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Biological Parameters and Biomass and Abundance Indices of Two Demersal Species, Turbot (*Scophthalmus maximus*) and Thornback Ray (*Raja clavata*), Estimated by a Trawl Survey in Western Black Sea

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Abstract: In this study, we determined the biological characteristics and indices of abundance and biomass of two demersal species, turbot and thornback ray, through a scientific trawl survey of Bulgarian Black Sea waters in the autumn of 2020. Turbot is among the most valuable fish species in the Black Sea, and thornback ray is a sensitive cartilaginous species with a significantly declining abundance throughout the Mediterranean region. The stock biomass of turbot was estimated at 1467.6 tons, with a relative abundance of 896,922 individuals, and those of the thornback ray were 1187.9 tons and 519,606 individuals, respectively. Mean turbot abundance, interpolated into 0.5° latitude/longitude grid cells, ranged between 52 and 120 ind$\cdot$km^{-2}, with a mean biomass of 78.26–238.31 kg$\cdot$km^{-2}, and for the thornback ray, these indices were within the limits of 0–107 ind$\cdot$km^{-2} and 0–219 kg$\cdot$km^{-2}. The distribution of the different length classes of the two fish species by depth layer was analyzed. Length–weight relationships were estimated based on combined samples of both sexes and separately for female and male individuals, allowing a better understanding of growth patterns.

Keywords: demersal fish; length frequency distribution; length–weight relationships; biomass and abundance; spatial patterns

Key Contribution: The autumn 2020 bottom trawl survey revealed the biomass, spatial patterns, and biological traits of two sensitive bottom species in the western Black Sea, turbot and thornback ray. Size structure variability across depth strata was evaluated, as were its effects on fluctuations in abundance and biomass. The growth type variability by sex was also estimated.

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1. Introduction

Turbot (*Scophthalmus maximus*) is a bony flatfish (order Pleuronectiformes) that is naturally distributed around the European coast, from the Baltic Sea across the Atlantic Ocean and in the Mediterranean and Black Seas. Turbot is an important commercial species in the Black Sea (BS), with high market prices, and is fished by otter trawls, gillnets, beach seines, and trammel nets [1]. In this brackish and anoxic basin, the turbot distributional range includes coastal waters with depths of up to 150 m, and the maximum abundance is found within the broad shelf area. The spawning season of turbot occurs between April and June [1–3]. This species exhibits sexual dimorphism, with females outgrowing males and achieving sexual maturity later than males [4]. Generally, the two sexes are characterized by low growth rates, and the maximum absolute length in the BS region is up to 100 cm at the age of 10–12 years, with a weight of 12–15 kg [4–6]. Based on the fact that turbot is of high importance for BS fisheries, and because of the population decrease related to overfishing, the species is among the priority indicators in the assessment of the BS fish stock state.

Recent data on bycatch in turbot fisheries show that the superorder Batoidea is among the most affected elasmobranchs [7,8]. Elasmobranchs are a group of cartilaginous fish, including sharks, rays, and skates, and are considered the most endangered group of marine fish in the Mediterranean region [9]. Cartilaginous species exhibit low diversity in the BS, with only 10–11 species present in this region [10–15]. Thornback ray is the dominant skate species across the southeastern Black Sea coast, accounting for >80% of the total skate biomass [16]. Geographically, this species is distributed in the coastal waters of the northeast Atlantic, Mediterranean, and Black Seas [17], and temperature is considered the main factor shaping its distribution [18]. Generally, low fecundity, slow growth, and late maturity are typical for most skate species, making them particularly sensitive to fishing pressure [19]. Although thornback ray is not a direct fishery target, it is among the most abundant skates in bycatches [20]. In the Bulgarian Black Sea waters, skate bycatch is often found in midwater and beam trawls, gillnets, and longline fisheries. Data on the landed catch of thornback ray in Bulgarian waters showed a reduction from 93 t in 2011 to 9 t in 2019 [21], which implies a decreasing population of the species.

The current status of thornback ray in the Mediterranean and Black Seas has been evaluated by the International Union for Conservation of Nature (IUCN) as Near Threatened [22], and *S. maximus* is listed as a species of Least Concern [23]. Estimating fish biomass and abundance is essential for sustainable management of fish resources. Techniques such as trawl, camera, acoustic, and baited remote underwater video system (BRUVS) surveys can be used to determine the spatial distribution of fish abundance and biomass in different habitats and seasons [24–26]. In comparison, the length–weight relationship (LWR) converts fish length measurements to weight estimates, which can be used to monitor growth models and fish population health [27]. Alterations in biological parameters can indicate the effects of human activities, such as overfishing, on harvested stocks [28,29]. Therefore, basic biological parameters are used in stock assessment models to form the basis for fishery management decisions [30]. Recently, turbot stock dynamics in the Black Sea was analyzed within the framework of the Scientific, Technical, and Economic Committee for Fisheries (STECF, up to 2015) and the workgroups of the General Fisheries Commission for the Mediterranean (GFCM, 2016–2020). However, elasmobranchs are often characterized as data-limited species, and information on thornback ray abundance is scarce, particularly in the western Black Sea. Stock analyses of thornback ray were carried out during the 90s of the 20th century [31,32], leading to a large gap in the literature, which hinders the full understanding of species dynamics and trends.

This study aimed to present new information on the biological traits of two demersal species, turbot and thornback ray, which form the main catch and elasmobranch bycatch, respectively, from a scientific demersal survey in the autumn of 2020. Our main goal was to assess the relative biomass and abundance indices of these two demersal species and their spatial distribution, and to derive length–weight relationships (LWRs) based on combined samples of the two sexes and separately for females and males, which are indicative of specific growth types.

2. Materials and Methods

2.1. Data Collection

The data in this study were obtained from a scientific demersal trawl survey in the Bulgarian Black Sea as part of the National Fisheries Data Collection Program, focusing on the evaluation of the biological parameters of demersal species, with an emphasis on the quantity, size, and sex structure of the turbot and major bycatch. The survey encompassed the territorial waters between Durankulak (north) and Ahtopol (south) within the 100 m isobath. The techniques used for data collection, verification, processing, analysis, and stock assessment followed the methodology generally applied in the Bulgarian Black Sea zone [7,8,33–35].

2.2. Scientific Survey

The survey was performed in December 2020, with sampling sites randomly distributed within the continental shelf and upper coastal slope at depths of 15–100 m (Figure 1).

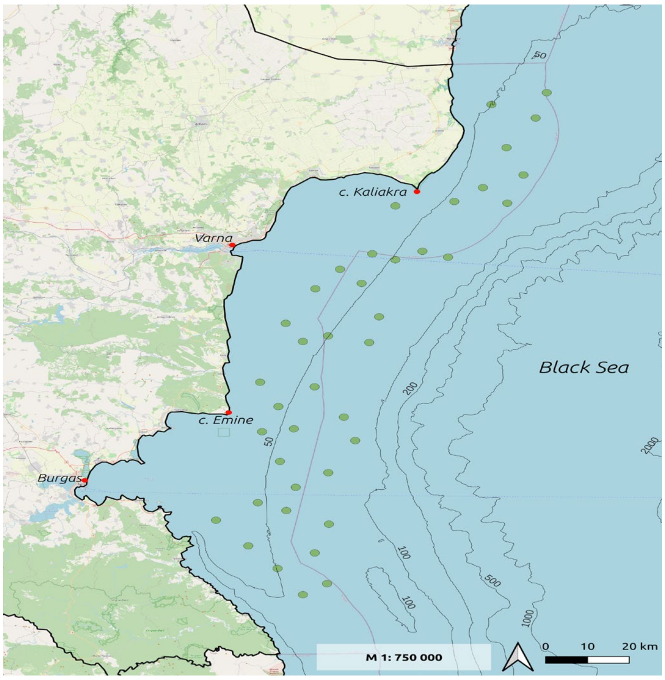


Figure 1. Map of the surveyed sector of the western Black Sea, XII, 2020.

The survey region was divided into three strata depending on depth: stratum 1 (15–50 m), stratum 2 (50–75 m), and stratum 3 (75–100 m). Sampling was conducted in 40 randomly chosen fields, each of which was a rectangle with sides of 5′Lat × 5′Long, with a total area of 62.58 km^2. Forty demersal trawls were performed, and the duration of each haul was 60 min at a trawling speed of 2.2–2.6 knots.

The quantities of priority catch and bycatch were measured on board the fishing vessel, together with species identification of the bycatch organisms. The sex of the collected thornback ray specimens was determined, and their lengths were measured to the nearest centimeter and weighed to the nearest gram. The turbot length and weight data included all collected specimens (n = 187). However, the collected small turbot individuals, with lengths < 450 mm, should be returned alive to the sea based on the Fishery Act (BG), and sex differentiation of these specimens was not performed. Sex was determined only for larger turbot specimens with lengths of > 450 mm (n = 109, 58.3% of all collected specimens).

2.3. Data Analyses

The "swept area" method [25] was used for the calculation of biomass and abundance indices per depth stratum.

Additionally, the biomass and abundance indices of the two species were interpolated into 0.5° latitude/longitude grid cells (given as the average of the standardized catch per unit area (CPUA), kg·km^{-2}, and as the average of the standardized numbers of individuals, ind·km^{-2}) using an R script (version 0.2.01) in RoME and Biondex (version 3.1) [36].

The same script was used to present the length frequency distribution (LFD) of abundance (ind·km^{-2}) by depth strata.

The length–weight relationships are presented as exponential relations based on Equation (1):

$$(\mathrm{W, g}) = \mathrm{a}(\mathrm{TL, cm})^{\mathrm{b}} \tag{1}$$

where W is the total weight (g), TL is the total length (cm), and a and b are constants.

Equation (2) was used to calculate the confidence interval for the value of the regression slope.

$$\beta_1\!: \mathrm{b}_1 \pm \mathrm{t}_{1-\alpha/2,\mathrm{n}-2} \times \mathrm{se}(\mathrm{b}_1) \tag{2}$$

where b_1 is the slope coefficient, $t_{1-\alpha/2,n-2}$ is the critical value for the confidence level $1-\alpha$ with $n-2$ degrees of freedom, n is the total number of observations in the dataset, and $se(b_1)$ is the standard error of b_1.

A *t*-test was used to determine whether the regression coefficient *b* differed significantly from the expected cubic value of 3.

The XLSTAT software (19.03) was used for data processing and to compose the linear/weight histograms of the two sexes of both species. Relative frequency histograms were used to represent the overall proportion of data in a given length/weight group. Boxplot graphs were applied with the same software to show the variability of sizes of both fish species (with information for the mean values, median, 25–75% hinge, and minimal and maximal observed values).

3. Results

3.1. Mean Length and Weight of Turbot and Thornback Ray

A total of 187 turbot specimens, with a total catch weight of 301.56 kg, and 105 thornback ray individuals, with a weight of 237.14 kg (78% of the turbot catch), were collected during the survey.

The total length of the collected specimens of *S. maximus* ranged between 100 and 740 mm, with an average value of 374.14 mm ± 1.2 SE (*n* = 187, for the combined dataset of juvenile, female, and male specimens, Figure 2a). The average weight of the turbot was 1612.62 g ± 104.33 SE, oscillating between 40 g and 8320 g (Figure 2b).

The total length of *R. clavata* varied between 380 and 920 mm, with weights of 460–5680 g (*n* = 105 for the combined data for both sexes, Figure 2a,b).

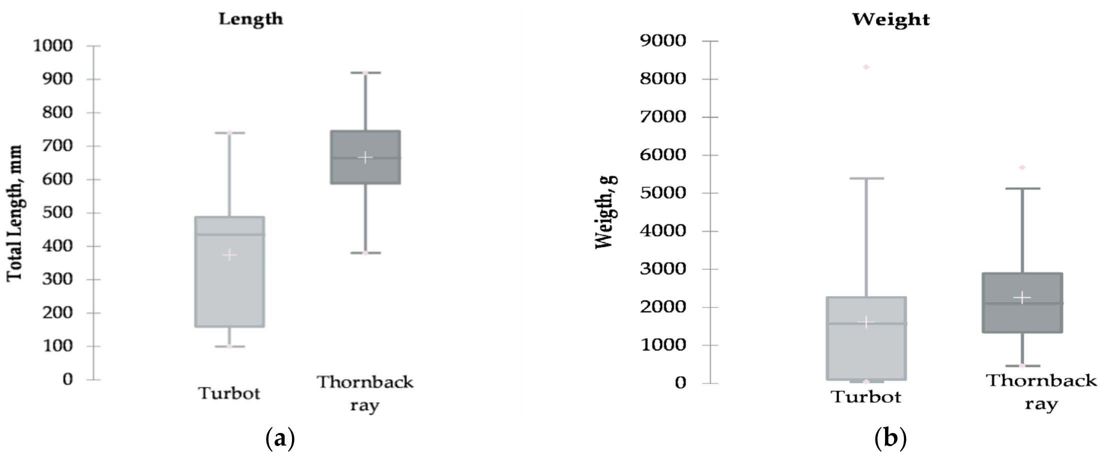


Figure 2. Box plots of (**a**) fish length (mm) and (**b**) weight (g), based on all collected specimens, *n* = 187 for turbot, *n* = 103 for thornback ray (indicated: mean, medians, range of values: 25–75%, minimum and maximum values).

The length of turbot females ranged from 420 to 740 mm, with weights of 1350–8320 g, whereas for thornback ray females, these parameters were 490–920 mm and 810–5680 g, respectively. For males, the biological parameters for turbot were 390–610 mm and 1310–3950 g, and for thornback rays, they were 380–900 mm and 460–4520 g.

The dominant size classes of turbot were 400–550 mm (78.90% of all specimens), with a weight of 1000–3000 g (75.22%, Figure 3a,b). For both sexes of *R. clavata*, the 500–750 mm length class predominated (69.52% of all specimens) with weights of 1000–3000 g (67.61%, Figure 3c,d).

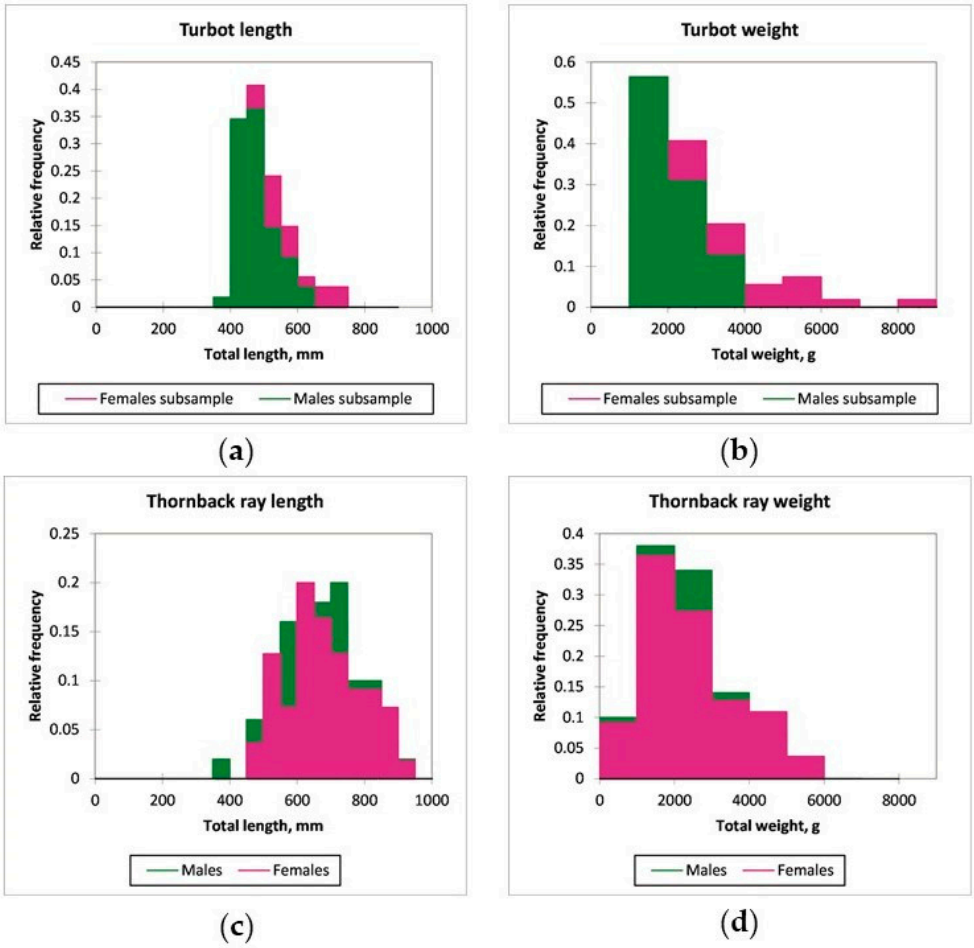


Figure 3. Distribution of length (mm; (**a**,**c**)) and weight classes (g; (**b**,**d**)) of both fish species by sex. (Data for turbot included a subsample with lengths > 450 mm, as explained in the methodology section.).

3.2. Biological Traits and Length Frequency Distribution by Depth Strata

The minimum mean length of turbot was found in coastal waters with depths < 50 m, corresponding to the maximal species abundance of 108.53 ind·km^{-2} (Table 1a). The mean abundance of turbot decreased with depth, and was minimal (41.55 ind·km^{-2}) in the depth stratum of 75–100 m.

By the depth strata, the mean length of the thornback ray varied between 632.83 and 723.65 mm, with the highest levels in the deep waters (Table 1b). The minimum mean length and abundance of thornback rays were detected in coastal waters, whereas the maximum abundance was observed at depths of 50–75 m.

By analyzing the size structure of the turbot population (Figure 4a), we could discriminate the distribution patterns of young (<450 mm) and adult individuals in the autumn period. Young turbot individuals mostly inhabited coastal waters (depth stratum 1, Figure 4a), whereas larger size classes were oriented at depths of > 50 m, and the maximum mean weight and length of turbot were recorded at depths of 75–100 m.

Although the maximum average abundance of thornback ray was found at depths of 50–75 m, larger individuals prevailed at depths of 50–100 m (depth strata 2 and 3, Figure 4b).

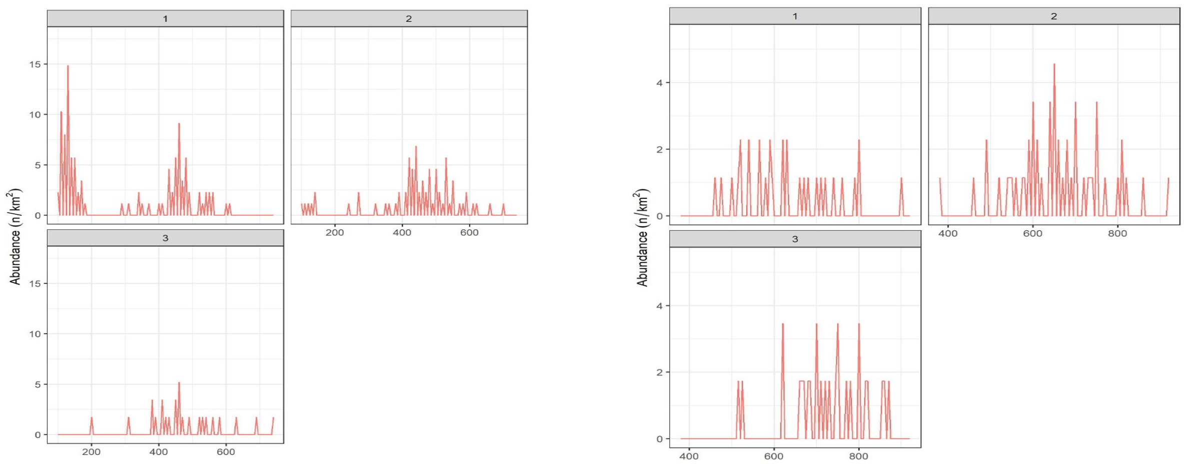
Table 1. Distribution of the mean length (mm), mean weight (g), mean biomass (kg·km^{-2}), and mean abundance (ind·km^{-2}) by depth strata: (**a**) turbot and (**b**) thornback ray.

(**a**)

Biological Parameters of Turbot	Depth Stratum 1 (15–50 m)	Depth Stratum 2 (50–75 m)	Depth Stratum 3 (75–100 m)
Mean length (mm)	298.84	440	473.33
Mean weight (g)	1078	2068	2440
Mean abundance (ind·km^{-2})	108.53	77.61	41.55
Mean biomass (kg·km^{-2})	116.99	160.45	101.37

(**b**)

Biological Parameters of Thornback Ray	Depth Stratum 1 (15–50 m)	Depth Stratum 2 (50–75 m)	Depth Stratum 3 (75–100 m)
Mean length (mm)	632.83	655.81	723.65
Mean weight (g)	1930	2128	2801
Mean abundance (ind·km^{-2})	34.27	55.92	45.01
Mean biomass (kg·km^{-2})	66.14	118.99	126.34



(**a**) (**b**)

Figure 4. Length frequency distribution (mm) of abundance (ind·km^{-2}) by depth strata (1, 2, 3) of *S. maximus* (**a**) and *R. clavata* (**b**) in December 2020.

3.3. Spatial Distribution of Biomass and Abundance Indices

The biomass and abundance indices interpolated into 0.5° latitude/longitude grid cells allowed us to infer more detailed information regarding the spatial orientation of the two demersal species. At this spatial scale, the turbot average abundance ranged within the limits of 52–120 ind·km^{-2} with a mean biomass of 78.26–238.31 kg·km^{-2} (Figure 5a,b). The maximum average abundance of 112–120 ind·km^{-2} was detected in the coastal zone along the central to the northern shores, while the maximal biomass of turbot, varying between 173.53 and 238.13 kg·km^{-2}, was observed off the northern coasts. This difference in the spatial distribution models of turbot abundance and biomass corresponds to changes in size structure with depth and orientation of young individuals (with high abundance and low weight) in coastal areas.

Thornback ray was mainly distributed from the central to the south coast at depths of > 50 m. The abundance and biomass distribution of thornback ray followed a similar spatial model (Figure 5c,d), as the highest average abundance of the species was within the limits of 52–107 ind·km^{-2}, with the highest biomass of 126.53–219.85 kg·km^{-2}.

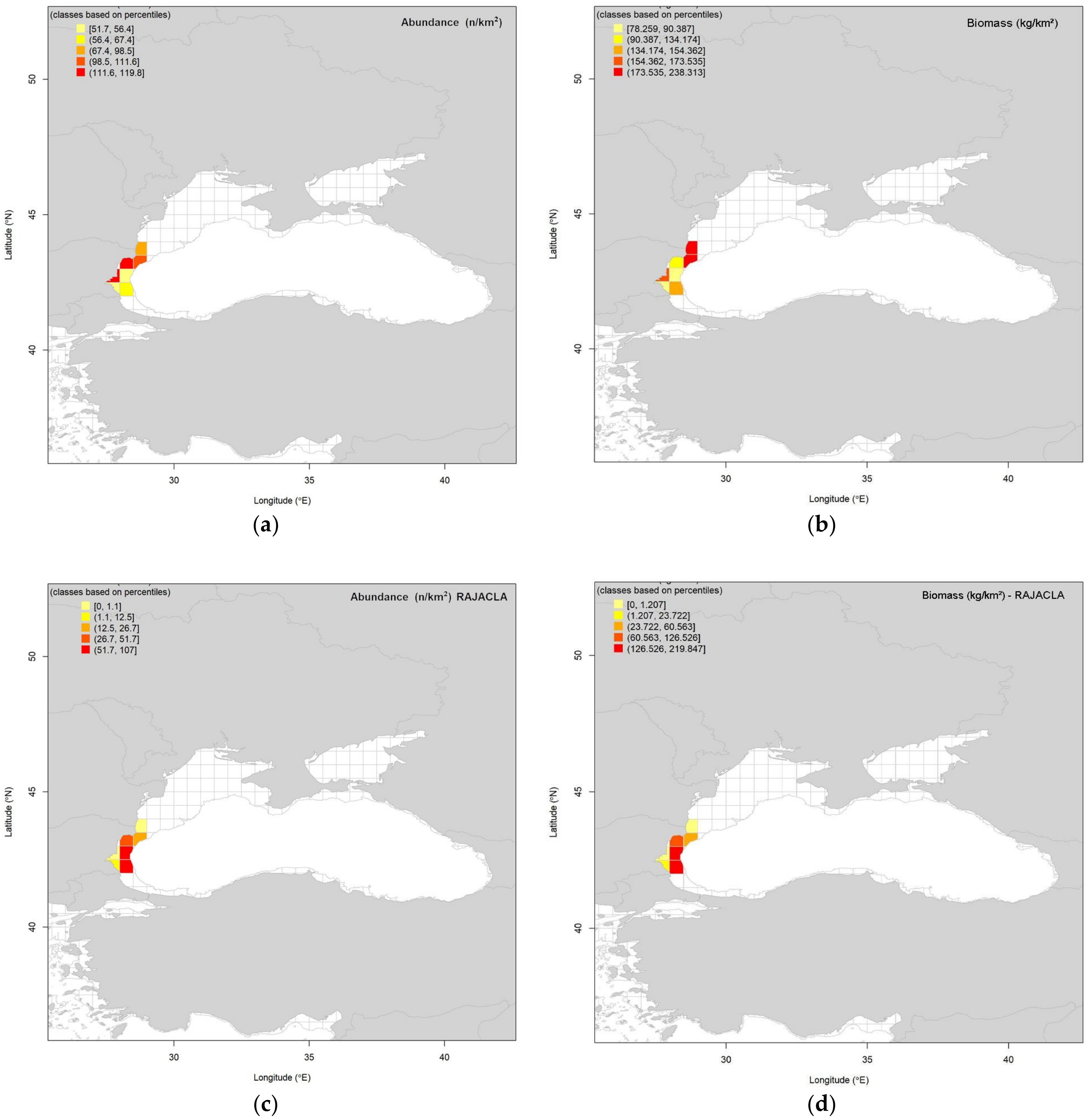


Figure 5. Spatial distribution of relative abundance (ind·km^{-2}) and biomass (kg·km^{-2}) of *S. maximus* (**a**,**b**) and *Raja clavata* (**c**,**d**) in December 2020.

The turbot stock biomass in Bulgarian Black Sea waters was assessed at 1467.62 tons in autumn 2020, with a relative abundance of 896,922 individuals. The stock biomass and abundance of thornback ray were estimated at 1187.89 tons and 519,606 individuals.

3.4. Length–Weight Relationships (LWRs)

Negative allometric growth of turbot was inferred during the autumn season in the study area, with a coefficient *of* b = 2.596 for the combined dataset.

The LWRs of this species were as follows:

W = 0.092TL$^{2.59}$, R^2 = 0.99 (*n* = 187, 95% CI of b = 2.5955–2.5967 for combined data for the two sexes; Figure 6a).

W = 0.0227TL$^{2.97}$, R^2 = 0.95 (*n* = 54, 95% CI of b = 2.9657–2.9713 for females' dataset; Figure 6b, F).

W = 0.0485TL$^{2.75}$, R^2 = 0.92 (*n* = 55, 95% CI of b = 2.7498–2.7567, for males' dataset; Figure 6b, M).

Accordingly, data from the combined dataset indicated that in large specimens, the increase in length preceded the increase in weight. Data by sex were extracted from subsample measurements, including individuals with a length of > 450 mm (according to the Fishery Act in Bulgaria). In this subsample, the female specimens showed isometric growth (b = 3), as the *t*-test did not indicate a statistically significant difference in slope b from the expected value of 3. However, the negative allometric growth of male specimens was estimated to be b < 3 (*t*-test = −2.264, *p* = 0.0138). In the subsample, the turbot sex ratio was balanced: 1.01 M:1 F.

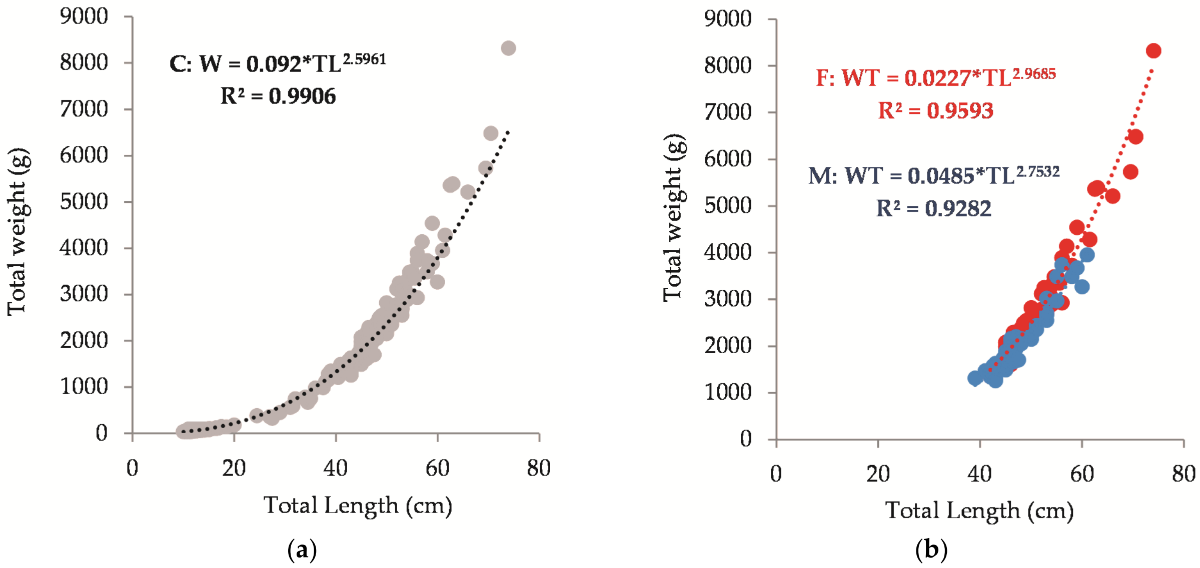


Figure 6. LWRs of *S. maximus* in the western Black Sea in autumn 2020: (**a**) combined dataset (including small individuals < 45 cm, which were returned alive to the sea based on the Fishery Act (BG), (**b**) females (F, red), and males (M, blue).

LWR studies of *S. maximus* in different geographical regions (Table 2) showed that the b values varied between 2.21 and 3.795. A positive allometric growth type (mostly for the combined data of the two sexes and female specimens) was estimated in 17 case studies (47% of all studies). However, the prevailing growth type for male individuals was negative allometric growth, and in only one case (in the North Sea), the coefficient *b* indicated positive allometric growth of males (b = 3.0988). Therefore, the results of the current study correspond well with those of the other case studies.

The LWRs of *R. clavata* estimated during the autumn of 2020 are as follows:

W = 0.0062TL$^{3.03}$, R^2 = 0.97 (*n* = 105; 95% CI of b = 2.922–3.139 for the combined dataset; Figure 7a).

W = 0.0041TL$^{3.13}$, R^2 = 0.97 (*n* = 55; 95% CI of b = 3.129–3.133 for females' dataset; Figure 7b, F).

W = 0.0098TL$^{2.92}$, R^2 = 0.97 (*n* = 50; 95% CI of b = 2.913–2.918 for males' dataset; Figure 7b, M).

Thus, the LWRs of *R. clavata* demonstrated isometric growth in Bulgarian waters based on the combined dataset (*t*-test showed no significant difference in the slope b from the cubic value of 3), which was related to the positive allometric growth of females (*t*-test = 1.802, *p* = 0.039) and the isometric growth of males (*t*-test = −1.098, *p* = 0.14) (Figure 7). The sex ratio of this species was close to 1:1 (1 M:1.1 F).

Comparing the data from 38 case studies on the LWR of *R. clavata* in different geographical areas, the b value varied between 2.3 and 3.7 (Table 3), and a predominantly positive allometric growth type was inferred (89.5% of all studies). Males may reach the

L∞ value at shorter lengths and live longer, which has been confirmed by many studies of *R. clavata* populations [9,37–39]. Data from the Black Sea region showed mixed results for LWRs, and different growth types were specified. The differences between growth parameters imply the influence of many factors such as temperature, food availability, and mineral intake [14,27]; thus, seasonality of growth may be observed [40]. Additionally, the fishing equipment used for sample collection and fishing time might affect LWRs [41] and should be considered in analyses of fish growth and fitness in marine habitats.

Table 2. Parameters of LWRs of turbot (*S. maximus*) from different geographical localities.

a	b	Sex	L (cm)		R^2	*n*	Locality	Ref.
			L Min	L Max				
0.0044	3.386	C	50	75	-	4	Buchan, 1981–85	Coull et al. [42]
0.0105	3.168	C	2	80	0.998	394	Bay of Biscay	Dorel [43]
0.0105	3.173	C	5	59	0.994	124	East and West Channel	
0.0168	2.93	F	3	48	0.98	283	Gulf of Lion	Vianet [44]
0.0218	2.92	M	3	45	0.98	290	Gulf of Lion	
0.02102	2.93	F	3	25	0.992	158	Sète, Grau-du-Roi and SaintesMarie-de-la-Mer	Robert and Vianet [45]
0.0219	2.92	M	3	47.5	0.98	171	Sète, Grau-du-Roi and SaintesMarie-de-la-Mer	
0.011	3.104	C	25	79	0.99	155	Adriatic Sea	Arneri [46]
0.01508	3.09	C	-	-	-	242	ICES	Bedfofrd [47]
0.129	2.6564	C	17.5	68.8	0.952	-	Black Sea	Anonymous [48]
0.007	3.248	C	10	61	0.977	63	Eastern Black Sea	Ak et al. [49]
0.001	3.278	C	44.7	71.7	0.84	50	BG Black Sea	Yankova [15]
0.00802	3.26	C	20	60	0.982	101	North Sea	Frose [50]
0.0179	3.02	C	9	56	0.973	2953	Baltic Sea	
0.013	3.11	F	-	-	-	-	Southern North Sea	Van der Hammen [41]
0.022	2.95	M	-	-	-	-	Southern North Sea	
0.0112	3.1702	F	22.5	63.5	0.966	184	North Sea	Wilhelms [51]
0.0138	3.0988	M	20.5	56.5	0.952	221	North Sea	
0.0128	3.1267	C	4.5	72.5	0.983	944	North Sea	
0.0085	3.158	C	14	70	0.989	-	Southwestern Black Sea coast	Eryilmaz and Dalyan [2]
0.01	3.15	C	23.5	46	0.914	22	French Catalan coast	Crec'hriou [52]
0.066	2.688	C	17	63	-	74	Northeastern Atlantic Ocean	Mahé [53]
0.0147	3.11	C	28.5	47.9	0.99	20	Bay of Kiel	Frose [54]
0.0179	3.02	C	9	56	0.973	2953	Baltic Sea	
0.00802	3.26	C	20	60	0.982	101	North Sea	

Table 2. *Cont.*

a	b	Sex	L (cm) L Min	L Max	R^2	*n*	Locality	Ref.
0.000431	2.21	C			-	-	BG Black Sea	STECF 13–20 [55]
0.000011	3.13	C			-	-	BG Black Sea	
0.000013	3.11	F			-	-	BG Black Sea	
0.000041	2.78	M			-	-	BG Black Sea	
0.000424	2.22	F			-	-	BG Black Sea	
0.000022	2.92	M			-	-	BG Black Sea	
0.000021	2.94	F			-	-	BG Black Sea	
0.000008	3.17	C			-	-	BG Black Sea	
0.00004	2.799	M			-	-	BG Black Sea	
0.0000007	3.795	F			-	-	BG Black Sea	
0.0000339	2.837	C			-	-	BG Black Sea	
0.092	2.596	C	10	74	0.96	187	BG Black Sea	Present study
0.0227	2.96	F	42	74	0.95	54	BG Black Sea	
0.0485	2.75	M	39	61	0.93	55	BG Black Sea	

C, combined data; M, male; F, female; N, number of samples; Min, minimum; Max, maximum; a and b, LWR coefficients; R^2, coefficient of determination.

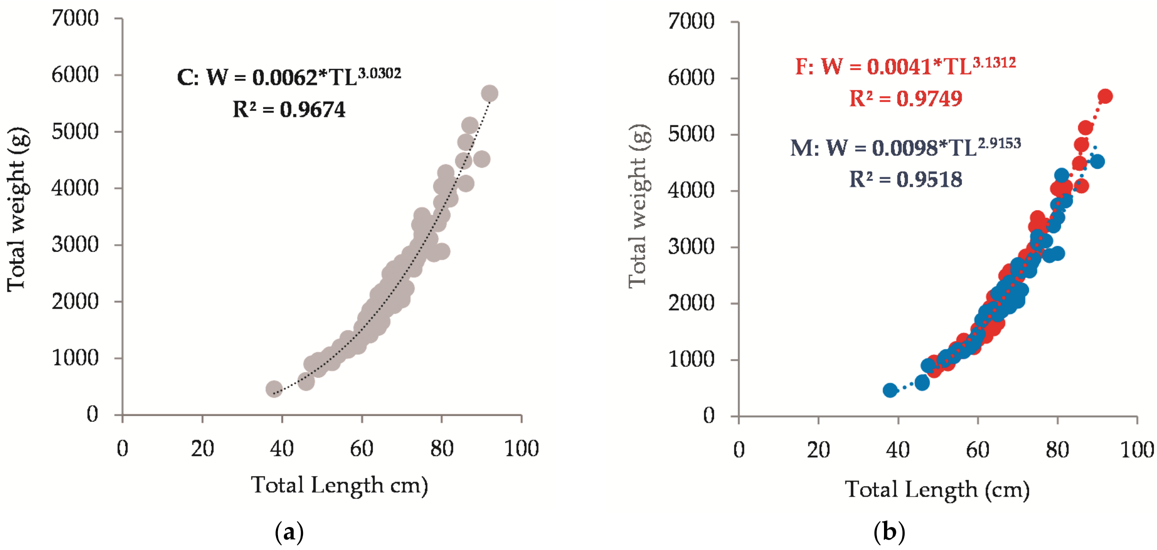


Figure 7. LWRs of *R. clavata* from the Bulgarian Black Sea during the trawl surveys in autumn 2020: (**a**) combined dataset for the two sexes; (**b**) females (F, red) and males (M, blue).

Table 3. Length–weight relationships (LWRs) of thornback ray (*R. clavata*) from different geographical localities.

a	b	Sex	L (cm) L min	L max	R^2	*n*	Locality	Ref.
0.0032	3.19	C	10	101	0.998	960	East and West Channel	Dorel [43]
0.0032	3.2	C	11	98	0.998	123	Bay of Biscay	
0.0022	3.27	C				74	(ICES division), 1986	Bedford et al. [47]
0.0016	3.29	C	20.5	99	0.872	29	North Aegean Sea, 1999–2000	Filiz and Mater [56]
0.0016	3.3	C	20.5	99	0.94	37	North Aegean Sea, 2003 (March)	
0.0018	3.25	F	20.5	99	0.861	21	North Aegean Sea, 1999–2000	
0.0006	3.56	M	29.7	67	0.968	8	North Aegean Sea, 1999–2000	

Table 3. *Cont.*

a	b	Sex	L (cm) L min	L max	R^2	*n*	Locality	Ref.
0.0025	3.23	C	30.6	86.2	0.927	63	Nazaré to St André, 1997	Mendes et al. [40]
0.0011	3.41	C					Northern and central Adriatic Sea, 1996–2006	Krstulović Sifner et al. [57]
0.0021	3.27	C	15.3	95.2	0.99	86	Gulf of Cadiz, 2009–2011	Torres et al. [39]
0.001	2.3	C	56	79	0.86	24	Black Sea, 2006–2008	Yankova et al. [15]
0.023	2.64	C	25	70	0.76	75	Iskenderun Bay/2010–2011	Başusta et al. [58]
0.001	3.35	C	8.5	77	1	8	Northwestern Mediterranean/2011–2013	Barría et al. [59]
0.0081	2.98	C	9.5	95.5	0.984	73	North Sea/1959–2004	Wilhelms [51]
0.002	3.25	C	39	59	0.957	25	French Catalan coast/2007–2010	Crec'hriou et al. [52]
0.001	3.29	C	13.2	90	0.971	63	Black Sea/2009–2011	Kasapoglu et al. [60]
0.003	3.17	C	3	112		608	Northeastern Atlantic Ocean/2013–2015	Mahé et al. [53]
0.003	3.2	C	25	70	0.977	19	Lebanese waters/2012–2014	Lteif et al. [61]
0.0187	3.01	J	22	31		12	Shetland, Moray Firth, Buchan, S. Minch	Coull et al. [42]
0.0024	3.2	J	14.5	38.1	0.996	18	Balearic Islands, 1995–1996	Merella et al. [62]
0.0014	3.36	J	13.7	54	0.98	13	Algarve, 1996–1997	Borges et al. [63]
0.0074	2.87	J	12.2	70	0.893	24	Northern Sea of Marmara, 2006–2007 (November–March)	Bok et al. [64]
0.003	3.17	F	18.4	91.6	0.99		Caernarfon Bay, north Wales, 2003 (February–September)	Whittamore et al. [65]
0.004	3.13	M	26.9	77.8	0.99		Caernarfon Bay, north Wales, 2003 (February–September)	
0.0084	3.3	F			0.984	1124	Carmarthen Bay, British Isles, 1974–1975	Ryland et al. [38]
0.0019	3.17	M			0.984	1019	Carmarthen Bay, British Isles, 1974–1975	
0.0019	3.28	M	11	85.1	0.981	256	Eastern Adriatic Sea/1997–2001	Pallaoro et al. [66]
0.0012	3.39	F	11.4	105	0.978	278	Eastern Adriatic Sea/1997–2001	
0.0015	3.34	C	11	105	0.978	534	Eastern Adriatic Sea/1997–2001	
0.005	3	M	48	95	0.96		Southeastern Black Sea, 2002–2003	Demirhan et al. [67]
0.0003	3.7	F	34.3	88.2	0.94		Southeastern Black Sea, 2002–2003	
0.001	3.42	C	34.3	95	0.91	52	Southeastern Black Sea	
0.0007	3.53	C	11.3	69.5	0.98	130	Sea of Marmara coasts/2011–2014	Barrientos-Medina et al. [68]
0.0005	3.6	M	12.8	69.5	0.98	66	Sea of Marmara coasts/2011–2014	
0.0008	3.5	F	11.3	67.5	0.99	64	Sea of Marmara coasts/2011–2014	
0.0016	3.33	M	11	81			Mediterranean: south of Sicily and south of Malta/1990–2018	Geraci et al. [69]
0.0015	3.35	C	9.5	110			Mediterranean: south of Sicily and south of Malta/1990–2018	
0.0014	3.36	F	9.5	110			Mediterranean: south of Sicily and south of Malta/1990–2018	
0.0062	3.03	C	38	92	0.97	105	BG Black Sea	Present study
0.0041	3.13	F	49	92	0.97	55	BG Black Sea	
0.098	2.92	M	38	90	0.97	50	BG Black Sea	

C, combined data; M, male; F, female; N, number of samples; Min, minimum; Max, maximum; a and b, LWR coefficients; R^2, coefficient of determination.

4. Discussion

In order to evaluate the status and susceptibility of demersal species, it is essential to identify the characteristics and spread of their abundance and biomass indices. Consequently, this study assessed the stock biomass, biological characteristics, and relative abundance/biomass indices of two bottom species that are both targeted and unintentionally captured in the Bulgarian Black Sea waters. The primary threats to these species include excessive fishing, environmental contamination, and habitat destruction. Therefore, the gathered data may be useful in devising management strategies to mitigate the effects of human activities. This is especially crucial for data-scarce sensitive species like *R. clavata*.

In the 1990s, a stock analysis of the thornback ray estimated its biomass to be around 6000 tons in the entire Black Sea [31]. In 1991, the biomass of *R. clavata* was estimated to be 4800 t in the waters of Georgia, the northeastern BS, and Crimea. In 1992, the biomass of the species was estimated to be 8300 tons based on extensive surveys of the northwestern Black Sea, Crimea, the northeastern Black Sea, and the Caucasian coast. By 1994, the biomass of the thornback ray in the northwestern Black Sea, Crimea, and the northeastern Black Sea dropped to between 900 and 1400 tons [32]. Our data indicate that the stock of fish along the Bulgarian coast is approximately 1190 tons. The absence of other estimates, particularly for this area, makes it difficult to evaluate changes in species abundance. Nevertheless, the landed catch data of thornback ray in Bulgarian waters [21] point to a declining population of the species.

Previous research on turbot stock in the BS showed that the maximum level was between 6000 and 10,000 tons in the 1960s [70]. The turbot stock in Bulgarian BS waters fluctuated between 447.38 t and 1966.2 t from 2006 to 2009 [71]. From 2009 to 2012, the stock in this region decreased, and the average biomass during this period was approximately 304 tons. Since 2014, turbot stock has fluctuated between 803.76 and 1745.2 tons, with an average of 1100.9 tons [7,8,34,35], and this study showed a stock biomass of 1467.6 t. Therefore, we can infer that the turbot biomass in the western BS has been relatively stable in recent years, in contrast to the downward trend observed from 2009 to 2012. It should be noted that in Bulgaria and Romania, as European Union member states, the turbot fishery is managed by a common quota of 150 tons, which is evenly divided between the two countries.

During the 2020 autumn survey, turbot abundance rose in the coastal waters off the central and northern Bulgarian coasts (up to 120 ind$\cdot$km^{-2}), while the highest biomass was observed in the north (up to 238.31 kg$\cdot$km^{-2}) at depths greater than 50 m. The spatial differences in the distribution of turbot biomass and abundance, combined with size structure analysis by depth, suggested particular patterns of juvenile and adult distribution, with a greater presence of juveniles in coastal waters and adults at depths greater than fifty meters. This particular arrangement makes juvenile turbot particularly susceptible to fishing pressure. A literature review revealed that adult turbot individuals exhibit strong seasonal migrations [1,21,37,43]. The majority of the stock congregates at depths of 60–90 m during the winter and migrates to the shore in the spring for reproduction and in the fall for intensive feeding. In this regard, the spatial orientation of adults in our study was more common in late autumn and winter.

Information regarding the spatial distribution of thornback ray in the BS is scarce. Some sources indicate that the areas of its relatively more substantial concentration in the western BS are between the 60- and 80-m isobaths along the entire coast length [30]. The current survey showed that the species was present mainly along the central and southern coast at depths of 50–75 m, with the highest abundance of 52–107 ind$\cdot$km^{-2} and the highest average biomass of 127.53–218.85 kg$\cdot$km^{-2}. An almost synchronous model of the spatial distribution of biomass and abundance of thornback rays was found in the autumn of 2020. A recent study of batoid assemblages along the Turkish Mediterranean coast showed a positive correlation with bottom depth, near-bottom chlorophyll-a, and the finest bioseston and a negative correlation with Secchi disk depth and water salinity [72]. Some connections with the bottom megafauna distribution were considered in this study, based on the feeding characteristics of the batoid species. In the Black Sea, feeding, reproduction, and growth of thornback ray were studied in the southern region, where the main dietary components were European anchovy (*Engraulis encrasicolus*), Mediterranean horse mackerel (*Trachurus*

trachurus), whiting (*Merlangus merlangus euxinus*), gobies (*Gobius* sp.), shrimps (*Upogobia pusilla*, *Crangon crangon*) and crabs (*Liocarcinus depurator*, hermit crabs) [67,73–75]. The lack of information on the biology of thornback ray in the western Black Sea makes it difficult to infer trends in species dynamics and relationships with environmental characteristics and food availability.

Finally, our study provided data on the LWRs of *S. maximus* and *R. clavata*. The important component in the LWR is the coefficient *b*, which refers to differences in growth and condition between small and large individuals in the respective area at a given point in time [76]. A very important part of ichthyological studies is the accumulation of a large set of data that cover a wide range of geographic, seasonal, and interannual variations in order to sensibly discuss isometric versus allometric growth of the species as a whole, based on mean b [76]. Consequently, our study contributes to the formation of a larger LWR Black Sea dataset for both the demersal species.

Data on demersal fish species distribution, abundance, and LWRs represent the first step toward implementing stock management assessments. Further accumulation of information (including environmental data and nutritional biology) and modeling would allow a better understanding of the biology and ecology of the two species and their interannual and seasonal variations and would be helpful for proper species management.

5. Conclusions

The demersal trawl survey in the autumn of 2020 allowed the establishment of stock biomass, spatial distribution patterns, and biological traits of two sensitive bottom species in the western Black Sea, turbot and thornback ray. Spatial differences in the distribution of turbot biomass and abundance were observed, corresponding to changes in the size structure of this species across depth strata. Juvenile turbot stages have been found in coastal waters, making them more susceptible to fishing pressure. There were synchronous spatial patterns of biomass and abundance of thornback ray, with the highest concentrations in the central and southern regions and at depths greater than 50 m. The sex ratios of the studied demersal fish species were relatively balanced. LWR analyses based on a combined dataset demonstrated negative allometric growth of turbot and overall isometric growth of *R. clavata*. However, for both species, there was a distinction between the growth types of males and females, with females of *R. clavata* exhibiting positive allometric growth and males displaying isometric growth, while female turbot specimens had isometric growth and males had negative allometric growth.

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Institutional Review Board Statement: No specific ethical approval was required: (i) the research does not describe laboratory experiments with animals (fishes); (ii) the described fish species, turbot (*Scophthalmus maximus*) and thornback ray (*Raja clavata*), are typical fishery subjects in the Black Sea, studied within the framework of the National Fisheries Data Collection Program in Bulgaria, with financial support from the EU; (iii) as a data collection methodology, a widely applied fishery technique, namely bottom trawling, was used; (iv) the research methods were approved by the National Agency of Fisheries in Bulgaria; and (v) specific procedures for animal treatment are not required.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author. The data are not publicly available due to institutional restrictions.

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