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Article

Trophic Ecology of Slender Snipe Eel *Nemichthys scolopaceus* Richardson, 1848 (Anguilliformes: Nemichthyidae) in the Central Mediterranean Sea

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Abstract: The slender snipe eel *Nemichthys scolopaceus* Richardson, 1848 is cosmopolitan in tropical and temperate seas, inhabiting the mesopelagic and bathypelagic zone between 200 and 1000 m depth. It is known to be an active predator in DSL (Deep Scattering Layer) and NBA (Near Bottom Assemblage), feeding mostly decapods and euphausiids crustaceans, and playing a central role in carbon fluxes through meso and bathypelagic ecosystems. Despite its potential importance in deep trophic web ecosystem, *Nemichthys scolopaceus* has been little investigated about its trophic ecology. The aim of this paper is start to fill this knowledge gap. A total of 35 specimens of *N. scolopaceus* caught through bottom trawling in Mediterranean Sea were analyzed in laboratory for stomach content. As expected, mainly decapod crustaceans were found, in particular *Plesionika martia*, *Pasiphaea multidentata*, *Funchalia woodwardi*, *Robustosergia robusta* species. The degree of digestion observed was in all cases rather high. Our findings seem to confirm the specialist diet of *Nemichthys scolopaceus* based on shrimp-like crustaceans.

Keywords: deep-water species; feeding habits; morphological prey counts; pelagic eel; *Nemichthys scolopaceus*

1. Introduction

The slender snipe eel *Nemichthys scolopaceus* Richardson, 1848 is a cosmopolitan Anguilliformes, reported in the Atlantic, Indian, and Pacific Oceans and in the Mediterranean Sea [1]. *N. scolopaceus* is known to inhabit the mesopelagic and bathypelagic depth strata [2,3], mainly between 200 and 1000 m [4]. Differently from the other Nemichthyidae species, which don't seem to be strong vertical migrants, *N. scolopaceus*, conversely, seems to carry out wide vertical displacements along the water column to capture prey [5,6]. According to Gartner et al. [7], *N. scolopaceus* was frequently observed in both the DSL (Deep Scattering Layer) and NBA (Near Bottom Aggregation) layers, over the North Carolina and Virginia continental slopes, in the western North Atlantic Ocean.

This species shows marked sexual and ontogenetic dimorphism. At the juvenile stage, all individuals have non-occlusible, beak-like jaws armed with very small villiform teeth. As soon as

reaching sexual maturity, males are subjected to jaws radically shortening and complete loss of teeth [8] while females keep a morphology similar to juveniles. These deep changes in the physical features of male specimens are likely due to semelparity, a biological phenomenon in which reproduction is rapidly followed by death [9]. Moreover, the male *N. scolopaceus* will not be able to catch their preys, concentrating their energy on reproduction to the detriment of their life [8]. Adult males were found rarely in the Mediterranean Sea [10].

Nemichthyid eels may have several predation strategies, including ambushing prey that passes near them while they maintain a vertical body position [11], or actively chasing [7,12]. In the Gulf of Maine (North-Atlantic) *N. scolopaceus* fed exclusively on crustaceans, mostly decapods, and euphausiids, avoiding potential prey that were very abundant in that habitat ('oceanic rim' ecosystem, [13], such as fishes, cephalopods, and other crustaceans (e.g. amphipods, crabs, copepods). This prey selectivity, linked to the high biomass of decapod crustaceans and large euphausiids in this oceanic zone and their ecological importance, and the fact that *N. scolopaceus* is one of the few mesopelagic fish predators of shrimps and euphausiids in the area, underlined the central role in carbon fluxes through meso and bathypelagic ecosystems [6].

On the other hand, the metabarcoding analysis of gut contents carried out by Bucklin et al. [14] highlighted that the slender snipe eel *N. scolopaceus*, though foraged mostly on large crustaceans, occasionally preyed smaller zooplankton (e.g. copepods), pelagic mollusks, and fish.

The aims of this study were to expand the knowledge about *Nemichthys scolopaceus*, fill the gap of information about its trophic ecology, especially in the Mediterranean Sea, and compare our findings with other studies carried out in other zones of the global ocean. In particular, we tried to understand if also in the Central Mediterranean Sea this Nemichthyidae feed exclusively (or almost exclusively) large shrimp-like crustaceans, as just highlighted [6,14,15].

2. Materials and Methods

2.1. Study Area and Samples Collection

A total of 35 *N. scolopaceus* specimens were collected through bottom trawling (Table 1). 23 of these as bycatch of commercial fishing in the Gulf of Patti (Southern Tyrrhenian Sea, Central Mediterranean) during the summer of the years 2022-23. The remaining 12 specimens were collected during three oceanographic cruises of scientific fishing (NAUCRATES and MEDINEA in 2022, MEDITS in 2024), off the Calabria and Campania coast in the Southern Tyrrhenian Sea, and between Sardinia Island and Tunisian coast in the Sardinia Channel, respectively (Figure 1). A standard bottom trawl is the equipment that is normally used in commercial fishing. The net is made up of two panels with a 40 mm square mesh net. The sampling equipment utilized both in MEDINEA22 and NAUCRATES22 is quite similar to a standard commercial bottom trawl, with the same square mesh size, but has some experimental features like the adding of a metallic grid in the NAUCRATES22 cruise. The sampling gear used during the MEDITS campaign is totally different: it consists of a four-panel bottom trawl (model IFREMER GOC73) capable of operating between 10-800 m deep. The net has a mesh side of 10 mm, which means it has a mesh opening of 20 mm and a selectivity as low as possible. The trawl generally operates with a vertical opening of 2-3 m (although the maximum vertical opening is 7.40 m), and a horizontal opening between 35-40 m. In most cases, *N. scolopaceus* were captured near the seabed, at depths between 18 and 700 m. The specimens were frozen on board at -20°C.

Table 1. Collection of metadata for *Nemichthys scolopaceus* samples from all the cruises.

Campaign	Fishing Area	Local Date	Lat. N	Long. E	Sampling depth (m)	Local time (Start-Finish)	Specimens caught (per time)	Specimen ID number
Commercial fishing	Gulf of Patti (ME)	May-June 2022	38°14.346'	15°7.818'	300-700	-	11	7CB, 13CB, 14CB, 15CB,

								18CB, 21CB, 22CB, 23CB, 24CB, 25CB, 26CB 34CB, 35CB, 36CB, 37CB, 38CB, 39CB, 40CB, 41CB, 42CB, 47CB, 48CB, 49CB
		May-June 2023				12		
NAUCRATES 22	Pa-Ca Canyon	12/10/2022	38°25.91'	10°42.24'	309-305	12:53-17:35	1	28CB
		19/10/2022	38°13.65'	10°37.32'	323-358	22:20-1:47	1	31CB
		14/10/2022	38°15.00'	10°37.32'	370-311	12:30-16:33	2	32CB, 33CB
MEDINEA22	Pa-Ca Canyon	14/10/2022	38°03.60'	10°47.28'	332-349	19:07-23:07	2	29CB, 30CB
MEDITS24	GSA10	21/06/2024	39° 28.24'	15° 44.27'	583-626	07:13-08:13	2	44CB, 45CB
		22/06/2024	39° 13.18'	16° 02.19'	83-86	06:51-07:21	1	50CB
		22/06/2024	39° 06.21'	15° 55.49'	634-619	14:46-15:46	1	46CB
		25/06/2024	38° 10.56'	14° 51.02'	26-18	12:00-12:30	1	51CB
		26/06/2024	38° 07.70'	13° 38.44'	568-529	16:15-17:15	1	43CB

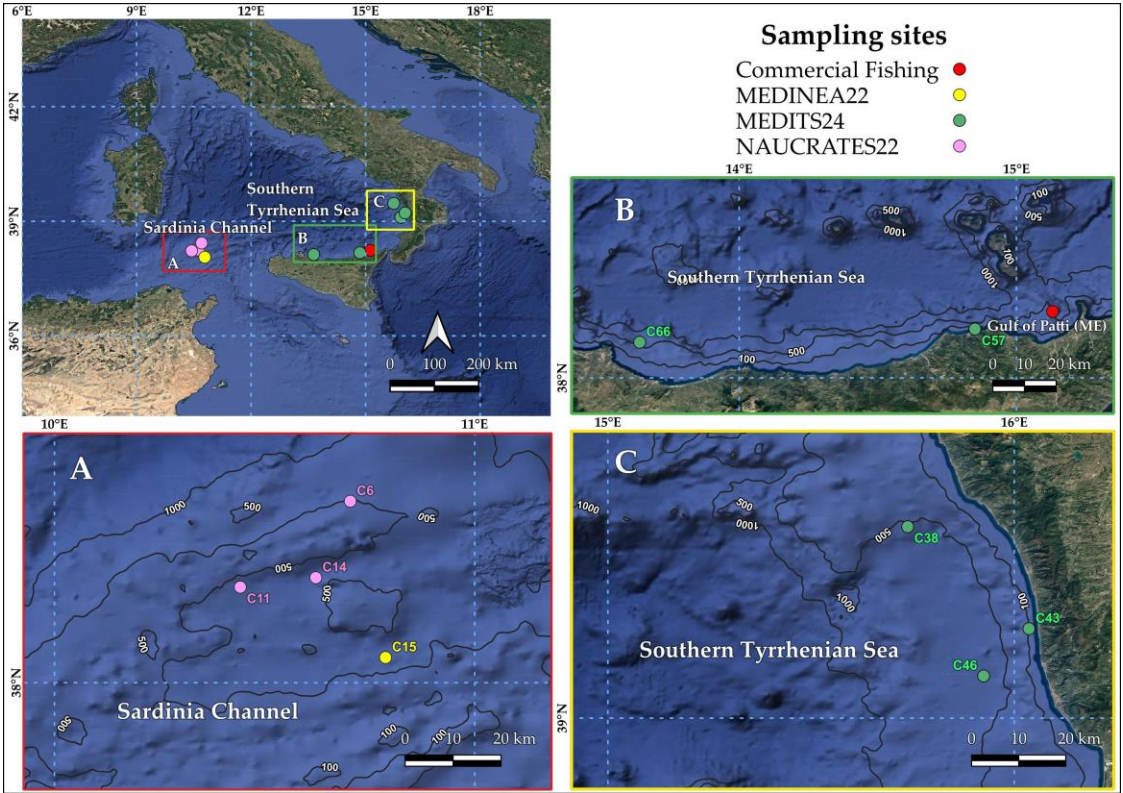


Figure 1. Study area in the Central Mediterranean Sea.

2.2. Laboratory Analysis

In the laboratory, the specimens of *N. scolopaceus* were thawed, and the biomass and morphometric measurements were carried out. The Wet Weight (WW, $\pm 0,01$ g) was taken operating analytical balance (Sartorius-ENTRIS32O2-1S 0,01g) after drying the fish body with blotting paper. Measurements of Total Length (TL to the nearest 0.5 cm) were carried out. Moreover, because the peculiar morphology of this Nemichthyidae, with its long and very thin body, can cause fragmentation of the tail or snout, the distance between the eye and gill cover was measured (EGD: Eye-Gill cover Distance, ± 0.1 mm, Figure 2)

The stomachs were extracted and preserved in ethanol/seawater solution (70/30). Subsequently, the stomachs were dried with blotting paper, weighted (WW) by mean analytical balance (Mettler-Toledo AG204 0.1 mg) and carefully opened operating with scissors and forceps under stereomicroscope (ZEISS STEMI SV 8 and Leica WILD M10) observation.

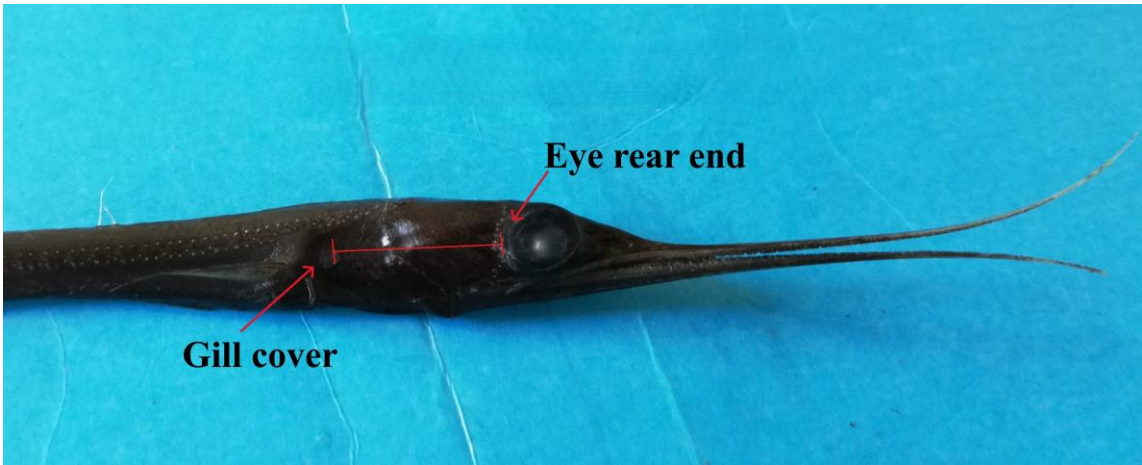


Figure 2. Eye-Gill cover Distance (EGD).

Stomach fullness degree was estimated from 0 to 4, with 0 = empty stomach, 1 =only traces of prey, 2 = stomach filled from partly to half, 3 = stomach full but not stretched, and 4 = a full and stretched stomach. The degree of digestion of prey items was evaluated according to the following scale: 1 = no evident signs of digestion, prey whole and complete; 2 = prey partly digested with missing portions; 3 = prey from enough to strongly digested, only pieces remaining; and 4 = almost totally digested, only traces remaining [6]. Prey identification was carried out to species if possible, or to the lowest feasible taxonomic level, by the following taxonomic manuals: [16] for decapods crustaceans; [17] for fish otoliths and [18,19] for fish scales). Prey items were preserved in ethanol/seawater solution (70/30). After prey extraction, the stomach tissues were weighted to obtain the stomach content's weight (subtracting this weight from full stomach weight). Subsequently, the biomass of preys was calculated according to [20–25].

2.3. Trophic Indexes

Trophic indexes were calculated for individuals with stomachs containing food, with the aim to evaluate the dietary composition of *N. scolopaceus*. First of all, Percentage of Vacuity: $\%vacuity = \frac{nes}{nt}$, where nes is the number of empty stomachs, while nt is the total number of stomachs. The degree of stomach fullness was estimated by the index %SCI (Stomach Content Index) as follows: $\%SCI_x = \frac{\sum_n^1 w}{TW - (\sum_n^1 w)} \times 100$, where the numerator reports the sum of the weights of the prey found in the stomach of the predator *x*, and the denominator reports the value resulting from the difference between the weight of the predator and that of the prey ingested by it. The average value of %SCI was subsequently calculated.

The importance of each prey i was assessed by calculating the following food indices. Percentage in number: $\%Ni = \frac{ni}{nt} \times 100$, where ni is the total number of individuals of prey i found in the stomachs, while nt is the total number of prey; Weight percentage: $\%Wi = \frac{wi}{wt} \times 100$, where wi is the total weight of individuals of prey i found in the stomachs, while wt is the total weight of all prey; Percentage frequency: $\%Fi = \frac{nsi}{ns} \times 100$, where nsi is the number of stomachs containing prey i , while ns is the total number of stomachs containing prey. The Relative Importance Index [26–28] was also estimated for each prey i , which takes into account and integrates the values of the previous food indices ($\%N$, $\%W$, $\%F$): $IRIi = \frac{(\%Ni + \%Wi) \times \%Fi}{\sum IRI}$. The percentage contribution of the Relative Importance Index for each prey i ($\%IRIi$) was then estimated for each prey i ($\%IRIi$) on the total prey: $\%IRIi = \frac{IRIi}{\sum IRI} \times 100$.

The feeding strategy of *N. scolopaceus* was evaluated by applying the graphic method of [29], modified by [30], which plots on a two-dimensional graph the specific abundance of each prey category with respect to the frequency of finding of the prey itself in the stomach contents. This method allows us to deduce information on the importance of the prey and the feeding strategy used by the predator. In this graphical representation, the specific abundance of each prey i (Pi) is calculated as follows: $Pi = \frac{\sum Si}{\sum Sti} \times 100$, where Si is the total abundance (as weight or number) of prey i ; Sti is the total stomach content only of the samples in whose stomachs prey i is present.

The trophic level (TROPH; [31]) of *N. scolopaceus* was estimated by mean the weight participation and the trophic level of each prey species to the diet: $TROPH = 1 + \sum DCj \times TROPHj$ where $TROPHj$ is the fractional trophic level of prey j and DCj represents the fraction of j in the diet of *N. scolopaceus*. The TROPH can range from 2.0, for herbivorous/detritivorous, to 5.0, for piscivorous/carnivorous organisms [32–34]. Trophic level values of each prey item were evaluated according to [33].

3. Results

3.1. Trophic Ecology

The 35 *N.s scolopaceus* specimens examined for stomach contents ranged from 500 to 1325 mm Total Length (TL), having a mean value of 807.97 mm (Standard deviation: ± 189.95 mm). The individuals were assigned, according their TL, to size classes of 100 mm: from 500 to 590 mm TL (6 specimens), from 610 to 690 mm TL (6 specimens), from 730 to 785 mm TL (5 specimens), from 815 to 890 mm TL (6 specimens), from 900 to 995 mm TL (6 specimens), and from 1000 to 1088 mm TL (5 specimens) with only one specimen that measured 1325 mm (Figure 3).

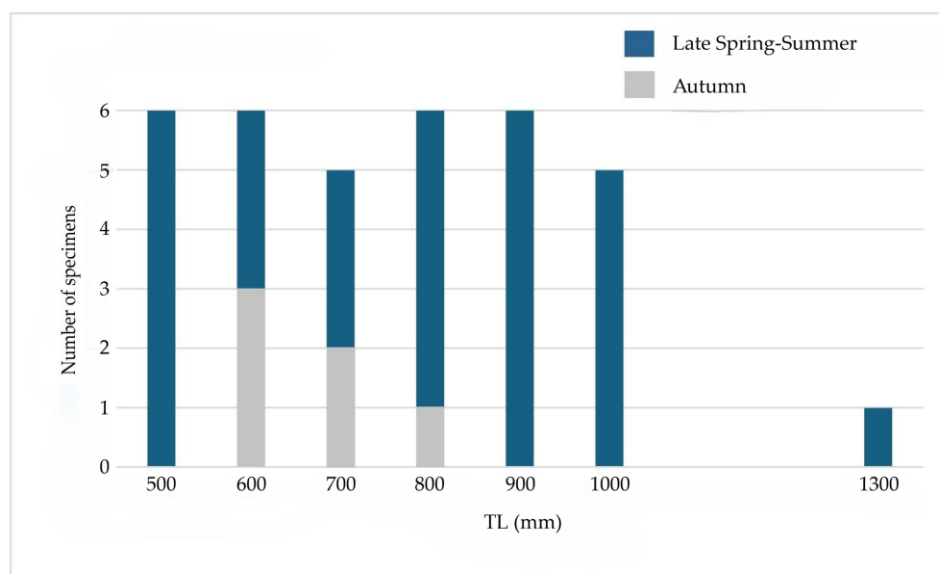


Figure 3. Size classes and seasons of *Nemichthys scolopaceus* sampled in the study area.

The Wet Weight resulted from 2.94 to 76 g (Mean WW: 31.29 g; standard deviation ± 23.23 g), while the Eye-Gill cover Distance varied from 5.8 to 25.5 mm (Mean EGD: 16.5 mm; standard deviation ± 5.45 mm, Figure 4). Between individuals here investigated, no adult males were present, given the presence of beaks, that are absent in males after metamorphosis.

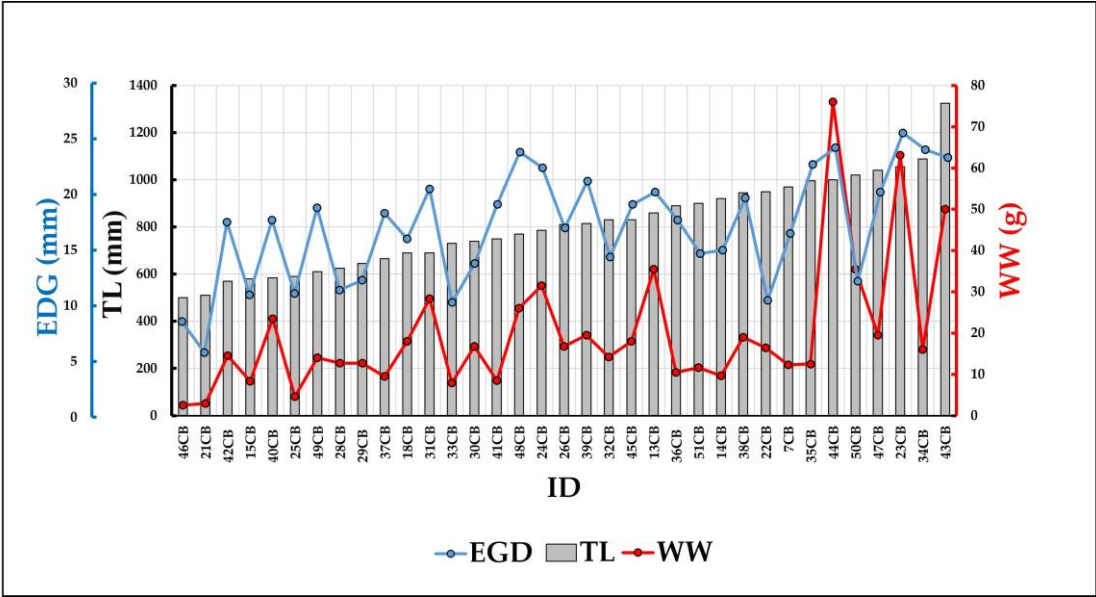


Figure 4. Relationship between TL (Total Length), EGD (Eye Gill cover Distance) and WW (Wet Weight) of *N. scolopaceus* examined specimens.

Of the 35 stomachs analyzed, 4 were empty, while 31 contained prey items (% vacuity= 11.43%). The Stomach Content Index (SCI) ranged from 0.0028% to 14.5629%, with a mean value of 1.65%. A total of 34 preys were found in stomachs of *N. scolopaceus* (Figure 5), with a mean number of 1.097 prey per specimen. The list of food items of *N. scolopaceus* is reported in Table 2, together with the values of dietary indexes (%N, %W, %F, %IRI) for each prey. Among the 31 stomachs containing food items, 12 contained only unidentifiable traces because of the high degree of digestion. In the remaining ones, we observed mainly decapod crustaceans, in particular: *Plesionika martia* (A. Milne-Edwards, 1883), *Pasiphaea multidentata* (Esmark, 1866), *Funchalia woodwardi* (Johnson, 1868), *Robustosergia robusta* (Smith, 1882), the genera *Funchalia* and *Plesionika*, and unidentified crustaceans. Moreover, we found traces of Teleostei: one otolith of *Stomias boa* (Risso, 1810), and scales of Macrouridae. Some sand was found in one stomach.

The degree of digestion observed was in all cases rather high (2-4; preys partially, highly, or almost completely digested). We did not find any prey whole and complete. Unidentified preys resulted the most numerically abundant (%N=35.29) and frequently found (%F=38.71) in stomachs of *N. scolopaceus* in the present study, followed by unidentified crustaceans (%N= 17.76; %F=19.35) and decapods (%N=14.71; %F=12.90). On the biomass level, has been confirmed the prevalence of unidentified preys (%W=35.52%), unidentified crustaceans (%W=15.81%), and decapods (%W=13.18%), but was possible starting to notice the importance of Teleostei Macrouridae (%W=11.05%), *Plesionika martia* (%W=9.31%), and *Plesionika* sp. (%W= 8.33%). Calculation of %IRI further highlighted the relevance of Teleostei Macrouridae (%IRI= 18.66%), *Plesionika* sp. (%IRI=15.19%), and *Plesionika martia* (%IRI= 10.46%), with standing out of *Pasiphaea multidentata* (%IRI=10.47%).

The estimated value of the index of trophic level (TROPH) for *N. scolopaceus* is 4.40.

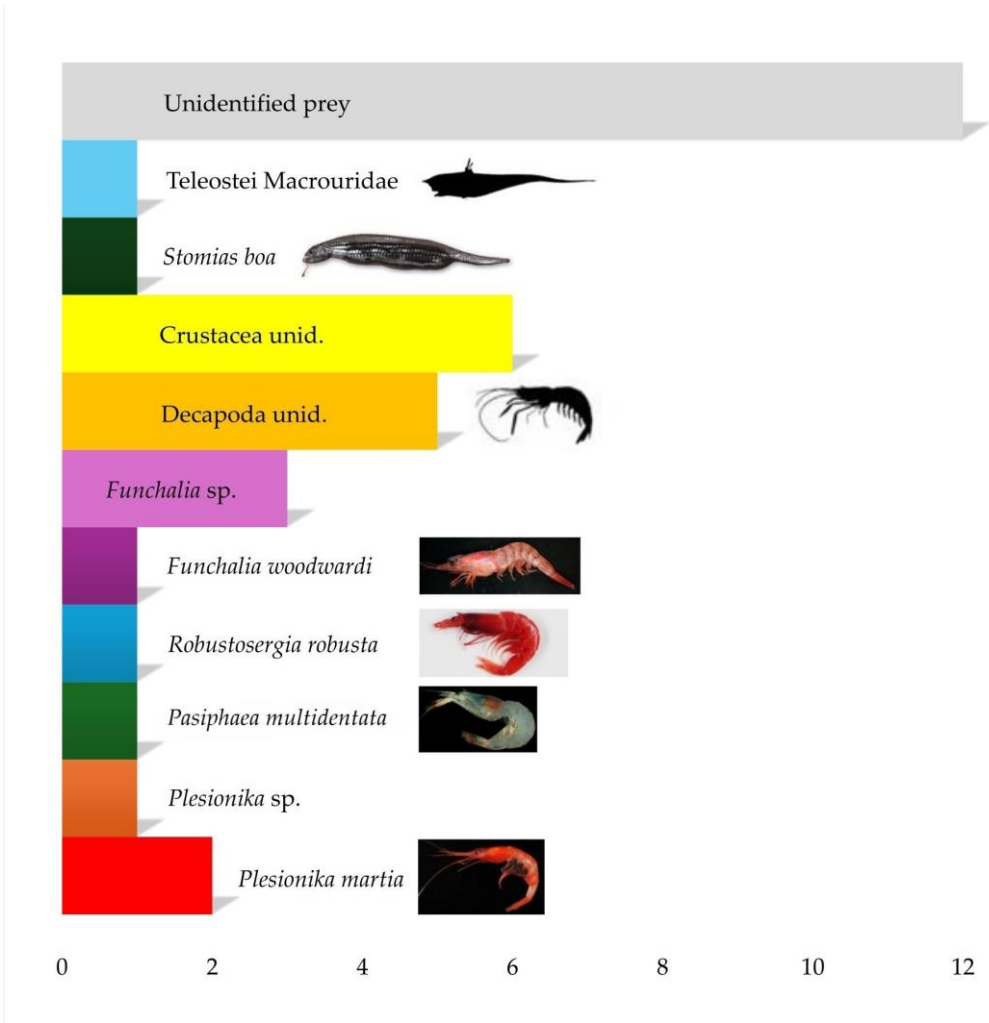


Figure 5. Number of preys found in stomachs of Nemichthys scolopaceus in the study area.

Table 2. Preys of Nemichthys scolopaceus with trophic indexes.

Phylum/ Subphylum/ Class/Order	Family	Species/Taxa	%Ni	%Wi	%Fi	%IRIi
ARTROPODA						
CRUSTACEA						
Malacostraca						
Decapoda	Pandalidae	<i>Plesionika martia</i> (A. Milne-Edwards, 1883)	5.88	9.31	6.45	10.46
		<i>Plesionika</i> sp.	2.94	8.33	3.23	15.19
	Pasiphaeidae	<i>Pasiphea multidentata</i> Esmark, 1866	2.94	4.65	3.23	10.47
		<i>Robustosergia robusta</i> (Smith, 1882)	2.94	0.78	3.33	5.53
	Peneidae	<i>Funchalia woodwardi</i> Johnson, 1868	2.94	0.23	3.33	4.82
		<i>Funchalia</i> sp.	8.82	0.43	9.68	4.70
		Decapoda unid.	14.71	13.18	12.90	8.10
		Crustacea unid.	17.65	15.81	19.35	7.45
CHORDATA						
VERTEBRATA						

Teleostei						
Stomiiformes	Stomiidae	<i>Stomias boa</i> (Risso, 1810)	2.94	0.72	3.33	5.44
Gadiformes	Macrouridae	Macrouridae unid.	2.94	11.05	3.33	18.66
Unidentified			35.29	35.42	40.00	9.17

3.2. Feeding Strategy

The graphic method of Costello [29], modified by Amundsen [30], plots on a two-dimensional graph the specific abundance, for the number (Figure 6a), and for weight (Figure 6b) of each prey category with respect to the frequency of finding the prey itself in the stomach contents, showed that the diet of *N. scolopaceus* was dominated by unidentified preys both in numerical and biomass point of view of biomass, while other prey items if considered at species levels, don't stand out for abundance either weight. Nevertheless, the predominance of crustaceans was highlighted by considering them to the group level, regardless of single species, genera, and family (hence including unidentified crustaceans; Figure 7).

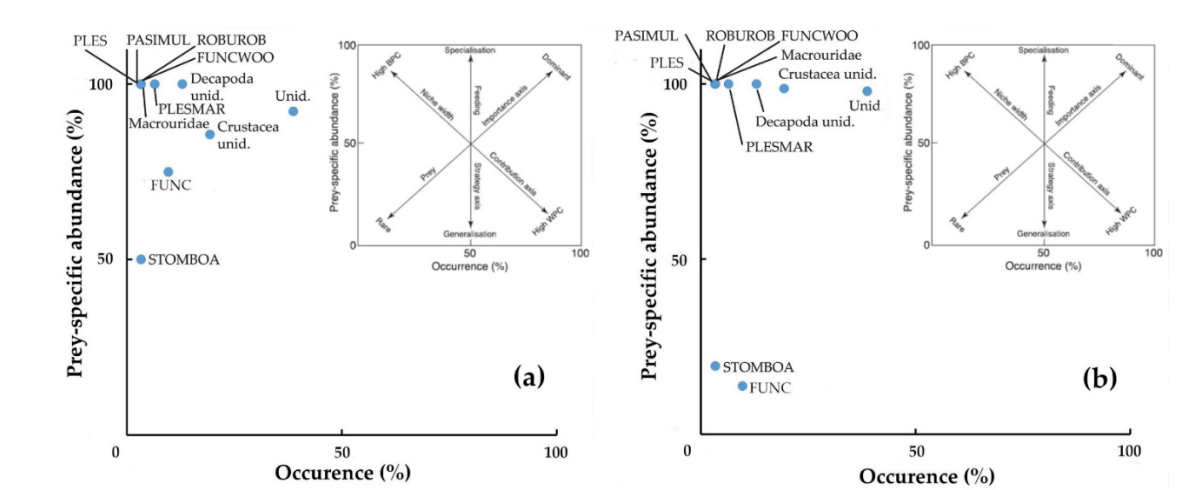


Figure 6. The graphic method of Costello (1990), modified by Amundsen et al. (1996), which plots on a two-dimensional graph the specific abundance, for number (a), and for weight (b) of each prey category with respect to the frequency of finding of the prey itself in the stomach contents. BPC: between-phenotype component; WPC: within-phenotype component. FUNC: *Funchalia* sp., FUNCWOO: *Funchalia woodwardii*, PASIMUL: *Pasiphaea multidentata*, PLES: *Plesionika* sp., PLESMAR: *Plesionika martia*, ROBUROB: *Robustosergia robusta*, STOMBOA: *Stomias boa*.

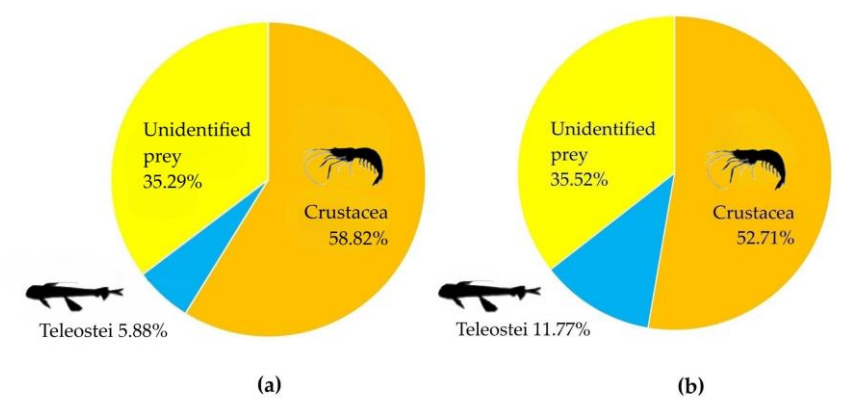


Figure 7. Percentage in number (a), and in weight (b) of preys of *Nemichthys scolopaceus*, considering them to group level, regardless of single species, genera and family.

4. Discussion

The slender snipe eel *Nemichthys scolopaceus* has been poorly studied in general, especially from the trophic point of view. In particular, in the Mediterranean Sea, the food habits of this Nemichthyidae have never been investigated. Only three recent studies focused on the diet of *N. scolopaceus*, all carried out in the NW Atlantic [6,14,15]. The present paper aims to contribute to filling the gap of knowledge about the trophic ecology of *N. scolopaceus*, particularly in our study area. Of the 35 specimens of *N. scolopaceus* examined by us, 31 had stomachs containing preys and 4 were empty, resulting in a vacuity percentage of 11%, decisively lower than that detected by [6] (30%), in turn even less of other mesopelagic predator fishes [12], that proved to be until 60%. This finding could confirm that *N. scolopaceus* has a higher consumption rate with respect to other mesopelagic fish. However, the high percentage of stomachs containing preys might be due to the slow digestion of this Nemichthyidae [6,35,36], which carries food to remain in the stomach for a longer time. In addition, the long digestion time did not permit an evaluation of the feeding chronology in an accurate way [6]. Moreover, the degree of digestion of preys found by us in the stomachs was in all cases rather high (2-4; preys partially, highly, or almost completely digested). We did not find any prey whole and complete. Prey might have been ingested more than 24 hours before fish sampling [6,12,35,36], also because of the relatively big size of preys found in this study, as soon as in previously [6,15].

According to some latest studies [6,15], in the stomachs of *N. scolopaceus* mainly decapod crustaceans are found, as we did in this study. However, we did not detect any traces of euphausiids, which conversely represented a relevant portion of diets of *N. scolopaceus* [6,15]. Nevertheless, given the considerable percentage of unidentified preys because of their high degree of digestion, we did not totally exclude that also in the Mediterranean Sea *N. scolopaceus* feeds on euphausiids, in addition to decapod crustaceans. Further studies will be necessary to investigate this aspect of food habits of this Nemichthyidae in the Mediterranean Sea. Moreover, in the stomach contents of *N. scolopaceus* we found traces of teleosts, as soon as stated by [14]. However, given also that in the studies of [6,15] no traces of fish have been found, and given that we found only one otolith (*Stomias boa*) and three scales (Macrouridae), we could hypothesize secondary ingestion, in other words, the possibility that otolith and scales found by us in the stomachs of *N. scolopaceus* originated in turn by stomach contents of crustaceans eaten by *N. scolopaceus* itself. In support of this hypothesis, it must be said that at least two of preys found by us in eels's stomach contents, the decapods *Pasiphaea multidentata* and *Plesionika martia*, are known to be active predators of small fishes, as well as scavengers [37,38]. Moreover, either in the study of [14] no whole fish specimen was found in the stomach contents of *N. scolopaceus*, but rather the presence of teleosts has been detected by mean DNA metabarcoding [14], which could not exclude the possibility of secondary ingestion. Further reinforcement to this hypothesis is the predation strategy of *N. scolopaceus*. In fact, this eel is highly selective for shrimp-like crustaceans, also in function of its morphology [5,6,15,39]. The thin and elongated jaws of juvenile and adult female individuals of *N. scolopaceus* are covered with innumerable and very little villiform teeth, which can stick to the crustaceans's antennae; this fact, joined to the extension of this latter, helps the mechanism of crustacean entrapment by entanglement of antennae [5,6,15,39]. According to [6,15] this peculiar feeding way, together with non-occlusible jaws, could contribute to making this Nemichthyidae extremely selective for large crustaceans, avoiding other potential prey present in the environment, such as fishes, cephalopods, and other crustaceans (e.g. amphipods, crabs, copepods). Further studies may serve to shed light on this aspect as well, in addition to the apparent absence of euphausiids that we detected.

Prey found by us in the stomach contents of *Nemichthys scolopaceus* are benthic (*Plesionika martia*, Macrouridae) and benthopelagic (*Pasiphaea multidentata*) organisms linked to muddy bottoms between 300 and 700 m of depth [12,16,18,20–23,25,37,38] or mesopelagic (*Robustosergia robusta*, *Funchalia woodwardi*, *Stomias boa*) organisms that can be found near the bottom [7,12,16,21,25] at the same depths. Most specimens of this Anguilliformes investigated in the present study were caught exactly at these depths, near the bottom, where, as just stated, the crustacean and fish species detected

in their stomachs can frequently be found. Therefore, the type of preys found in the present study can only confirm the statement of [7] that, in NW Atlantic, observed *Nemichthys scolopaceus* in the Near Bottom Aggregations. The finding of some sand in the stomach of one specimen of *N. scolopaceus* examined by us was a further sign that this eel fed frequently near the bottom. On the other hand, two specimens (on 35 sampled) of *Nemichthys scolopaceus* investigated in the present paper were caught at low depth during daytime, in one case at 83-86 m few hours after sunrise (around h 7:00), in the other case at the very low depth of 18-26 m, with the sun around noon (h 12-12:30). This fact could confirm that *N. scolopaceus*, despite living habitually between 200 and 1000 m (or deeper) [40], is able to carry out wide displacements along water column to catch preys [5,6].

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