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Distribution and Population Structure of Discarded *Parastichopus regalis* (Holothuroidea) from the Shrimp Trawling Fishery in the Sea of Marmara

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Abstract

Royal sea cucumber *Parastichopus regalis* is frequently caught as a bycatch in shrimp fishery with beam trawl in the Sea of Marmara (SoM). This study presents the first assessment of the distribution patterns and population structure of the royal sea cucumber in the SoM. The dataset was obtained based on the area scanning method with underwater visual counting techniques (<50 m) and beam trawling (≥50 m). A total of 1,377 royal sea cucumbers were sampled off the Kapıdağ Peninsula and Marmara Islands between May 2022 and April 2023 at monthly intervals. The gutted lengths of the samples ranged from 6.65 to 30.70 cm. No gonads were found from October to March according to macroscopic examinations; thus, the gonadal cycle starts in April, peaks in July where there gonadosomatic index gain its maxima for both sexes, and completes in September. The mean annual biomass was calculated as 30.5 kg·km^{-2}, and the highest value obtained in a fishery operation reached 100.8 kg·km^{-2}. The distribution patterns of royal sea cucumber seasonally varied however further studies on the relationships between food availability, social interaction, and biotic factors are needed to understand relevant spatiotemporal patterns.

Introduction

Holothuroids are widespread marine invertebrates, occurring in both shallow and deep habitats (Ramón et al., 2010; Pierrat et al., 2022). They are an effective source of income for many fisheries areas worldwide (Purcell et al., 2012; Galimany et al., 2018). Sea cucumbers are deposit feeders, which feed by consuming diatoms and bacteria mixed with seafloor debris (Purcell et al., 2016; Ramón et al., 2019). These species mop up particulate organic matter that covers benthic vegetation on hard reef surfaces (Hamel and Mercier, 2008). Due to their rich nutritional content, they are harvesting as food worldwide for centuries; especially in Far East countries. There are almost 1200 holothuroid species in the world's seas, 10 of which are in the Turkish seas (Aydın, 2016; Aydın et al., 2019; Aydın et al., 2024). Holothurians are not traditionally consumed in Türkiye. Almost all the harvested product is exported to various countries (Aydın et al., 2023; Karadurmuş and Aydın, 2023).

Parastichopus regalis (Cuvier, 1817), also named royal sea cucumber, is a holothurian species belonging to the family Stichopodidae. It is the only Stichopodidae species present in the Mediterranean Sea. The distribution extent of the species includes the coasts of the Mediterranean Sea, the Marmara Sea (SoM), and the eastern and western Atlantic Ocean (Ramón *et al.*, 2010). It is a benthic species located in an extensive depth range from 5 m to 800 m (Tortonese, 1965), being particularly dense at 50-300 m depths (Ramón et al., 2010). It is common in the SoM (Aydın, 2008), but its distribution patterns are unknown. Stocks are impacted by trawling and dredging but not exploited globally. The species is rated globally in the "Least Concern" (LC) category in The IUCN Red List of Threatened Species (Mercier and Hamel, 2013). Information on the royal sea cucumber's biology and ecology is limited, with some exceptions on genetic differentiation among populations (Maggi and González-Wangüemert, 2015), biotechnological aspects (Santos et al., 2015), immune response to different temperatures (Galimany *et al.*, 2018), and sediment particle size selection during feeding (Ramón et al., 2019). There are also some studies of the depth-dependent distribution pattern (Ramón et al., 2010) and reproductive biology (Ramón et al., 2022) of the species in the Balearic Sea.

The incidental catch remains a global management problem for sustainable fisheries. Sea cucumbers are vulnerable to overfishing because of complicated ecological and biological characteristics and high fishing pressure on their typical habitat (Purcell et al., 2013; Rakaj and Fianchini, 2024). Considering the ecosystem services, the overexploitation of populations can potentially cause severe cascading effects in the ecosystems. For this reason, identifying the factors affecting species distributions is crucial to understanding the interactions of fisheries with catch species (Purcell et al., 2016; Rakaj and Fianchini, 2024). Royal sea cucumber is caught as bycatch with beam trawls in shrimp fisheries in the SoM, but the effect of fishing activities is unknown on the populations (Aydın, 2008; Ramón et al., 2010). This study aims to reveal several aspects of the biology of P. regalis, including abundance, biomass, reproduction and spatio-temporal distribution patterns in the SoM (Türkiye). Within this context, potential impacts of fishing activities to the royal sea cucumber populations may be revealed, contributing to the development of effective management strategies for sustainable fisheries.

Materials and Methods

Study Area

The SoM acts as a biological corridor, connecting the Mediterranean and the Black Sea. The study area is located in the southern part of the SoM, which is defined as the geographical sub-area (GSA) 28 in the Mediterranean and is an ecologically critical area with many islands and gulfs around it (Figure. 1) (Karakulak et al., 2023). The area is characterized by extensive and shallow shores (<100m) followed by a deep-sea system of more than 200 m. Hydrographic dynamics with

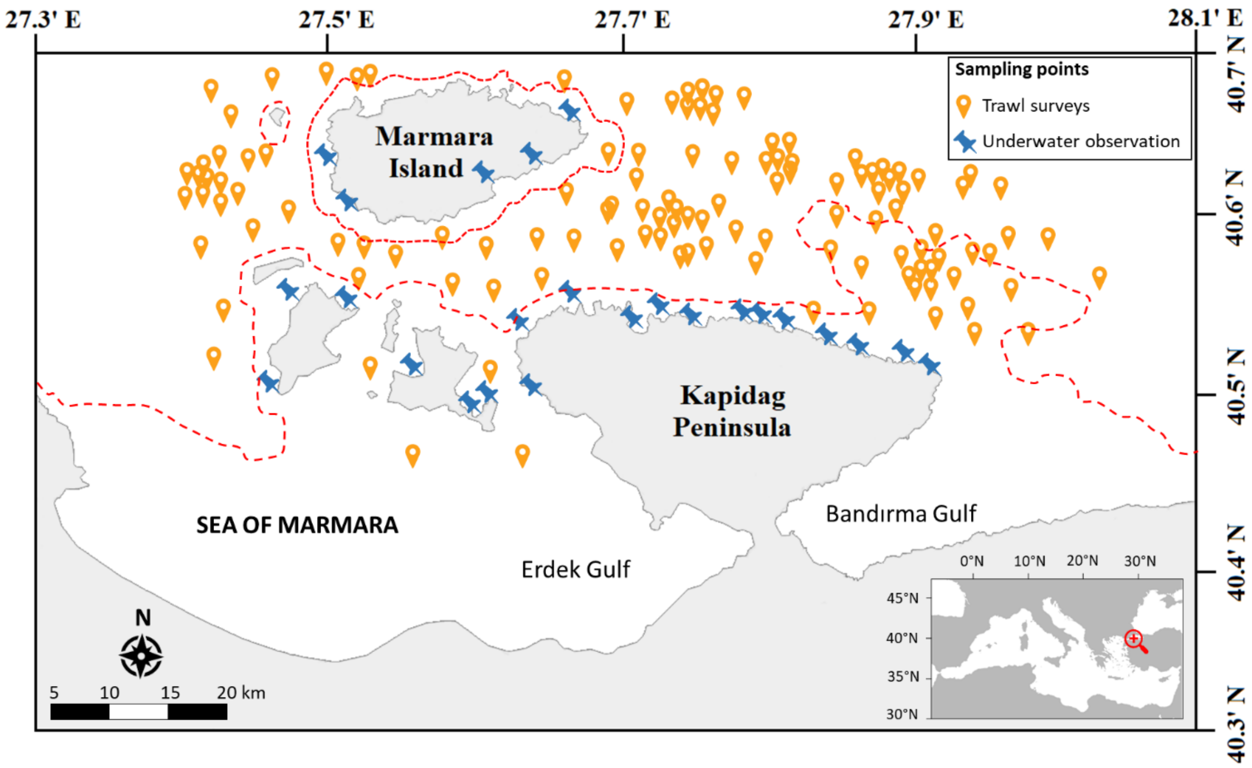

Figure 1. Map of the study area (Geographical Sub-Area 28, southern part of the Sea of Marmara), with sampling sites grouped according to sampling method. The red dashed lines represent depth contours corresponding to 50 m.

physical, chemical, and biological characteristics in the region support the survival of a wide variety of species (Keskin, 2012). The study area also covers the Kapidag Peninsula surrounding and several islands such as Marmara, Pasalimani, Avsa, Koyun, Ekinlik, Fener, Tavşan, Haliada and Mola. The gulf areas, namely Bandirma and Erdek, are characterized by calm and shallow waters, and the poor current causes the area to be vulnerable to unexpected changes such as temperature changes, algal blooms etc. (Keskin, 2012). The last occurrence was the mucilage event seen in 2021, which caused devastating effects on benthic habitats and organisms (Karadurmuş and Sarı, 2022). While fishing activities for migratory fish species in the SoM are the main target of industrial fisheries, shrimp species with beam trawl have been preferred for subsistence fisheries (Ulman et al., 2013). In particular, the beam trawl fleet exploits the fishing ground up to 200 m, the commercial valuable deep-water rose shrimp (*Parapenaeus longirostris* Lucas, 1846), which is widespread in the region (İşmen et al., 2016).

Field Sampling

This study was conducted with commercial shrimp beam trawling fisheries and SCUBA diving operations between May 2022 and April 2023 (Figure. 1). The study area was grouped in 5 different depth contours as non-fishing (x1:<50 m, closed to beam trawl fishing areas in the SoM) and as fishing areas (depth ranges; x2: 50–100 m, x3: 100–150 m, x4: 150–200 m, x5: ≥200 m). Trawl surveys were conducted monthly by the commercial beam trawl vessel called Nihal-1 (10.5 m in length, 4.60 in width and 280 HP) between 20 and 226 m depth range. Sampling effort is not equal between depth zones and months. The hauls were randomly taken monthly to represent all depths. A total of 8.88 km^2 area was swept in 120 beam trawl surveys at randomly selected stations in the study area. Experimental trawl surveys were done with a twin beam trawl, composed of a frame (10 m length and 50 cm height) forming the general beam structure and a bag of 11 m in length behind it (mesh size 32 mm). It can be predicted that there is no loss of small-sized royal sea cucumber due to the small mesh size used in shrimp fishing. Duration of each haul varied between 1.9 and 2.4 hours depending on meteorological conditions, and the towing speed was approximately 2.4 knots. During each tow, information about the geographical position, towing duration, tow length and depth was recorded using a marine navigator system (MaxSea Marine Navigation Software®). Trawl surveys were conducted with the experimental fishing permit from the Republic of Türkiye Ministry of Agriculture and Forestry throughout the year. The Mediterranean International Trawl Survey (MEDITS) protocol was largely adhered to, but the haul times were kept constant at approximately 2 hours. The species, which is more abundant between 50 and 300 m in the Mediterranean (Ramón et al., 2010), is known to be distributed in shallow waters down to 5 m (Tortonese, 1965). For this reason, underwater observations were used for sampling purposes in shallow areas (in areas shallower than 42 m) where trawling gear was not operating effectively. Underwater surveys were also performed seasonally by SCUBA diving along underwater expanding squares methods in each site (Pizarro et al., 2017) during the daytime. Two divers swam along the variable route (depending on water visibility) using a diving compass, identified and counted royal sea cucumbers, recording them on their underwater flip charts. A total area of 112,000 m^2 was surveyed in 24 sites at depths ranging from the coastline to 42 m based on the SCUBA diving. A data set regarding spatial distribution was created by combining data obtained from underwater and beam trawl surveys.

Data Collection

The royal sea cucumber in the total catch was separated on the deck. The size and weight of holothurians can change during morphometric measurements due to their ability to extract and expel internal organs or relaxation. In addition, being dead or alive drives differences in body size (Aydın, 2019). Therefore, the collected samples were stored in plastic tanks (400 L) with flow-through seawater onboard until the removed internal organs. A longitudinal incision (approximately 3 cm cut) was made along the lateral surface of the specimens to remove the respiratory tree, gonads, and digestive tract (Ramón et al., 2022). The gutted sample kept in seawater may contract in size; therefore, the length of the sample was measured from the mouth to the anal orifice as quickly as possible after the eviscerated was removed (Ramón et al., 2010; Aydın, 2019). The gutted length (GL) was measured using a long jaw caliper with 0.01 cm precision, while body weight (GW) was weighed using a motorised digital balance with 0.01 g precision. All samples were grouped into 3 cm GL classes by sex for population distribution. The sex was determined according to the presence of oocytes in the female's tubules. Sex determination was conducted macroscopically, considering the consistency of the tubules, opacity and color of the gonads (Ghobadyan et al., 2012; Ramón et al., 2022). The population density and biomass were estimated as follows;

$$\text{Density} = \sum \text{Number of individuals} / \sum \text{Scanned area (km}^2\text{)}$$

$$\text{Biomass} = \sum \text{Gutted weight (kg)} / \sum \text{Scanned area (km}^2\text{)}$$

The Gonadosomatic Index (GSI) of the royal sea cucumber was calculated with the following formula (Ramón et al., 2022):

$$\text{GSI (\%)} = \frac{\text{Drained gonad weight (Wg, g)}}{\text{Total fresh gutted weight (GW, g)}} \times 100$$

Statistical Analysis

This study tests the hypotheses that depth, season, and spatial differences between closed and open fishing areas significantly influence the biomass and distribution of royal sea cucumbers in the SoM. The normality assumption of the dataset was examined to ensure the appropriateness of the chosen statistical tests. Histograms provided visual representations of the frequency distribution of each variable. Q-Q (quantile-quantile) plots were utilized to compare the quantiles of the data with the theoretical quantiles of a normal distribution. Additionally, Shapiro-Wilk plots were constructed to visualize how the data points deviated from a normal distribution. Any deviations from normality were considered indicative of non-normality. To assess the homogeneity of variance across groups, which is important for accurate statistical analysis, Levene's test was employed. Levene's test is a non-parametric test used to assess whether the variances of different groups are equal. This was particularly relevant for the seasonal and depth-related density analysis, as well as the gender-based analysis of length, weight, and GSI. Levene's test was applied to the data from different groups to determine whether significant differences existed in variance. The Kruskal-Wallis test was employed to assess whether density varies across different seasons and depths simultaneously. Gender-based differences in average length, weight and GSI were examined using non-parametric tests due to the non-normality of the data. The Mann-Whitney U test was applied to compare these variables between male and female groups. Statistically significant variation of the sex ratio from the theoretical ratio (1:1) was detected using the Chi-square test (χ^2) (Düzgüneş et al., 1983). The descriptive statistics of the data were calculated using the statistics software ver. 26 SPSS®. Significance levels for all statistical tests were established at α=0.05 a priori (Sokal and Rohlf, 1969). To explore the relationships between average density and biomass, depth, and season of royal sea cucumber within the study area, a 2D contour plot was generated using OriginLab® software.

Results

Overall, the royal sea cucumber biomass caught was 251 kg. The annual average biomass was estimated as 30.5 kg·km-2. Spatial and temporal trends in biomass are presented in Table 1. This study revealed that depth distribution inferred from the biomass were located at depths ranging from 39 to 226 m for the royal sea cucumber. The annual average biomass of royal sea cucumber was highest in the 100-150 m section (46.3 kg·km^{-2}), followed by 150–200 and 50–100 m sections (Figure. 2a). The lowest biomasses occurred in shallower (<50 m) and deeper (≥200 m) waters were similar, with 12.9 and 15.1 kg·km^{-2}, respectively (Figure. 2a). Mean biomass between depth contours (KW test, H=49.911, df=4, P<0.001) showed significant variation. The mean biomass of royal sea cucumber was significantly different (U test, U=272.5, Z=–4.320, P<0.001) across closed (with a mean of 12.9 kg·km^{-2}) and open fishing areas (with a mean 33.2 kg·km^{-2}) (Figure. 2a). Mean biomass was highest during autumn [September, October, November] (45.3 kg·km^{-2}) and lowest during spring [March, April, May] (21.9 kg·km^{-2}). Biomass was close to average in the warm season with 32.2 kg·km^{-2} (Figure. 2b). No specimens were caught at one site in autumn, three in winter [December, January, February], and two in spring. The mean biomass of royal sea cucumber significantly differed across seasons.

Relationships between average density (Figure. 3) and biomass (Figure. 4), depth and season were explored using a 2D contour plot. The distribution of royal sea cucumber inside the study area was heterogeneous and patchy. Clustering was evident from 120 m to 160 m deep in summer [June, July, August] and autumn, and it was mainly concentrated towards deeper waters in the cold season. The royal sea cucumber was partially absent in winter at <50 m section (with 32.1 kg·km^{-2} density and 5.5 kg·km^{-2}

Table 1. Density (ind·km^{-2}) and biomass (kg·km^{-2}) variations of *Parastichopus regalis* in different depth ranges and seasons

Depth range (m)	Density (ind·km^{-2})				Annual
	Summer	Autumn	Winter	Spring	
<50	98.4	137.4	32.1	68.4	84.1
50–100	207.3	295.7	86.8	126.2	180.9
100–150	313.5	484.2	189.4	208.4	306.8
150–200	198.7	315.7	248.3	174.8	232.1
≥200	82.4	37.0	145.5	60.5	82.8
Total	203.0	297.4	140.1	138.6	194.8
Depth range (m)	Biomass (kg·km^{-2})				Annual
	Summer	Autumn	Winter	Spring	
<50	14.7	20.1	5.5	11.0	12.9
50–100	33.1	43.6	14.8	21.0	28.3
100–150	48.2	71.4	30.2	30.4	46.3
150–200	34.4	48.0	38.9	28.7	37.0
≥200	12.6	17.2	23.6	9.0	15.1
Total	32.2	45.3	22.6	21.9	30.5

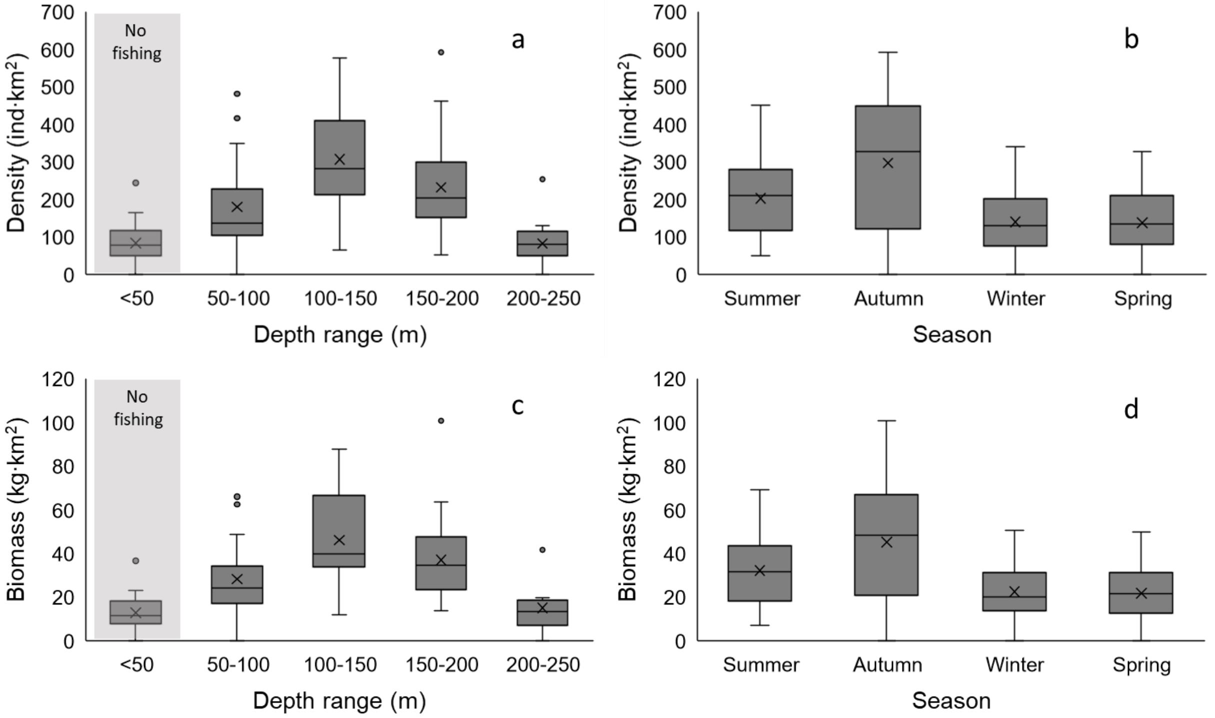

Figure 2. Box-plots showing average density (ind·km^{-2}) and biomass (kg·km^{-2}) of *Parastichopus regalis* based on depth range (a and c) and season (b and d). The × icon in the boxes represent the mean values, and whiskers represent the standard deviations. Error bars represent 95% confidence intervals. The shaded part in section "a" and "c" represents the closed-depth range of beam trawling.

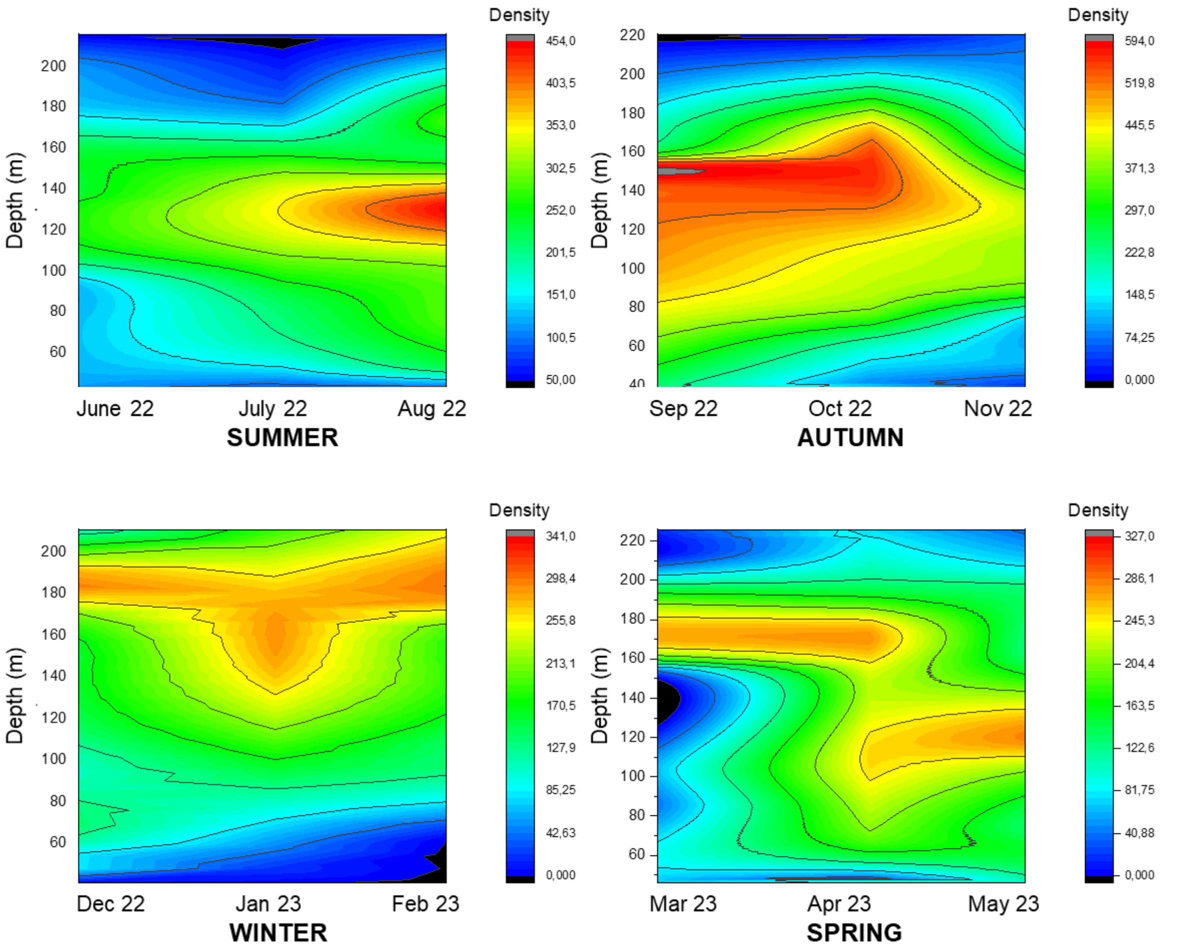

Figure 3. Contour plots and response surface plots for effects of depth (m) and season on density (ind·km^{-2}).

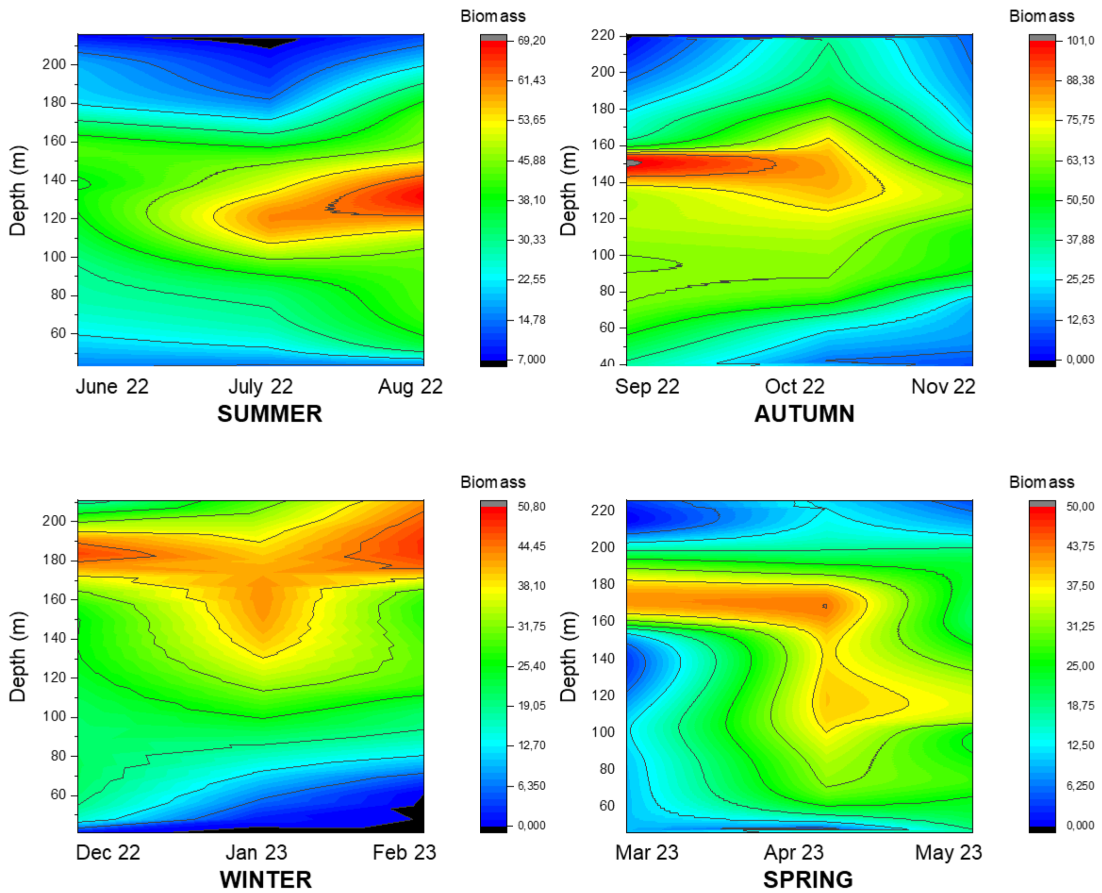

Figure 4. Contour plots and response surface plots for effects of depth (m) and season on biomass (kg·km^{-2}).

biomass), while average density and biomass showed an increasing trend in the other three seasons. Conversely, in the ≥200 m section, the highest density and biomass was observed in winter (with 145.5 ind·km^{-2} density and 23.6 kg·km^{-2}), and a sharp decrease in spring. Royal sea cucumber biomass was below average throughout the year at <50 m and ≥200 m sections.

A total of 1,377 royal sea cucumbers (483 females, 292 males, and 602 unsexed) were examined during the study period. The size and weight of the population ranged between 6.65−30.70 cm and 16.80−418.00 g (Table 2). Females were abundant in entire size classes, except the 15 cm size class. The TL frequency distribution differed from the normal distribution in females (KS-test, Z=0.059, n=483, P<0.001) and males (KS-test, Z=0.054, n=292, P<0.01). The mean size (U test, U=69533.0, Z=-0.326, P=0.744) and weight (U test, *U*=68221.0, Z=-0.761, P=0.447) were not significantly different between females and males.

Overall sex ratio was 1:0.60, which is highly significantly different from the theoretical ratio of 1:1 (χ^2=66.673, *df*=1, P<0.001) (Table 3). The gonads were absent from October to March, and sex could not be determined in 43.7% of the samples (Figure. 5). Gonads were visible in at least 50% of individuals after the 18 cm size class, and sex discrimination was possible. The gonads allowed sex discrimination in 78% of individuals at the largest size class 30 cm. The mean GSI was estimated as 2.35, 2.27, and 2.32 for females, males, and combined sexes, respectively. The mean GSI were not significantly different among the sexes (U test, U=16090.0, Z=-0.599, P=0.549). The highest GSI values were observed in July, with 5.70±5.33 for females and 5.49±4.45 for males, respectively (Figure 5). The mean GSI were significantly different across months for females (KS-test, H=150.573, df=5, P<0.001) and males (KS-test, H=94.827, df=5, P<0.001).

Table 2. Descriptive statistics of *Parastichopus regalis* in the Sea of Marmara by sexes

Sex	n	Gutted Length, cm		Gutted Weight, g	
		Mean±SE	Range	Mean±SE	Range
Female	483	18.73±0.26	6.90−30.70	157.72±3.55	19.00−418.00
Male	292	18.86±0.34	8.70−30.70	162.11±4.68	33.00−416.00
Unknown	602	17.35±0.22	6.65−30.50	140.37±2.87	16.80−369.00
Combined	1377	18.16±0.15	6.65−30.70	151.07±2.04	16.80−418.00

Table 3. Sex ratios of *Parastichopus regalis* according to months.

	Number of specimens				Sex ratio	
	Female	Male	Unknown	Combined	Female:Male	χ^2
Months						
May' 22	43	24	–	67	1:0.56	5.388 *
June' 22	53	33	–	86	1:0.62	4.651 *
July' 22	66	39	–	105	1:0.59	6.943 **
Aug' 22	99	49	–	148	1:0.49	16.892 ***
Sep' 22	172	106	–	278	1:0.62	15.669 ***
Oct' 22	–	–	238	238	–	–
Nov' 22	–	–	107	107	–	–
Dec' 22	–	–	71	71	–	–
Jan' 23	–	–	62	62	–	–
Feb' 23	–	–	84	84	–	–
Mar' 23	–	–	40	40	–	–
Apr' 23	50	41	–	91	1:0.82	0.890 ^{ns}
Total	483	292	602	1377	1:0.60	66.673 ***

df: 1, χ^2: Chi-square value, ^{ns}: not significant, *: P<0.05, **: P<0.01, ***: P<0.01

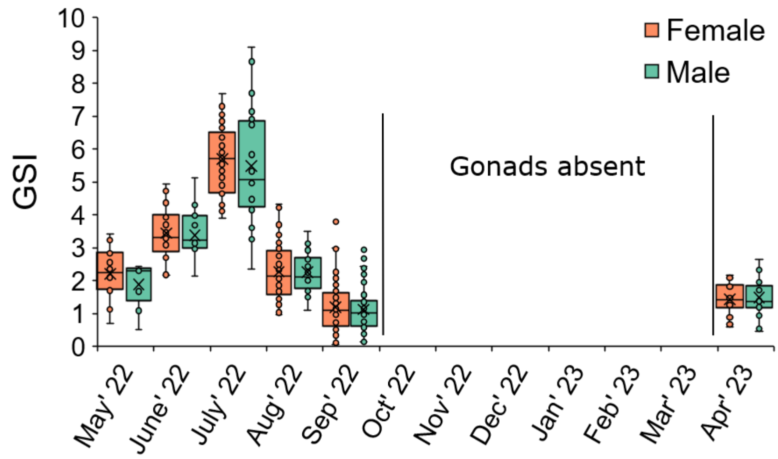

Figure 5. Boxplot of the monthly Gonadosomatic Index (GSI) for *Parastichopus regalis*.

Discussion

This study presents the distribution of the royal sea cucumber between 39 m and 226 m depth in the SoM. According to Tortonese (1965) that royal cucumber could be found at a broad depth from 5 to 800 m. Ocaña et al. (1982) reported that the species is distributed in the Alboran Sea between 80 and 290 m. Ramón et al. (2010) recorded wide distribution at depths between 50 and 747m in the northwestern Mediterranean. Scannella et al. (2022) reported that the species prefers soft bottoms in the 50 to 200 m depth range in the Central Mediterranean Sea. Ramón et al. (2010) found no individuals shallower than 50 m in their sampling with bottom trawl in the Northwestern Mediterranean. During the study, individuals reaching the shallowest 39 m were recorded, which is thought to be locally attached to suitable habitat. This study presents the notable first-time biomass of 12.9 kg·km^{-2} in waters shallower than 50 m. Trawling in shallower areas was limited due to the bottom structure. However, royal sea cucumber individuals were not found in underwater surveys up to 42 m depth, which commonly consists of sandy-muddy habitat. It is worth noting that holothurians can bury themselves in soft substrates, which may have resulted in them not being encountered during dives. However, whether the royal sea cucumber exhibits this behavior requires further investigation. The spatial and temporal patterns of royal sea cucumber varied significantly over time (Figure. 3 and Figure. 4). Considering the density patterns (Figure. 3), individuals occurred in a broader range depth during the winter, while clustered in summer and autumn. The SoM is represented in a narrow range of 14 to 16°C at depths greater than 35 m throughout the year (Özsoy and Altıok, 2016). Previous studies (Galimany et al., 2018; Scannella et al., 2022) have not found significant effects on the spatial density of royal sea cucumber over the observed temperature range. Royal sea cucumber is sensitive to food availability, and biotic factors could affect abundance and spatial patterns (Scannella et al., 2022). To expand our knowledge of this species, further studies are recommended focusing on the relationship of spatial and temporal distribution with the social environment, biotic factors, and food availability.

The overall sex ratio was calculated differently from a theoretical ratio (1:1) in this study (Table 3). Contrary to the current study, a balanced result (of which 80 were females, 98 were males) for the royal sea cucumber has been reported from the northwestern Mediterranean Sea by Ramón et al. (2022). Several studies on reproductive biology verify the female-biased sex ratio of holothurians (Gaudron et al., 2008; Santos et al., 2017; Venâncio et al., 2022). Unbalanced sex ratios are likely due to the tendency to cluster into same-sex groups (Shiell and Uthicke, 2006; Muthiga et al., 2009). An unbalanced sex ratio may be potentially influenced by one sex exhibiting cryptic behaviors during the day as observed in *H. floridana* (Ramos-Miranda et al., 2017). Ramón et al. (2022) reported that gonads were not visible in 88% of 1728 samples. In this study, the gonads were macroscopically evident in 56.3% of the samples, with a higher rate. As this study was conducted over a single year, potential inter-annual variability in oceanographic conditions, such as shifts in water temperature, may result in earlier or later spawning periods. Further long-term studies that incorporate multi-year datasets and environmental monitoring are necessary to fully understand the relationship between spawning periods and oceanographic variables, and to account for potential variations. The haul duration may have significantly affected the presence of gonads. Like most holothurians (Bertolini, 1930), the royal sea cucumber sharply contracts its body wall muscles and protrudes its internal organs in stressful situations (Ramón et al., 2019). This situation limits the year-round monitoring of sex ratios and may lead to different results. The period when the gonads were not visible coincided with the post-spawning period. As maturation progresses, the tubule coloration in males and females changes from translucent to creamy, becoming more prominent, enabling sex differentiation (Ramón et al., 2022). Several studies corroborated the complexity of reproductive biology (gonad occurrence, sex identification and maturity length) of royal sea cucumber (Santos et al., 2014; Ramón et al., 2022). In addition to detailed histological studies (Ramón et al., 2022), further studies on the recruitment and settlement of this species are needed to support current knowledge.

The population structure of royal sea cucumber in the SoM (with an average of 18.16 cm and a maximum of 30.7 cm size) is close to that in previous research. Previous studies reported the average size of the royal sea cucumber as 18.7 cm for the combined sexes (Ramón et al., 2010), and 19.67 and 18.45 cm for females and males, respectively (Ramón et al., 2022). Differently, individuals under heavy fishing pressure from the Mediterranean Spanish coast (Maggi and González-Wangüemert, 2015) were represented in smaller sizes with a mean of 13.35 cm size (max 26 cm). Several studies (González-Wangüemert, 2015; Félix et al., 2021; Azevedo e Silva et al., 2023) emphasize the potential effects of fishing pressure on sea cucumber populations. Significantly high biomass in the fisheries area rejects the fishing pressure hypothesis. Low biomass in sheltered areas is associated with the distribution pattern of species. Although similar sampling methods were used (bottom or beam trawl), differences in size distribution between studies may also be affected by sampling depth (Ramón et al., 2010), abiotic (salinity or oxygen demands) (Gullian, 2013) and biotic factors (spawning strategy, predation, food availability) (Viyakarn et al., 2020).

The entire SoM is closed to sea cucumber fishery (In the Official Gazette of the Republic of Türkiye dated 9 March 1997). The royal sea cucumber, protected and regulated by laws, cannot be landed and sold in the SoM. Contrary to this, the hotspot distribution areas (from 50 to 200 m depth) are open to shrimp fisheries, except at depths shallower than 50 m. Fishermen catch and discard individuals that they cannot sell and are not allowed to keep. The royal sea cucumber demonstrates an exceptionally high survival rate of up to 95% when reintroduced to the sea, which can be attributed to its resilience to changes in hydrostatic pressure conditions (Barreiro et al., 2018). In addition, shrimp fishery with beam trawl is subject to seasonal bans (15 April–31 August and 1–31 January), and this period coincides with the spawning season of the royal sea cucumber. However, our demographic findings do not allow interpretation of stock welfare, local regulations, non-consumption in the domestic market and high survival rate after discard contributes to the maintenance and recruitment of royal sea cucumbers.

Conclusion

The findings shed light on several important aspects of the species' ecology, highlighting the intricate interplay between its distribution patterns, demographic characteristics, and potential impacts of fishing activities. The identification of hotspots of royal sea cucumber population distribution, coupled with the understanding of its movement patterns, enables targeted fisheries management. By pinpointing areas where incidental catches are likely to occur, fisheries regulations and practices can be tailored to minimize the accidental capture of this species. This not only reduces bycatch but also helps in conserving the population, contributing to the overall health of the marine ecosystem. Future fisheries management can take advantage of this knowledge by reinforcing and potentially adjusting the timing of the bans to ensure that the reproductive cycle of the royal sea cucumber remains undisturbed.

Ethical Statement

Formal consent is not required for this study. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

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Author Contribution

Uğur Karadurmuş: Conceptualization, methodology, formal analysis, investigation, writing - original draft, writing - review & editing, visualization, project administration, funding acquisition. Hakkı Dereli: Conceptualization, methodology, writing - review & editing. Mehmet Aydın: Conceptualization, methodology, writing - review & editing, supervision. All authors read and approved the final manuscript.

Conflict of Interest

All authors declare that they have no actual, potential, or perceived conflicts of interest.

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