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Biological aspects of the common torpedo, *Torpedo torpedo* (Linnaeus, 1758) (Elasmobranchii: Torpedinidae), in the central Mediterranean Sea (Sicily, Ionian Sea)

F. TIRALONGO[1,2,3]*, G. MESSINA[1], M. V. BRUNDO[1], & B. M. LOMBARDO[1]

[1]*Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università degli Studi di Catania, Catania, Italia,* [2]*Ente Fauna Marina Mediterranea, Avola, Italia, and* [3]*GRIS, Gruppo Ricercatori Italiani sugli Squali, Razze e Chimere, Genova, Italia*

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Abstract
Data on the biology of *Torpedo torpedo* from the Ionian Sea are absent, and in the Mediterranean Sea, most of the published works focus on the reproductive biology of the species and are not recent. Several biological and ecological aspects of *Torpedo torpedo* were investigated between March and May 2019 on the coast of Sicily (Ionian Sea) between Avola and Marzamemi. Morphological (disc width–weight relationships, total length-disc width relationships), population (size-frequency distribution, sex ratio, fecundity), and ecological (habitat, diet) characteristics were studied. Stomach content analysis revealed that *T. torpedo* is a generalist piscivore, feeding on a wide variety of benthic and benthopelagic fish: Levin's index value (B*i*) was 0.82. The analysis of the sex ratio showed a higher proportion of males vs. females. Females were, on average, larger than males. Fecundity showed a positive correlation with body size, with the smallest mature female being 14.9 cm in disc width and 24.8 cm in total length. The ovarian fecundity ranged from 3 to 20 eggs. In the study area, both adults and juveniles of the species were caught in considerable numbers with trammel nets. We also provide data from some specimens of *Torpedo marmorata* caught during the study period.

Keywords: Torpedo marmorata*, elasmobranchs, fecundity, diet, fisheries*

Introduction

Sharks and other elasmobranchs are among the top predators in the marine environment and play an important role in structuring and regulating marine communities (Stevens et al. 2000; Bornatowski et al. 2014). However, due to their low fecundity and late age at maturity (a k-selected life history strategy), elasmobranchs are particularly vulnerable to fishing pressure. Furthermore, they are often affected by high bycatch rates (Ragonese et al. 2003; White et al. 2012). Several studies have shown that over the last few decades, the elasmobranch populations of the Mediterranean Sea have dramatically declined as a result of overfishing (Soldo 2003; Cavanagh & Gibson 2007; Bradai et al. 2012; Giovos et al. 2019).

In Italian seas, electric rays (Torpedinidae) are represented by three species and two genera: *Torpedo* Duméril, 1806 and *Tetronarce* Gill, 1862. The genus *Torpedo* comprises the common species *Torpedo marmorata* Risso, 1810 and *Torpedo torpedo* (Linnaeus, 1758); while, *Tetronarce nobiliana* (Bonaparte, 1835) is a rare species and was only occasionally caught in the Mediterranean (Bakiu & Troplini 2018). These species have low or no commercial value and are usually discarded (Relini et al. 2000; Scacco et al. 2002; Tiralongo et al. 2018b). However, due to their susceptibly to fishery activities, the management, and conservation of these vulnerable species require special attention.

The common torpedo, *T. torpedo*, is an Atlanto-Mediterranean species whose distribution extends from the southern Bay of Biscay and throughout the Mediterranean Sea to Angola (Froese & Pauly 2019). It is listed as "data deficient" in the IUCN Red List (Serena et al. 2009). This species mainly inhabits soft bottoms of coastal waters, down to a depth of about 150 m (Fischer et al. 1987). It is usually caught with trammel nets and trawls and considered as bycatch or

*Correspondence: F. Tiralongo, Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università degli Studi di Catania, Via Androne 81, 95124, Catania, Italia. Tel: 0957306048. Fax: 0957306048. Email: francesco.tiralongo@unict.it

discard (Relini et al. 2000; Scacco et al. 2002; Tiralongo et al. 2018b). The maximum recorded total length (TL) is 60 cm, but common sizes range from 20 to 40 cm total length.

In the Mediterranean Sea, data about the biology and ecology of *T. torpedo* are scarce, not recent and mainly deal with reproductive biology (Consalvo et al. 2007 and references therein). Hence, the aim of this study is to provide additional understanding of the biology and ecology of this species. In particular, we investigated disc width–weight relationships, total length-disc width relationships, size frequency distribution, diet composition, habitat, sex-ratio, and fecundity of *T. torpedo* caught as discard in the cuttlefish, *Sepia officinalis* Linnaeus, 1758, fishery in Sicily (Ionian Sea, central Mediterranean). Additional data are also provided for the less common congeneric species *T. marmorata*.

Materials and methods

A total of 164 specimens of *T. torpedo* were collected from fishermen using trammel nets in the south-east coast of Sicily (Ionian Sea), along the coastline extending for about 21 km from Avola to Marzamemi (Figure 1). In order to better represent the population, specimens were randomly selected from different fishing vessels operating in the area. The specimens were collected between the 20th March and 10th May 2019, at 4–25 m depth, during the fishing season of the cuttlefish, *S. officinalis* (Tiralongo et al. 2018b). Trammel nets were deployed overnight (from 6 pm to 4 am) for about 10 h, on sandy and mixed bottoms (sand and rocks), close to *Posidonia oceanica* seagrass meadows.

Each specimen was weighed and measured (disc width and total length), and the sex determined by the presence or absence of claspers. Weight and disc

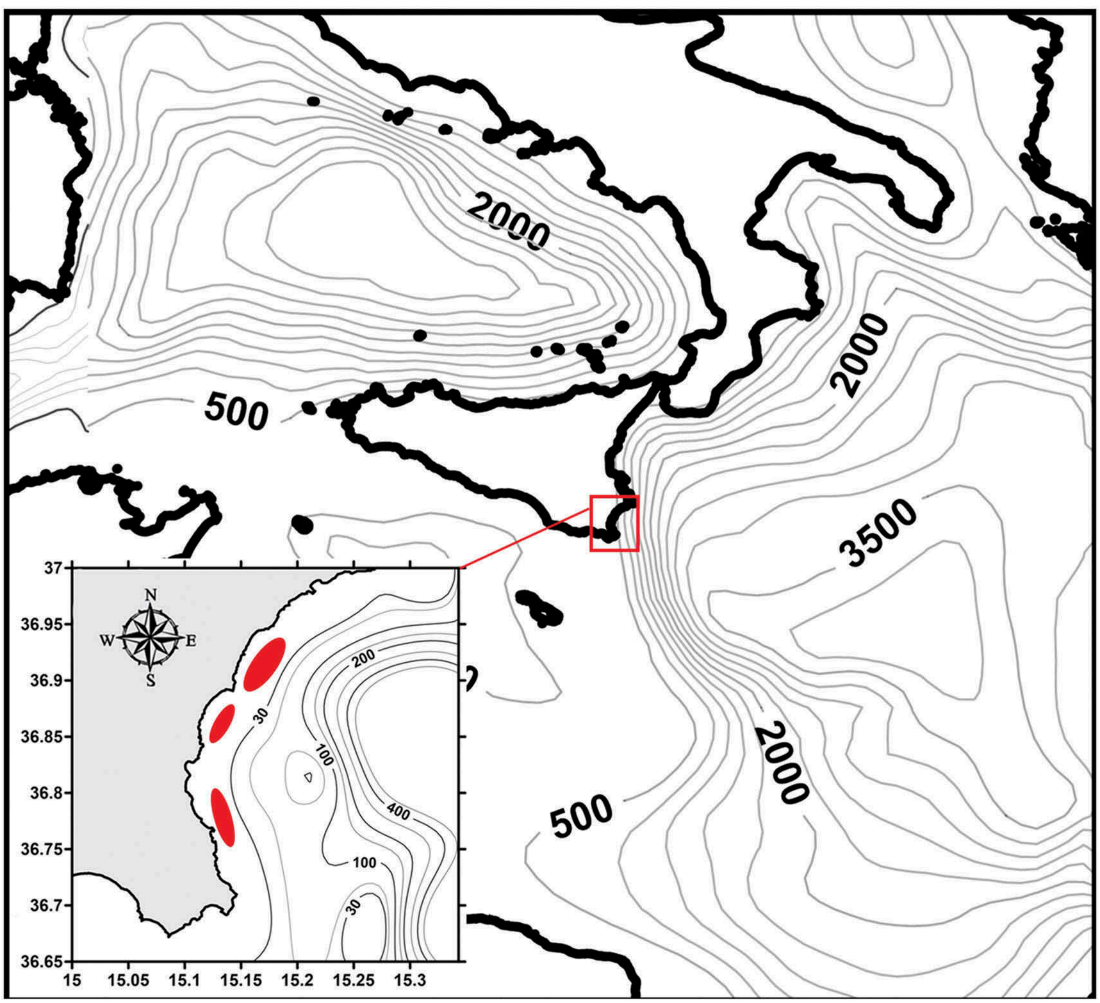

Figure 1. Study area (indicated in red) in the Ionian coast of Sicily (central Mediterranean Sea).

width measures were used for the disc width–weight relationships following the formula: $W = aDW^b$, where W is the weight in grams (g), DW is the disc width in centimeters (cm), a is the intercept and b is the slope of the regression curve. Total length and disc width measures were used for the length–width relationships following the formula: DW = yTL + x, where y is the slope and x is the intercept of the regression line. Disc-width frequency distributions were constructed for both sexes. A chi-square test was used to verify if there was a significant difference ($\alpha = 0.05$) between the observed and the expected sex ratio (M:F, 1:1) of the whole sample. To test if the regressions of the weight (W) on disc width (DW) were significantly different ($\alpha = 0.05$) for the two sexes, and to test if the regressions of the disc width on total length (TL) were significantly different ($\alpha = 0.05$) for the two sexes, an analysis of covariance (ANCOVA) was employed.

Adult females with yellow-yolked ovarian eggs were analyzed: ripe oocytes were removed from the ovaries, then counted and their total weight taken to the nearest gram (g). The ovarian fecundity, defined as the total number of oocytes (NO), was plotted against the total length (TL) and the disc width (DW) in cm of mature females (Consalvo et al. 2007). Linear regression was used to estimate the NO-TL relationships, following the formula NO = yTL + x, and to estimate the NO-DW relationships, following the formula NO = yDW + x, where x is the intercept and y is the slope of the regression line.

The stomach was removed from each fish as soon as possible after capture and its content analyzed. All the prey items in the stomachs were counted, washed in clean seawater and dried with blotter paper, identified to the lowest taxonomic level possible and weighed to the nearest 0.1 g.

The frequency of occurrence (%F), percentage weight (%W), percentage abundance (%N) and the Index of Relative Importance (%IRI) were calculated for each prey category (Hyslop 1980; Carrassòn et al. 1997). The vacuity index (percentage of empty stomachs) was also calculated.

According to the value of their percentage abundance (%N), preys were grouped into three categories (N'Da 1992): dominant (N > 50%), secondary (10% <N < 50%) and accidental (N < 10%).

Standardized Levins' index (B*i*) was used to evaluate the breadth of the diet (Krebs 1989):

$$B = \frac{1}{\sum p_j^2}$$

$$Bi = \frac{B - 1}{B_{max} - 1}$$

where p_j is the relative frequency specimens in the jth prey item and B_{max} is the total number of prey item categories found. B*i* is comprised between 0 (narrow trophic niche) and 1 (wide trophic niche); if B*i*<0.40 the species is considered a specialist, if 0.40< Bi<0.60 is considered an "intermediate", if B*i*>0.60 is considered a generalist (Novakowski et al. 2008).

To evaluate whether the number of the analyzed stomachs was sufficient to describe the diet of the species, a cumulative prey curve (Brown et al. 2012) was computed with R software (R Core Team 2018) using the package "vegan". The estimated number of prey groups and associated SD were plotted against the cumulative number of individuals whose stomach was examined.

The eight specimens of T. *marmorata* caught during the study were sexed, measured (disc width and total length in cm) and weighed to the nearest gram (g). Data about habitat and depth of capture were collected through interviews from fishermen.

Results

Out of the total 164 specimens studied, 101 (61.59%) were males and 63 (38.41%) were females. The sex ratio (M:F, 1.6:1) was significantly different from 1:1 (chi-square: $p < 0.05$) and was skewed towards males. Females showed, on average, larger sizes than males (Figure 2, Table I), ranging from 12.5 to 48.3 cm in total length, from 7.9 to 30.1 cm in disc width and from 34 to 1798 g in weight. ANCOVA showed that females were heavier than males (p-value <0.05) of the same size; they were also slightly wider, but not statistically significant (p-value = 0.08), than males. The disc width–weight relationships for both sexes and combined are reported in Table II and graphically represented in Figure 3: a negative allometry was found in all cases. We also calculated the parameters of the linear regression of the total length-disc width relationships for both sexes (DW = 0.586TL + 0.529, for males; DW = 0.606TL + 0.148, for females) and combined (DW = 0.596TL + 0.324) (Figure 4).

Most females (58.73%) were mature, their sizes and weights are reported in Table I. The two smallest mature females had an identical total length of 24.8 cm, a disc width of 14.9 and 15.2 cm and a weight of 256 and 268 g. Fecundity (number of eggs) and total length (and disc width) were highly correlated (n = 37; R^2 = 0.918 and 0.941,

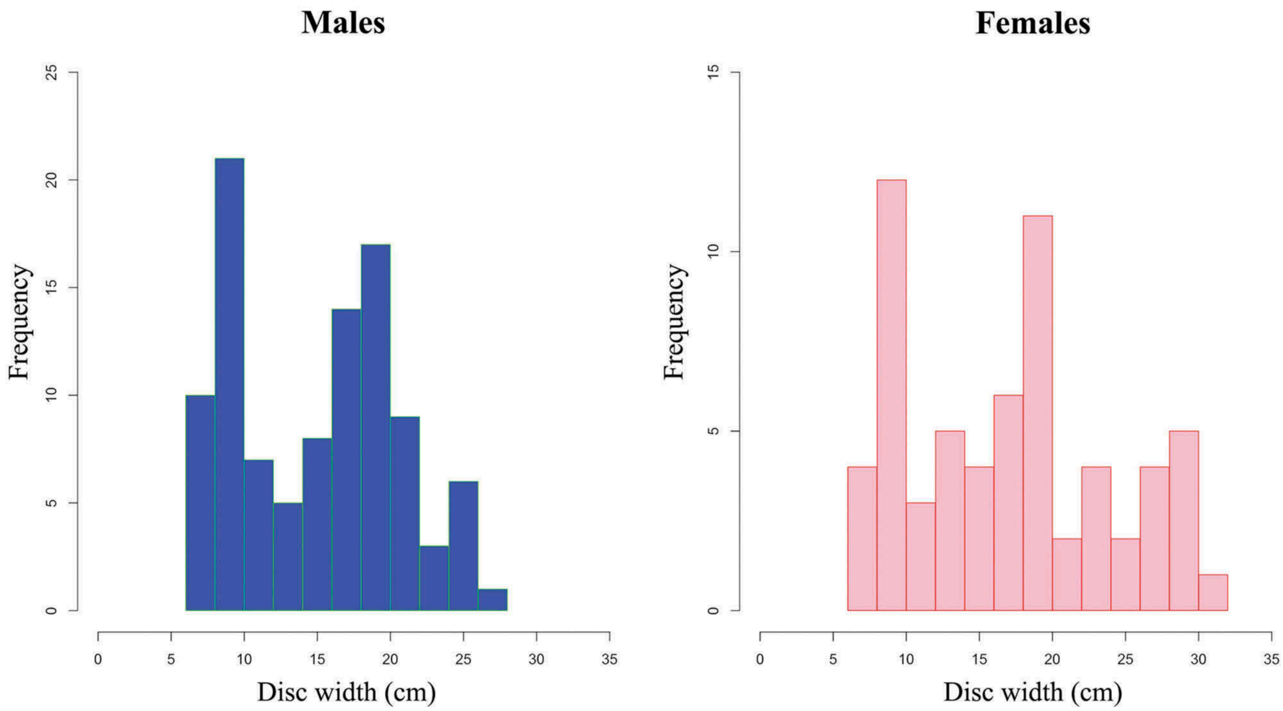

Figure 2. Size composition by sex of *Torpedo torpedo*.

Table I. Sex distribution, total length, disc width (cm) and weight (g) of *Torpedo torpedo* in the Ionian Sea (Sicily, central Mediterranean Sea). The sex ratio (M:F, 1.6:1) was significantly different from 1:1 (chi-square: $p < 0.05$).

		Total length (TL) - cm			Disc width (DW) - cm			Weight (W) - g		
SEX	N	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
M	63	12.1–41.3	25	9.52	6.9–26.2	15.17	5.62	25–1059	309	267.86
F	101	12.5–48.3	27.71	11.42	7.9–30.1	16.94	6.97	34–1798	501	510.82
Combined	164	12.1–48.3	26.04	10.34	6.9–30.1	15.85	6.21	25–1798	382.76	389.93
Mature F	37	24.8–48.3	35.74	7.38	14.9–30.1	21.69	4.81	256–1798	790.2	487.4

Table II. Disc width–weight relationship parameters of *Torpedo torpedo* in the Ionian Sea (Sicily, central Mediterranean Sea); C.I. = 95% confidence interval.

SEX	N	a	C.I. a	b	C.I. b	R^2	p-value
M	101	0.104	0.085–0.127	2.825	2.745–2.900	0.98	<0.05
F	63	0.112	0.093–0.134	2.837	2.771–2.904	0.99	<0.05
Combined	164	0.103	0.089–0.119	2.844	2.789–2.899	0.99	<0.05

respectively; p-value < 0.01) (Figure 5): NO = 0.637TL – 14.025 and NO = 0.99DW – 12.731. The number of eggs ranged from 3 to 20, and their total weight from 23 (5 eggs) to 143 g (20 eggs).

The analysis of the cumulative prey curve indicated that relatively few stomachs (about 45) are necessary to obtain a sufficient sample to describe the overall diet of *T. torpedo* (Figure 6). Out of the 164 specimens analysed, only 57 had prey in their stomach (vacuity index of 34.76%). The stomach content analysis revealed that *T. torpedo* is predominantly piscivorous, a total of at least 13 prey fish (belonging to nine families) were found in their stomachs (Table III). However, no preference was observed between prey fish species: the value of the standardized Levins' index (B*i*) was 0.82 (the digested category was included in the analysis), indicating a wide trophic niche. Furthermore, from a total of 13 prey types, no

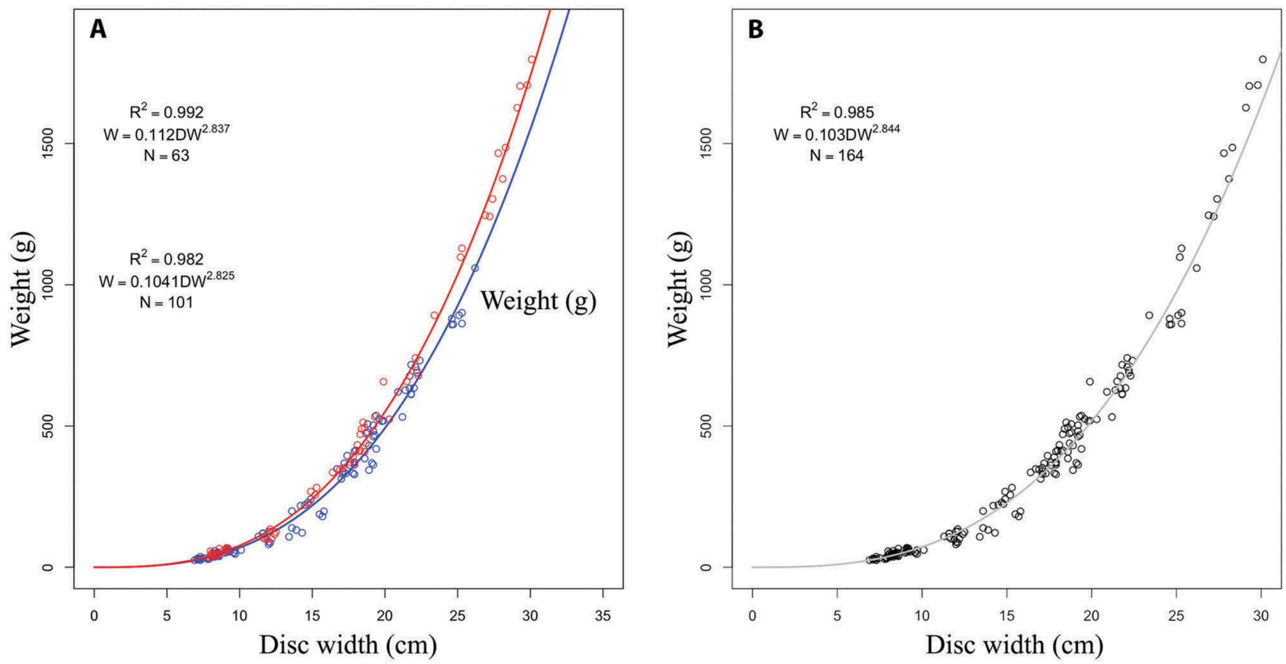

Figure 3. Disc width–weight relationships of *Torpedo torpedo* for both sexes (A) and combined (B). A: in red for females and blue for males.

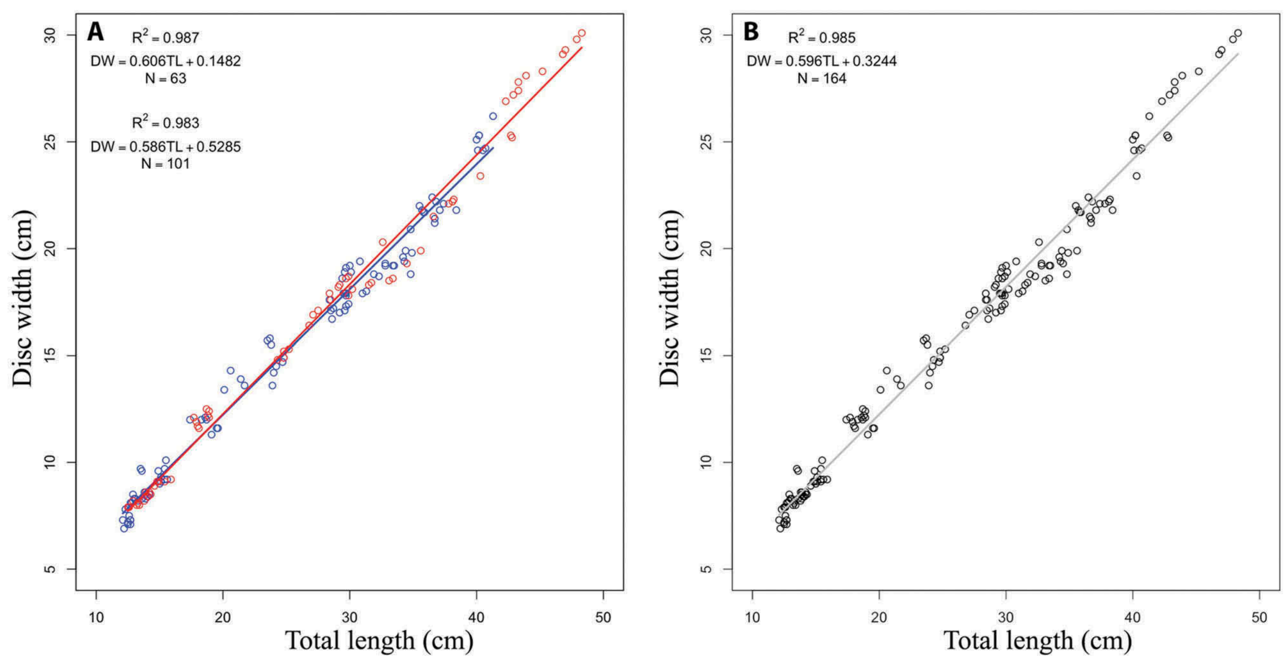

Figure 4. Total length-disc width relationships of *Torpedo torpedo* for both sexes (A) and combined (B). A: in red for females and blue for males.

dominant (%N > 50) ones were found, and only some prey types were included into the category of "secondary preys" (10%<N < 50%). All the other prey types were included into the category of "accidental preys" (Table III). The values of %IRI, %F and %W also indicated no clear dominance of any prey (Table III). However, most of the prey were benthic fish that inhabit shallow sandy bottoms (Table III).

During the study period, a total of eight specimens (six females and two males) of *T. marmorata* were collected on predominantly rocky bottoms. Their total length (TL) ranged from 28.1 to

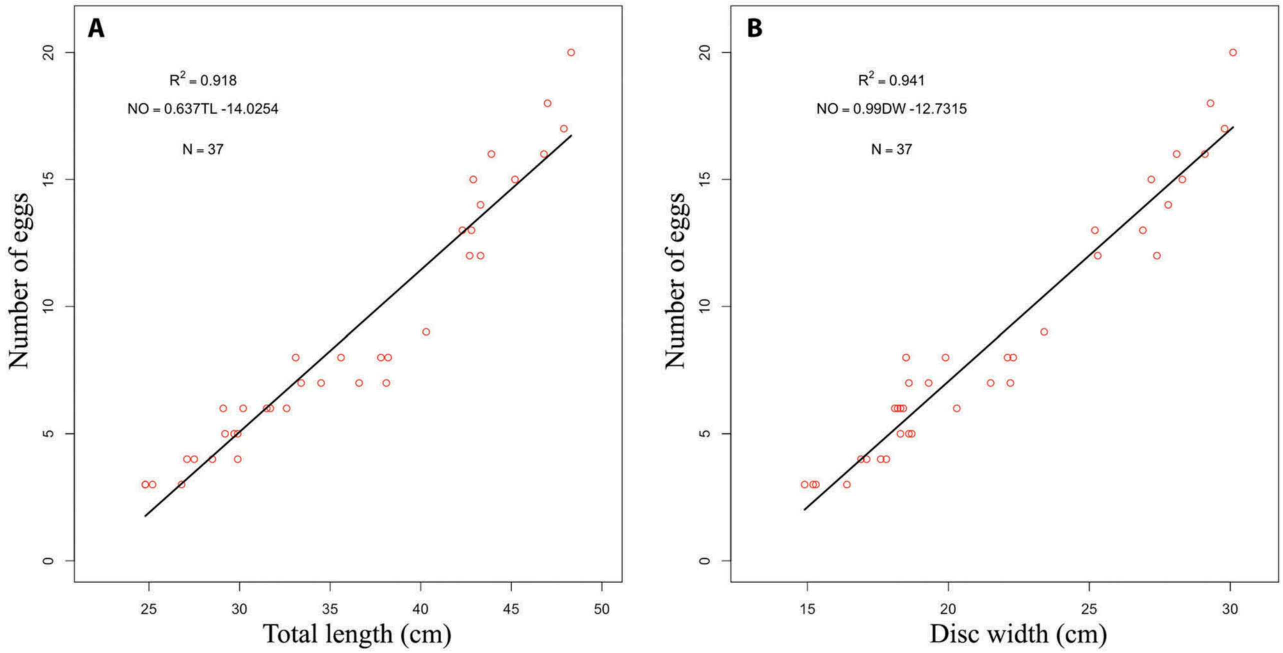

Figure 5. Fecundity (number of eggs, NO) of *Torpedo torpedo* in relation to total length (A) and disc width (B).

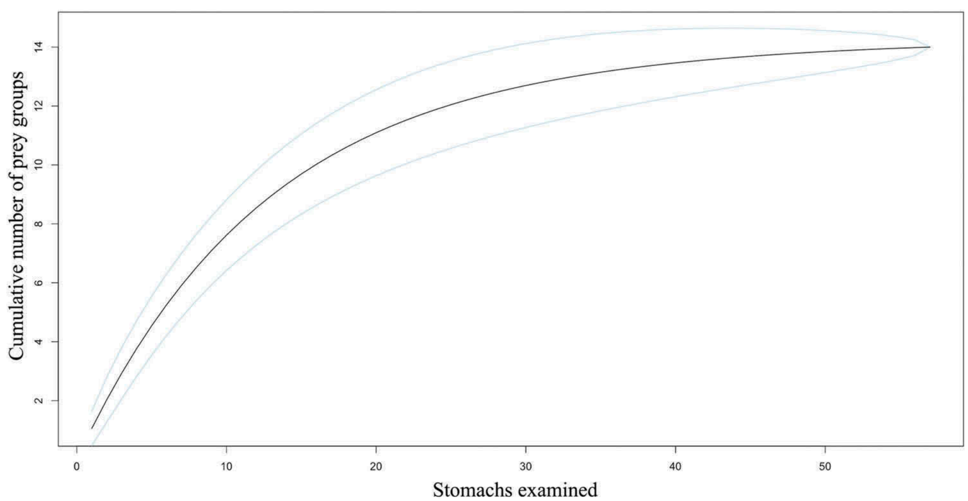

Figure 6. Cumulative prey curve as a function of sample size for all stomachs analyzed of *Torpedo torpedo*. Standard deviation (SD) represented with light blue lines.

51.2 cm (mean = 40.1, SD = 7.9), the disc width (DW) ranged from 16.3 to 33.5 cm (mean = 25.7, SD = 6), and the weight (W) ranged from 435 to 3024 g (mean = 1491.5, SD = 882.5).

Discussion

Fish caught during this study were predominantly male. A recent study conducted in the area (Tiralongo et al. 2018b), as well as another study from the Atlantic Ocean (Capapé et al. 2000), showed the same results. This could be explained by the presence of sexual segregation, a common phenomenon in cartilaginous fish (Wearmouth & Sims 2008). Both adults and juveniles were caught in the area. In particular, more than half of the females were mature. Female specimens showed a clear increase in fecundity with size, and age at first maturity was similar to that found by other authors (Consalvo et al. 2007; El Kamel-Moutalibi

Table III. Diet composition of *Torpedo torpedo* from the Ionian Sea (Sicily, central Mediterranean Sea). %F = percentage frequency of occurrence; %N = percentage in number; %W = percentage in biomass; IRI = index of relative importance of prey items and its percentage (%IRI).

Food items	%F	%N	%W	IRI	%IRI	Habits
Bothidae						
Bothus podas	**12.28**	**11.76**	8.96	254.51	**14.36**	Benthic
Congridae						
Ariosoma balearicum	**10.53**	**10.29**	**13.3**	248.36	**14.01**	Benthic
Congridae	3.51	2.94	3.92	24.07	1.36	Benthic
Gobidae						
Pomatoschistus sp.	**12.28**	**14.71**	1.61	200.37	**11.31**	Benthic
Gobius sp.	7.02	5.88	7.33	92.72	5.23	Benthic
Labridae						
Coris julis	**12.28**	**14.71**	9.26	294.32	**16.61**	Bentho-pelagic
Symphodus tinca	8.77	7.35	**18.21**	224.24	**12.65**	Bentho-pelagic
Symphodus sp.	3.51	2.94	5.69	30.28	1.71	Bentho-pelagic
Mullidae						
Mullus surmuletus	1.75	1.47	1.53	5.26	0.30	Bentho-pelagic
Soleidae						
Solea solea	8.77	7.35	8.92	142.74	8.05	Benthic
Sparidae						
Lithognathus mormyrus	7.02	5.88	7.25	92.16	5.20	Bentho-pelagic
Triglidae						
Chelidonichthys lucerna	5.26	4.41	5.96	54.59	3.08	Benthic
Uranoscopidae						
Uranoscopus scaber	5.26	4.41	7.06	60.38	3.41	Benthic
Digested	7.02	5.88	1	48.3	2.73	

Values >10% are in bold.

et al. 2013) in specimens from the Mediterranean Sea. On the other hand, Atlantic specimens were found to reach maturity at larger sizes (TL 6.2 cm greater for females) (Capapé et al. 2000) than Mediterranean specimens analysed in the current study. The presence of ripe eggs in the ovaries of mature females of *T. torpedo* from the end of March to the beginning of May suggested that ovulation takes place between late winter and early spring, as observed in other studies (Quignard & Capapé 1974; Capapé et al. 2000; Consalvo et al. 2007); while parturition probably take place between the end of August and the beginning of September, as was found in the nearby north African coast (Quignard & Capapé 1974; Abdel-Aziz 1994). Eggs were more abundant on the right side of the reproductive tract, as discussed by other authors (Ranzi 1932; Quignard & Capapé 1974). This particularity is due to the fact that the right genital tract is more developed than the left one.

The disc width–weight relationships showed a negative allometric growth in both sexes. Female specimens were, on average, larger than males, but no significant differences were found in the relationships between total length and disc width of the two sexes. Males and females attained similar sizes to those of specimens from the Tyrrhenian Sea (Consalvo et al. 2007).

The large number of specimens caught in the area suggests that *T. torpedo* is likely to be common in shallow waters along the Ionian coast of Sicily (central Mediterranean Sea). In particular, during the fishing season of *S. officinalis, T. torpedo* represented about 47–51% of total elasmobranch catches of trammel nets (Tiralongo et al. 2018b). In this area, the species is in sympatry with another common species of elasmobranch, *Raja radula* Delaroche, 1809; however, while fishermen caught both adults and juveniles of *T. torpedo*, most of the specimens of *R. radula* were juveniles (Tiralongo et al. 2018a, 2018b). In addition, considering the different feeding habits of the two species in the area, the trophic niche does not overlap, resulting in little direct competition between the two species. Indeed, while *Raja radula* (especially juveniles) mainly feeds on small benthic crustaceans (Tiralongo et al. 2018b), *T. torpedo* is a generalist piscivore, as demonstrated by the current study and in the last published study on the diet of the species (Romanelli et al. 2006). Indeed, only fish (at least 13 species), with no preferences for any particular species, were found in the stomachs of *T. torpedo*. However, benthic species with preference for sandy bottoms, such as gobies, flatfish and conger eels, were the main prey found in the stomachs of the common torpedo (Table III). Similar results were found in specimens from the Tyrrhenian Sea and from

Egyptian Mediterranean waters (Minervini & Rambaldi 1985; Minervini et al. 1985; Abdel-Aziz 1994; Romanelli et al. 2006). The interspecific differences in the diet of the two species (*T. torpedo* and *R. radula*) can be explained by the fact that only *T. torpedo*, thanks to its electric organs, is able to stun its preys before swallowing them, and therefore this ambush predator feeds on larger and more mobile prey such as fish. The great percentage of empty stomachs (107 out of 164) could be explained by the fact that actively swimming specimens which have not eaten for some time have a greater chance to run into trammel nets (Minervini & Rambaldi 1985; Romanelli et al. 2006). In contrast, specimens that have recently fed are less active by staying on the bottom to digest their prey, and consequently lowering their likelihood of being caught. Although the congeneric *T. marmorata* is considered a deeper species, more common on soft bottoms (Capapé 1979; Fischer et al. 1987), the eight specimens collected during the study period were caught in the same bathymetric range (4–25 m) of *T. torpedo*. However, unlike *T. torpedo* that prefers shallow sandy (or mixed) bottoms, *T. marmorata* was caught on rocky bottoms. Hence, the rarity of *T. marmorata* in the area could be related, at least in part, to the fishing method and target species (*S. officinalis*) and, consequently, to the bottom nature in which the nets were set. Indeed, when interviewed, trammel net fishermen claimed that they usually caught *T. marmorata* when the net is set on mainly or entirely rocky bottoms, even in shallow waters, or on coralligenous at greater depths. Furthermore, considering the total lengths of the eight specimens collected, all the individuals were virtually adults (Consalvo et al. 2007), and some of them of large size.

In conclusion, our study provides new data on the biology and ecology of *T. torpedo* in the central Mediterranean Sea, where no data were available for the Sicilian Ionian coast. *Torpedo torpedo* resulted to be common in the investigated area, where both adults and juveniles inhabit sandy or mixed bottoms in shallow waters; while, the marbled electric ray (*T. marmorata*) prefers rocky bottoms. Furthermore, within the same bathymetric range investigated for *T. torpedo*, *T. marmorata* is probably less rare than usually thought. Targeted studies on this sympatric species are needed to provide additional data, for example, on if there is trophic competition between it and *T. torpedo*, and, more generally, to prepare management plans in order to protect these potentially vulnerable k-selected species. Finally, the impact of fishing activities on these species should not be overlooked, especially considering the high percentage of both juveniles and mature females of *T. torpedo* caught during the study.

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Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

F. Tiralongo http://orcid.org/0000-0002-1625-0149

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