Shaghude 2014) and the passage of the East Africa Coastal Current (EACC) (Semba et al. 2019).

Phytoplankton identification and determination of chlorophyll-*a*

Sampling took place in July and September 2016, representing the SE monsoon season as well as in December 2016 and January 2017, representing the NE monsoon season. Each of the three sites was sampled once a month (10 stations each), giving a total of 120 stations (Figure 1). To collect phytoplankton, a net (mesh size 35 µm) was used. The samples were fixed using Lugol’s solution according to Anderson and Karlson (2017) and preserved for two weeks. A light microscope with magnification of x20 was used to identify phytoplankton species based on the previous studies and other materials (Bryceson 1977, Sahu et al. 2013, Moto 2017). Due to limitation of the mesh size of the net that was used to collect phytoplankton (35 µm), a bias was introduced whereby the smaller ones, especially picophytoplankton (< 2 µm) and the nanophytoplankton (2–20 µm) were missed out; only a part of microphytoplankton (20–200 µm) could be collected.

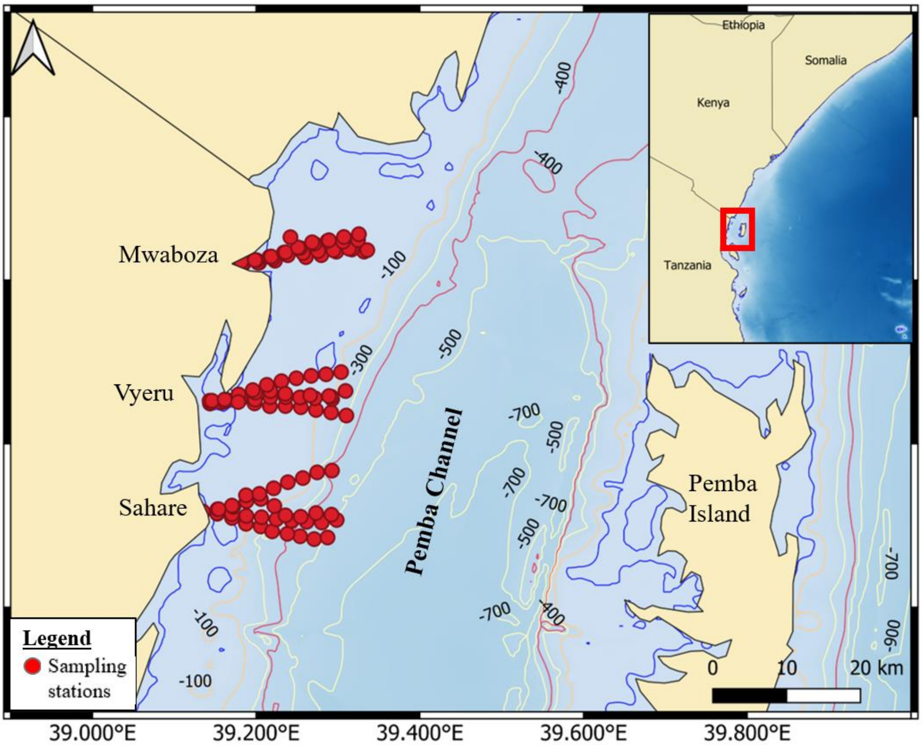

Figure 1: Map of the western Pemba Channel showing the transects and associated stations (red dots) in the study area. The inset map locates the study area in East Africa and the western Indian Ocean region.

Sampling for chlorophyll-*a* determination was done in the surface layer of the water column (in the top 0.5 m), samples were then filtered through 0.45 µm membrane filters, which were stored frozen (-20 °C) for later analysis. The filters were soaked in 10 ml of 90 percent acetone overnight at 4 °C for Chl-*a* extraction. Afterwards, the samples were centrifuged at 4000 rpm for 10 minutes, and the supernatant was decanted into a clean test tube. A spectrophotometer (UV 1601-Shumadzu Cooperation, Tokyo, Japan) was used to measure the absorbance of the samples. Then, Chl-*a* concentration was calculated as per Parsons et al. (1984).

Remotely-sensed chlorophyll-*a* data

Monthly satellite Chl-*a* level 3 merged data from August 2016 to August 2017 and 2019/2020 at 4 km resolution were retrieved from the Ocean Colour Climate Change Initiative (OC-CCI) project: https://rsg.pml.ac.uk/thredds/ncss/grid/CCI_ALL-v4.2-MONTHLY/dataset.html. The level 3 data product has been subjected to atmospheric correction and appropriate quality flags applied. The OC-CCI provides a rare long-term merged data series from different sensors, highly suitable for studying long-time events and climatology. For this study, monthly means for the whole study area (longitude 39.10° to 39.40° E and latitude 4.60° to 5.10° S) were computed. Previous studies along the eastern and western Pemba Channel have validated the use of remotely-sensed Chl-*a* data as proxy for phytoplankton biomass using *in-situ* data (Kizenga 2020, Peter 2013). As this dataset was retrieved for the purpose of identifying the link between phytoplankton biomass and small pelagic fish catches, this was the best way to extract the data, as the small-pelagic fishing grounds are shared by fishermen from the three sites.

Small pelagic fish

One-year catch data for small pelagic fish (August 2016–August 2017) came from two landing sites of the sampled area (Sahare and Vyeru). In addition, two-year anchovies (locally known as *uono*) catches from Sahare landing site, spanning from January 2019 to December 2020, were used in this study. Unfortunately, no small pelagic catches were recorded in Mwaboza landing site during the study period. At the two landing sites, recording of the data is normally done for 16 days consecutively in each month, based on occurrence of the new moon (during darkness), when the fishermen use lamps to attract the small pelagic fish. The recorded data are then used to estimate the monthly catch in kilograms. Data processing and reporting have been done in terms of seasons. The SE monsoon season (May to September) and the NE monsoon season (November to March). Data recorded during the inter-monsoon months of April and October were only included in the correlation analysis with Chl-*a* for both the 2016/2017 and 2019/2020 periods. It should be noted that, the fish catch data used in this study are fish landings rather than the catch per unit effort (CPUE) data, which would be more suitable. Regrettably the CPUE data were not available at the landing sites. Nonetheless, different studies along the East African waters and other parts of the world have correlated landings and phytoplankton biomass, as it has shown to be a good representative of the available resource (Kassi et al. 2018, Jebri et al. 2020, Kizenga et al. 2021).

Statistical analyses

One-way ANOVA (Analysis of Variance) was used to test for specific differences between phytoplankton groups followed by Tukey post hoc test as appropriate. Mann Whitney U test was used to test the seasonal differences in small pelagic fish catches as the data were not normally distributed. The seasonal differences in phytoplankton composition for the sites were compared using *t*-test. The relationships between Chl-*a* and catches were checked using Pearson's correlation test.

Results and Discussion

Phytoplankton community structure

Three main taxonomic groups (classes) of phytoplankton were identified at the three sampled sites, including Bacillariophyceae (diatoms), Dinophyceae (dinoflagellates), and Cyanophyceae (cyanobacteria) (Table 1, Annex 1). Regardless of the season or the site, it was consistently observed that diatoms had the highest number of species, followed by dinoflagellates, and to a lesser extent the cyanobacteria (Figure. 2). Other classes of phytoplankton were rarely observed. A similar trend in such dominance had been observed by Limbu and Kyewalyanga (2015) and Moto et al. (2018), who sampled in Zanzibar coastal waters (eastern and western sides of Unguja Island). The total number of all phytoplankton species encountered at each sampling site for the entire sampling period did not vary significantly (F (2, 796) = 0.962, p = 0.383). Numerically, Sahare site was found to have a relatively high number of phytoplankton species (111 species: diatoms 72, dinoflagellates 32 and cyanobacteria 7), followed closely by Mwaboza site (109 species: diatoms 66, dinoflagellates 35, cyanobacteria 6, Crysophyceae 1 and Dictyochophyceae 1) and finally Vyeru site, with relatively smaller number of phytoplankton species (95 species: diatoms 63, dinoflagellates 30 and cyanobacteria 2). Some species exhibited spatial-temporal distribution, being found at all the three sites in one or both seasons (Table 1). The dominating phytoplankton species have a considerable impact on Chl-*a* concentrations, which was used in the correlation analysis with small pelagic fish. Such species, which were found at each site all the time included two diatoms: *Chaetoceros spp* and

Thallasiothrix frauenfeldii; one dinoflagellate *Amphidinium, spp;* and one cyanobacterium *Trichodesmium erythraeum* (*T. erythraeum*). However, the dominance of individual species could be site-specific. For example, Moto et al. (2018) found that the most cosmopolitan diatoms (genera) in Zanzibar waters were *Chaetoceros, Rhizosolenia and Nitzschia*, while for dinoflagellates the genera *Ceratium* and *Protoperidinium* dominated. Also, studying the Pemba Channel during the SE monsoon season, Sekadende et al. (2021) revealed that the genus *Chaetoceros* was rare, while *Nitzschia* was dominant.

Table 1: Most common phytoplankton species found at Mwaboza, Vyeru and Sahare sites, and in one or both of the two seasons, the NE and the SE monsoon. The presence or absence of other less-common individual phytoplankton species for a given season is shown in Annex 1.

S/N	Bacillariophyceae	Dinophyceae	Cyanophyceae
1.	*Chaetoceros sp.*	*Amphidinium inflatum*	*T. erythraeum*
2.	*Coscinodiscus sp.*	*Amphisolenium sp.*	
3.	*Coscinodiscus thonii*	*Ceratium candelabrum*	
4.	*Nitzschia pungens*	*Ceratium fusus*	
5.	*Rhizosolenia alata*	*Ceratium trichoceros*	
6.	*Rhizosolenia stolterfothii*	*Ceratium tripos*	
7.	*Thalassiothrix frauenfeldii*	*Gymnodinium sp.*	
8.		*Protoperidinium pyriforme*	

The seasonal differences in phytoplankton composition for all the three sites combined were highly significant (t (796) = 6.389, p = 0.000); and this has been observed to be true at all the three sites. The number of phytoplankton species was significantly higher during the NE monsoon season compared to the SE monsoon season at the Sahare (t (264) = 3.037, p = 0.003), the Vyeru (t (264) = 3.796, p = 0.000), and the Mwaboza (t (264) = 4.236, p = 0.000) sites. These findings are mirroring the observed Chl-*a* concentrations, which regardless of the site were significantly higher during the NE monsoon (Figure 3) as compared to the SE monsoon season (Kyewalyanga et al. 2020, Peter et al. 2021). This could be attributed to differences in the nutrient concentrations between seasons, caused by local upwelling in the study area during the NE monsoon season (Halo et al. 2020, Kyewalyanga et al. 2020). Under normal conditions, studies have shown the opposite, with the SE monsoon season being more productive in terms of Chl-*a* concentrations than the NE monsoon season (Limbu and Kyewalyanga 2015, Semba et al. 2016, Moto and Kyewalyanga 2017, Peter et al. 2018, Kizenga et al. 2021).

A modest latitudinal trend in the number of phytoplankton species was observed in the identified phytoplankton groups, where diatoms and dinoflagellates decreased or increased from north to south and vice versa (Figure 2). However, the reason behind such a trend is not clear, since Chl-*a* concentrations did not show a similar latitudinal (site-wise) trend. Instead, the values were relatively higher at the middle transect (Vyeru) compared to values from the northern and southern transects (Figure 3).

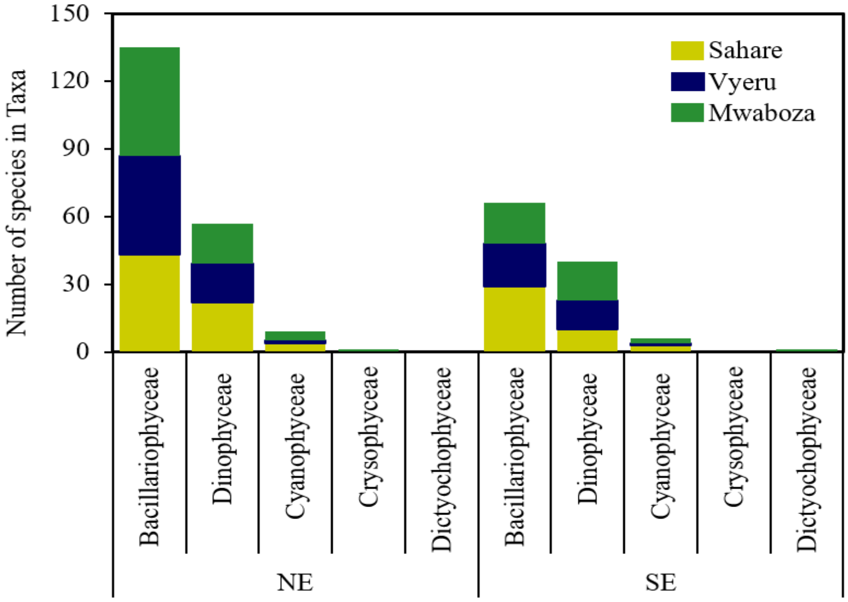

Figure 2: Number of phytoplankton species in Sahare, Vyeru and Mwaboza during the NE and SE monsoon seasons.

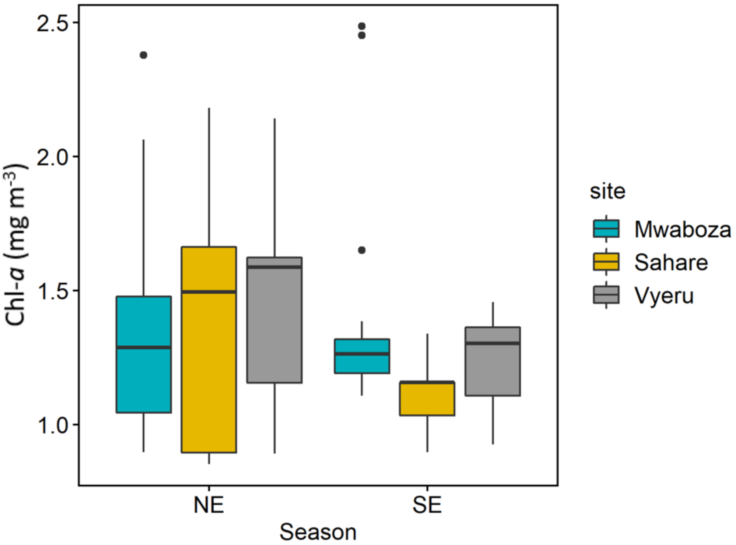

Figure 3: Chlorophyll-*a* concentration variations at Mwaboza, Vyeru and Sahare sites during the NE and the SE monsoon seasons, showing the higher biomass during the NE season (modified from Kyewalyanga et al. 2020).

Small pelagic fish catch

Four species of small pelagic fish were recorded in the 2016/2017 data, including anchovies (locally known as *uono*), Indian mackerel (*bangra*), sardinella (*dagaa papa*) and silver-stripe round herring (SSRH, locally called *msumari*). The most abundant species of small pelagic fish identified at the landing sites during both the SE and NE monsoon seasons were anchovies, which had the largest total catch of 126 tonnes and 121 tonnes in the NE and SE monsoon seasons, respectively (Figure 4). The second abundant group was sardinella, followed by the SSRH and lastly the Indian mackerel species, which had the lowest total catch amounting to only 5.5 tonnes during the NE season and 2.7 tonnes in the SE season (Figure 4).

Numerically, the maximum, minimum, and total catches for all four small pelagic fish species were consistently higher during the NE monsoon season than in the SE season. The differences in the seasonal mean values of the landed catch for small pelagic fish were only statistically significant for the SSRH (U (19) = 83, *p* = 0.013) and for the Indian mackerel (U (19) = 77, *p* = 0.045). However, there were some monthly variations in the catch within the NE monsoon season. For example, the biggest capture of sardinella and Indian mackerel occurred in November, whereas the highest catch of anchovies occurred in February, and the highest catch of SSRH occurred in January. Moreover, for sardinella, the average catch was only about 3.4 tonnes, while the maximum value for the NE monsoon season reached 18.5 tonnes. However, the differences between seasons for this group were insignificant (U (19) = 54, *p* = 0.791). The catch for the SE monsoon season also exhibited a similar trend.

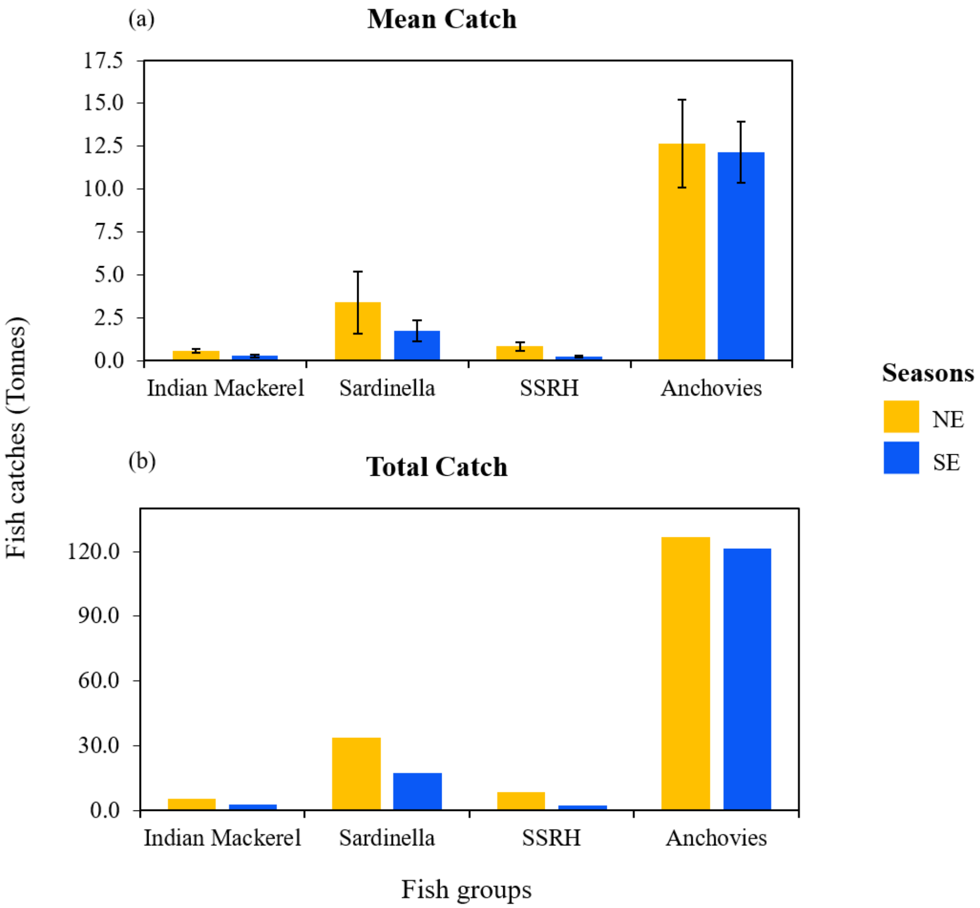

Figure 4: Fish catch (in tonnes) of landed small pelagic fish groups (combined for Sahare and Vyeru sites) during the SE monsoon season (May–September) and the NE monsoon season (November–March), (a) Mean catches with standard error of the means and (b) Total catches.

Relationship between phytoplankton biomass (Chl-*a*) and small pelagic fish catches

Two-year seasonal cycles (2019–2020) of satellite Chl-*a* as a proxy indicator for phytoplankton biomass were plotted against the fish catch seasonal cycles (Figure 5a). Anchovy catches were very high (41 tonnes) in October-the transition period from SE to NE monsoon seasons. Another high peak (35 tonnes) was observed in February during the NE monsoon season. Similarly, a notable highest Chl-*a* concentration (1.26 mg m^{-3}) was observed in October, matching the anchovy highest catch. The lowest catches were recorded in September during the SE monsoon season followed by November (beginning of the NE monsoon season) with 11 tonnes and 14 tonnes, respectively. However, the lowest Chl-*a* concentrations were observed in August followed by July, both in the SE season, with 0.589 mg m^{-3} and 0.619 mg m^{-3}, respectively. Pearson's correlation revealed that the relationship between Chl-*a* and anchovy catches was positive although not significant with $r = 0.47$, $p = 0.12$, implying that on average an increase in one variable matched the increase in the other.

The one-year cycle for Chl-*a* from August 2016 to August 2017 (Figure 5b), as well as the pooled total capture data for all small pelagic fish analyzed in this work, revealed a similar relationship to that shown in Figure 5a, although with a lesser degree of correlation. The highest total catch for all small pelagic fish was observed in October 2016 (68 tonnes), followed by November (55 tonnes). However, there was a mismatch in relation to Chl-*a*, where the highest concentration was observed in May 2017 (0.888 mg m^{-3}) followed by June (0.809 mg m^{-3}). The lowest fish catch was observed in April 2017 (15 tonnes) followed by June 2017 (19 tonnes) as shown in Figure 5b. Here, the lowest Chl-*a* concentration was also observed in April 2017 (0.551 mg m^{-3}) and August 2016 (0.565 mg m^{-3}). Pearson's correlation was done for all the four groups of small pelagic fish and their total catch against Chl-*a* concentrations, and revealed a statistically insignificant positive relationship between Chl-*a* and SSRH ($r = 0.03$, df = 12, $p = 0.91$), anchovy ($r = 0.07$, df = 12, $p = 0.82$) and total catches ($r = 0.05$, df = 12, $p = 0.87$). On the other hand, Indian mackerel and sardinella exhibited an insignificant negative relationship with Chl-*a* with $r = -0.18$, df = 12, $p = 0.55$ and $r = -0.01$, df = 12, $p = 0.96$, respectively.

The highly improved positive relationship between Chl-*a* and anchovy catches in the two-years seasonal cycle explains the link between phytoplankton biomass and anchovies as direct feeders on phytoplankton. The feeding behaviour of these foraging fish species mainly depends on the life stages and the availability of food. Different studies have explained the feeding behaviour of these fish species (Krishnakumar et al. 2008, Hulkoti et al. 2013). In most cases, they are found aggregated in areas with high phytoplankton biomass near shore or in upwelling regions (Bodiguel and Breuil 2015). However, the relationship between phytoplankton biomass and anchovy catches was not as strong as would have been expected, and this could have been influenced by their food preferences, especially when zooplankton are abundant. In many cases, it has been explained that zooplankton constitute the major food proportion for most small pelagic fish followed by phytoplankton and other food materials (Hulkoti et al. 2013). Since zooplankton consume phytoplankton, and the small pelagic fish feed mostly on zooplankton, thus, correlation between small pelagic fish and zooplankton would be stronger than that with phytoplankton. Also, a strong relationship is only observed when the competition from other fish groups of the same trophic level is low. However, anchovies have been shown to exhibit a negative relationship with other small pelagic fish such as sardines of family Clupeidae (MacCall 2009). These fish species compete fiercely for the resources and the outcompeted group either migrates or flourishes in a different season. As explained earlier, in this area there are other small pelagic fish that could be competitive to anchovies resulting in a weaker relationship.

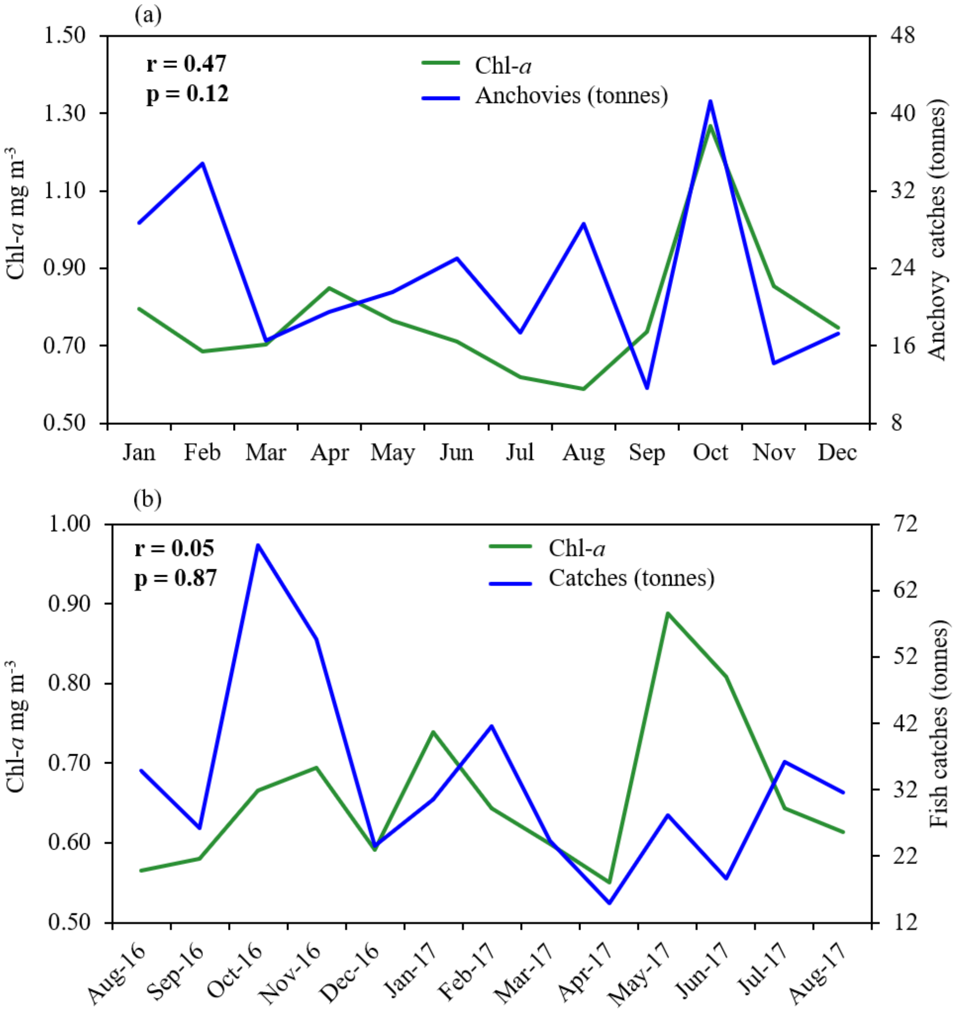

Figure 5: Seasonal cycles in (a) Chl-*a* and anchovy catches from 2019 to 2020 (2-year monthly data averaged to create one seasonal cycle) at the Sahare site and (b) Chl-*a* and total small pelagic fish catches for the four species from August 2016 to August 2017 for the two sites of Sahare and Vyeru.

The results in Figure 5b showed a very weak relationship between the pooled-up catch of the four species and Chl-*a*. Both figures showed high fish catch in October, however, Chl-*a* was highest in May when the catches were very low. Groupwise, anchovy and silver-stripe round herring showed a very weak positive link to phytoplankton biomass, while sardinella and Indian mackerel displayed very weak negative links to phytoplankton biomass. The opposite relationships displayed by the investigated groups indicate an inverse relationship between groups, where they peak at different seasons to reduce the competition for food, breeding, and other shared resources (MacCall 2009). These fish groups though they have many similarities, also have different environmental preferences from their feeding, migratory behaviour, and other environmental factors that make them abundant in different seasons.

The data used for this part were only for one year, from August 2016 to August 2017. This period is too short to really show a clear relationship between these ecosystem variables. Examining the anchovy/Chl-*a* correlations over a one-year and two-year timeframe explains this clearly. In the one year, the relationship was very weak with r = 0.05, but using a two-year cycle improved the relationship greatly to r = 0.47. Also, other than food (phytoplankton biomass) there are other environmental parameters such as oxygen, temperature and pH that can influence the fish behaviour and aggregation (Sekadende et al. 2020b, Kizenga et al. 2021). Some studies have also observed negative or weak positive relationships between small pelagic fish groups with Chl-*a*. Interestingly, the relationships were significantly positive with other environmental parameters, as illustrated by Kizenga (2020).

Conclusion

The results revealed that regardless of the site or season, the phytoplankton group with the highest number of species is that of diatoms followed by dinoflagellates, showing that the two groups play important roles in the food webs of the coastal waters of Tanzania. Seasonally, phytoplankton species and biomass (Chl-*a*) were found to be higher during the NE than the SE monsoon, which is an opposite trend to several previous studies (such as, Limbu and Kyewalyanga 2015, Semba et al. 2016, Kizenga et al. 2021), indicating the importance of local dynamics that included mixing, inputs from land and local upwelling; which could bring in nutrients, as shown by Kyewalyanga et al. (2020). The link between Chl-*a* and small pelagic fish was found to be positive and highly improved for anchovies collected over two years; while the one-year data for individual species or pooled data had very weak positive or negative relationships. To understand the actual contribution of phytoplankton biomass to small pelagic fish abundance, further studies that would assess long-term time series satellite Chl-*a* as related to the abundance of individual species of small pelagic fish are recommended.

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Declaration of Interest

The author declares that there is no conflict of interest in any aspect.

References

Abdellaoui B, Berraho A, Falcini F, Santoleri JR, Sammartino M, Pisano A, Idrissi MH and Hilm K 2017 Assessing the impact of temperature and chlorophyll variations on the fluctuations of sardine abundance in Al-Hoceima (South Alboran Sea). *J. Mar. Sci. Res. Dev.* 7(4): 1–11.

Anderson DM and Karlson B 2017 Preservatives and methods for algal cell enumeration. In: Anderson DM, Boerlage SFE and Dixon MB (Eds) Harmful Algal Blooms (HABs) and desalination: A guide to impacts, monitoring and management (pp. 509–517), Intergovernmental Oceanographic Commission of UNESCO, Paris.

Bachiller E and Irigoien X 2015 Trophodynamics and diet overlap of small pelagic fish species in the Bay of Biscay. *Mar. Ecol. Prog. Ser.* 534: 179-198.

Barlow R, Lamont T, Kyewalyanga M, Sessions H, van den Berg M and Duncan F 2011 Phytoplankton production and adaptation in the vicinity of Pemba and Zanzibar Islands, Tanzania. *Afr. J. Mar. Sci.* 33(2): 283-295.

Bodiguel C and Breuil C 2015 Report of the meeting on the small marine pelagic fishery in the United Republic of Tanzania. SFFAO/2015/34. IOC-SmartFish Programme of the Indian Ocean Commission (pp. 90), FAO Ebene, Mauritius.

Bryceson I 1977 *An ecological study of the phytoplankton of the coastal waters of Dar es Salaam*. PhD Thesis, University of Dar es Salaam.

Halo I, Sagero P, Manyilizu M and Mahongo SB 2020 Biophysical modelling of coastal upwelling variability and circulation along the Tanzanian and Kenyan coasts. *WIO J. Mar. Sci.* 1: 43-61.

Hulkoti SH, Shivaprakash SM, Anjanayappa HN, Somashekara SR, Benakappa S, Naik ASK, Prasad LG and Kumar J 2013 Food and feeding habits of mackerel *Rastrelling kanagurta* (Cuvier) from Mangalore region. *Environ. Ecol.* 31(2a): 672-675.

Jebri F, Jacobs ZL, Raitsos DE, Srokosz M, Painter SC, Kelly S, Roberts MJ, Scott L, Taylor SFW, Palmer M, Kizenga H, Shaghude Y, Wihsgott J and Popova E 2020 Interannual monsoon wind variability as a key driver of East African small pelagic fisheries. *Sci. Rep*. 10.

Kamukuru AT, Mahongo SB, Sekadende BC and Sululu JS 2020 Age, growth and mortality of the anchovy *Stolephorus commersonnii* (Lacepède, 1803)(Clupeiformes) caught off the coast of Tanga, Tanzania. *WIO J. Mar. Sci.* 1: 95-104.

Kassi J-B, Racault M-F, Mobio BA, Platt T, Sathyendranath S, Raitsos DE and Affian K 2018 Remotely sensing the biophysical drivers of *Sardinella aurita* variability in Ivorian waters. *Remote Sens.* 10(5): 785.

Kizenga HJ 2020 *Seasonal variation of primary productivity and small pelagic fish catches along the western coast of Pemba Island*. MSc Thesis, University of Dar es Salaam.

Kizenga HJ, Jebri F, Shaghude Y, Raitsos DE, Srokosz M, Jacobs ZL, Nencioli F, Shalli M, Kyewalyanga MS and Popova E 2021 Variability of mackerel fish catch and remotely-sensed biophysical control in the eastern Pemba Channel. *Ocean Coast. Manage.* 207: 105593.

Krishnakumar PK, Mohamed KS, Asokan PK, Sathianandan TV, Zacharia PU, Abdurahiman KP, Shettigar V and Durgekar RN 2008 How environmental parameters influenced fluctuations in oil sardine and mackerel fishery during 1926-2005 along the south-west coast of India? *Marine Fisheries Information Service* 198: 1-5.

Kyewalyanga MS, Peter N, Semba M and Mahongo SB 2020 Coastal upwelling and seasonal variation in phytoplankton biomass in the Pemba Channel. *WIO J. Mar. Sci.* 1: 19-32.

Limbu S and Kyewalyanga M 2015 Spatial and temporal variations in environmental variables in relation to phytoplankton composition and biomass in coral reef areas around Unguja, Zanzibar, Tanzania. *SpringerPlus* 4: 646.

MacCall AD 2009 Mechanisms of low-frequency fluctuations in sardine and anchovy populations. In: Checkley D, Alheit J, Oozeki Y and Roy C (Eds) *Climate change and small pelagic fish* (pp. 285-299), Cambridge University Press, Cambridge.

Mahongo SB and Shaghude YW 2014 Modelling the dynamics of the Tanzanian coastal waters. *Journal of Oceanography and Marine Science* 5: 1-7.

Mayala PJ 2018 *Assessment of socio-economic value of the small pelagic fishery in Mafia Island, Tanzania*. United Nations University Fisheries Training Programme, Iceland [final project]. http://www.unuftp.is/static/fellows/document/philipo16prf.pdf

Moto E 2017 *Seasonal variability of phytoplankton diversity and biomass in the coastal waters of Unguja Island, Zanzibar*. PhD Thesis, University of Dar es Salaam.

Moto E and Kyewalyanga M 2017 Variability of chlorophyll-a in relation to physico-chemical variables in Zanzibar coastal waters. *Adv. Ecol. Environ. Res.* 2(12): 475-492.

Moto E, Kyewalyanga M, Lyimo T and Hamisi M 2018 Species composition, abundance and distribution of phytoplankton in the coastal waters off Zanzibar Island. *J. Bio. Environ. Sci.* 12(5): 108-119.

Mwaipopo R and Mahongo SB 2020 Adaptive capacity of small pelagic fishing communities in coastal Tanga (Tanzania) to changes in climate-related phenomena. *WIO J. Mar. Sci*. 1: 127-144.

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

Parsons TR, Maita Y and Lalli CM 1984 *A Manual of Chemical and Biological Methods for Seawater Analysis* (pp. 173) Pergamon Press, Oxford.

Passow U and Carlson CA 2012 The biological pump in a high CO_2 world. *Mar. Ecol. Prog. Ser.* 470: 249-271.

Peter N 2013 *Phytoplankton distribution and abundance along Zanzibar and Pemba Channels*. MSc Thesis, University of Dar es Salaam.

Peter N, Semba M, Lugomela C and Kyewalyanga MS 2018 The influence of physico-chemical variables on the spatial and seasonal variation of chlorophyll-a in coastal waters of Unguja, Zanzibar, Tanzania. *WIO J. Mar. Sci*. 17(2): 25-34.

Peter N, Semba M, Lugomela C and Kyewalyanga M 2021 Seasonal variability of vertical patterns in chlorophyll-a fluorescence in the coastal waters off Kimbiji, Tanzania. *WIO J. Mar. Sci.* 20(1): 21-33.

Sahu KC, Baliarsingh SK, Srichandan S, Lotliker AA and Kumar TS 2013 *Monograph on Marine Plankton of East Coast of India-A Cruise Report*. Indian National Centre for Ocean Information Services (pp. 146), Hyderabad, India.

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

Sekadende B, Scott L, Anderson J, Aswani S, Francis J, Jacobs Z, Jebri F, Jiddawi N, Kamukuru AT, Kelly S, Kizenga H, Kuguru B, Kyewalyanga M, Noyon M, Nyandwi N, Painter SC, Palmer M, Raitsos DE, Roberts M, Sailley SF, Samoilys M, Sauer WHH, Shayo S, Shaghude Y, Taylor SFW, Wihsgott J and Popova E 2020a The small pelagic fishery of the Pemba Channel, Tanzania: What we know and what we need to know for management under climate change. *Ocean Coast. Manage.* 197: 105322.

Sekadende BC, Sululu JS, Kamkuru AT, Igulu MM and Mahongo SB 2020b Preliminary findings on the food and feeding dynamics of the anchovy *Stolephorus commersonnii* (Lacepède, 1803) and the Indian mackerel *Rastrelliger kanagurta* (Cuvier, 1817) from Tanga Region, Tanzania. *WIO J. Mar. Sci.* 1: 71-80.

Semba M, Kimirei I, Kyewalyanga M, Peter N, Brendonck L and Somers B 2016 The decline in phytoplankton biomass and prawn catches in the Rufiji-Mafia Channel, Tanzania. *WIO J. Mar. Sci.* 15: 15-29.

Semba M, Lumpkin R, Kimirei I, Shaghude Y and Nyandwi N 2019 Seasonal and spatial variation of surface current in the Pemba Channel, Tanzania. *PLoS One* 14(1): 0210303.

Annex 1

Phytoplankton composition for the three transects located at Sahare, Vyeru and Mwaboza villages during the northeast monsoon (NE) and the southeast monsoon (SE) seasons. Five classes identified include: Bacillariophyceae (Diatoms), Dinophyceae (Dinoflagellates), Cyanophyceae (Cyanobacteria), Crysophyceae and Dictyochophyceae. The most dominant species occurring at each study site in each season are shown in **bold**.

	SITES	**Sahare**		**Vyeru**		**Mwaboza**	
N	**Taxon**	**NE**	**SE**	**NE**	**SE**	**NE**	**SE**
1	Bacillariophyceae (diatoms)						
2	*Amphiprora gigantea*	+	-	-	-	+	-
3	*Amphiprora sp.*	+	-	-	-	-	-
4	*Asterionella notata*	+	-	+	-	-	-
5	*Asterionella glacialis*	-	+	-	-	-	-
6	*Asterolampra marylandica*	-	+	-	-	-	-
7	*Asteromphalus hepaticus*	-	-	-	-	-	+
8	*Bacillaria paxillifer*	+	+	-	+	+	-
9	*Bacteriastrum elongatum*	+	-	+	-	+	-
10	*Bacteriastrum hyalinum*	+	-	-	-	+	-
11	*Bacteriastrum minus*	-	+	-	-	-	-
12	*Biddulphia pulchella*	-	+	-	-	-	-
13	*Bacteriastrum varians*	+	-	+	-	+	-
14	*Cerataulina pelagica*	+	-	-	-	+	-
15	*Chaetoceros affine*	-	-	+	-	-	-
16	*Chaetoceros breve*	-	-	-	-	+	-
17	*Chaetoceros coaretatum*	-	-	-	-	+	-
18	*Chaetoceros compressum*	-	-	-	-	-	+
19	*Chaetoceros costatum*	-	-	+	+	+	-
20	*Chaetoceros curvisetum*	-	-	+	-	+	-
21	*Chaetoceros decipiens*	+	-	+	-	-	-
22	*Chaetoceros didymus*	+	-	+	-	-	-
23	*Chaetoceros pendulum*	+	-	-	-	-	+
24	*Chaetoceros diversum*	-	-	-	-	+	+
25	*Chaetoceros peruvianum*	+	-	+	-	+	-
26	*Chaetoceros messanense*	-	+	+	-	-	-
27	*Chaetoceros seychellarum*	-	+	-	-	-	-
28	*Chaetoceros skeleton*	-	+	+	-	-	-
29	***Chaetoceros sp.***	**+**	**+**	**+**	**+**	**+**	**+**
30	*Climacodium frauenfeldianum*	+	-	+	-	+	-
31	*Climacosphenia moniligera*	-	-	+	+	+	-
32	*Coscinodiscus lineatus*	+	-	+	+	+	-
33	*Coscinodiscus marginatus*	-	+	+	-	+	-
34	***Coscinodiscus sp.***	**+**	**+**	**-**	**+**	**+**	**+**
35	***Coscinodiscus thonii***	**+**	**+**	**+**	**+**	**+**	**-**
36	*Cylindrotheca closterium*	-	-	-	-	+	-
37	*Diatoms hyaline*	-	+	-	+	+	+
38	*Diplopsalopsis orbicularis*	-	-	+	-	-	-
39	*Diploneis bombus*	-	-	-	-	+	-
40	*Diploneis sp.*	-	-	-	-	+	-
41	*Ditylum sol*	-	-	-	+	-	-
42	*Eucampia cornuta*	+	+	-	-	+	-
43	*Eucampia sp.*	-	-	-	-	-	+

44	*Eucampia zodiacus*	+	-	-	-	+	-
45	*Guinardia flaccida*	+	-	+	-	+	-
46	*Hemiaulus indicus*	+	-	+	-	+	-
47	*Hemiaulus sinensis*	+	-	+	-	-	-
48	*Haslea wawrikae*	-	+	+	-	-	-
49	*Isthmia japonica*	-	+	-	-	-	+
50	*Isthmia sp.*	+	-	-	-	-	-
51	*Isthmia enervis*	-	-	+	-	+	-
52	*Leptocylindrus minimus*	-	-	+	-	+	-
53	*Leptocylindrus danicus*	+	-	-	-	-	-
54	*Lithodesmium undulatum*	+	-	-	-	+	-
55	*Navicula sp.*	+	-	-	+	-	-
56	*Nitzschia longissima*	-	+	-	+	+	-
57	*Nitzschia sigma*	+	-	-	-	+	+
58	***Nitzschia pungens***	**+**	**+**	**+**	**+**	**+**	**-**
59	*Nitzschia seriata*	-	-	+	-	-	-
60	*Nitzschia sp.*	+	+	-	+	-	-
61	*Odontella sinensis*	+	-	+	-	+	+
62	*Odontella sp.*	-	-	+	-	-	-
63	*Paralia sulcata*	+	-	+	+	-	+
64	*Phaeodactylum tricornutum*	-	-	-	-	+	-
65	*Planktoniella sol*	-	+	-	-	-	-
66	*Pleurosigma angulatum*	-	+	-	-	-	+
67	*Pleurosigma naviculaceum*	+	-	+	-	+	-
68	*Pleurosigma rhombeum*	-	-	+	+	+	-
69	*Pleurosigma sp.*	-	-	+	-	-	-
70	*Protoperidinium sphaericum*	-	-	+	-	-	-
71	*Rhabdonema adriaticum*	-	-	+	-	-	-
72	***Rhizosolenia alata***	**-**	**+**	**+**	**+**	**+**	**+**
73	*Rhizosolenia arafurensis*	-	-	+	-	-	-
74	*Rhizosolenia bergonii*	+	+	-	+	-	+
75	*Rhizosolenia calcar-avis*	-	+	+	-	-	-
76	*Rhizosolenia cochlea*	-	-	-	-	+	-
77	*Rhizosolenia cylindrus*	+	-	+	-	-	-
78	*Rhizosolenia delicatula*	-	-	+	-	+	+
79	*Rhizosolenia hebetata*	+	-	-	-	-	-
80	*Rhizosolenia hyalina*	+	+	+	-	+	-
81	*Rhizosolenia setigera*	+	-	-	+	+	-
82	***Rhizosolenia stolterfothii***	**+**	**+**	**+**	**-**	**+**	**+**
83	*Rhizosolenia styliformis*	-	-	-	-	+	-
84	*Roperia tesselata*	-	+	-	-	-	-
85	*Striatella unipunctata*	-	-	-	-	+	-
86	*Synedra Formosa*	-	-	-	-	+	-
87	*Thalassionema nitzschioides*	-	-	+	-	-	-
88	*Thalassiothrix delicatula*	-	+	-	-	-	-
89	***Thalassiothrix frauenfeldii***	**+**	**+**	**+**	**+**	**+**	**+**
90	*Thalassiothrix longissima*	+	-	+	-	+	-
	Dinophyceae (Dinoflagellates)						
1	***Amphidinium inflatum***	**+**	**+**	**+**	**+**	**+**	**-**
2	*Amphisolenia bidentata*	+	-	-	-	-	-
3	***Amphisolenia sp.***	**+**	**+**	**+**	**+**	**+**	**+**
4	***Ceratium candelabrum***	**+**	**-**	**+**	**+**	**+**	**+**

5	*Ceratium furca*	-	+	-	+	+	+	
6	***Ceratium fusus***	**+**	**+**	**+**	**-**	**+**	**+**	
7	*Ceratium gibberum*	+	-	-	+	+	+	
8	*Ceratium gravidarum*	+	-	-	-	-	-	
9	*Ceratium macroceros*	-	-	-	-	-	+	
10	*Ceratium massiliense*	+	-	+	-	-	-	
11	***Ceratium trichoceros***	**+**	**-**	**+**	**+**	**+**	**+**	
12	***Ceratium tripos***	**+**	**+**	**+**	**+**	**+**	**-**	
13	*Dinophysis caudata*	+	-	-	-	-	-	
14	*Dinophysis doryphorum*	+	-	+	+	+	-	
15	*Dinophysis sp.*	-	+	-	-	-	+	
16	*Diplopsalis lenticula*	-	-	-	-	+	-	
17	*Dissodinium pseudolunula*	-	-	-	-	-	+	
18	*Gonyaulax sp.*	-	-	-	-	-	+	
19	***Gymnodinium sp.***	**+**	**-**	**+**	**+**	**+**	**+**	
20	*Heteraulacus polyedricus*	-	-	-	-	-	+	
21	*Heterocapsa triquetra*	-	-	-	-	+	-	
22	*Katodinium sp.*	-	-	-	+	-	-	
23	*Ornithocercus quadratus*	+	+	+	-	-	-	
24	*Peridinium quinquecorne*	-	-	-	-	+	-	
25	*Podolampas bipes*	+	+	-	-	-	+	
26	*Prorocentrum compressum*	-	-	+	-	-	-	
27	*Protoperidinium curtipes*	-	-	+	+	-	+	
28	*Protoperidinium depressum*	+	+	+	-	-	-	
29	*Protoperidinium grande*	+	+	-	-	+	-	
30	*Protoperidinium oceanicum*	-	-	-	-	+	-	
31	*Protoperidinium pentagonum*	+	-	+	-	-	+	
32	***Protoperidinium pyriforme***	**+**	**-**	**+**	**+**	**+**	**+**	
33	*Protoperidinium sphaericum*	-	-	+	+	+	+	
34	*Pyrocystis pseudonoctiluca*	+	-	-	-	-	-	
35	*Pyrophacus horologium*	+	-	+	-	+	-	
	Cyanophyceae (Cyanobacteria)							
1	*Anacystis marina*		+	-	-	-	-	-
2	*Nostoc sp.*	-	+	-	-	+	-	
3	***Trichodesmium erythraeum***	**+**	**+**	**+**	**+**	**+**	**+**	
4	*Richelia intracellularis*	+	-	-	-	+	-	
5	*Schizothrix mexicana*	-	+	-	-	+	+	
6	*Spirulina subsalsa*	+	-	-	-	-	-	
	Crysophyceae							
1	*Distephanus speculum*	-	-	-	-	+	-	
	Dictyochophyceae							
1	*Dictyocha fibula*	-	-	-	-	-	+	

\+ Species present; - Species absent.