



Article Feeding Habits of Predatory Thermophilic Fish Species and Species with Subtropical Affinity from Recently Extended Distributional Range in Northeast Adriatic Sea, Croatia

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Abstract: The study investigates feeding habits of thermophilic species and species with subtropical affinity in the fishing catch in the Bay of Medulin (northeastern Adriatic Sea), and contributes to the knowledge about their presence in recently extended distributional range. In our methodology, the presence of the *Seriola dumerili, Sphyraena sphyraena, Lichia amia, Coryphaena hippurus, Caranx crysos, Pomatomus saltatrix,* and incidence of *Trachinotus ovatus* is recorded. A total of 220 specimens are captured during 2017, 2018 and 2019. A dietary assessment is performed, and the index of relative importance IRI was calculated for each prey category. Diet overlap is calculated using Schoener's index, based on IRI. The principal diet of *C. hippurus* included *Sardina pilchardus* and *Loligo vulgaris. Pomatomus saltatrix* consumed species from the Sparidae family and *T. ovatus* crustaceans from the Mysidacea family. Different species from genus *Atherina* are represented important foods for *L. amia, S. dumerili* and *S. sphyraena*. Diets of significant importance for *L. amia* included fishes from the family Sparidae, for *S. sphyraena* from the Carangidae family, and *S. dumerili* from the Clupeidae and Muliidae families. Our analysis of diet overlap is based on IRI suggests no diet overlap between analysed fish species from Medulin Bay, and that these species utilise differing trophic niches.

Keywords: marine fish; extended distributional range; North Adriatic; Istria

1. Introduction

The Mediterranean Sea is a marine biodiversity hotspot [1]. It is also an ecoregion impacted by severe biodiversity threats [2], mostly because of the ongoing warming trend, due to climate change [3]. Changes in biochemical and physical properties of seawater, resulting from global warming, are likely to alter marine biodiversity, trigger trophic web mismatches, encourage diseases and toxic algal blooms, and encourage the propagation of thermophilic species [4].

Climatic conditions of the Mediterranean Sea are characterised by cold winters in the northern region, and long and warm summers in the south [3,5,6], influencing the distribution of ichthyofauna. Subtropical species are commonly found in warmer eastern and southern parts, Lessepsian migrants in the south, and Atlantic migrants in the west; while boreal species reside in the northern regions [1,7,8]. At the end of the 20th and



Citation: Iveša, N.; Piria, M.; Gelli, M.; Trnski, T.; Špelić, I.; Radočaj, T.; Kljak, K.; Jug-Dujaković, J.; Gavrilović, A. Feeding Habits of Predatory Thermophilic Fish Species and Species with Subtropical Affinity from Recently Extended Distributional Range in Northeast Adriatic Sea, Croatia. *Diversity* 2021, 13, 357. https://doi.org/10.3390/ d13080357

Academic Editor: Michael Wink

Received: 29 June 2021 Accepted: 31 July 2021 Published: 3 August 2021

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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). beginning of the 21st century in the Atlantic, as well as in the Mediterranean, the widening of the range of distribution of thermophilic fish species and species with subtropical affinity has been observed in the northern parts, where they were previously not present or were rarely recorded [9–12]. Additionally, the number of allochthonous thermophilic species has increased, leading to changes in infralittoral communities, reduced genetic diversity, a loss of function and structure of habitats, and an increased risk of biotic homogenisation [13–15]. The invasion of non-native species will continue to alter local biodiversity records, mainly in its eastern basin, which can spread rapidly northwards and westwards, due to the warming of the Mediterranean Sea [1].

Recently, a list of 51 Mediterranean fish species extended their distribution range to the northern Mediterranean has been published [16,17]. This has been confirmed by numerous findings of thermophilic species and species with subtropical affinity in the northernmost part of the Mediterranean, and the northern Adriatic Sea [18–21]. However, it was considered that these newly recorded thermophilic species, such as blue runner, *Caranx crysos* (Mitchill, 1815) [22], could not successfully form self-sustaining populations in the North Adriatic, and that they were expected to be seen mostly in warmer months of the year [23,24]. Nonetheless, it has been observed that predatory non-native fish species, for example, bluefish, *Pomatomus saltatrix* (Linnaeus, 1766), adapt well to conditions in new habitats and form large populations in the northernmost part of the Adriatic [25]. Similarly, the common dolphinfish, *Coryphaena hippurus* Linnaeus, 1758, became more common in the eastern part of the Adriatic Sea, and the presence of its juvenile stages has been recorded and confirmed [26,27].

The results of recent studies on the visual census of thermophilic fish species and species with sub-tropical affinity in the Bay of Medulin (North Adriatic, Istria) indicate the increased frequency of presence of the greater amberjack, *Seriola dumerili* (Risso, 1810) and the Mediterranean barracuda, *Sphyraena sphyraena* (Linnaeus, 1758); frequent occurrences of the leerfish, *Lichia amia* (Linnaeus, 1758); and incidences of the pompano, *Trachinotus ovatus* (Linnaeus, 1758) and *P. saltatrix* [28]. These species, indigenous in the Adriatic Sea, were not abundant in its southern part until about 20 years ago [17]. However, they have been unrecorded in scientific literature and unseen by local fishers (personal communication: Davor Iveša, Darko Kuzmanić). in the northern Adriatic.

Literature on the feeding habits of the aforementioned fish species from their indigenous habitat is abundant [29–33], but data on their dietary pattern in recently extended distributional range, in the eastern Adriatic Sea, are scarce. Thus, this study aims to investigate the feeding habits of the thermophilic *C. crysos*, *C. hippurus*, *S. sphyraena* and the species with subtropical affinity *L. amia*, *P. saltatrix*, *S. dumerili*, and *T. ovatus* caught in their newly extended habitat in the northeast Adriatic Sea, the Bay of Medulin. Specifically, the study examined the: (1) Main dietary items of prey available in the environment; (2) prey items of importance for each thermophile species and species with sub-tropical affinity; and (3) diet overlapping between investigated species. The period during which the largest number of individuals was caught, and the frequencies of their occurrence in the fishing catch, are also presented.

2. Material and Methods

2.1. Study Area and Fish Sampling

The study was conducted at three stations in the Bay of Medulin (Istria, Northern Adriatic): Dražice (44°47'18.4" N 13°54'54.1" E), Školjić (44°46'55.6" N 13°55'08.1" E) and Kažela (44°48'06.7" N 13°55'24.7" E) (Figure 1). Unlike other parts of the coastal area in Istria, this area is specific for its diverse habitats and richness in nutrients [34]; http://www.bioportal.hr/gis/, accessed on 15 October 2020). In the inner part of the bay, there are coastal lagoons, while the rest of the area is dominated by large shallow bays with diverse marine habitats, such as underwater reefs, caves and biocenoses of seagrass meadows [35]. There are 76 professional small-scale fishers, using gillnets as the main



fishing gear, targeting fish in the wider area of the Bay of Medulin. They significantly contribute to the local commercial fishery.

Figure 1. Sampling locations in the Bay of Medulin.

At each station, the collection of thermophilic fish and fish with subtropical affinity was conducted during regular fishing operations in the period from early summer (June) to early winter (February) during 2017 and 2018, and January 2019. After fish catches were analysed from these two years, additional samples were undertaken five times at each station, from August to October 2019. Gillnets were 8 m high with a mesh size of 32 or 40 mm made of polyamide filaments, 0.25 mm in diameter. The length of 40 mm mesh size gillnet was 140 m, while the length of 32 mm mesh size gillnet was 120 m. There were 52 deployments of the 40 mm mesh size gillnet performed simultaneously at each of three stations, making a total of 156 deployments. Only at station Dražice, a single gillnet of 32 mm mesh size was laid 18 times together with the deployment of the 40 mm mesh size gillnet.

The nets were deployed two to three times per month, from June until February, at each sampling site. Using the entanglement method, gillnets were laid close to the coast, attempting to deploy as close as possible to the seashore, and extended horizontally towards the sea. The last fifty meters were set in a semicircular manner to increase fish catchability. From the beginning to the end of the gillnets, the sea depth ranged from 1.5 to 12 m. The start and end of each gillnet net were marked by a buoy. Gillnets were deployed around one hour before sunset and retrieved the next morning within one hour following sunrise. For deployment and hauling, a 5.95 m wooden fishing boat, with an 8 horsepower outboard engine was used. A hydraulic winch was used to haul the gillnets via a 4 KW Honda power aggregate.

Additionally, a coastal purse seine was used to catch smaller specimens. The coastal purse seine was of 9 mm mesh size (three polyamide threads), 30 m long and 6 m high. It

was deployed four times in 2019 at two sites (three hauls at Dražice station at the end of August, and one at the beginning of September at Školjić station) during daylight hours. When thermophilic fish or fish with sub-tropical affinity were detected and confirmed by visual observations using snorkelling equipment, this determined the location of its deployment.

2.2. Gut Content Analysis, Diet Overlap and Prey Importance

Sampled specimens were frozen immediately after capture to preserve the gut contents. After thawing, the total length (TL, in cm) and weight (W, in g), mouth height (MH, in cm) and width (MW, in cm) were measured. The number of gill rakers was counted on the first branchial arch at the right side. After measurements, each specimen was dissected, the entire content of the gut (stomach and the anterior third of the intestine) was removed, weighed and fixed in 96% ethanol. Recognisable organisms were subsequently identified to the family or genus level, when possible.

Assessment of the fish diet was based on the frequency of occurrence (F%), numerical frequency (N%) and mass frequency (W%) of the different diet components [36], using the following formulas:

$$F\% = \frac{f_i}{\sum f} \times 100 \tag{1}$$

where f_i is a number of guts containing each prey item and Σf is the total number of guts with food;

$$N\% = \frac{n_i}{\sum fn} \times 100 \tag{2}$$

where n_i is the total number of a particular prey item and Σn is the total number of prey items consumed by the fish;

$$W\% = \frac{w_i}{\sum w} \times 100 \tag{3}$$

where w_i is the total mass of a single prey item and Σw is the total mass of prey items consumed by the fish.

The analysis of changes in feeding habits was performed using the following indices [36]:

$$Fulness index (FI\%) = \frac{Total gut content weight}{Fish weight} \times 100$$
(4)

$$Vacuity \ coefficient \ (VI\%) = \frac{Number \ of \ empty \ guts}{Total \ number \ of \ guts \ analysed} \times 100$$
(5)

The index of absolute ($IAI\alpha$) and relative importance IRI was calculated for each prey category.

$$IAI\alpha = F\% + N\% + W\% \tag{6}$$

$$IRI = 100 \times \frac{IAI\alpha}{\sum_{\alpha=1}^{n} IAI\alpha}$$
(7)

where: α —specific prey category

n—number of different prey categories

Diet overlap was calculated using the index proposed by [37] based on IRI:

$$\alpha = 1 - 0.5\left(\sum_{i=1}^{n} |PV_{xi} - PV_{yi}|\right)$$
(8)

where n = number of prey items $PV_{xi} =$ percentage of prey item *i* in species *x* and $PV_{yi} =$ percentage of prey item *i* in species *y*. Values range from 0 (no feeding overlap) to 1 (total feeding overlap), and values > 0.60 represent significance.

2.3. Statistical Analysis of the Fish Feeding Habits

Constrained Canonical Correspondence Analysis (CCA) with response data log transformations, both above test and unrestricted permutations were implemented in CANOCO v.5 software package [38] to analyse the importance of identified prey items based on mass frequency (response variables) in the diet of *L. amia, S. dumerili* and *S. sphyraena*, caught at different sampling sites (explanatory variables). To test importance in prey selectivity, mouth size, number of gill rakers and specimen size classes (<30 and >30 cm in TL) were used as explanatory variables. Explanatory variables, fish species and sampling sites, were expanded into dummy variables, and specimen size classes were presented as factors. Fish species represented with less than 20 specimens, and specimens with empty guts or guts containing only detritus were excluded from CCA analysis.

3. Results

In 2017, 2018 and January 2019, out of 52 gillnet deployments, thermophilic species and species with sub-tropical affinity were caught 30 times. Most individuals were detected in the period from late summer to late autumn. In 2019, when targeted fishing was performed from August to October, species were caught all five times out of five gillnets deployments, and caught four times by coastal purse seine (Appendix A Table A1).

In total, three thermophilic species and four species with subtropical affinity (220 specimens) were captured and analysed: One specimen of *C. crysos*, six specimens of *C. hippurus*, thirty-three specimens of *S. sphyraena*, twenty-two specimens of *L. amia*, eight specimens of *P. saltatrix*, one hundred and forty-seven specimens of *S. dumerili*, and three specimens of *T. ovatus*. Specimen sizes lower than 25 cm were not possible to catch by gillnets, due to its mesh size, therefore purse seine nets were used. In this way, juveniles of *S. sphyraena* and *T. ovatus* were captured, as well as smaller sample sizes of *S. dumerili*. TL of captured specimens ranged between 7.85 and 66.8 cm, and W from 4.01 to 2850.30 g (Table 1; Appendix A Table A1). Eighty-one specimens have been found with empty stomachs, or with stomachs containing only detritus, consisting of unrecognised particles of ingested food, micro and macro plastic, and metal particles.

One specimen of *C. crysos* (FI% = 0.62, TL = 37.5 cm; W = 628.0 g) was caught at the Dražice location in November 2018. Only unrecognisable remains of a bony fish (Pisces) were found in its stomach. Occasionally *C. hippurus*, *P. saltatrix* and *T. ovatus* were found in gillnets during the sampling period, and two juvenile specimens of *T. ovatus* were caught by coastal purse seine net. The main food items for *C. hippurus* were European pilchard, *Sardina pilchardus* (Walbaum, 1792), from Clupeidae family, and cephalophod, common squid, *Loligo vulgaris* Lamarck, 1798. *Pomatomus saltatrix* consumed unidentified species of Sparidae family, and *T. ovatus* fed on crustaceans from the order Mysidacea (Table 1, Figure 2).

Important food items for *L. amia, S dumerili* and *S. sphyraena* were represented by species from the genus *Atherina*, but each of these three species seems to consume different *Atherina* species. Beside *Atherina*, significant food items for *L. amia* are represented by fishes from Sparidae family, for *S. sphyraena* from Carangidae family (including *Trachurus* sp.) and for *S. dumerili* fish from Clupeidae and Muliidae family (Table 1, Figure 2).

Coryphaena hippurus Lichia amia Pomatomus saltatrix Seriola dumerili Sphyraena sphyraena Trachinotus ovatus TL = 41.70 - 44.60TL = 24.00 - 66.80TL = 30.50 - 41.60TL = 19.30-41.00 TL = 13.40 - 38.60TL = 7.85 - 66.80 $\textit{FI\%} = 1.55 \pm 1.97$ $FI\% = 0.44 \pm 0.45$ $FI\% = 2.62 \pm 2.81$ $FI\% = 1.55 \pm 1.92$ $FI\% = 1.38 \pm 1.89$ $FI\% = 2.50 \pm 0.94$ Abbreviation *VI*% = 33.33 VI% = 13.64VI% = 33.33VI% = 54.55*VI*% = 33.33 VI% = 36.05MouthW = 3.3MouthW = 4.6MouthW = 4.1MouthW = 4.1MouthW = 1.6MouthW = 1.2Prey Item MouthH = 4.3MouthH = 4.8MouthH = 4.3MouthH = 3.9MouthH = 2.9MouthH = 1.5NoBraRig = 9NoBraRig = 10 NoBraRig = 12 NoBraRig = 16 NoBraRig = 0 NoBraRig = 36n = 6n = 22n = 8n = 147n = 33n = 3N%F% W%N%F% W% N%F% W%N%F% W%N%F% W%N%F% W%0.89 11.37 Oblada melanura OblMel 2.33 Pagellus erythrinus PagEry 1.94 3.14 6.61 0.89 2.33 1.02 0.32 0.52 1.18 Boops boops BoopBop Sparidae n.d. SparidND 8.04 11.63 5.59 14.29 20.00 64.91 7.44 8.90 8.34 Sardina pilchardus 1.62 SardPilc 50.00 50.00 94.55 1.57 7.67 9.95 9.31 5.00 5.26 5.21 Clupeidae n.d ClupeiND 10.68 Atherina hepsetus AtherHep 44.64 23.26 39.87 10.36 9.95 6.52 Atherina boyeri AtherBoy 8.04 9.30 3.87 11.65 8.38 3.73 15.00 15.79 3.72 24.11 18.60 23.10 16.83 17.28 9.17 5.00 5.26 5.29 Atherina sp. AtherSp Mullus barbatus MullBarb 7.12 2.09 11.25 7.74 Mullus sp. MullSp 4.85 4.19 2.27 1.57 4.39 15.00 TrachuSp 15.79 74.83 Trachurus sp. 3.57 Belone belone BelonBel 9.30 1.96 Sphyraena sp. SphyraSp 0.65 1.05 0.74 8.04 21.47 9.75 55.00 52.63 Pisces n.d PiscesND 13.95 13.11 71.43 60.00 31.19 19.09 10.80 0.08 33.33 0.15 0.52 99.52 Mysidiacea Mysidiac 0.32 0.02 33.34 96.79 Isopoda Isopoda 1.79 4.65 0.07 1.29 2.09 0.05 5.00 5.26 0.15 LoliVulg Loligio vulgaris 50.00 50.00 5.45 1.29 2.09 9.89 Seppia officinalis SepOffic 0.65 1.05 1.19 Cephalopoda n.d CephalND 14.29 20.00 3.90 1.62 2.62 2.42 Posidonia oceanica PosidOce 2.33 0.03 + Zoostera sp. ZoosterS 2.33 0.01 + 1.57 0.02 + 0.40 Hymenoptera n.d 33.33 3.05 -

Table 1. Frequency of occurrence (*F*%), numerical frequency (*N*%), mass frequency (*W*%), vacuity coefficient (*VI*%) and fullness index (*FI*%) \pm standard deviation of the prey items consumed by six species caught in the Bay of Medulin (TL = size range as the total length in cm; *n* = number of analysed specimens; n.d—not determined; MouthW = average mouth width (cm); MouthH = average mouth height (cm); NoBraRig = mode of the number of rakers on the right gill arch).



Figure 2. *IRI* prey importance for five fish species *Coryphaena hippurus*, *Lichia amia*, *Pomatomus saltatrix*, *Seriola dumerili*, *Sphyraena sphyraena* and *Trachinotus ovatus* caught in the Bay of Medulin.

Eigenvectors (λ) of the CCA explained over 79% of the cumulative fitted variability on the first four axis (λ 1 = 0.4859, 40.93%; λ 2 = 0.1979, 67.60%; λ 3 = 0.1615, 71.21%; λ 4 = 0.1025, 79.84%). CCA analysis suggests that important food items of *L. amia* were garfish, *Belone belone* (Linnaeus, 1760), and different species of *Atherina*, a pelagic prey consumed at Kazela sampling station. At Školjić and Dražice sampling stations, *S. dumerili* consumed benthopelagic organisms, such as cephalopods, Mysidaceae crustaceans, common pandora, *Pagellus erythrinus* (Linnaeus, 1758), and demersal species represented by *Mullus* species. In the diet of *S. sphyraena*, the most important prey was represented by pelagic genus *Trachurus* from the family Carangidae. The number of gill rakers for *S. dumerili*, and mouth height and width for *S. dumerili* and *L. amia*, represent an important meristic trait in prey selectivity. Specimens < 30 cm in TL were related to Dražice sampling station, *S. sphyraena* feeding habits and *Atherina* sp. as prey items (Figure 3). Analysis of diet overlap based on *IRI* and W% proposed by Schoener, suggest no diet overlap between analysed species caught in Bay of Medulin (Table 2).

Species	Coryphaena hippurus	Lichia amia	Pomatomus saltatrix	Seriola dumerili	Sphyraena sphyraena	Trachinotus ovatus
Coryphaena hippurus	-	0.00	0.00	0.08	0.00	0.00
Lichia amia	0.00	-	0.20	0.52	<u>0.26</u>	<u>0.12</u>
Pomatomus saltatrix	0.00	0.19	-	0.27	<u>0.39</u>	<u>0.11</u>
Seriola dumerili	0.13	0.36	0.21	-	0.40	<u>0.11</u>
Sphyraena sphyraena	0.00	0.19	0.11	0.28	-	<u>0.11</u>
Trachinotus ovatus	0.00	0.13	0.01	0.01	0.01	-

Table 2. Schoener index results based on *IRI* (underlined values) and mass frequency *IRI* (bold values) of feeding overlap of six thermophilic species caught in Bay of Medulin during 2017, 2018 and 2019.



Figure 3. Canonical Correspondence Analysis (CCA) ordination diagram representing the mass percentage of main prey items consumed by three fish species (*Lichia amia, Seriola dumerili, Sphyraena sphyraena*) caught at each sampling site (Dražice, Kažela, Školjić) in the Bay of Medulin; Monte Carlo permutation test results on all axes: Pseudo-F = 2.0, p = 0.002 (\rightarrow explanatory variables, \blacktriangle -specimen size class, Δ -prey item). See Table 1 and Appendix A Table A1 for abbreviations.

4. Discussion

The catch by gillnets for the purpose of this research suggest that adults of *P. saltatrix* and *S. sphyraena* inhabit the Bay of Medulin from June until February. Other species, *C. crysos, C. hippurus, L. amia, S. dumerili* and *T. ovatus,* were detected only from August until December.

The most numerous species with sub-tropical affinity caught in the Bay of Medulin was *S. dumerili*, whose diet was characterised by a large variety of prey items. The most important prey were benthopelagic cephalopods, crustaceans Mysidaceae, *P. erythrinus* and pelagic species of the genus *Mullus*. Indeed, its diet is dominated by smaller pelagic fish, which usually form schools (*Trachurus, Sardina, Engraulis*), bentho-pelagic fishes

(Merlucius, Boops, Atherina) and benthic fish species (Gobius, Syngnathus, Hippocampus) [39]. Crayfish, bivalve molluscs and cephalopods were less common in its diet in other parts of the Mediterranean [30,32,40,41]. Prevalence of benthopelagic taxa (Sparidae, Atherina sp., Mullus sp.), detected by this research, may indicate opportunistic behaviour, i.e., targeted predation of species associated with seagrass habitats, typical for this area [42]. Apart from the genus Atherina, a significant component of the S. dumerili diet was red mullet, Mullus barbatus, Linnaeus, 1758, which spawns in the Adriatic from April to July [43], and whose recruits are available at the time when S. dumerili appears in the Bay of Medulin. In addition, the research has been conducted in shallow water (up to a maximum of 12 m), which may allow cruise-chase predators to actively search the entire water column and select potentially available prey, especially in circumstances of high visibility. Furthermore, isopod crustaceans have been identified in the digestive tracts of *S. dumerili*, *S. sphyraena* and L. amia in this research. However, it seems that isopod crustaceans represent accidentally acquired prey. All three species consumed fishes from genus Atherina. The presence of isopods in their digestive system could be related to the infection of A. boyeri by the parasitic Isopoda, Mothocya epimerica Costa, 1851 in the Adriatic Sea [44].

Lichia amia is a top predator in shallow coastal areas. The diet of specimens from the Atlantic Ocean consists of pelagic and benthic prey, which usually form schools (*Trachurus, Engraulis, Scomber, Argyrosomus, Umbrina, Pomadasys, Pagellus, Mugil, Atherina* and *Cheimerius*) [45,46]. Similarly, in the Bay of Medulin, specimens of *L. amia* smaller than 30 cm in TL consumed *Atherina* sp. and bogue *Boops boops* (Linnaeus, 1758). Specimens larger than 30 cm in TL, beside *Atherina* sp. and saddled seabream *Oblada melanura* (Linnaeus, 1758), consumed epipelagic garfish *Belone belone* (Linnaeus, 1760), solitary predator which could be found mainly in offshore areas hunting crustaceans, and also schooling fishes [47]. Therefore, *L. amia* could compete for diet with *B. belone* and may affect its abundance in coastal areas of eastern Adriatic.

According to the literature [31,48], the European anchovy, Engraulis encrasicolus (Linnaeus, 1758), S. pilchardus, round sardinella, Sardinella aurita Valenciennes, 1847, B. boops and picarel Spicara smaris (Linnaeus, 1758) have been reported as the main diet of S. sphyraena, while crustaceans were represented by deep-water pink shrimp Parapenaeus longirostris (Lucas, 1846). Our results demonstrate that the primary prey for S. sphyraena was represented by Trachurus sp. and Atherina sp. In the north Adriatic, T. mediterraneus is the most common species of *Trachurus*. With spawning occurring during the spring and early summer [49,50], juveniles occur near the shore in late summer and early autumn [51], often in association with meroplanktonic scyphozoan jellyfishes, such as Cotylorhiza tuberculata (Macri, 1778), [52,53], or Rhizostoma pulmo (Macri, 1778), recently reported as abundant in the northern Adriatic [54]. Sphyraena sphyraena consumes small pelagic fish preys, that are in great abundance, and Atherina sp. was one of the most important prey for specimen sizes < 30 cm [55], which overlaps with results presented in this paper. Two species of atherinids are abundant in the Adriatic: Big-scale sand smelt, Atherina boyeri Risso, 1810, and Mediterranean sand smelt, Atherina hepstetus Linnaeus, 1758. Both fish species are gregarious, with the affinity to inhabit lagoons and estuaries. Atherina boyeri numerically dominate along the eastern Adriatic coast [56,57], and large shallow bays and coastal lagoons, such as Medulin Bay, providing favourable habitat conditions and making them available to incoming predators. Similarly, L. amia also consumed Atherina sp., which represents a prey of great abundance in the Bay of Medulin. However, our results suggesting that S. sphyraena prefers A. boyeri, while L. amia preferably consumes A. hepstetus, with no diet overlap existing between them. Nevertheless, such different prey consumption suggests that these species compete with some commercially important ones, such as European seabass, Dicentrarchus labrax (Linnaeus, 1758) or common dentex, Dentex dentex (Linnaeus, 1758) [58,59]. The natural diet of larger specimens (\approx 30 cm in TL) of *D. labrax* consists mainly of A. boyeri and mugilids (Mugilidae) fry and juveniles [58], which seems overlapping with the feeding habits of S. sphyraena and L. amia, as well as S. dumerili. Similarly, the main food of D. dentex is represented by Trachurus sp. and S. pilchardus following

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by *Penaeus kerathurus* (Forskål, 1775), *S. officinalis, L. vulgaris* and Mediterranean tapeweed *Posidonia oceanica* (Linnaeus) Delile, 1813 [59]. The main food items of *D. dentex* coincides with the main food items found in the diet of *S. sphyraena* and *L. amia*, as well as *S. dumerili* from the Medulin Bay.

The first record of *C. crysos* in the Bay of Medulin confirms two previous findings of this species in the northeast Adriatic, suggesting that global warming may play an important role in its extended migration routes and the possibility of its establishment in the near future [22,60]. In addition to climate change, other factors, such as anthropogenic activities, have facilitated the northward movement of this species [61]. According to the comparison with the published data [22,24,60,62,63], it is the largest reported specimen found in the Adriatic Sea, and it is among the largest recorded individuals of this species in the Mediterranean. Only one adult *C. crysos* was captured, its stomach content consisting only of remains of fish (Pisces). To some extent, this coincides with previously published data that this species is opportunistically predatory, consuming mainly pelagic fishes in combination with crustaceans, molluscs and cephalopods in lower proportion [47,64].

Occurrences of *C. hippurus* in the northern Adriatic could be explained by the presence of floating marine anthropogenic debris in large densities along the Adriatic coast [65,66], caused by the natural movement of the Gulf Stream from the Strait of Otranto along the eastern Adriatic, and back along the Italian coast [67]. Coryphaena hippurus has been observed in the vicinity of floating objects, and such phenomena could contribute to its spreading to the northern Adriatic, to habitats rich in prey [68]. This species is epipelagic, and also opportunistically predatory, feeding on almost all forms of fish and zooplankton, as well as crustaceans and squids [69]. Results of this research reveal S. pilchardus as primary, and L. vulgaris as complementary prey for C. hippurus found in the Bay of Medulin. This suggests that *C. hippurus* is likely a threat to native *D. dentex*, given that its primary prey represents S. pilchardus following by L. vulgaris [59]. Moreover, C. hippurus feeding habits may overlap with Atlantic bonito, Sarda sarda (Bloch, 1793), another common native species in Medulin Bay, whose primary prey are S. aurita, S. pilchardus and the E. encrasicolus [70]. Specimens of *C. hippurus* were found in the shallow part of the Bay of Medulin, which may indicate its migration to shallow water in search of prey. Indeed, C. hippurus was recorded in mid-October when L. vulgaris migrates to shallow water [71], and S. pilchardus prepares for spawning in productive bays along the Adriatic coast [72].

In contrast to *C. hippurus*, the diet of *T. ovatus* consists of pelagic crustaceans and fishes, with the important contribution of molluscs, occasionally cnidarians, benthic foraminiferans and annelids, with a small fraction of insects, without any dominant prey, which characterises generalist feeders [33,73]. In the Bay of Medulin, *T. ovatus* consumed similar food items with the highest relative proportion of pelagic crustaceans from the order Mysidaceae. For the Adriatic Sea, *T. ovatus* was recorded as a vagrant, but in the late 1990s, for the first time, its fingerlings were found in southeast regions [74], and thereafter this species formed self-sustaining populations [73]. It seems to be migrating northwards, probably due to increased salinity and water temperatures [67,75].

Only eight specimens of *P. saltatrix* were recorded in this study, caught only in gillnets, although this species is more abundant in the area [28], as in other parts of the Mediterranean and Adriatic [76–78]. Due to the low number of specimens caught in the Bay of Medulin, and because food was partly digested, it was not possible to identify to the species level the food items found in the stomach. It was possible to conclude that the diet consisted mostly of undetermined Sparidae species and other fish, and of cephalopods in a lower amount. This species is difficult to capture in regular nets because it is known to destroy the gear and result in fish escapes through torn pens [79,80]. *Pomatomus saltatrix* is an agressive predatory fish, which feeds predominantly on pelagic species of Atherinidae and Engraulidae [29], *S. aurita*, Mediterranean horse mackerel, *Trachurus mediterraneus* (Steindachner, 1868) and demersal species, such as comber *Serranus cabrilla* (Linnaeus, 1758) and surmulet *Mullus surmuletus*, Linnaeus, 1758 [80] in the Mediterranean Sea. [81]

suggested that their far northern feeding migrations are interconnected with shoals of *Mullus* sp., which are the main fish group in many coves around the Istrian peninsula.

Although all investigated species are widening their distribution range, our results suggest no existence of diet overlap between them. However, it seems that their feeding strategies may affect local indigenous species, particularly those of commercial value, such as *D. labrax* or *D. dentex* [82]. The investigation was done on a limited number of caught specimens, probably because most of the described species are still establishing their populations in the newly extended area. Moreover, juveniles were underrepresented, hence it was not possible to perform a detailed analysis of size-dependent feeding habits and ontogenetic dietary shift.

Fish diversity estimates of the Mediterranean and the Adriatic have been changed, new species are described or reclassified, and depletion of indigenous top predators in the basin has been noted [1]. The northern Adriatic is facing an increase in seawater temperature and major changes in mechanisms and trophic structures that have facilitated the spread of thermophilic species [67]. However, by expanding the range of thermophilic ichthyofauna and species with sub-tropical affinity to the northern Adriatic, as in the case of the Bay of Medulin where these species are still not sufficiently valued by the marketplace, the potential for the seasonal trophic exploitation of new sources could be recognised [83], particularly due to the depletion of local commercially important targeted species [84]. Finally, from this research, we can conclude that the occurrence of thermophilic fish species and species with sub-tropical affinity has become commonplace during the warmer months of the year in the northern Adriatic, with the possibility that they have found their own trophic niche in the area. However, the impact of this occurrence on the entire community remains unknown, and future research should be focused on this issue.

Author Contributions: All authors contributed extensively to the work presented in this paper. A.G. and M.P. designed the study. N.I., M.G., A.G. and T.T. collected the data. N.I., I.Š., T.R. and K.K. analysed and interpreted the results. N.I. and M.P. prepared the manuscript. A.G., J.J.-D. and T.T. finalised the article. All authors have read and agreed to the published version of the manuscript.

Funding: The authors did not receive support from any organisation for the submitted work.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available because no valid data repositories exist.

Acknowledgments: We would like to thank the anonymous reviewers for their constructive comments that greatly improved the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. List of the seven sampled fish species, their scientific and common names, abbreviations, sampling sites, the total number of specimens caught in each sampling month (n), minimal (min) and maximal (max) total length and weight, and type of net used from 2017–2019 from the Medulin bay, Istria (G = gillnet; S = coastal purse seine net).

		uo			Sampling Site															
Scientific Name and Authority	Common Name	riati		Sampling		Dražice					Školjić						Kažela			
		brev	Year	Month	Type	11	TL (cm)		W (g)		и	TL (cm)		W (g)		n	TL (cm)		W	(g)
		Ab			or Net		Min	Max	Min	Max	'n	Min	Max	Min	Max		Min	Max	Min	Max
Seriola dumerili (Risso, 1810)				9	G	2	26.0	27.2	213.7	238.1										
		SeriDumr	2017	10	G	7	22.9	35.1	129.6	539.0	15	29.5	36.7	319.9	626.3					
				11	G	2	28.7	31.8	285.8	402.0	3	33.1	36.4	331.9	661.4					
				9	G	7	19.7	32.7	94.1	392.2										
	Greater		2018	10	G	2	27.9	32.1	314.4	377.7	7	29.9	34.7	298.9	568.8	7	34.7	41.0	458.2	774.0
	anderjack			11	G						5	32.4	40.6	352.5	836.8					
			2019	8	S	9	19.5	23.2	70.1	152.4										
				9	G, S	5	24.3	29.4	168.1	319.3	24	19.3	31.3	99.6	348.2					
				10	G	4	31.7	35.8	352.1	538.4	18	26.1	39.9	194.9	662.1	30	30.1	38.3	322.3	651.3
			2017	6	G	1	1 34.1 350.0		0.0											
	Bluefish			10	G															
				11	G											3	31.8	35.1	332.0	388.0
Pomatomus saltatrix (Linnaeus, 1766)				12	G	1	1 39.6		499.9											
				11	G				1	41.6 662.0		2.0								
			2019	1	G	1	30.5 220.0													
				10	G											1	39	9.3	49	0.4
Sphyraena sphyraena (Linnaeus, 1758)	Mediterranean barracuda	SphrSphr	2018	2	G						1	38	3.6	21	3.3					
				6	G	2	35.7	35.9	190.9	194.3										
				11	G	8	31.5	38.3	142.6	236.7										
			2010	8	G, S	21	13.4	35.3	8.3	150.4										
			2019	9	G	1	35	5.6	16	2.2										

Scientific Name and Authority	Common Name	uo		Sampling Site																
		∕iati		Sampling				Dražic	e			Školjić						Kaže	ela	
		brev	Year	Month	Type of Not	n	TL (cm)		W (g)		n	TL (cm)		W (g)		n	TL (cm)		W (g)	
		Ab			01 Ivet		Min	Max	Min	Max		Min	Max	Min	Max		Min	Max	Min	Max
Lichia amia (Linnaeus, 1758)	Leerfish		2017	10	G						2	27.9	34.9	253.8	359.8	2	31.6	36.1	213.1	447.0
			2018	10	G											9	35.2	44.9	432.4	830.0
		Amia		11	G											4	37.8	41.3	476.6	672.5
				12	G											1	66	5.8	285	50.3
		Lich		8	S	2	24.0	26.9	124.5	174.0										
			2019	9	S						1	21	1.3	28.0						
				10	G											1	34	4.2	33	8.0
Coryphaena hippurus Linnaeus, 1758	Common dolphinfish	ı.	2017	10	G											6	41.7	44.6	392.2	512.2
Caranx crysos (Mitchill, 1815)	Blue runner	1	2018	11	G	1	32	7.5	62	8.0										
Trachinotus ovatus (Linnaeus, 1758)	Pompano	ı	2019	8	S	2	7.8	8.4	4.0	5.5										
			2018	11	G											1	31	1.6	30	8.8

Table A1. Cont.

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