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Insights into 'Srdelara' Purse Seines: Landing Composition and Trophic Relationships in the Pelagic Food Web

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Abstract: This study analysed commercial 'Srdelara' purse seine landings in the Central Eastern Adriatic from November 2020 to March 2022. The observed commercial landings demonstrated typical seasonal variations, with a peak from September to November and the lowest landings recorded from spring to early summer. Sardines dominated the purse seine landings, comprising 97.9% of the total landing, followed by anchovies at 1.3%, with occasional by-catches or other species. Biological analysis involved collecting samples of eight pelagic fish species (sardine, anchovy, round sardinella, Atlantic bonito, Atlantic horse mackerel, Atlantic mackerel, chub mackerel and bogue) captured by the aforementioned fishing gear during the study period. The length frequency distributions of the investigated fish species were predominantly unimodal, with the exception of the Atlantic horse mackerel. Moreover, the length–weight relationships indicated isometric growth for each examined species. Stable isotope analysis revealed overlapping isotopic niches among the eight analysed fish species, with estimated mean trophic positions ranging from 3.0 to 4.7, indicating consumption of prey across approximately two trophic levels. The round sardinella and bogue had the smallest isotopic niche, while Atlantic mackerel had the widest one. This study highlights the need for further research to evaluate the observed overlap among pelagic species, particularly between small and medium-sized pelagic fish, as this interaction could significantly impact their biomass. Determining the extent of this overlap is crucial for improving management strategies and ensuring the sustainability of pelagic fish stocks in the Adriatic Sea.

Keywords: pelagic fish species; length–weight relationship; stable isotopes; isotopic niche overlap; Adriatic; north-eastern Mediterranean

Key Contribution: This study provides a comprehensive analysis of landing composition and trophic relationships within the 'Srdelara' purse seine fishery in the Central Eastern Adriatic, highlighting sardine dominance and seasonal landing variations. Overlapping isotopic niches, as proxies for trophic niches, underscore the distinct feeding habits of key pelagic species.

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1. Introduction

Pelagic ecosystems include a diverse array of organisms that are intricately interconnected within a complex ecological network. To develop a comprehensive understanding of these ecosystems, it is important to elucidate their fundamental drivers. Specifically, a crucial aspect lies in unravelling the dynamics of their food webs [1]. Within a pelagic ecosystem, the bulk of its fish biomass is attributed to pelagic fish species [2]. These pelagic fish, which encompass sardines, anchovies, mackerels and tunas, constitute a pivotal component of this ecosystem, functioning as key predators and prey. Beyond their ecological significance, pelagic fish species hold considerable economic value. Notably, irrespective of their size, pelagic fish species face substantial fishing pressure on a global scale [3,4]; in the Mediterranean and Adriatic Seas, their catches account for more than 50% and over 75% of the total fish catches in the respective basins [4]. Pelagic fish species are also affected by

the climate change that can alter the physical and oceanographic characteristics of marine ecosystems and, consequently, impact their patterns of productivity and energy transfer efficiency [5,6].

Despite their similar way of functioning, each pelagic ecosystem exhibits unique characteristics [7]. Based on the recent fish stock assessments, the majority of Adriatic Sea fish stocks are currently overexploited or at risk of overexploitation [8], and a comprehensive analysis that embraces an ecosystem-based approach is imperative. One approach is to tackle the trophic interdependencies among the species inhabiting the Adriatic. The present study focuses on the structure of the part of pelagic food web with emphasis on eight pelagic fish commonly found in commercial catch of 'Srdelara' purse seines—the sardine *Sardina pilchardus* (Walbaum, 1792); the anchovy *Engraulis encrasicolus* (Linnaeus, 1758); the round sardinella *Sardinella aurita* (Valenciennes, 1847); the Atlantic bonito *Sarda sarda* (Bloch 1793); the Atlantic horse mackerel *Trachurus trachurus* (Linnaeus, 1758); the Atlantic mackerel *Scomber scombrus* (Linnaeus, 1758); the chub mackerel *Scomber colias* (Gmelin, 1789); and the bogue *Boops boops* (Linnaeus, 1758). In Croatia, the largest percentage of catches (90%) are made by 'Srdelara' purse seines (target species: sardines and anchovies, by-catch species: other small or middle-sized pelagic species), representing 3% of the total fishing vessels operating in the Croatian fishing grounds [9]. Upon reviewing the literature concerning the eight investigated species, their feeding habits have primarily been assessed through stomach content analysis, which corresponds to the 'last meal' consumed by these species [10–15]. However, the implementation of stable isotope analysis (carbon [$\delta^{13}C$] and nitrogen [$\delta^{15}N$]) could offer a more profound understanding of the ecological network. Namely, $\delta^{15}N$ is a valuable indicator of an organism's trophic position (TP; [16,17], while $\delta^{13}C$ can unveil crucial insights into the origin of the organic matter [18].

The primary objectives of this study were: (i) to provide detailed information on the landing composition of 'Srdelara' purse seines, focusing both on the wider East Adriatic coast and more specifically within the study area; (ii) to investigate the trophic ecology of the species under investigation by applying stable isotope analysis.

In doing so, this research sought to illuminate the intricate trophic interactions that collectively mould the ecological landscape of this area.

2. Materials and Methods

2.1. Study Area

The Adriatic Sea is the northernmost part of the Mediterranean Sea. Due to its physical, chemical and biological properties, the Adriatic Sea is divided into the very-shallow Northern Adriatic (<35 m), the Central Adriatic (~140 m) and the Southern Adriatic, with an average depth of >200 m and maximum depth up to 1228 m [19]. The Central Eastern Adriatic Sea is generally considered an oligotrophic area [20]. It is characterized by increasing nutrient conditions from offshore areas to coastal ones [21]. In this area (Figure 1), as with the entire Croatian fishing grounds, purse seine fishing plays a crucial economic and social role, contributing to ≈90% of total catches, with a primary focus on anchovies and sardines [9].

2.2. Official Purse Seine 'Srdelara' Landing Data

Official landing data for the Croatian fishing grounds and the fishing zone G2, where the study was conducted, were provided by the Ministry of Agriculture, Directorate of Fisheries. The data included total monthly landings by species for the period from November 2020 to March 2022.

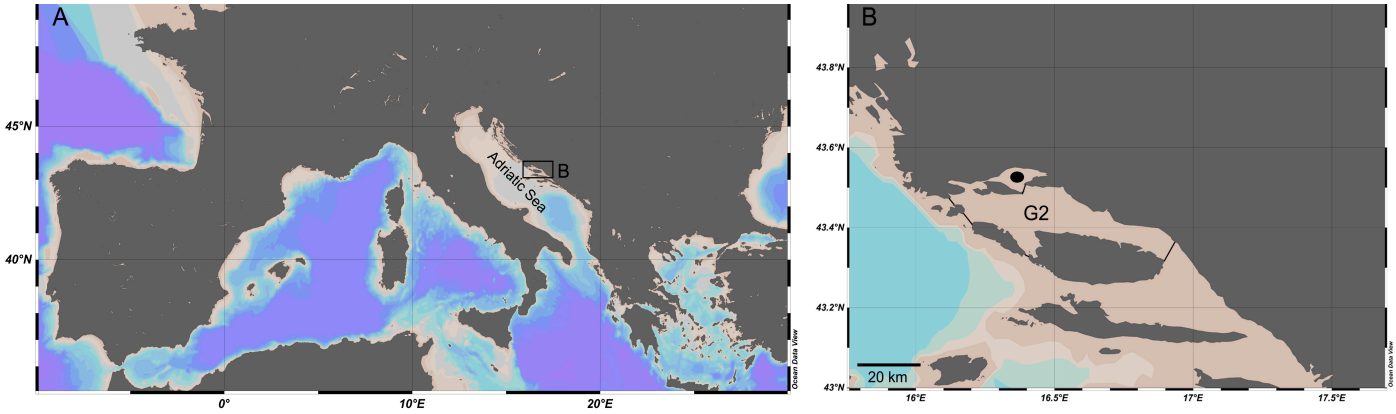

Figure 1. The investigated area: the Central Eastern Adriatic (**A**), precisely fishing subzone G2 (**B**).

2.3. Fish Sampling and Sample Preparation

Commercial purse seine catches in the Central Eastern Adriatic, specifically within fishing zone G2 (Figure 1), were sampled seven times from November 2020 to March 2022 (November and December 2020, beginning and end of April and August 2021, March 2022). This sampling process was conducted whenever opportunities arose, taking into consideration the limitations imposed by the coronavirus disease 2019 (COVID-19) pandemic and its associated lockdowns as well as the fishing ban (January and May) in force for 'Srdelara' purse seines during the investigated period. Upon a vessel's arrival at the landing site, a box weighing approximately 5–6 kg containing landing samples for length frequency analysis and a random selection of five or more fish specimens from each species in the catch was collected for stable isotope analysis. The collected biological samples were immediately transported to the Institute of Oceanography and Fisheries, Split, Croatia. In the laboratory, the total length (TL $\pm$ 0.1 mm), fork length (FL $\pm$ 0.1 mm; used for Scombridae species) and weight (W $\pm$ 0.01 g) of each sampled specimen were measured. In total, 224 individuals belonging to the eight analysed species—sardine, anchovy, round sardinella, Atlantic bonito, Atlantic horse mackerel, Atlantic mackerel, chub mackerel and bogue—were sampled. All specimens were measured, and a small piece of dorsal-anterior muscle was dissected (skin and bones removed), put in marked plastic tubes and frozen (−20 °C) prior to further analysis. All collected samples were dried in an oven at 60 °C for 48 h and then ground using a mortar and pestle. Approximately 1 mg of homogenised sample was packed into a tin capsule for the $\delta^{15}N$ and $\delta^{13}C$ analysis. Additionally, zooplankton samples were collected in the same area during the summer months. These samples correspond to zooplankton samples collected during the same period of the year in the other parts of the Adriatic [14], which were also use for the data analysis in the present study. As we assessed the trophic positions of migratory species, we integrated baseline offshore data (from [14]) with coastal data from this study, both collected during the same period of the year. According to [14,22], the most abundant mesozooplankton were copepods, cladocerans and a combination of bivalve and other larvae, which together represented the majority of the ambient mesozooplankton. For both studies, zooplankton samples were collected using a standard WP2 plankton net with a 200-µm mesh size (mouth opening, 0.255 m^2). The WP2 net was hauled vertically from the near-bottom to the surface, and three samples were collected on two sampling occasions (June and August 2021). Each sample was filtered, and filtered zooplankton were dried at 60 °C for 48 h and homogenised with a mortar and pestle. Each sample was divided into two subsamples. One subsample was subjected to acid fumigation treatment to eliminate inorganic carbon [23]; the other subsample was not treated. The zooplankton samples were packed into tin capsules. Zooplankton carbon isotope data were obtained from the treated subsamples, while nitrogen isotope data were obtained from the untreated subsamples.

The processed samples were analysed in the commercial laboratory at the Stable Isotope Facility located at the University of California, Davis, in the United States. Stable isotope measurements for $\delta^{13}C$ and $\delta^{15}N$, along with elemental percentages for carbon and nitrogen, were determined by using a PDZ Europa ANCA-GSL elemental analyser connected to a PDZ Europa 20–20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, United Kingdom). The standard deviation was consistent at ±0.1‰ for $\delta^{13}C$ and ±0.3‰ for $\delta^{15}N$ over an extended period of time. The final delta values are reported relative to the international Vienna PeeDee Belemnite (VPDB) standard for carbon and air for nitrogen.

2.4. Data Analysis

The monthly fluctuations in the commercial landings (official data provided by the Croatian Ministry of Agriculture, Directorate of Fisheries) obtained from 'Srdelara' purse seine landings in fishing subzone G2 were analysed. The trend of commercial landings in fishing subzone G2 was compared with official data pertaining to the commercial 'Srdelara' purse seine landings from the entire Croatian fishing grounds during the investigated period. Additionally, the same analysis of the 'Srdelara' purse seine landings within the study area was performed.

The length frequency analysis was carried out for each species based on the collected biological samples. The length–weight relationship was determined by applying exponential regression, $W = aL^b$, where W is the fish weight (g), L is the TL or FL (cm) and a and b are constants. Statistical analyses were performed with Excel and SPSS 5.5, with $p < 0.05$ considered to be a statistically significant difference. Differences in the growth type between the species was determined with Student's *t*-test.

Each fish species' modal TP was estimated and compared with the R package tRophicPosition (Version 0.8.0; [24]). For this endeavour, the $\delta^{15}N$ and $\delta^{13}C$ zooplankton isotope values from the present study and a previous publication [14] were used as the trophic baseline ($\lambda = 2$), and the oneBaseline model option was run. A trophic discrimination factor (TDF) based on aquatic consumers from [25] ($\Delta^{15}N = 2.9 \pm 0.32$; $\Delta^{13}C = 1.3 \pm 0.30$) was used.

Furthermore, to analyse the niche overlap between eight analysed pelagic fish species we applied the standard ellipse area (SEA) and Bayesian standard ellipse (SEAb) metrics, which provide an estimate of the isotopic niche [26,27]. For sardines and anchovies, the species for which we conducted continuous seasonal sampling, we provide a detailed seasonal analysis of isotopic niche overlap. For other species, only the overall overlap is presented. Seasonal isotopic niche overlap for sardines and anchovies was estimated by calculating the standard ellipse area corrected for a small sample size (SEAc), which is based on the core 40% of the $\delta^{15}N$ and $\delta^{13}C$ values. The sizes and overlaps of isotopic niches were estimated with the R package SIBER (Version 2.1.4; [27]) based on the $\delta^{15}N$ and $\delta^{13}C$ values, as it has been shown that the isotopic niche is a good proxy for the trophic niche [28].

3. Results

3.1. Analysis of the Commercial 'Srdelara' Purse Seine Landings

During the investigated period (November 2020 to March 2022) in the study area (fishing subzone G2), the official data regarding the commercial 'Srdelara' purse seine landings indicated the highest monthly landings from September to the end of November (387.4 to 225.4 tonnes) and the lowest values from spring to the beginning of summer (51.1 to 4.2 tonnes). The oscillations in the commercial 'Srdelara' purse seine landings in fishing subzone G2 showed the same monthly trends for commercial 'Srdelara' purse seine landings in the entire Croatian fishing grounds (Supplementary Figure S1). Indeed, there were no significant differences between trends of the monthly landings in fishing subzone G2 and the entire Croatian fishing grounds during the investigated period (Kolmogorov–Smirnov test, $p > 0.1$).

Quantitative–qualitative analysis of the commercial 'Srdelara' purse seine landings obtained in fishing subzone G2 based on data provided by the Croatian Ministry of Agriculture showed that the dominant species was sardines (97.9%), while anchovies only represented 1.3% of the landings. Besides these target species, chub mackerels, Atlantic mackerels, Atlantic horse mackerels, bogues, round sardinellas and white seabream were noted, while gilt-head breams, John Dories, European squids, Atlantic black skipjacks, Atlantic bonitos, garfish and European sprats were caught sporadically (Supplementary Figure S2).

3.2. Length Frequency Distribution and the Length–Weight Relationship

Overall, 444 specimens of the eight analysed pelagic species were collected and their body length and weight data are presented in Table 1. The length frequency distribution of the studied species was primarily unimodal, except for the Atlantic horse mackerel, which showed a bimodal distribution (Figure 2). The length–weight parameters for each species are detailed in Table 1. Although the allometric coefficient for some species was below or above 3, statistical analysis revealed that the eight examined species exhibited isometric growth. In other words, the fish demonstrated equal proportional increases in both length and weight during their growth (Table 1).

Table 1. Length (total length or fork length for Scombridae) and weight values (range, mean and standard deviation [SD]) along with the obtained length–weight parameters (coefficient a, allometric coefficient b and coefficient of determination [r^2]) for the eight analysed fish species caught with 'Srdelara' purse seines in the Central Eastern Adriatic (fishing subzone G2) from November 2020 to March 2022.

		Length (cm)		**Weight (g)**		**Length–Weight Relationship**		
	N	**Range**	**Mean ± SD**	**Range**	**Mean ± SD**	**a**	**b**	**r^2**
Sardine	205	11.1–16.0	12.9 ± 0.86	8.92–32.80	14.79 ± 3.30	0.013	2.743	0.751
Anchovy	78	9.4–15.3	12.6 ± 1.33	5.27–22.00	12.25 ± 3.82	0.008	2.883	0.822
Atlantic horse mackerel	40	15.0–27.5	18.6 ± 3.28	26.31–184.00	59.67 ± 41.86	0.004	3.234	0.988
Bogue	44	14.0–23.4	17.1 ± 1.81	28.39–109.00	50.32 ± 14.53	0.036	2.537	0.955
Chub mackerel	15	14.5–20.8	18.2 ± 1.94 *	30.40–104.67	64.24 ± 22.16	**	**	**
Atlantic mackerel	7	23.0–27.0	24.5 ± 1.38 *	126.59–250.23	178.42 ± 48.18	**	**	**
Round sardinella	5	20.4–24.7	22.1 ± 1.80	62.98–117.88	85.00 ± 23.16	**	**	**
Atlantic bonito	50	43.5–64.0	54.4 ± 3.57 *	987.58–3303.83	2192.41 ± 460.24	0.006	3.210	0.931

* For Atlantic bonito, Atlantic mackerel and Chub mackerel, FL is expressed in the table. ** Not applicable due to small sample size.

3.3. Stable Isotope Analysis

The estimated mean TP of the eight analysed pelagic species ranged from 3.0 to 4.7 (Figure 3), indicating that the sampled species consumed prey over approximately two different trophic levels. The isotopic data, including the TP for each species, are presented in Table 2. The SEA values of the analysed fish species ranged from 0.21‰^{2} for the round sardinella to 2.89‰^{2} for the Atlantic mackerel; the sardine had an SEA value of 1.54 ‰^{2} (Table 3). The isotopic niches overlapped among almost all of the analysed species (Figure 4A,B, Table 3), but the most pronounced isotopic niche overlaps were between the round sardinella and the anchovy (71%), the bogue and the round sardinella (68%), the bogue and the Atlantic horse mackerel (66%), the Atlantic horse mackerel and the sardine (67%), the anchovy and the sardine (47%), the Atlantic bonito and the Atlantic mackerel (37%), the chub mackerel and the Atlantic bonito (37%), the sardine and the Atlantic mackerel (37%) and the Atlantic mackerel and the sardine (20%).

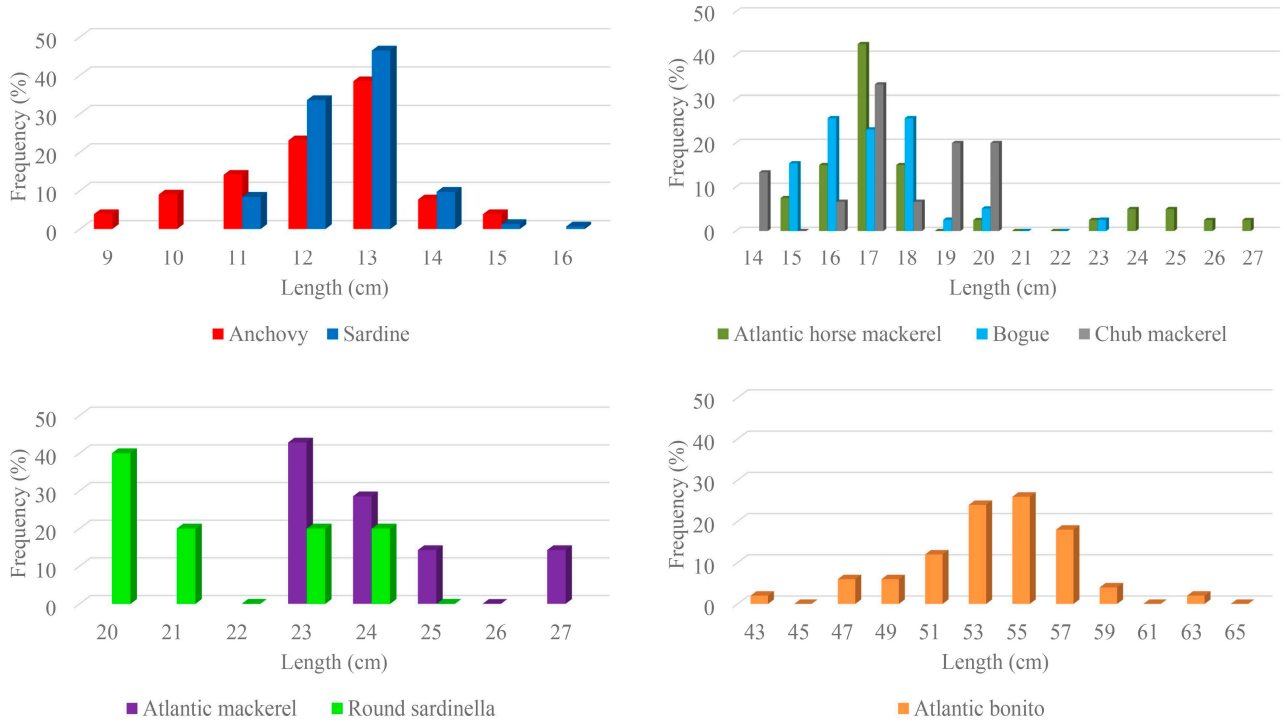

Figure 2. Length frequency distribution of the eight analysed fish species (anchovy, sardine, Atlantic horse mackerel, bogue, chub mackerel, Atlantic mackerel, round sardinella and Atlantic bonito) caught with commercial 'Srdelara' purse seines in the Central Eastern Adriatic, November 2020 to March 2022.

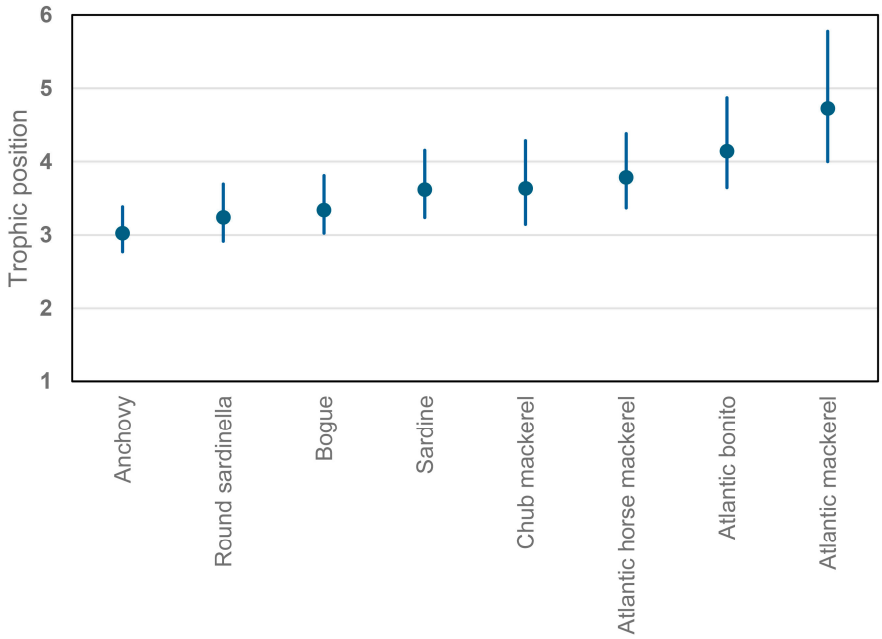

Figure 3. Modal (95% Bayesian credibility intervals) estimated trophic position for eight species (anchovy, round sardinella, bogue, sardine, Chub mackerel, Atlantic horse mackerel, Atlantic bonito, Atlantic mackerel) sampled in the Central Eastern Adriatic from November 2020 to March 2022.

Table 2. Descriptive overview of the mesozooplankton and eight fish species used for stable isotope analysis (N—number of individuals, TL—total body length in cm, FL—fork length, TP—trophic position, CI—95% credibility interval).

Mesozooplankton * (mean ± SD) δ^{15}N: 4.5 ± 0.6 ‰; δ^{13}C: −23.4 ± 1.5‰					
Species	**N**	**Range TL/FL (cm, mean TL/FL ± SD)**	**Range δ^{15}N (mean ± SD, ‰)**	**Range δ^{13}C (mean ± SD, ‰)**	**TP (95%CI)**
Anchovy	63	9.8–15.3 (12.8 ± 1.2)	6.0–9.0 (7.4 ± 0.8)	−19.9–−17.9 (−18.9 ± 0.5)	3.0 (2.8–3.4)
Atlantic bonito	10	52.5– 57.0 (55.0 ± 1.5) **	9.9–11.5 (10.5 ± 0.5)	−18.5–−16.6 (−17.6 ± 0.6)	4.1 (3.7–4.9)
Atlantic horse mackerel	26	15.5–27.5 (19.5 ± 3.9)	7.8–12.4 (9.5 ± 1.0)	−18.9–−17.8 (−18.4 ± 0.3)	3.8 (3.4–4.4)
Atlantic mackerel	7	23.0–27.0 (24.5 ± 1.4) **	9.9–13.2 (12.2 ± 1.1)	−20.8–−17.8 (−18.9 ± 1.0)	4.7 (4.0–5.8)
Bogue	24	14.0–20.0 (17.2 ± 1.5)	7.7–9.5 (8.3 ± 0.5)	−19.1–−18.1 (−18.5 ± 0.3)	3.3 (3.0–3.8)
Chub mackerel	14	17.7–20.8 (19.1 ± 1.3) **	6.9–11.2 (9.1 ± 1.6)	−18.2–−17.5 (−17.8 ± 0.2)	3.6 (3.1–4.3)
Round sardinella	5	20.4–24.7 (22.1 ± 1.8)	7.5–8.2 (8.0 ± 0.3)	−18.7–−18.1 (−18.4 ± 0.2)	3.2 (2.9–3.7)
Sardine	75	11.1–16.0 (13.1 ± 1.1)	7.2–11.0 (9.0 ± 1.0)	−21.1–−18.4 (−19.5 ± 0.6)	3.6 (3.2–4.2)

* Mean values of mesozooplankton data from this study and [14]. ** For Atlantic bonito, Atlantic mackerel and Chub mackerel, FL is expressed in the table.

Table 3. Standard ellipse area (SEA) and the SEA overlap percentage between the analysed fish species (the values indicate SEA overlap of the species in the row with the species in the column).

Species	**SEA (‰^{2})**	**Anchovy**	**Atlantic Bonito**	**Atlantic Horse Mackerel**	**Atlantic Mackerel**	**Bogue**	**Chub Mackerel**	**Round Sardinella**	**Sardine**
Anchovy	0.91		0	17	0	21	20	20	42
Atlantic bonito	0.87	0		32	37	0	26	0	31
Atlantic horse mackerel	0.61	25	49		33	39	11	24	77
Atlantic mackerel	2.89	0	10	6		0	4	0	19
Bogue	0.35	54	0	66	0		26	68	63
Chub mackerel	0.62	28	37	10	22	14		14	2
Round sardinella	0.21	70	0	56	0	92	35		52
Sardine	1.54	26	19	32	43	15	1	9	

The seasonal SEAc values for the anchovy ranged from 0.45‰^{2} (December) to 0.91‰^{2} (April), and were in general lower than the SEAc values for the sardine, which ranged from 0.25‰^{2} (February) to 1.34‰^{2} (December). Seasonal interspecies overlap was only recorded in April, while it was not recorded in August, November and December (Table 4). There were variations in the seasonal isotopic niche overlaps within each species. For the anchovy, the highest overlap was between April and August, while there was no overlap between those two months and December. For the sardine, the seasonal isotopic niches were more segregated: the only notable overlap was between April and August (Figure 4C,D, Table 4).

Table 4. Standard ellipse area corrected for a small sample (SEAc) and the SEAc overlap percentage for seasonal anchovy and sardine samples (the values indicate SEAc overlap of the species in the row with the species in the column).

			Anchovy				**Sardine**			
Species	**Month**	**SEAc (‰^{2})**	**Apr**	**Aug**	**Nov**	**Dec**	**Feb**	**Apr**	**Aug**	**Nov**	**Dec**
Anchovy	Apr	0.91		59	14	0	0	34	0	2	0
	Aug	0.78	69		29	0	0	43	0	11	0
	Nov	0.7	18	33		21	0	0	0	0	0
	Dec	0.45	0	0	33		0	0	0	0	0
Sardine	Feb	0.25	0	0	0	0		0	0	0	31
	Apr	1.11	28	30	0	0	0		0	57	24
	Aug	0.97	0	0	0	0	0	0		21	0
	Nov	1.01	2	8	0	0	0	62	20		17
	Dec	1.34	0	0	0	0	6	19	0	13	

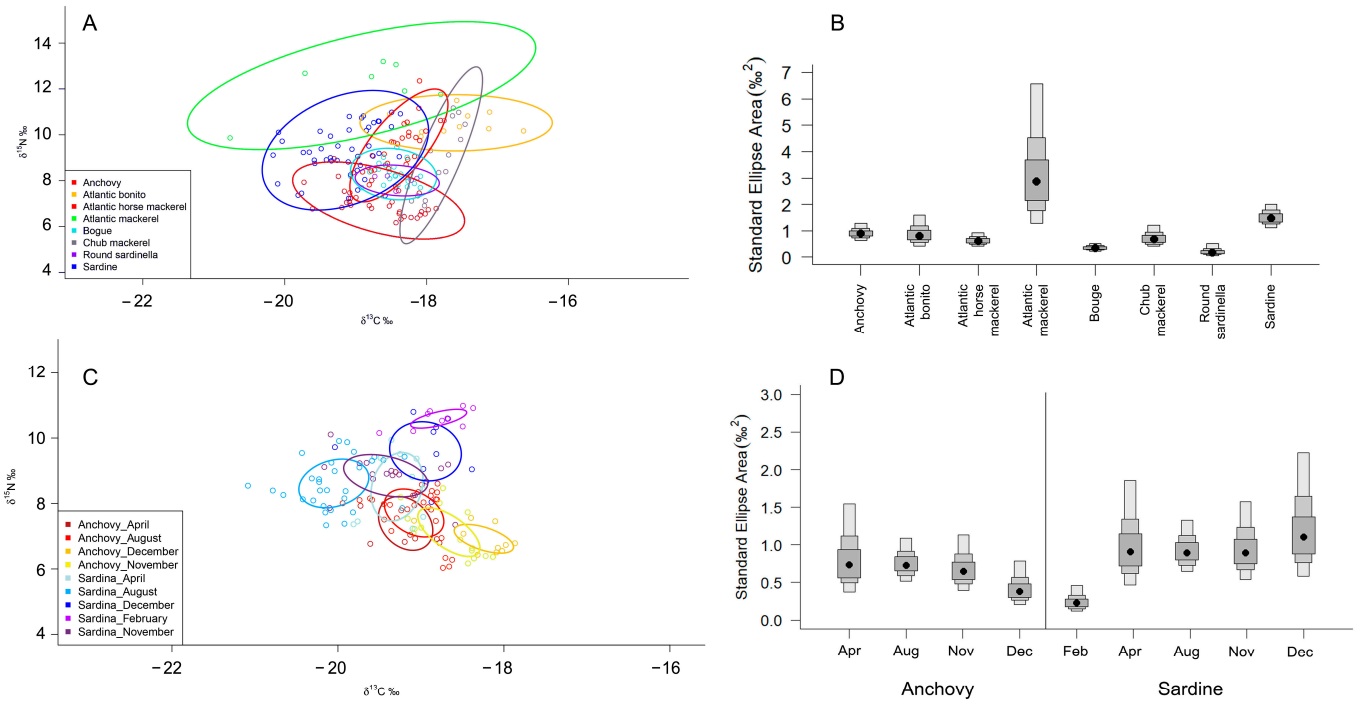

Figure 4. Variations in carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), the standard ellipse area (SEA) and isotopic niche overlap for (**A**) the eight analysed fish species during the colder period of year (November–April) and (**C**) between the sardine and the anchovy (standard ellipse area corrected for a small sample size [SEAc]) throughout the entire investigated period. Posterior distribution of the SEAb for eight analysed pelagic fish species (**B**) and seasonally sampled sardine and the anchovy (**D**). SEA—Standard Ellipse Area, SEAb—Bayesian Standard Ellipse. Black dots represent modes; the shaded boxes represent the 50%, 75% and 95% credible intervals (from dark grey to light grey).

4. Discussion

4.1. Landing Composition of Srdelara' Purse Seines

During the investigated period (November 2020 to March 2022), the monthly commercial 'Srdelara' purse seine landings in the Central Eastern Adriatic, specifically within fishing subzone G2, exhibited variability. This trend in landings and its seasonal patterns mirrored those observed across the entire Croatian fishing grounds. The anticipated seasonal fluctuations in commercial landings align with the migratory nature of the targeted species. These migrations, driven by spawning or feeding behaviours, have been well-documented and characterised by [29]. A quantitative–qualitative analysis of the 'Srdelara' purse seine landings reaffirmed the gear's high selectivity, with sardines and anchovies dominating the landings, while other medium-sized pelagic fish comprised the majority of the by-catch. This observation is in line with previous findings [30–35] conducted in the Adriatic and Mediterranean Sea using the same fishing gear.

The length ranges of the eight investigated species align with earlier studies [13,36–41] conducted in this area. The length–weight relationship of the eight examined species, particularly the allometric coefficients (a and b), demonstrated a strong alignment with their regression lines provided by FishBase. Minor discrepancies in the allometric coefficients for each species can be attributed to several factors, including variations in sampling time, stomach fullness, gonad maturity, sex, size distribution, health, general fish condition and differences in preservation techniques [42].

4.2. Trophic Ecology of Investigated Pelagic Species

The TP of each investigated species was calculated based on the obtained stable isotope values. The TP values reported in the present study almost completely coincide with what

has been reported for these species, whether they come from the Adriatic Sea [14,43,44] or the Mediterranean Sea [45–47]. Namely, the lowest and highest TPs were attributed to the anchovy and the Atlantic mackerel, respectively. Small differences in TP values may be due to variations in the sampled environments, as discussed by [14], or because the present study included fish specimens of different body lengths. This observation is in line with the understanding that many researchers have highlighted, where marine pelagic habitats show a strong relationship between trophic levels and body size. This relationship is believed to play a significant role in shaping the food web dynamics of marine ecosystems [48–52].

The isotopic niches, as a proxy for trophic niches, of the eight investigated fish species showed a high degree of overlap, which according to previous studies [53,54] might be expected because all of the investigated species inhabit the same ecological niche, which implies that they will potentially be forced to share food resources. Among the analysed pelagic fish species, the round sardinella and the bogue had the smallest isotopic niches, and they showed notable overlap. According to previous studies that employed stomach content analysis, these two species are omnivores that tend to mainly feed on zooplankton, although their stomachs also contained plant material [45,55–57]. Given that the previous literature has not characterised these species as specialists regarding their feeding behaviour, their narrower isotopic niche might be due to limited food resources in order to try to avoid direct competition for resources with other pelagic fish species.

Among the middle-/large-sized pelagic fish species (Atlantic bonito, Atlantic horse mackerel, Atlantic mackerel and chub mackerel), the Atlantic mackerel had the widest isotopic niche and the Atlantic horse mackerel had the narrowest isotopic niche. Based on the available literature, the Atlantic mackerel exclusively feeds on a wide range of pelagic prey like euphausiids, mysids, decapods and fish that have higher trophic levels [43,47]; the present study confirmed these findings. The results regarding the Atlantic horse mackerel isotopic niche are consistent with data obtained by [14,43]. Those studies also indicated that middle-sized pelagic fish preferentially feed on a wide range of copepods, as evident by their high niche overlap with sardines, which nevertheless have a lower trophic level than decapods. Contrary to our expectations, the Atlantic bonito—although a piscivorous predator that prefers clupeiforms [58–60]—had somewhat lower $\delta^{15}N$ values than the Atlantic mackerel, indicating its lower TP in the investigated food web. This might be attributed to the fact that the Atlantic mackerel probably applies filter and particulate feeding methods to maximise its intake [61], which was also evident in the present study due to its larger niche size. This may be due to the fact that Atlantic bonito specimens were collected in March, which, according to [59,62], is before their peak feeding season in summer. However, further research, including seasonal sampling and stomach content analysis, is needed to gain a deeper understanding of the feeding ecology of this species. Stable isotope analysis of chub mackerels proved that this middle-sized pelagic fish species prefers prey at a low trophic level, in contrast to the other middle-sized pelagic fish species investigated in the present study. Our findings corroborate studies conducted in the Adriatic Sea [14,43] on the chub mackerel.

Regarding the small pelagic fish species, the anchovy showed a narrower isotopic niche than the sardine, a finding that has been reported by [14,43,54]. The anchovy's narrow isotopic niche confirms once again that this small pelagic fish is a diet specialist [14]. Furthermore, the anchovy isotopic niche overlapped with the isotopic niche of all middle-sized pelagic fish species, except for the Atlantic mackerel, with the greatest overlap with the sardine. On the other hand, the sardine had the second largest isotopic niche, and it overlapped with all of the analysed fish species, with the greatest overlap with the Atlantic mackerel. This outcome could be expected because both of these pelagic species are filter feeders that prefer zooplankton. The isotopic niche dynamics of the anchovy and sardine were investigated seasonally due to the selective nature of fishing gear. The findings suggest distinct shifts in the dietary preferences of these small pelagic species, particularly during their spawning periods (sardine: December to February; anchovy: April

to August; [63]). This aligns with previous research employing stomach content analysis in the same geographic area [13], which highlighted that anchovies primarily target larger, high-energy prey such as decapod larvae during spring and autumn, while sardines predominantly consume euphausids and fish eggs in spring and summer. Furthermore, the interspecies overlap in April underlines the increased energetic demands of these fish, potentially driven by the need to accumulate energy before spawning or to recover from the energy depletion associated with spawning, as reported previously by [13,54].

5. Conclusions

Based on the aforementioned findings, it is evident that the commercial 'Srdelara' purse seines represent selective fishing gear that primarily target sardines and anchovies, with by-catch species occurring sporadically throughout the year. The stable isotope analysis conducted in this study, discussed alongside with the findings from previous studies on stomach content and stable isotope analysis, has established an overlap in isotopic niches among the analysed species. Given these outcomes, there is a pressing need for further research that incorporates biomass data of the studied species [64]. This is particularly crucial in the Adriatic Sea, where recent stock assessments have highlighted the overexploitation of small pelagic fish. Understanding the trophic structure of this ecosystem is imperative for ensuring its stability and sustainability in the face of exploitation pressures.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/fishes9120516/s1, Figure S1. Oscillation of the monthly commercial 'Srdelara' purse seine landings in fishing subzone G2 (black area) and the entire Croatian fishing grounds (grey area), November 2020 to March 2022.; Figure S2. Quantitative-qualitative composition of the commercial 'Srdelara' purse seine landings in the Middle Eastern Adriatic, November 2020 to March 2022: (A) the contribution of the main small pelagic fish species to the landings and (B) the contribution of by-catch species within the 'Other' category.

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