



Spatiotemporal analysis of micronekton biomass at the mouth of the River Plate

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ABSTRACT. The region adjacent to the River Plate is renowned for its fishing activity and abundant biodiversity. Both are closely linked to the significant local river flows responsible for fertilizing extensive marine areas. Among the several biological communities, micronekton deserves special attention as it serves as a vital trophic link between primary production and top predators in the ecosystem. Recognizing its importance, this study evaluates the spatio temporal variability of epipelagic micronekton biomass at the mouth of the River Plate. Numerical modeling outputs of micronekton functional groups were obtained from the Spatial Ecosystem and Population Dynamics Model (SEAPODYM), coupled with *in situ* environmental data (precipitation, wind direction, and intensity) from 2015 to 2019. The results revealed greater aggregations of epipelagic micronekton near the river mouth. There was a seasonal disparity in micronekton biomass in the zone influenced by river drainage, with higher biomass values observed during the summer and lower values during the winter. This seasonal difference was attributed to winds from the northeast and southeast quadrants, as the micronektonic plume is susceptible to their effects. However, precipitation data did not exhibit a significant correlation with *in situ* flow data nor with quantitative micronekton measurements. This discrepancy may be attributed to the positioning of the data collection stations relative to the dimensions of the mouth of the River Plate.

Keywords: Neotropical estuary; physical-biological interactions; trophic ecology; remote sensing; nektons.

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Introduction

Micronekton consists of aquatic organisms ranging in length from 2 to 20 cm. Although taxonomically diverse, micronekton primarily comprises small fish (including larvae and juveniles), cephalopods (such as small species in juvenile stages), and crustaceans (adult euphausiids, pelagic decapods, and mysids) (Payri et al., 2019; Phillips et al., 2009). Micronekton exhibits a heterogeneous distribution across all oceans, driven by currents both horizontally and vertically, and can be found at depths of up to 1000 m within the water column (Percy et al., 1977). These organisms conduct daily vertical migrations, exporting carbon through processes such as respiration, excretion, and mortality, which collectively contribute to the biological pump (Hernández-León et al., 2019; Hidaka et al., 2001). Moreover, this group holds significant relevance in maintaining the trophic web, serving as prey for various epipelagic and nektonic predators, including tunas and sharks, which adjust their migration patterns in response to the micronekton's position in the water column. Marine mammals and birds also benefit from the presence of micronekton in the aquatic environment (Bertrand et al., 2002; Young et al., 2015).

Micronekton exhibits a global distribution in aquatic systems and is directly influenced by environmental variations (Duffy et al., 2017). Hence, understanding the dynamics of factors such as precipitation, currents, and winds is essential for elucidating the ecology of micronekton and its role in aquatic trophic networks (Irigoien et al., 2014). Despite its environmental significance, the majority of studies on this subject focus on shelf and ocean basin regions (Kloser et al., 2009), overlooking efforts to attain a deeper understanding of this topic in transitional environments.

In this study, we analyzed the spatiotemporal composition of micronekton in the adjacent marine zone of the River Plate, situated on the Atlantic coast at 35°S between Argentina and Uruguay (Nagy et al., 2008). This

region comprises a complex hydrographic system where water masses from various sources converge, giving rise to frontal systems characterized by significant spatiotemporal variability and high biological productivity. Consequently, it serves as a habitat for commercially important species (Negri et al., 1986). The extent of this environment's impact on the adjacent marine areas depends on flow magnitude and wind intensity and direction. Under such conditions, the river plume can extend nearly 900 km northeast of the estuary, affecting other fishing areas south of Brazil (Piola et al., 2008).

The continental shelf adjacent to the River Plate estuary has been identified as a priority area for conservation due to its ecological significance (Phillips et al., 2009). Consequently, developing strategies for the protection and sustainable management of this area is crucial. Therefore, studies that examine the spatiotemporal dynamics of micronekton in this region are imperative for promoting its sustainable use and management.

Considering the above, this study used outputs from the Spatial Ecosystem and Population Dynamics Model (SEAPODYM) to assess fluctuations in micronekton biomass at the mouth of the River Plate. SEAPODYM is an ecosystem model designed to simulate changes in abundance over time and space among various lower (zooplankton) and middle (micronekton) functional groups, as well as target fish species ranging from larvae to adults (Lehodey et al., 2008). These groups are delineated based on pelagic zones, with the euphotic depth serving as a vertical delimiter, while net primary production serves as a key input parameter for the model. Within this context, the objective of this study is to analyze whether the micronekton community in the epipelagic zones is influenced by the mouth of the River Plate, and to evaluate the effects of precipitation rates and the direction and intensity of winds on their aggregations.

Material and methods

The River Plate (Figure 1) is a large estuarine system located in a temperate coastal plain (Laborde & Nagy, 1999). It is characterized by shallow depths (~10 m) and a low tidal range (~1 m), factors that promote constant vertical mixing (Simionato et al., 2004). The main driving forces of estuarine circulation include tides, winds, and continental runoff (Dogliotti et al., 2016). The flow entering the estuary exhibits high variability, as studied in various scenarios by Mechoso and Iribarren (1992) and Robertson and Mechoso (1998).

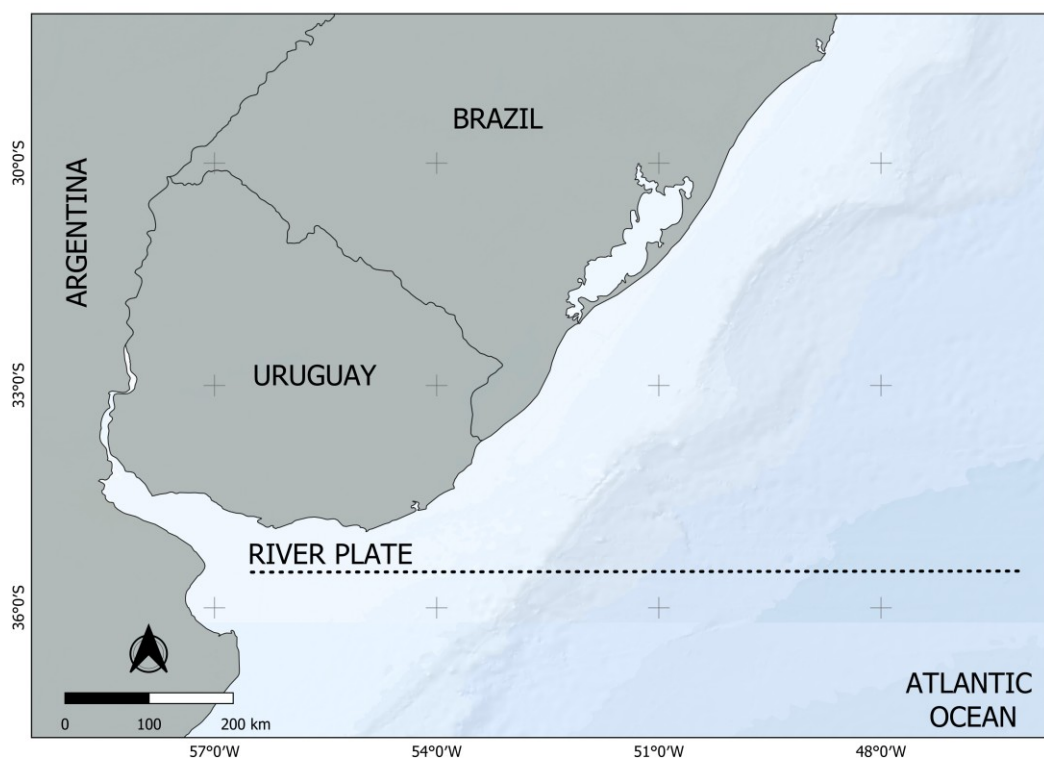


Figure 1. Study area demonstrating the location of the transect at the mouth of the River Plate.

At the river mouth, there is a significant convergence between river discharge and marine waters from the Atlantic Ocean, resulting in an extensive mixing zone with mixohaline characteristics (Acha et al., 2008). These waters penetrate the estuary, forming a nearly permanent two-layer saline wedge structure whose

degree of mixing may vary (Guerrero et al., 1997). The adjacent continental shelf features a gentle slope, with its edge reaching depths of approximately 3,000 m (Hernández-Molina et al., 2010). This region is highly susceptible to the potential impacts of climate change, as well as the interannual natural effects of the El Niño-Southern Oscillation (ENSO) phenomenon, which significantly influences coastal dynamics (Penalba & Rivera, 2016; Sathicq et al., 2015).

The Spatial Ecosystem and Population Dynamics Model (SEAPODYM) is a numerical model that characterizes the spatial and temporal dynamics of lower and middle trophic level populations (Senina et al., 2020; Senina et al., 2022). This model incorporates mass values of a functional group of zooplankton and six groups of micronekton (measured by wet weight), including both vertically migrating and non-migrating species (which serve as prey for larger fish), across marine epipelagic and mesopelagic layers (Lehodey et al., 2010; Lehodey et al., 2015). After obtaining the model outputs, a transect vector was designed to analyze fluctuations at the mouth of the River Plate, centered at a latitude of 35.5°S and spanning from 56.5°W to 46°W. This transect consisted of 53 analysis points distributed along the specified longitudes, covering the period from January 1, 2015, to December 31, 2019 (five years), with a daily temporal resolution and spatial resolution of 1/12°. The outputs used in this study were obtained from the Copernicus Marine Environment Monitoring Service (CMEMS) (<https://marine.copernicus.eu/>), which has been previously validated in the scientific literature.

A total of 1,826 transects (one per day over five years) were processed using SEAPODYM, each consisting of 53 points. The obtained profiles were categorized by season of the year (DJF – summer, MAM – autumn, JJA – winter, and SON – spring) to identify seasonal patterns throughout the study period. Simultaneously, each profile with 53 points was divided into two subclasses: (1) the zone influenced by the River Plate and (2) the zone unaffected by the River Plate. This division between zones was determined along the same transect, considering regions where the difference in micronekton biomass productivity was equal to or greater than 10 g m⁻².

The Mann-Whitney nonparametric statistical test (at a 5% significance level) was conducted to identify potential statistical differences between zones (1) and (2). Additionally, any statistical disparities between the seasons of the year were assessed using the Kruskal-Wallis test. Supplementary graphs were created to aid interpretation of results.

In situ data on accumulated monthly precipitation (in mm) and wind direction and intensity (in km.h⁻¹) were obtained from the National Meteorological Service – Argentina (SMN) for the mouth of the River Plate estuary. These data were used to gain a better understanding of the physical forcings primarily influencing local micronekton concentrations.

Results

Figure 2 presents the results of the profiles grouped by station (as indicated by the dotted line in Figure 1). It is evident that there is a significant difference (often exceeding 10 g m⁻²) from longitude 53°W, indicating a distinct boundary of influence of the River Plate estuary starting from this point toward higher longitudes (< 53°W). Although the longitudinal distribution pattern of the profiles is similar, there is a higher abundance of micronekton in the area under the influence of the River Plate during the summer months. On the other hand, the winter months exhibit the lowest micronekton levels in the area influenced by the mouth of the River Plate.

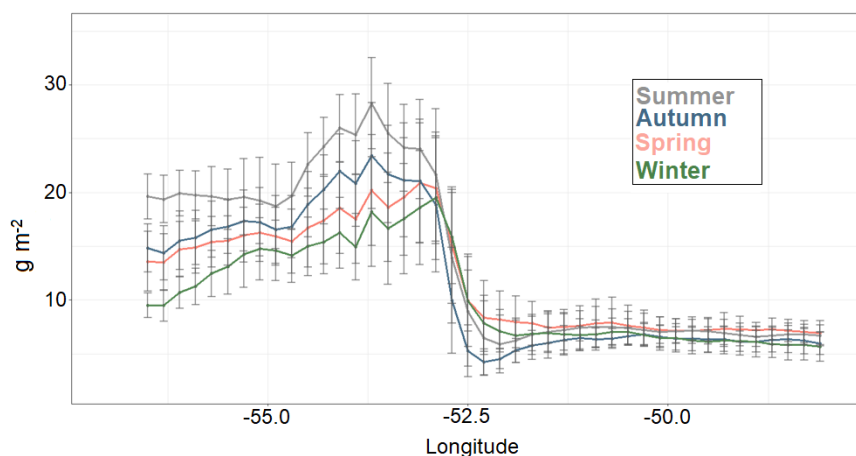


Figure 2. Micronekton profiles (mean and standard deviation – vertical gray bars) grouped by seasons.

The boxplot graphs illustrate the micronekton values grouped by season for zones influenced and not influenced by the mouth of the River Plate (Figure 3). These graphs depict average values of approximately 19 gm^{-2} in summer, around 16 gm^{-2} in spring, 17.5 gm^{-2} in autumn, and roughly 14 gm^{-2} in winter for regions influenced by the mouth of the River Plate. Conversely, for unaffected regions, mean values of approximately 7.5 gm^{-2} were observed in summer and spring, and about 6 gm^{-2} in autumn and winter.

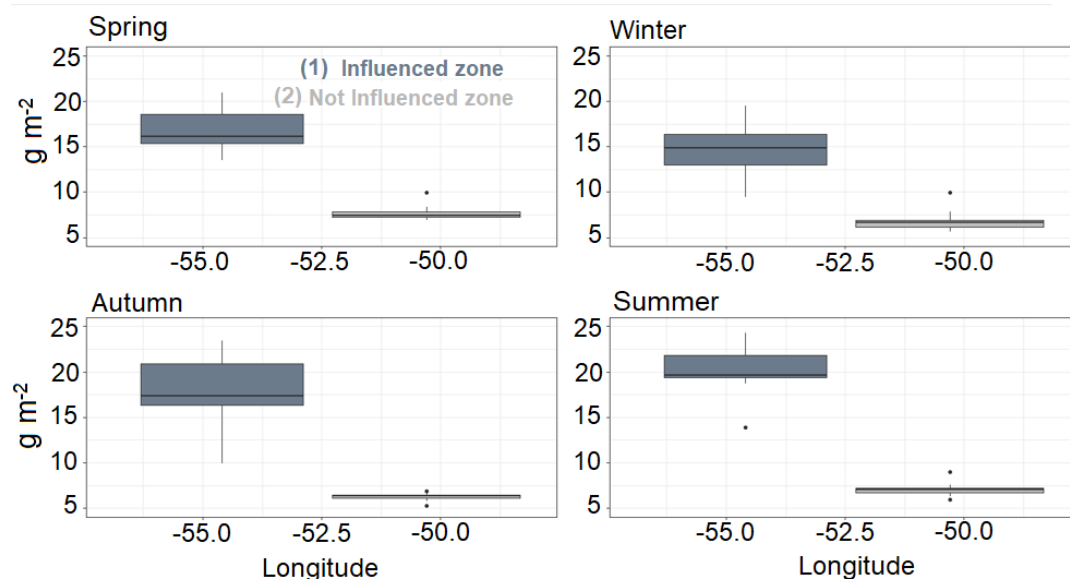


Figure 3. Boxplot with micronekton values in two subclasses: (1) zone influenced by the River Plate and (2) zone not influenced by the River Plate.

The Hovmöller diagram (see Figure 4), arranged on a daily scale, illustrates that the region influenced by the mouth of the River Plate exhibits peaks in micronekton biomass exports reaching approximately 40 gm^{-2} . Additionally, it is evident that the zone influenced by the River Plate estuary displays a fluctuating pattern throughout the analyzed series.

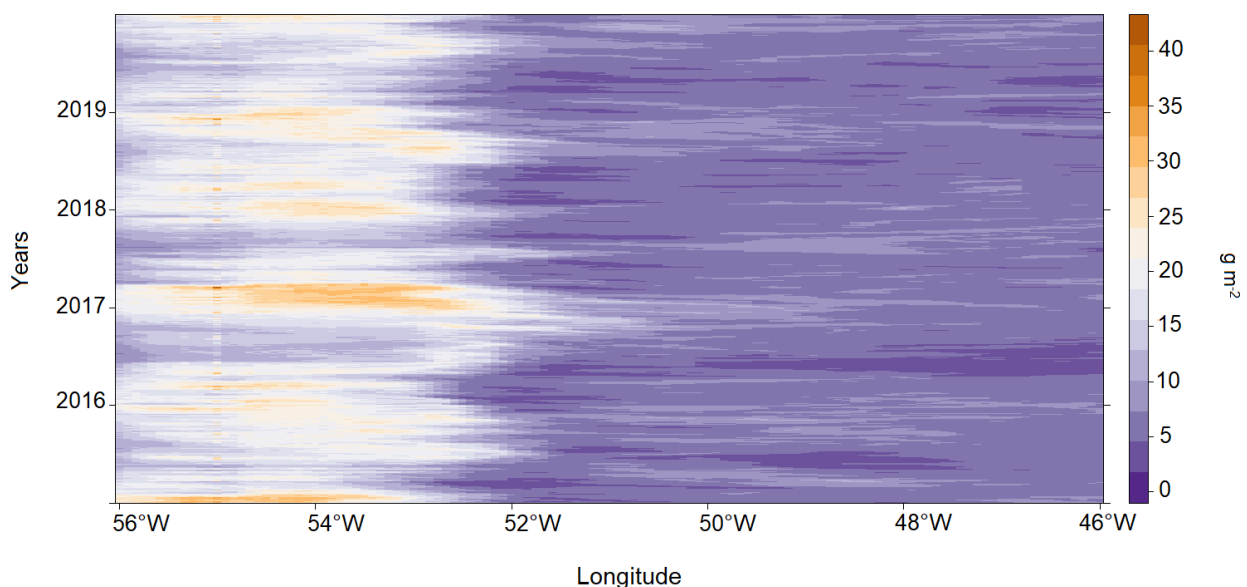


Figure 4. Hovmöller plot depicting 1,826 daily transects with maximum and minimum micronekton values in space and time.

To determine whether the disparities between the regions influenced and not influenced by the River Plate are statistically significant, we conducted the paired Mann-Whitney test (at a 5% significance level). This analysis corroborated the findings observed in Figures 2, 3, and 4, indicating a statistically significant difference between the zones within the same profile (with and without river drainage influence) ($Z = 9.44$ and $p\text{-value} < 0.00001$, significant at $p < 0.05$).

Following the aforementioned statistical test, we employed the Kruskal-Wallis test to assess whether there are statistically significant differences among the regions influenced by the River Plate. Similar to the paired test, the Kruskal-Wallis test indicates significant differences between seasons ($H = 76.99$ and $p\text{-value} < 0.00001$, significant at $p < 0.05$).

The wind directional field obtained from *in situ* data for the mouth of the River Plate during the study period suggests an omnidirectional pattern across all seasons, with a predominant occurrence in the northeast and southeast quadrants during autumn, spring, and summer (Figure 5).

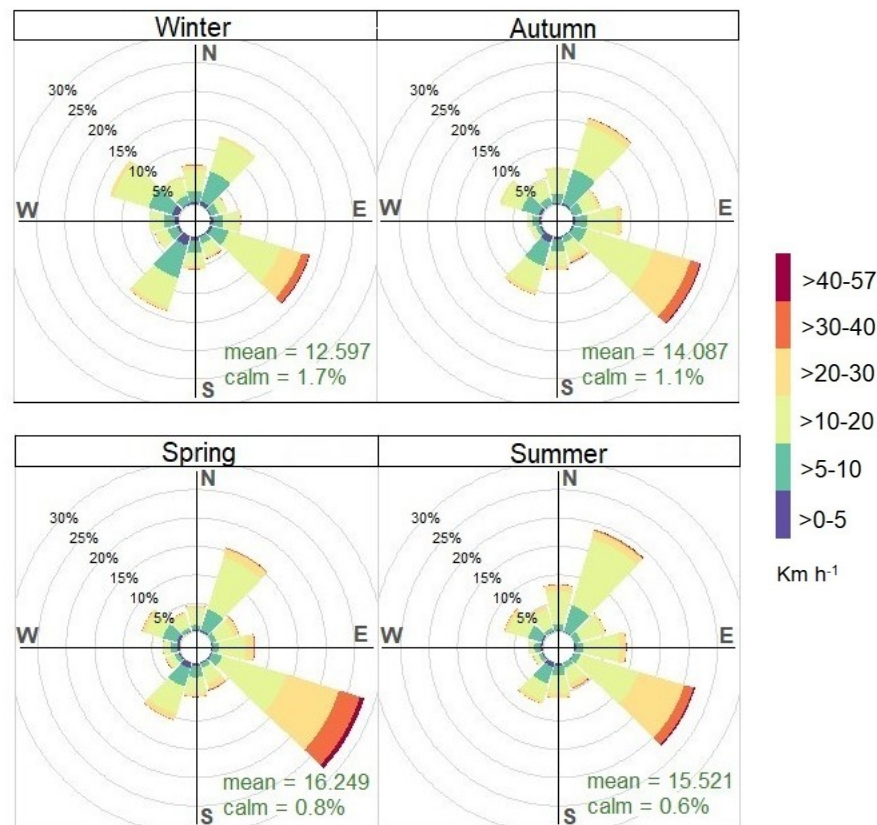


Figure 5. *In situ* wind data (direction and intensity) for the River Plate estuary.

Seasonal precipitation rates at the mouth of the River Plate reveal higher values during the summer period, reaching approximately 285 mm, with mean values around 112 mm (Figure 6). Conversely, the winter period exhibits contrasting dimensions to summer, with mean values of approximately 87 mm, also suggesting the possibility of months without precipitation.

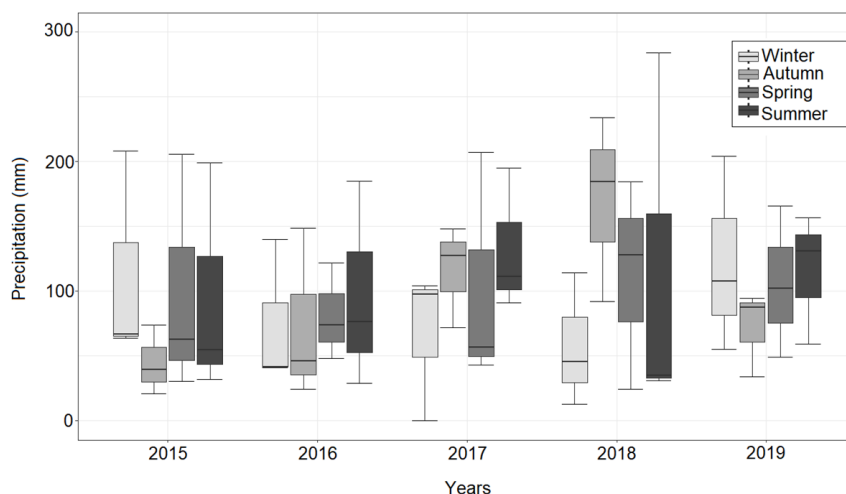


Figure 6. Accumulated precipitation per season for the River Plate estuary.

Discussion

The analyzed time series reveals changes in micronekton biomass as observations move away from the coast. This pattern is consistent with Brodeur et al. (2003). Additionally, Eduardo et al. (2021) documented reductions in myctophid catches with increasing depth, reflecting the lower availability of food in regions farther from the coast (Aron, 1962).

The highest abundance of micronekton at the mouth of the River Plate was observed during the summer months, while the lowest occurred during the winter months, indicating a distinct seasonal difference. This pattern can be attributed to the life cycle of these organisms, which typically utilize shallower areas as nursery grounds before migrating to more distant coastal regions (Gewant & Bollens, 2005).

Despite the precipitation data showing the highest values during the summer season (rainy season), statistically, there was no significant correlation with micronekton biomass. The relationship between precipitation and flows is complex, as highlighted by Garcia and Vargas (1998). Not all precipitation signals are reflected in flow, and this relationship can be influenced by various factors such as basin size, terrain slope, and soil type (Capozzoli et al., 2017). This complexity may explain the low correlation between flow and precipitation in the mouth of the River Plate region, which has a vast spatial extent, further complicating these correlations.

Approximately 8% of the ocean's area is occupied by coastal zones and continental shelf waters, sustaining 25% of the total oceanic primary production due to nutrient fertilization from rivers, upwellings, and internal remineralization of benthic-pelagic nutrients (Knoppers et al., 2009). The coastal zone, with its diverse ecosystems, has a higher production yield per square meter than the open ocean, despite the latter being responsible for most of the global primary production. However, it is the contributions from rivers like the River Plate, combined with the influence of wind direction and intensity, that fertilize the southern region of Santa Catarina (Ciotti et al., 1995).

Among the studies evaluating the variability of the fluctuating plume over time and space, the seasonal fluctuation of the River Plate plume is associated with northeast winds in summer and southeast winds in autumn and winter (Simionato et al., 2005), although wind stress from the southeast quadrant predominates throughout the year (Möller et al., 2008). This finding is consistent with the results of this study: during winter, there were larger aggregations of micronekton near the coast to the northeast. However, the trapping of water masses due to the directional field of the northeast wind can explain the peaks of micronekton biomass found in the summer months. Piola et al. (2008) found similar results for chlorophyll *a*, concluding that a primary production hotspot forms in summer, while in winter, it extends to areas further to the northeast, displaying vertically homogeneous concentrations along the water column.

The water surface temperature in the region near the mouth of the River Plate, which encompasses the analyzed transect, exhibits a homogeneous character during both summer and winter (Möller et al., 2008). This characteristic explains the higher aggregation of micronekton near the mouth compared to more distant continental regions. Additionally, due to its proximity to the continent-ocean interface, this area tends to have a higher concentration of nutrients compared to regions farther from the shelf (Knoppers et al., 2009), which also affects salinity.

River flow, the Coriolis force, and the balance between onshore and offshore winds control the distribution of surface salinity (Piola et al., 2008; Simionato et al., 2001), which in turn is correlated with micronekton aggregation. In the region of the studied transect, spanning from the city of Mar del Plata to the outer estuary of the River Plate, there is an area with homogeneous salinity (Möller et al., 2008), which may also account for the larger micronekton biomass near the mouth of the River Plate at the longitude threshold of -53°W .

Micronekton plays a fundamental role in the dynamics of the epipelagic food web, underscoring the importance of understanding its connections with trophic levels at the top of the chain to define ecologically significant areas and aid in the management of marine environments (Santora et al., 2012). A recent study by Duffy et al. (2017) unveiled, for the first time, the global extent of tuna diet on the micronekton community, demonstrating that squid was consistently one of the most consumed prey groups by tuna species. However, other commercially important coastal species also prey on this community, such as *Cynoscion guatucupa*, documented in the study by Negri et al. (2016), and *Merluccius hubbsi* reported in the study by Sánchez and Garcia (1999), where the diet consisted of zooplankton crustaceans, fish, and cephalopods, with dietary shifts linked to predator size. Additionally, in the work by Junior et al. (2006), euphausiids were described as the primary prey in the feeding habits of *Elagatis bipinnulata*.

The study suggests that micronekton aggregation fields may be associated with potential preferred habitats for pelagic species at higher trophic levels (Bertrand et al., 2002; Delpech et al., 2020; Duffy et al., 2017; Lehodey et al., 2008; Senina et al., 2020). Therefore, understanding where micronekton aggregates and elucidating how their biomass fluctuates in space and time are essential aspects for gaining insight into fish spatial occupation strategies and trophic interactions between species.

Conclusion

The results obtained from numerical modeling outputs, when combined with other environmental data, can help identify preferential zones for micronekton hotspots.

The *in situ* observations of precipitation data did not statistically demonstrate a positive correlation with the increase in micronekton abundance in the zone influenced by the River Plate. However, by analyzing wind data alongside theoretical principles, it was possible to elucidate the seasonal variation in micronekton biomass in the region. Thus, the findings presented here align with existing literature: during winter, micronekton biomass extends northward due to winds from the southeast quadrant. Conversely, in summer, micronekton biomass in the River Plate region partially extends southwestward due to winds from the northeast quadrant.

It is crucial to underscore that studies on trophic links in the region of the River Plate estuary are essential for enhancing our understanding of the distribution and abundance of local ichthyofauna, thereby aiding marine management efforts. We believe that the present study can help bridge the information gap regarding micronekton biomass at the mouth of the River Plate to some extent.

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