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Distributions of *Rhizostoma pulmo* (Macri, 1778) between the Kızılırmak and the Yeşilırmak coast of the Black Sea, Türkiye

by

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Abstract

This study examined the seasonal distributions of the medusa *Rhizostoma pulmo* along the coasts of the southern Black Sea between Kızılırmak and Yeşilırmak between April 2008 and March 2010. Monthly abundance and biomass values were determined, as well as population parameters. The effect of temperature on medusa distribution was also investigated. Results showed that medusa abundance and biomass were highest in autumn, following a period of increased temperature. In contrast, medusa was not observed during the spring season. It was possible to observe the *R. pulmo* individuals for five months for the first term of investigation period (2008-2009), and seven months for the second term (2009-2010). The highest abundance value was found to be 10 n/m^2 (November 2008 and September 2009) and the highest biomass value was 12.587,5 g/100 m^3 (October 2009).

Key words: Barrel jellyfish, Cinidarian, abundance, biomass, water temperature

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1. Introduction

Since the Black Sea is a semi-enclosed sea, it is more sensitive than open seas and therefore more easily negatively influenced (Bat et al. 2018). Bat et al. (2011) characterized the Black Sea as a highly productive ecosystem at all trophic levels. The Black Sea food chain became dominated by jellyfish in the 1990s and the biodiversity of its ecosystem degraded as a consequence (Shiganova 1998). Disruption of the ecological balance in the Black Sea led to dominant macro-zooplankton species. Due to changing dietary network relationships, a large part of the secondary production (zooplankton biomass) began to be consumed by jellyfish species. After entering the Black Sea ecosystem in the early 1980s, Ctenophore *Mnemiopsis leidyi* Agassiz, 1865 – that is transported with ballast waters – has resulted in radical changes. *M. leidyi* that occupy the same trophic level as fish has seen a decline in fish stocks and ichthyoplankton in the Black Sea. In the same way, after entering the Black Sea ecosystem in 1997, Ctenophore *Beroe ovata* Bruguière, 1789, feeding on *M. leidyi*, has led to improvements in the fish stocks of the Black Sea (Finenko et al. 2003; Svetlichny et al. 2004; Anninsky et al. 2005; Finenko et al. 2006; Oguz et al. 2008; Mutlu 2009).

Despite being largely underappreciated up until now, jellyfish play a significant role in controlling global marine plankton ecosystems, including biomass, spatiotemporal dynamics, and the community structure of the plankton. The jellyfish (more specifically medusae of the Phylum Cnidaria: Orders Rhizostomeae and Semaeostomeae) within coastal marine systems have received much attention recently. There are seven gelatinous macrozooplankton in the Black Sea ecosystem. These species are: Cnidaria *Rhizostoma pulmo* (Özer & Çelikkale 1998), *Aurelia aurita* (Demir 1954), *Chrysaora hysoscella* (Öztürk & Topaloğlu 2009), Ctenophora *Pleurobrachia pileus*, *Beroe ovata, Mnemiopsis leidyi* (Mutlu et al. 1994), *Bolinopsis vitrea* (Öztürk et al. 2011).

R. pulmo which is the most conspicuous and largest macro gelatinous species in the Black Sea has been observed in large numbers in the north-west part of the sea in the late 1960s and early 1990s. Afterwards, populations of *R. pulmo* have decreased between the years 1973 and 1974 in the north-west (Zaitsev & Mamaev 1997).

Although common gelatinous zooplankton species work well in the Black Sea, studies of the barrel jellyfish are limited (İşinibilir et al. 2017). *R. pulmo* is an important species in the Black Sea ecosystem and is a significant food source for many marine organisms, including fish, birds, and marine mammals. Its abundance and biomass can impact the dynamics of the food web and energy transfer within the ecosystem. *R. pulmo* is primarily a carnivore (Dönmez & Bat, 2019). The presence or absence of *R. pulmo* in the Black Sea can serve as an indicator of the state of the ecosystem's health (Oguz et al. 2001). Changes in *R. pulmo's* population size or distribution can reflect shifts in environmental conditions, such as changes in the water temperature, nutrient availability, or pollution levels (Purcell et al. 1999). However, it is important to note that large blooms of *R. pulmo* can have negative impacts on the ecosystem, such as reducing the availability of oxygen and potentially causing harm to other marine organisms. Thus, monitoring and understanding the population's dynamics and the ecology of *R. pulmo* is crucial for the sustainable management of the Black Sea's ecosystem. The scarcity of studies on the distribution of *R. pulmo* in the Black Sea makes it even more important to conduct further research on this species. Therefore, in this study, the distribution of *R. pulmo* in the region between Kızılırmak and Yeşilırmak, two of the most important and largest rivers flowing into the Black Sea, was studied.

2. Materials and methods

2.1. Measurement of physical parameters

The transparency of the water was measured at six stations details below with a 20 cm diameter Secchi disc. A Sınar brand mercury thermometer was used for temperature measurement, while pH values were determined with a KL-012 professional type pH meter.

2.2. Sampling period and area

The study was carried out between the Kızılırmak and Yeşilırmak rivers of the southern Black Sea. Six stations were chosen in different areas along the coast of Samsun; station 2 and 3 were in Atakum city, stations 1 and 4 in Ilkadım city; Station 5 was in Bafra city located 400 m from the stream mouth of the Kızılırmak river; Station 6 was located 800 m northeast of the stream mouth of the Yeşilırmak river (Figure 1). Monthly samples of the barrel jellyfish were obtained from April 2008 to March 2010, over a period of 23 months. In addition to horizontal and vertical samplings, the line transect method was carried out for the estimate of the medusa's abundance.

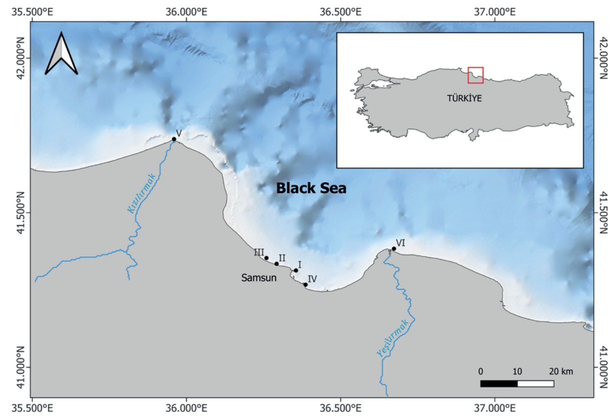

Figure 1

Sampling stations: (Station I: N 41°18'47.4" – E0 36°21'18.5", Station II: N 41°20'5.4" – E0 36°17'32.3", Station III: N 41°21'12. 6" – E0 36°15'34.4", Station IV: N 41°16'01.8" – E0 36°23'11.2", Station V N 41°44'18.1" – E0 35°57'35.3", Station VI N 41°23'01.2"– E0 36°40'23.2")

2.3. The estimation of the abundance and biomass of *Rhizostoma pulmo*

Both horizontal and vertical tows were used, implementing the same type of plankton net (mesh size, 1 mm; diameter, 80 cm; length, 3 m). In the vertical sampling, the barrel jellyfish were collected by vertical tows of a plankton net from depths of 25-30 cm to the sea surface for stations 1, 4 and 6. Horizontal sampling was towed by boat at speeds of 2 miles h^{-1} (15-20 min) for all stations. All the collected samples were measured with a digital hand scale. With regard to the Line Transect, to estimate the abundance of the barrel jellyfish per square metre the length and width of each transect was established at 40 m to 5 m in all sampling stations. Furthermore, the number of (individuals of) medusae per square metre was counted with visual observations on a gangboard (150 m far from the coast).

2.4. Statistical analysis

Statistical comparisons were computed using the Minitab 16 package. Biological, physical and chemical data were obtained via the Spearman rank correlation coefficient and one-way analyses of variance (ANOVA) and analyses of covariance (ANCOVA). Spearman correlation tests were used to determine the comparison of the relationships between the abundance of the biomass of *R. pulmo* and the temperature (Zar 1996).

3. Results

Barrel jellyfish were observed along the whole coast of Samsun. The barrel jellyfish reached values of maximum abundance and biomass in summer and autumn. In the sampling areas between the Kızılırmak and Yeşilırmak rivers, *R. pulmo* was seen only for a period of 5 months in 2008, but this extended to 7 months during 2009.

3.1. Environmental parameters

A 24-month sampling was carried out at stations I, II, III and IV between April 2008 and March 2010, and a 15-month sampling was carried out at stations V and VI between January 2009 and March 2010. Sampling could not be made at stations II and III in June 2008 and at stations V and VI in February 2009 due to weather conditions. The sea water temperatures and pH values of the stations studied are given in Figure 2.

The highest surface water temperature detected at station I was 26.5°C in August 2009, and the lowest surface water temperature value was 7.9°C in January 2009. The highest and lowest temperature values observed at station II were measured as 26.8°C in August 2009 and 7.2°C in January 2009, respectively. The highest surface water temperature measured at station III was observed in August 2009 as 27°C. The lowest temperature value was measured as 8.2°C in January 2009. In August 2008, when the surface water temperature was the highest at station IV, the water temperature was 27.1°C, the highest value measured at all the sampling stations (as mentioned by Dönmez & Bat, 2019). The lowest value of the surface water temperature was measured in January 2009 with 8.1°C. The highest temperature value measured at station V was measured as 26.3°C in August 2009. The lowest temperature value was measured as 7.2 in January 2009, and this value was the lowest temperature value among all the stations where temperature measurements were made (as mentioned by Dönmez & Bat, 2019). In the 14-month temperature measurements made at station VI located in the area where Yeşilırmak empties into the sea, the highest temperature value was determined as 26°C in August 2009 and the lowest temperature value as 7.3°C in January 2009.

It has been determined that seasonal pH values generally increase in spring and summer and decrease in autumn and winter. During the study period, the pH values measured in the surface waters of the stations varied between 7.8-8.9. The light transmittance values measured along the water column varied greatly depending on the wind conditions, precipitation, wave

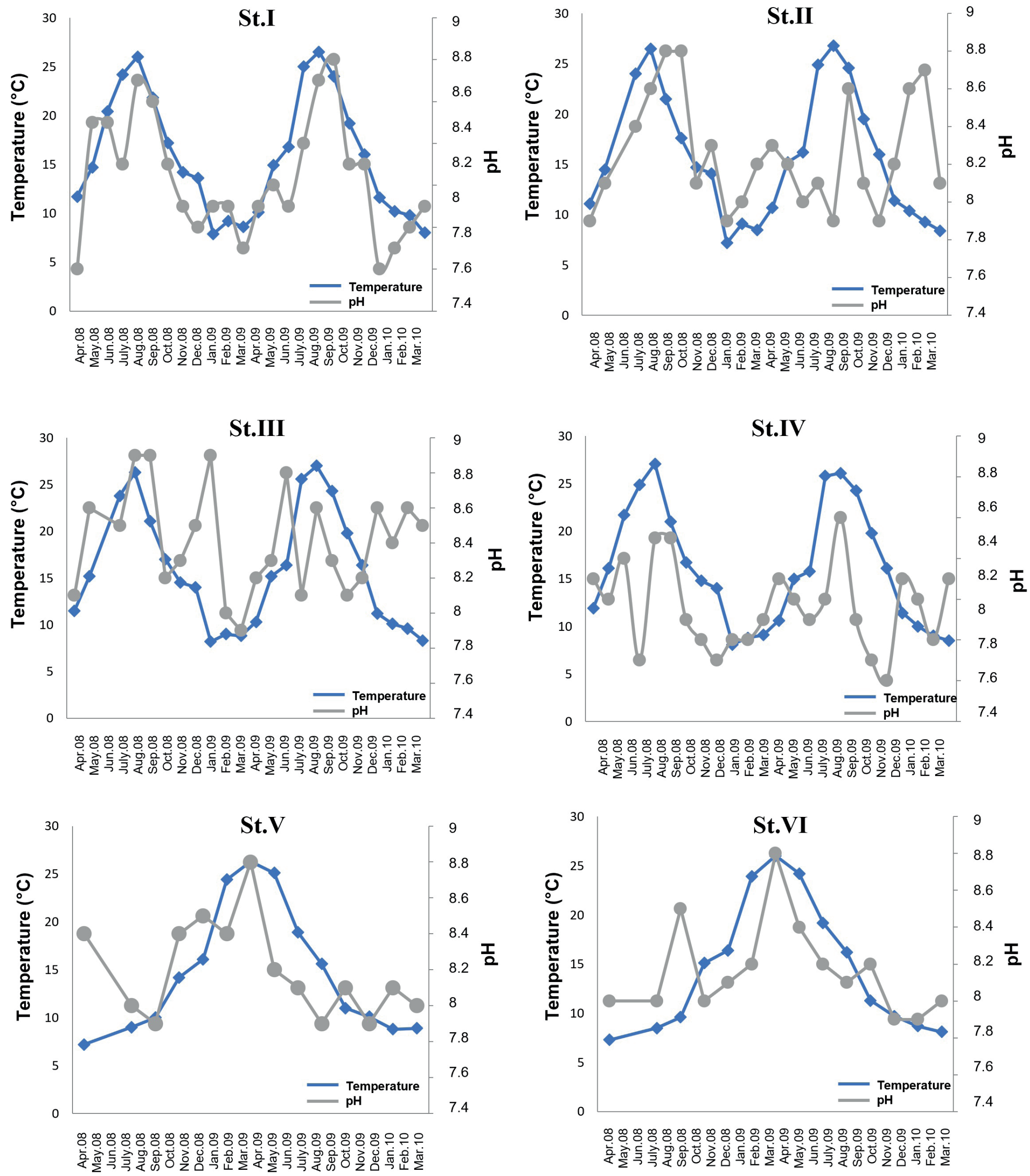

Figure 2

The sea water temperatures and pH values of the stations between the Kızılırmak and Yeşilırmak rivers of the southern Black Sea

heights, cloudiness and the presence of overgrowth species, and these values varied between 1.1-10.8 m (Figure 3).

3.2. Abundance and Biomass

3.2.1. Vertical distribution

The barrel jellyfish were observed in July, August, September, October, and December during all study periods for the vertical tows. The peak biomass value became 11.792 g m^{-2} in October 2009 at station IV. The barrel jellyfish abundance reached the highest values (10 n/m^2) in November 2008 at station IV and September 2009 at station VI (Figure 4). It was determined that the highest abundance value of *R. pulmo* at station I for 2008 and 2009 was in August with 8 n/m^2. The highest biomass value of *R. pulmo* individuals collected in vertical samples at station I was observed in October 2009 with 9.581 g/m^2.

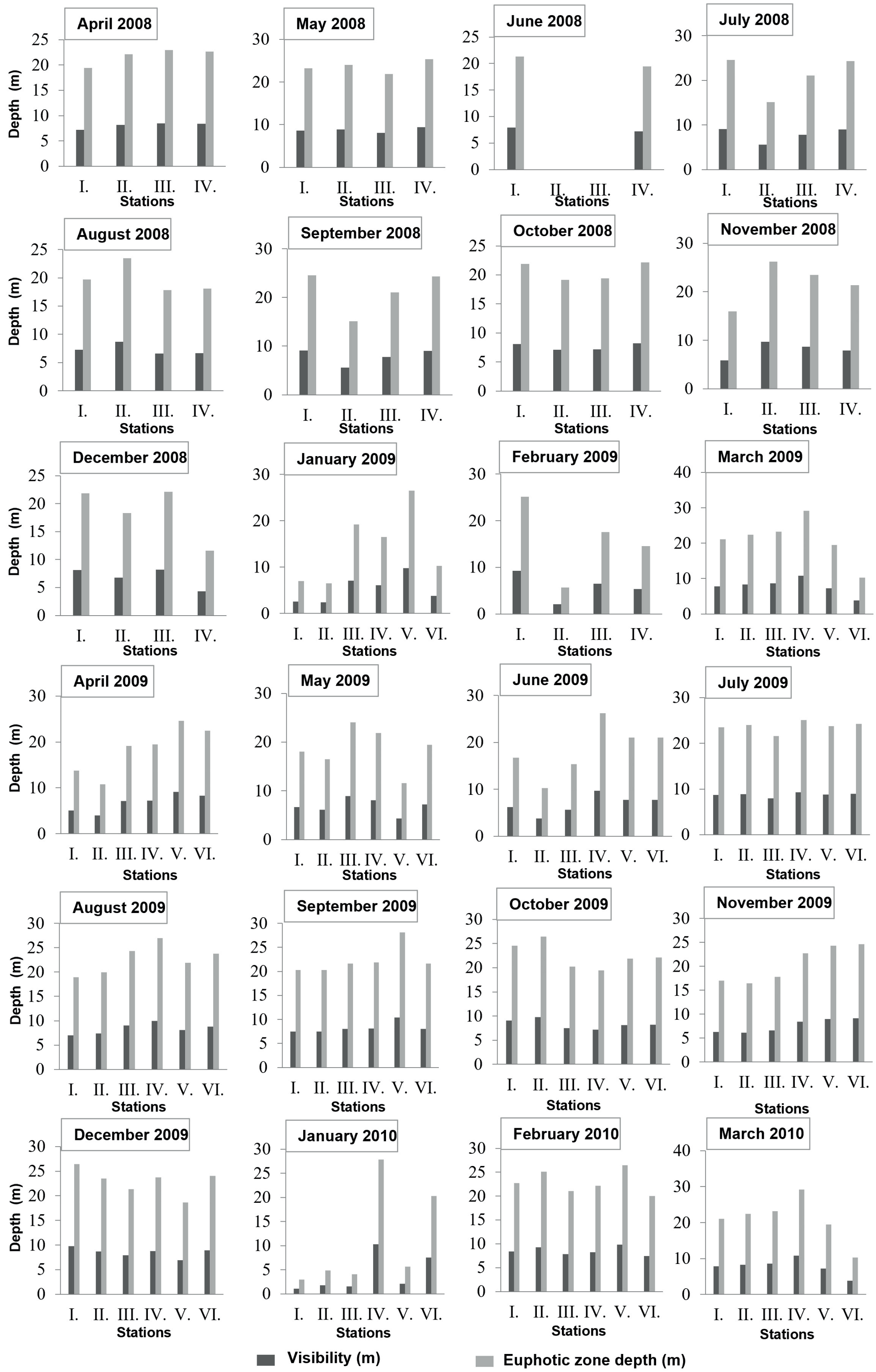

Figure 3

The Secchi disc depths

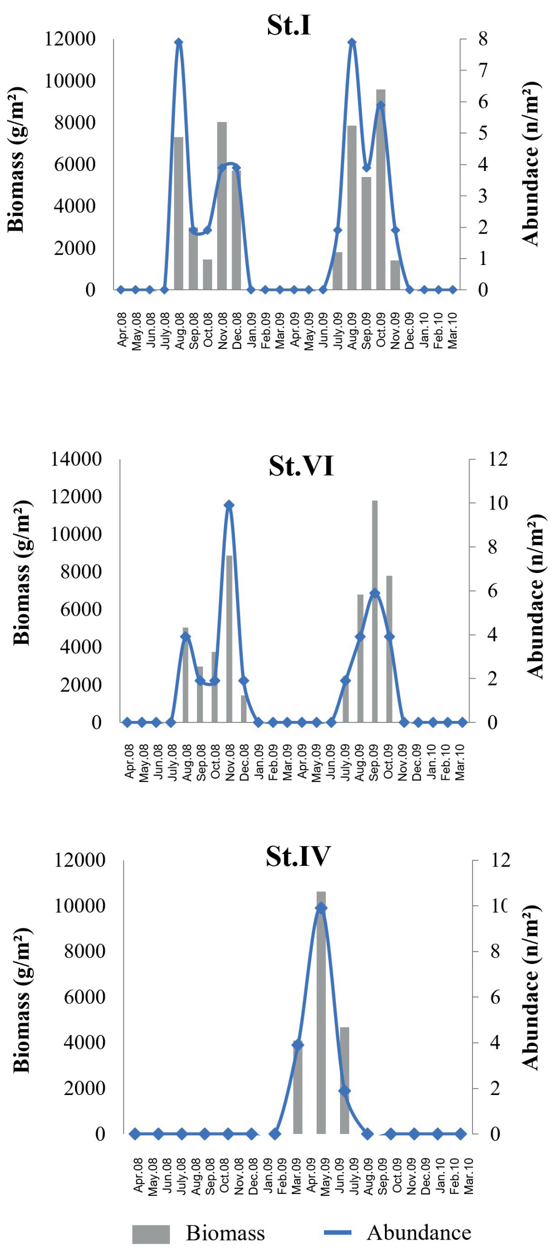

Figure 4

Vertical biomass and abundance variation of *R. pulmo* measured at stations I, IV and VI during the sampling period

3.2.2. Horizontal distribution

When the horizontal distribution of *R. pulmo* according to the stations is evaluated seasonally, it has been determined that this species is not seen at all in spring; it reaches high abundance and biomass values in summer and autumn, it is represented in small numbers in the first half of winter and is not seen at all in February (Figure 5). When the abundance and biomass ratios of *R. pulmo* were compared according to the months, it was observed that the abundance and biomass values were generally high in August and October and were represented with a low rate in December and January. The highest abundance and biomass values determined as results of horizontal sampling were 7.6 n/100 m^3 and 12.587.5 g/100 m^3, respectively. The abundance and biomass values observed in November and December of 2009 were lower than November and December of the previous period.

3.3. The abundance values of *R. pulmo* obtained from the surface observations.

The abundance values of *R. pulmo* individuals counted by surface observations were calculated for all stations and the results were compared with the monthly temperature values (Figure 6).

The highest and lowest values of the number of individuals were 0.31 n/m^2 and 0.007 n/m^2. It was determined that the number of individuals of *R. pulmo* increased towards the end of the summer months and was observed in high numbers in the autumn months. Parallel to the increase in temperature, *R. pulmo* individuals, which started to be seen towards the end of July, generally reached the highest abundance values in August and October. They disappeared in November, December, and January. The total number of individuals counted at station III was 563, with the highest abundance among the stations.

3.4. Length distribution of *R. pulmo* by months

The height of 696 *R. pulmo* individuals captured during the sampling period varied between 15.6-49 cm (Figures 7A and 7B.). The highest average length was 31 cm in September and October 2009. The average length of *R. pulmo* during the study period was 27 cm. In general, the length of *R. pulmo* individuals started to increase in August, and it was determined that the average heights reached the highest level in September and October for the study period.

4. Discussion

There are very few studies on the distribution of *R. pulmo* in the southern part of the Black Sea. Özer & Çelikkale (1998), studied the distribution of *R. pulmo* on the Trabzon coast between 1990-1992. They determined that individuals were seen between August and January, and that they reached the highest

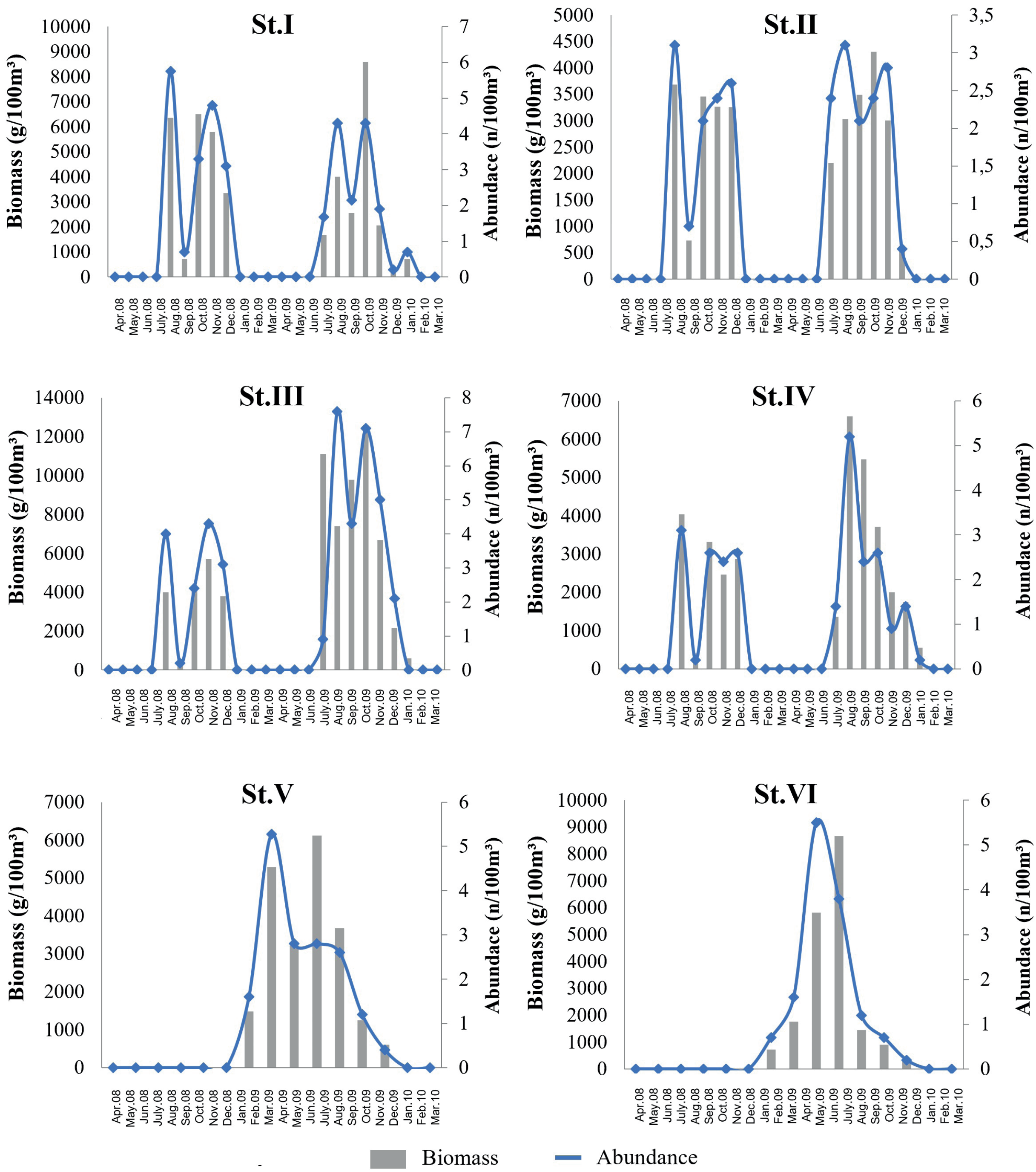

Figure 5

Horizontal biomass and abundance variation of *R. pulmo* measured at all stations during the sampling period

umbrella diameter (39.5 cm) and biomass values in November and December. In our study, the highest umbrella diameter and wet weight were 42.5 cm and 4730 g, respectively. These values have been the highest values recorded for the southern Black Sea so far. The months with the highest abundance and biomass values of *R. pulmo* for the coasts of the southern Black Sea between Kızılırmak and Yeşilırmak were August and October. The emergence and disappearance periods of the barrel jellyfish during the year are similar to the data obtained for the Trabzon coast (Özer & Çelikkale 1998). Mutlu (2009) emphasized that although *R. pulmo* is the most common species, especially along the southern coasts of the Black

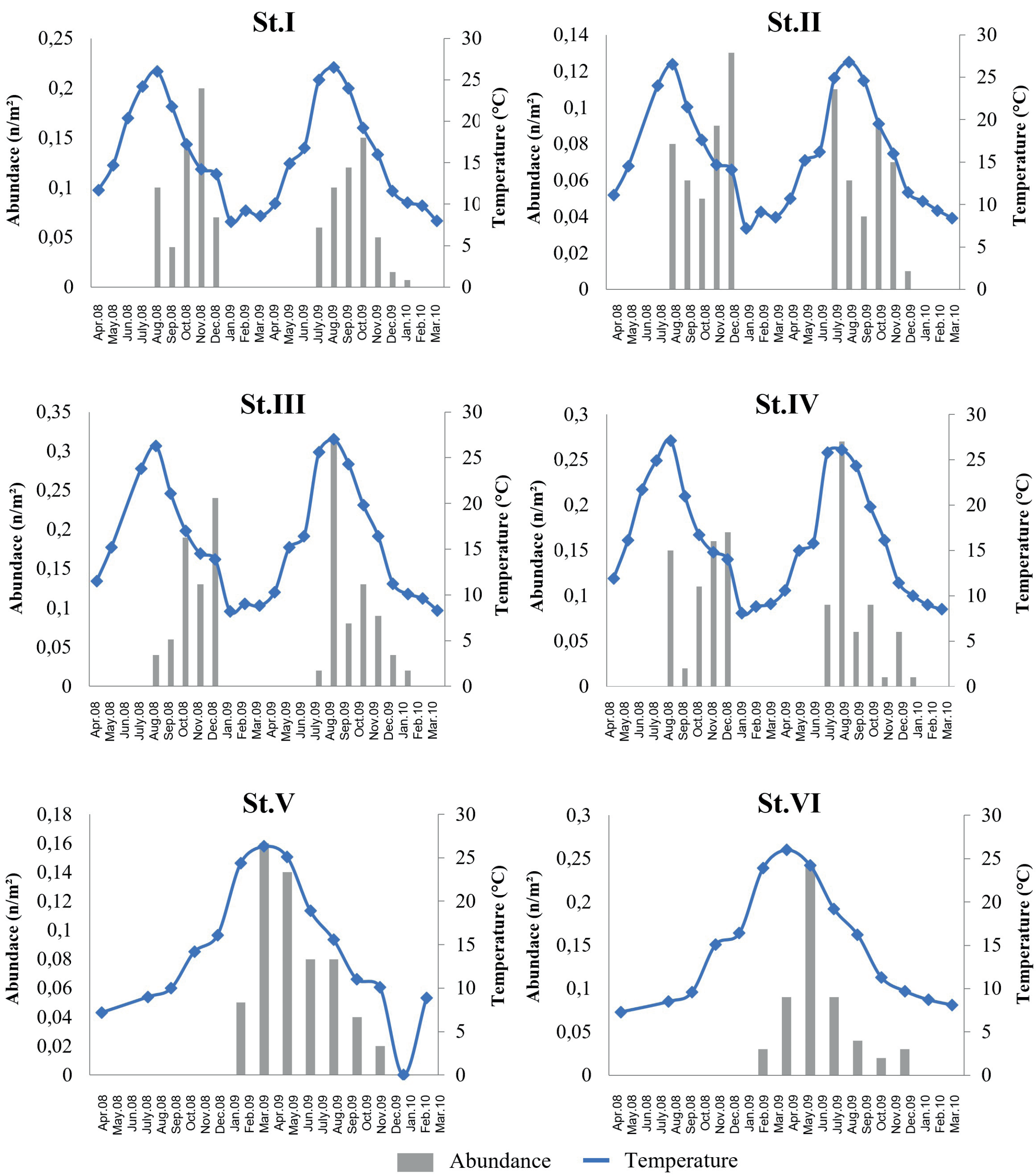

Figure 6

The abundance values of *R. pulmo* individuals with monthly temperature

Sea, this species was not observed in his research conducted between 2006-2007. However, in our study carried out between 2008 and 2010, *R. pulmo* was found intensively.

Environmental factors can directly affect the population size of jelly-like organisms (Purcell et al. 2007). Among these environmental factors, abiotic factors such as temperature, salinity, solar radiation and currents, and biotic factors such as nutrient availability, affect the presence of medusa (Wiebring et al. 2010). Considering the increased abundance of *Rhizostoma* species distributed in European waters at high temperatures, it has been suggested that warmer summer months lead to *Rhizostoma* spp. growth

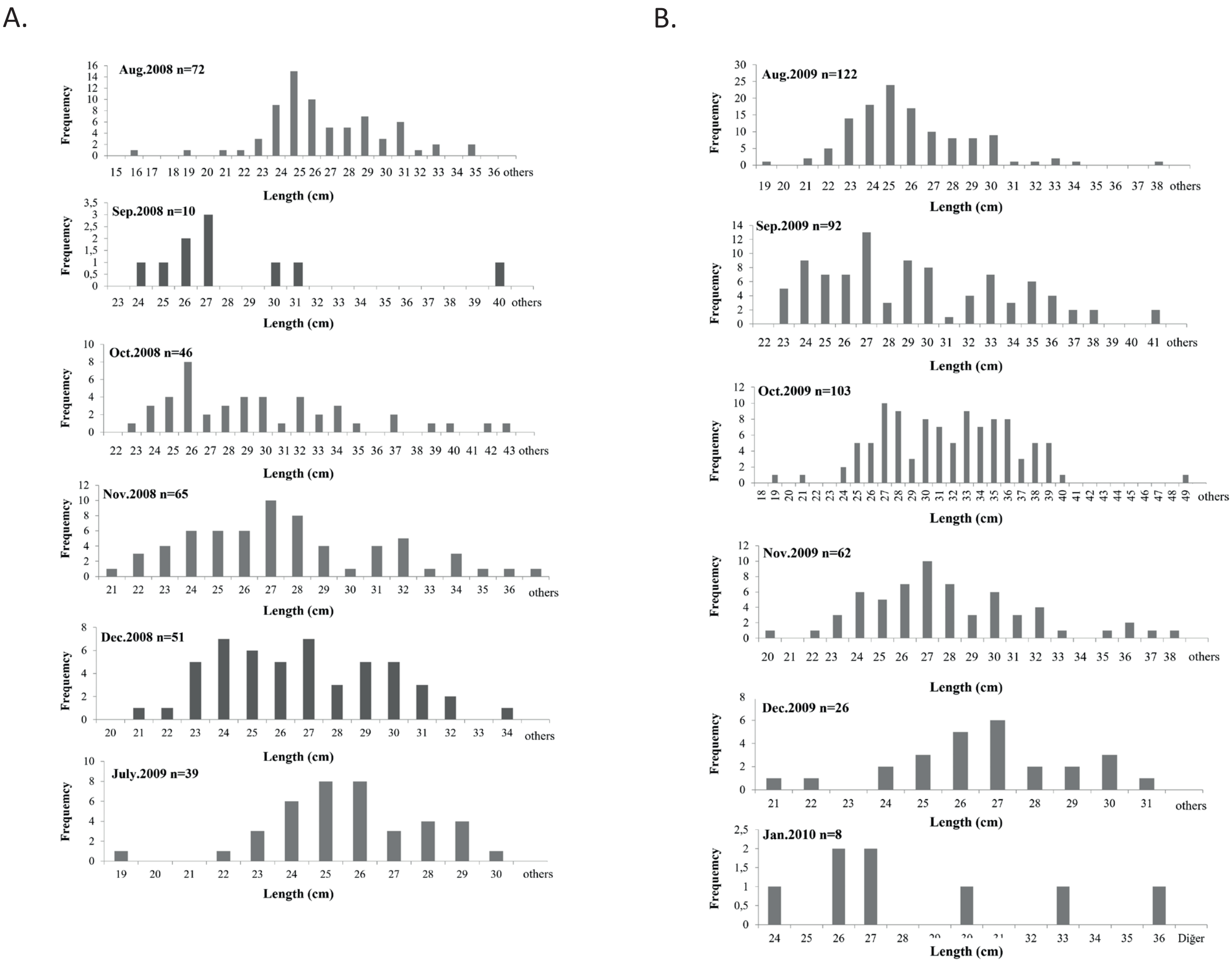

Figure 7

A. Length-frequency relationship of *R. pulmo* individuals (August 2008-July 2009); **B.** Length-frequency relationship of *R. pulmo* individuals (August 2009-January 2010)

(Lilley et al. 2009). Boero et al. (2016) pointed out that the two main global drivers of jellyfish blooms are global warming and overfishing. In this sense, they concluded that this gelatinous zooplankton appears to be expanding their distribution, as seen in the Mediterranean, probably due to both temperature increases and the gradual expansion of the Suez Canal.

In this study, it was determined that the monthly temperature values measured during the study period did not make a significant difference between the stations ($p > 0.05$). Lilley et al. (2009), based on the temperature values, when the distribution of *R. pulmo* individuals along the Samsun coast was examined, for the first half of the study period (2008), the maximum abundance of the distribution of *R. pulmo* individuals at the station IV was reached in August, when the temperature was 26°C. *R. pulmo* individuals, individuals which were seen for a total of 7 months in the second half of the study period, were observed in July 2009, unlike the previous study period, and reached the highest abundance in August and October (2009).

Alparslan (2001) stated that *R. pulmo* was not found in abundance in Çanakkale Harbour in any season, and that it is rarely found in summer and autumn. Alparslan (2001) did not observe the barrel jellyfish in the months of June and November and did so only at a low rate in June and November. Alparslan (2001) pointed out that the productivity of *R. pulmo* is mainly affected by temperature, salinity, and zooplankton biomass. In a study conducted in the Gulf of Izmit between July 2001 and November 2002, Isinibilir (2004) determined that the *R. pulmo* species was found at the end of summer and in the autumn months and stated that the occurrence of *R. pulmo* in this period

Figure 8

A. *Rhizostoma pulmo* in the dark, Atakum, **B.** *R. pulmo* clusters observed at Samsun Port station. *R. pulmo* individuals washed ashore by waves after the storm **C.** Atakum, **D.** Bafra (Original)

was due to the water temperature. Similarly, Lilley et al. (2009) argue that the high abundance of *Rhizostoma* spp. distributed in European waters may be related to temperature. Fuentes et al. (2011) determined that the barrel jellyfish was extensively distributed on the Catalan coasts of the Mediterranean and reached its highest numbers in July and August during the study period. In this study conducted between 2008 and 2010, the number of *R. pulmo* individuals identified was 242 for 2008 and 454 for 2009. Reyes Suárez et al. (2022) pointed out that blooms of *R. pulmo* in the North Adriatic Sea have been reported since the late 1800s and observed that the observed jellyfish density in 2021 reached more than 10 specimens per square metre.

Kogovšek et al. (2010) and Brotz & Pauly (2012) stated that the recurrence of *R. pulmo* blooms has increased in the last few decades. Similarly, between 2009 and 2015, the total number of sightings and number of bloom sightings of the most important common jellyfish taxa, including *R. Pulmo*, were observed along the Italian coastline. *R. pulmo* has been identified in increasing numbers over the years (Boero et al. 2016).

The results of this study show parallelism with the seasonal distribution studies of *R. pulmo* conducted outside of Turkish waters. Lakkis (1991) observed that the barrel jellyfish formed a heap in June-July 1986, depending on environmental conditions. Lakkis (1991) determined that in late May and early June 1986, when the surface water temperature suddenly rose from 23°C to 27.5°C, clusters of *R. pulmo* appeared along the Lebanese coast and continued until mid-August. It can be said that this effect created by the sudden increase in water temperature along the Lebanese coast in 1986 is also valid for the month of July in our study, when medusa were first seen in 2009. While no barrel jellyfish were encountered in July of the previous study period (2008), *R. pulmo* was found in all observation stations in July 2009. The temperature value of 16.2°C for June 2009 was determined as 25°C in July 2009. It was concluded that the temperature increases of about 9°C may have triggered the emergence of the barrel jellyfish seen in July 2009.

The fact that the average umbrella diameter sizes of the barrel jellyfish, which started to appear towards the end of the summer during the sampling period, vary according to the months, suggests that there may be more than one breeding period. There is evidence that water temperature changes trigger strobilation in many *Rhizostoma* spp. (Arai 1997; Holst et al. 2007). In addition to the fact that the release of ephyra has occurred due to the increase in temperature, the triggering of the release of ephyra with the decrease in temperature often occurs. It has been suggested that *Rhizostoma octopus* can reproduce twice a year in the German Gulf, in the spring and autumn seasons (Holst et al. 2007). This data, which was determined from the German Gulf, showed a parallelism in this study period, indicating that two growth periods were observed in the autumn season after the decrease in temperature and in the spring season due to the increase in temperature. On the other hand, Leoni et al. (2021) reported that blooming events of *R. pulmo* were observed in warm temperatures and benefited from warm temperatures.

The increasing populations of jellyfish may reflect the asexual reproductive success of benthic polyps (Scyphistomae) that produce young jellies (ephyra). Environmental factors such as nutrients, temperature, salinity, and the photoperiod are important for reproductive success and the seasonal timing of reproduction in marine invertebrates (Liu et al. 2008). Podocytes do not open below 10°C and the opening rate of podocytes increases at temperatures between 15 and 30°C. Increasing temperature from 2-10°C to 22°C triggers strobilation within 2 weeks. Although the temperature required for ephyra varies between 16-28°C, the optimum temperature is 24°C (Dong et al. 2009). This finding may explain why *R. pulmo* began to disappear from midwinter during the sampling period.

There are studies showing that the low flow of the river during the summer season leads to an increase in the number of gelatinous areas near the coast (Kingsford et al. 2000; Nicholls & Klein 2005). There is a positive relationship between the inflow of fresh water from rivers and the abundance of barrel jellyfish (Kingsford et al. 2000). High productivity is expected in areas where rivers flow into the sea due to nutrient input. When the *R. pulmo* was compared with the other 4 stations in terms of abundance and biomass values at stations V and VI, no significant difference was observed. It has been observed that *R. pulmo* individuals are more concentrated in the Adriatic Sea along the west coast, where the freshwater effect is more pronounced, than in the other areas where it is distributed (Kogovšek et al. 2010). Considering these findings, the fact that the *R. pulmo*, which is expected to be more dense than other jelly species and stations, is lower than predicted in terms of abundance and biomass values at stations V and VI can be attributed to its competition with other gelatinous species and its different ecological needs.

Rhizostoma individuals appear in large numbers on the water surface in still weather, but they go deeper into the water in rainy and windy weather. They show positive geotaxis in sunlight. On the other hand, it is also stated that they are found in heaps on the water surface when the sky is covered with clouds. Among the factors affecting the distribution of *R. pulmo* species, the effect of flow velocity plays a more dominant role than light intensity (Figure 8A, B). It can be said that the prevailing winds blowing from the sea to the land in autumn and the currents and waves formed by these winds carry the *R. pulmo* towards the shores. As a matter of fact, it was observed that the medusa drifted towards the shores with the waves formed by the autumn winds blowing from the north (north-west wind, north, north-east wind) during the study period formed heaps on the beach, especially in October and November. Considering the seasonal distribution, it is observed intensely in late summer and the autumn months. The medusa are thrown ashore by storms in autumn and winter (Figure 8C, D). The mass transfer of *R. pulmo* to the coastline with the autumn winds blowing towards the shores of the Black Sea stands as an important result. Unusual mass deaths of *R. pulmo* have been observed near the Dutch Wadden Sea (Lilley et al. 2009), the Sea of Marmara (Öztürk & Sümen 2020), and in the Gulf of Trieste (Reyes Suárez et al. 2022). The barrel jellyfish, which is thrown out of the sea by the waves with the autumn winds, may play an indirect role in reducing the effects of eutrophication. For this reason, the study areas consisting of the coastal strip and sandy areas should be monitored throughout the process.

It is interesting that *R. pulmo* individuals were rarely detected in the night observations carried out in August (2009) when the abundance of *R. pulmo* was high. Diurnal vertical migration is a common phenomenon seen in zooplankton species (Dupont et al. 2009). The daily migration of pelagic barrel jellyfish occurs, at least in part, as an active response to light levels. Mayer (1910) stated that *Rhizostoma* spp. show positive geotaxis to sun rays and cluster on the surface, and, on the contrary, they can show positive geotaxis in cloudy weather. Similar findings to those of Mayer (1910) were obtained in our current study area. The statistical correlation between light transmittance and distribution of *R. pulmo* was r = 0.40 and $p < 0.05$

(Spearman's rank correlation). Lakkis (1991) determined the statistical relationship between the distribution and light transmittance of *R. pulmo* as r = 0.90. A low positive correlation was observed with the effect of sun exposure, which is one of the climatic features, on the distribution of *R. pulmo* during the study period.

The highest known umbrella diameter of 70 cm for *R. pulmo* was obtained in the Aegean Sea and Burgaz Bay (Özer & Çelikkale 1998). The umbrella diameter of 42.5 cm, determined from the shores of the southern Black Sea between Kızılırmak and Yeşilırmak, collected from the shores of Lebanon (40 cm) in 1986 (Lakkis, 1991) and Trabzon (39.5 cm) in 1992 (Özer & Çelikkale 1998), was larger than the umbrella diameter of the *R. pulmo* samples. Commercial classification of edible medusa is generally made by measuring the umbrella diameter (Kingsford et al. 2000; Duyar & Sönmez 2006). If the umbrella diameter of the medusa exported to China is around 33 cm, it is considered as Class A, if it is between 25-33 cm, as Class B, if the diameter range is 17-25 cm, as Class C, and if the diameter group is less than 17 cm, it is considered as class D (Duyar & Sönmez 2006). The mean umbrella diameter of *R. pulmo* individuals obtained as a result of the study was 24.3 cm. In this study, *R. pulmo* is in the C class group according to the umbrella diameter averages.

Pérez-Ruzafa et al. (2002) stated that the overgrowth of *R. pulmo* and *Cotylorhiza tuberculata*, which are widely distributed along the shores of the Mar Menor, with increasing nutrient input will contribute positively to the regulation of nutrient balances and the elimination of eutrophication effects (Kingsford et al. 2000; Perez-Ruzafa et al. 2002). The Black Sea is one of the semi-enclosed polluted seas of a eutrophic character (Gucu, 2002; Oguz and Velikova 2010). The Samsun coasts, especially Kızılırmak, are under the influence of low flow untreated domestic, industrial, and agricultural wastes (Bakan & Böke Özkoç 2007; Bat et al. 2018). Pérez-Ruzafa et al. (2002) stated in their study, that *R. pulmo* and other gelatinous species distributed in the Black Sea may contribute to the elimination of high levels of productivity caused by excessive nutrient input and the improvement of the Black Sea's ecosystem.

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References

Alparslan, M. (2001). Succession of Scyphozoa – Ctenophora in the Harbour of Çanakkale. Turkish Journal of Marine Sciences, 7(1), 59–68.

Anninsky, B. E., Finenko, G. A., Abolmasova, G. I., Hubareva, E. S., Svetlichny, L. S., Bat, L., & Kideys, A. E. (2005). Effect of starvation on the biochemical compositions and respiration rates of ctenophores *Mnemiopsis leidyi* and *Beroe ovata* in the Black Sea. Journal of the Marine Biological Association of the United Kingdom, 85(3), 549–561. 10.1017/S0025315405011471

Arai, M. N. (1997). A functional biology of Scyphozoa. Chapman & Hall.

Bakan, G., & Özkoç, H. B. (2007). An ecological risk assessment of the impact of heavy metals in surface sediments on biota from the mid-Black Sea coast of Turkey. The International Journal of Environmental Studies, 64(1), 45–57. 10.1080/00207230601125069

Bat, L., Sezgin, M., Satilmis, H. H., Sahin, F., Üstün, F., Özdemir, Z. B., & Baki, O. G. (2011). Biological diversity of the Turkish Black Sea coast. Turkish Journal of Fisheries and Aquatic Sciences, 11(4), 683–692. 10.4194/1303-2712-v11_4_04

Bat, L., Öztekin, A., Şahin, F., Arıcı, E., & Özsandıkçı, U. (2018). An overview of the Black Sea pollution in Turkey. MedFAR, 1(2), 66–86.

Boero, F., Brotz, L., Gibbons, M. J., Piraino, S. & Zampardi, S. (2016). Impacts and effects of ocean warming on jellyfish. pp. 213-237. 10.2305/IUCN.CH.2016.08.en

Brotz, L., & Pauly, D. (2012). Jellyfish populations in the Mediterranean Sea. Acta Adriatica, 53(2), 213–232.

Demir, M. (1954). Report on the South Eastern coast of the Black Sea. İ.Ü.F.F. Hidrobiyoloji Araştırma Enstitüsü Yayınları. Seri B, I(4), 284–286.

Dong, J., Jiang, L.-X., Tan, K.-F., Liu, H.-Y., Purcell, E., Li P.-J., & Ye, C.-C. (2009). Stock enhancement of the edible jellyfish (*Rhopilema esculentum* Kishinouye) in Liaodong Bay, China: A review. Hydrobiologia, 616, 113–118. 10.1007/s10750-008-9592-9

Dönmez, M. A., & Bat, L. (2019). Detection of feeding dietary *Rhizostoma pulmo* (Macri, 1778) in Samsun coasts of the Black Sea, Turkey. E.Ü. Su Ürünleri Dergisi, 36(2), 135–144. 10.12714/egejfas.2019.36.2.05

Dupont, N. T., Klevjer, A., Kaartvedt, S., & Aksnes, D. L. (2009). Diel Vertical Migration of the Deep-water Jellyfish *Periphylla periphylla* Simulated as Individual Responses to Absolute Light Intensity. Limnology and Oceanography, 54(5), 1765–1775. 10.4319/lo.2009.54.5.1765

Duyar, H. A., & Sönmez, G. (2006). Denizanası İşleme Teknolojisi. [in Turkish]. E.Ü. Su Ürünleri Dergisi, 23(1/3), 403–405.

Finenko, G. A., Romanova, Z. A., Abolmasova, G. I., Anninsky, B. E., Svetlichny, L. S., Hubareva, E. S., Bat, L., & Kideys, A. E. (2003). Population dynamics, ingestion, growth and reproduction rates of the invader *Beroe ovata* and its impact on plankton community in Sevastopol Bay, the Black Sea. Journal of Plankton Research, 25(5), 539–549. 10.1093/plankt/25.5.539

Finenko, G. A., Romanova, Z. A., Abolmasova, G. I., Anninsky, B. E., Pavlovskaya, T. V., Bat, L., & Kideys, A. E. (2006). Ctenophores invaders and their role in the trophic dynamics of the planktonic community in the coastal regions off the Crimean coasts of the Black Sea (Sevastopol Bay). Oceanology, Academy of Sciences of the USSR, 46(4), 472–482. 10.1134/S0001437006040047

Fuentes, V., Straehler-Pohl, I., Atienza, D., Franco, I., Tilves, U., Gentile, M., Acevedo, M., Olariaga, A., & Gili, J.-M. (2011). Life cycle of the jellyfish; *Rhizostoma pulmo* (Scyphozoa: Rhizostomeae) and its distribution, seasonality and inter-annual variability along the Catalan coast and the Mar Menor (Spain, NW Mediterranean). Marine Biology, 158(10), 2247–2266. 10.1007/s00227-011-1730-7

Gucu, A. C. (2002). Can overfishing be responsible for the successful establishment of *Mnemiopsis leidyi* in the Black Sea? Estuarine, Coastal and Shelf Science, 54(3), 439–451. https://doi.org/10.1006/ecss.2000.0657

Holst, S., Sötje, I., Tiemann, H., & Jarms, G. (2007). Life cycle of the rhizostome jellyfish; *Rhizostoma octopus* (L.) (Scyphozoa, Rhizostomeae), with studies on cnidocysts and statoliths. Marine Biology, 151(5), 1695–1710. 10.1007/s00227-006-0594-8

İşinibilir, M. (2004). Abundance and distribution of pelagic Cnidaria, Ctenophora and effective factors on those in İzmit Bay. Doctoral dissertation University of İstanbul, Türkiye. (in Turkish).

İşinibilir, M., Okyar, A., & Öztürk, N. (2017). Venomous jellyfishes in the Turkish seas and their toxic effects. Aquatic Sciences and Engineering, 32(3), 154–169.

Kingsford, M. J., Pitt, K. A. & Gillanders, B.M. (2000). Management of jellyfish fisheries, with special reference to the order Rhizostomeae. In Gibson, R. N. & Barnes, M. (Eds.), Oceanography and Marine Biology: an annual review (38: pp. 85-156). Taylor & Francis.

Kogovšek, T., Bogunović, B., & Malej, A. (2010). Recurrence of bloom-forming scyphomedusae: Wavelet analysis of a 200-year time series. Hydrobiologia, 645(1), 81–96. 10.1007/s10750-010-0217-8

Lakkis, S. (1991). Aggregations of the scyphomedusa *Rhizostoma pulmo* in the Lebanese coastal waters during the summer of 1986. In Jellyfish blooms in the Mediterranean. Proceedings of the I1 Workshop on jellyfish in the Mediterranean Sea. Map Technical Reports Series no. 47. UNEP, Athens (pp. 119-127).

Leoni, V., Bonnet, D., Ramírez-Romero, E., & Molinero, J. C. (2021). Biogeography and phenology of the jellyfish *Rhizostoma pulmo* (Cnidaria: Scyphozoa) in southern European seas. Global Ecology and Biogeography, 30(3), 622–639. 10.1111/geb.13241

Lilley, M., Houghton, J., & Hays, G. C. (2009). Distribution, extent of inter-annual variability and diet of the bloom-forming jellyfish *Rhizostoma* in European waters. Journal of the Marine Biological Association of the United Kingdom, 89(1), 39–48. 10.1017/S0025315408002439

Liu, W. C., Lo, W. T., Purcell, E. F., & Chang, H. H. (2008). Effects of temperature and light intensity on asexual reproduction of the scyphozoan, *Aurelia aurita* (L.) in Taiwan, Jellyfish Blooms: Causes, Consequences, and Recent Advances: Proceedings of the Second International Jellyfish Blooms Symposium, held at the Gold Coast, Queensland, Australia, 24–27 June 2007 (pp. 247-258).

Mayer, A. G. (1910). Medusae of the World: The Scyphomedusae. Carnegie institution of Washington.

Mutlu, E. (2009). Recent distribution and size structure of gelatinous organisms in the southern Black Sea and their interactions with fish catches. Marine Biology, 156(5), 935–957. 10.1007/s00227-009-1139-8

Mutlu, E., Bingel, F., Gucu, A. C., Melnikov, V. V., Niermann, U., Ostr, N. A., & Zaika, V. E. (1994). Distribution of the new invader *Mnemiopsis* sp. and the resident *Aurelia aurita* and *Pleurobrachia pileus* populations in the Black Sea in the years 1991-1993. ICES Journal of Marine Science, 51(4), 407–421. 10.1006/jmsc.1994.1042

Nicholls, R. J., & Klein, R. J. (2005). Climate change and coastal management on Europe's coast. In: Vermaat, J., Salomons, W., Bouwer, L., Turner, K. (eds) Managing European Coasts. Environmental Science. (pp. 199–226). Springer, Berlin, Heidelberg. 10.1007/3-540-27150-3_11

Oguz, T., Ducklow, H. W., Purcell, J. E., & Malanotte-Rizzoli, P. (2001). Modeling the response of top-down control exerted by gelatinous carnivores on the Black Sea pelagic food web. Journal of Geophysical Research, 106(C3), 4543–4564. 10.1029/1999JC000078

Oguz, T., Fach, B., & Salihoğlu, B. (2008). Invasion dynamics of the alien ctenophore *Mnemiopsis leidyi* and its impact on anchovy collapse in the Black Sea. Journal of Plankton Research, 30(12), 1385–1397. 10.1093/plankt/fbn094

Oguz, T., & Velikova, V. (2010). Abrupt transition of the northwestern Black Sea shelf ecosystem from a eutrophic to an alternative pristine state. Marine Ecology Progress Series, 405, 231–242. 10.3354/meps08538

Özer, N. P., & Çelikkale, S. (1998). Seasonal occurance of jellyfish *Rhizostoma pulmo* (Macri, 1778) in the Black Sea. The Proocedings of the First International Symposiumon Fisheries and Ecology, 2-4 September 1998. FISHECO Secretariat.

Öztürk, B., & Topaloğlu, B. (2011). Monitoring of *Chrysaora hysoscella* (Linnaeus 1767) in Istanbul Strait and exist of the Black Sea. In: Abstract of National Water Days Symposyum, Turkish Marine Research Foundation, Istanbul Türkiye (pp.

14).

Öztürk, B., Mihneva, V., & Shiganova, T. (2011). First records of *Bolinopsis vitrea* (L. Agassiz, 1860) (Ctenophora: Lobata) in the Black Sea. Aquatic Invasions, 6(3), 355–360. 10.3391/ai.2011.6.3.12

Öztürk, İ. D., & Sümen, S. G. (2020). Unusual mass mortality of jellyfish *Rhizostoma pulmo* on the coast of the Sea of Marmara in December 2020. Journal of the Black Sea/Mediterranean Environment, 26(3), 343–351.

Pérez-Ruzafa, A., Gilabert, J., Gutierrez, J. M., Fernandez, A. I., Marcos, C., & Sabah, S. (2002). Evidence of a planktonic food web response to changes in nutrient input dynamics in the Mar Menor coastal lagoon, Spain. Hydrobiologia, 475(1), 359–369. 10.1023/A:1020343510060

Purcell, J. E., Malej, A., & Benović, A. (1999). Potential links of jellyfish to eutrophication and fisheries. In T. C. Malone, A. Malej, T. L. Harding, N. Smodlaka, & R. E. Turner (Eds.), Ecosystems at the Land-Sea Margin: Drainage Basin to Coastal Sea. Coast Estuar Stud, 55, 241–263. 10.1029/CE055p0241

Purcell, J. E., Uye, S. I., & Lo, W. T. (2007). Anthropogenic causes of jellyfish blooms and their direct consequences for humans: A review. Marine Ecology Progress Series, 350, 153–174. 10.3354/meps07093

Reyes Suárez, N. C., Tirelli, V., Ursella, L., Ličer, M., Celio, M., & Cardin, V. (2022). Multi-platform study of the extreme bloom of the barrel jellyfish *Rhizostoma pulmo* (Cnidaria: Scyphozoa) in the northernmost gulf of the Mediterranean Sea (Gulf of Trieste) in April 2021. Ocean Science, 18(5), 1321–1337. 10.5194/os-18-1321-2022

Shiganova, T. (1998). Invasion of the Black Sea by the ctenophore *Mnemiopsis leidyi* and recent changes in pelagic community structure. Fisheries Oceanography, 7(3-4), 305–310. 10.1046/j.1365-2419.1998.00080.x

Svetlichny, L. S., Abolmasova, G. I., Hubareva, E. S., Finenko, G. A., Bat, L., & Kideys, A. E. (2004). Respiration rates of *Beroe ovata* in the Black Sea. Marine Biology, 145, 585–593. 10.1007/s00227-004-1336-4

Wiebring, A., Helmholz, H. L., Lassen, S., Prange, A., & Jarms, G. (2010). Separation and analysis of different types of nematocysts from *Cyanea capillata* (L.) medusae. Hydrobiologia, 645(1), 203–212. 10.1007/s10750-010-0227-6

Zaitsev, Yu., & Mamaev, V. (1997). Marine Biological Diversity in the Black Sea: A Study of Change and Decline. GEF Black Sea Environ. Prog. U.N. Publ.

Zar, J. H. (1996). Biostatistical analysis prentice-hall international. Inc., New Jersey. 3rd Edition, Prentice Hall, Upper Saddle River.