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Research Paper

Microplastics in the bogue, *Boops boops*: A snapshot of the past from the southern Tyrrhenian Sea

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ABSTRACT

The present investigation focuses on *Boops boops* specimens gathered in the Gulf of Patti in 2010. Providing a snapshot from the past, this paper represents, chronologically, the first record of microplastic ingestion in the Mediterranean bogue. The plastic abundance and composition in gastrointestinal tracts of the bogue was assess, in order to improve the knowledge on spatial-temporal variability of microplastics pollution in the Mediterranean basin and in particular, in the southern Tyrrhenian Sea. In a total of 65 specimens, 180 particles of plastic (2.8 items/specimens), mainly belonging to microplastics class, were found. Fragments (63%) and fibres (30%) were the predominant shape categories. Eleven polymers were identified: polypropylene and polyethylene were the most abundant. Several synthetic polymers belonging to the class of elastomers were also observed. The study area is strongly influenced by the absence of trawl fishing activities and a low mixing level of the seabed that, together with the confluence of different watercourses and the presence of different kind of anthropic impact, including motorway, could make it a 'waste disposal site'. Finally, our results suggest the usefulness to retrieve older samples to better understand spatial-temporal changes in marine litter pollution over time.

1. Introduction

Marine litter is considered one of the main issues of anthropogenic pollution that has affected the marine ecosystem in the last few decades (Galgani et al., 2015). In particular, plastic litter is the most abundant type of marine debris, and its impact represents a serious hazard affecting worldwide biodiversity. Because the Mediterranean Sea is one of the most impacted regions in the world (Suaria et al., 2016; Llorca et al., 2020; Tsangaris et al., 2020), the scientific effort, in accordance with the recommendations of the Marine Strategy Framework Directive (MSFD; EC 2017/848), has mainly focused on monitoring and assessing the amount and composition of litter and microlitter in marine ecosystems as well as their impacts on marine fauna, to understand and to mitigate the potential effects at different trophic levels. In particular, the MSFD considers the study of fish stomach contents important to define the trends of marine plastic ingestion from European waters, especially in selected and standardised bioindicator species.

In this context, some researchers have proposed the most suitable organisms for plastic ingestion monitoring in the Mediterranean basin. They have generally considered the following criteria to individuate the

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key species: (a) background, habitat and trophic information; (b) feeding behaviour and spatial distribution; (c) commercial value and conservation status; and (d) available data on microlitter ingestion (Fossi et al., 2018; Bray et al., 2019; Tsangaris et al., 2020). Regarding microplastics (MPs) pollution in the Mediterranean Sea, the bogue – *Boops boops* (Linnaeus, 1758) – has been identified as a suitable small-scale indicator for monitoring MPs in coastal waters (Fossi et al., 2018) because it meets the suggested criteria (Tsangaris et al., 2020).

B. boops is a benthopelagic and gregarious species, inhabiting a broad depth range distribution from 0 to 350 m, commonly between 0 and 100 m. It occurs in coastal and pelagic waters on different types of bottom including sand, mud, rocks and seagrass beds. *B. boops* is an omnivorous species, feeding on a wide variety of prey, preferring crustaceans and cnidaria. The bogue is included within the top 13 most landed demersal fish species in the Mediterranean Sea (Lleonart and Maynou, 2003) and it is a commercial species caught by several Mediterranean fisheries. To date, MPs ingestion in *B. boops* has been widely documented in the Mediterranean Sea (Nadal et al., 2016; Garcia-Garin et al., 2019; Rios-Fuster et al., 2019; Savoca et al., 2019; Sbrana et al., 2020; Tsangaris et al., 2020) and it has been chosen as bioindicator species for MPs ingestion in the MEDSEALITTER, PLASTIC BUSTERS MPAs Interreg Project and UNEP/MAP MED POL programme. In particular, the recent study of Tsangaris et al. (2020) investigated the MPs ingestion by *B. boops* on Mediterranean basin scale supporting their suitability as bioindicator species. However, in the southern Tyrrhenian Sea only the Savoca et al. (2019) revealed the occurrence of man-made cellulose fibres in specimens of *B. boops.* Although the MPs ingestion by fish species has been investigated since 1988 (Fossi et al., 2018; Anastasopoulou and Fortibuoni, 2019) through the application of different plastic extraction methods (Pedà et al., 2020), about *B. boops* the most recent study date back to 2014 (Nadal et al., 2016).

In the light of these considerations, the present study investigates the MPs abundance and composition in gastrointestinal tracts (GITs) of Mediterranean bogue from 2010 with the aim to take a picture of the MPs pollution condition ten years ago. Thus, these data represent, chronologically, the first record of MPs ingestion for this species. Because, the bogue is a good bioindicator of MPs ingestion, this study, also, aims to provide further information on MPs pollution in the southern Tyrrhenian Sea, giving us the opportunity to improve the knowledge in this Mediterranean area.

2. Material and methods

2.1. Study area and sampling

Sampling was carried out in October 2010 on board the Scientific Research Vessel *Maria Grazia*, during an experimental trawl survey in the Gulf of Patti, licenced by national and local authorities (southern Tyrrhenian Sea, GSA 10) (Fig. S-1).

The Gulf of Patti is a Fishery Exclusion Zone (FEZ) and trawling has been banned since 1990 to date; only small-scale fisheries are permitted (Battaglia et al., 2017). It is characterised by different kinds of anthropogenic and natural factors including touristic activities and run-off processes due to the presence of several torrents coming from the hinterland (e.g. Timeto, Longano and Mazzarà) (AA.VV, 2016).

The bogue specimens employed (N=65) in this study were collected by trawl net from a single sampling site at a depth ranging from 205 to 250 m (mean depth: 225 m). Once on board, the bogues were sorted from the haul catch and counted, the overall weight was recorded and then the specimens were stored at -20°C.

2.2. MPs isolation

The laboratory analysis was carried out in the autumn of 2020. Each sampled specimen was measured (TL: total length, cm) and weighed (TW: total weight, g), GITs from the oesophagus to the end of the intestine were removed.

For the following basic-acid digestion, GITs were pooled in four groups based on the specimens' total length (cm length class: LC_15; LC_20; LC_25; LC_30). The digestion was carried out following the protocol of Schirinzi et al. (2020). In brief, GITs were weighed and placed into glass beakers in a 1:3 (w/v) ratio with 10% potassium hydroxide (KOH). The solution was incubated in a stove at 60 ± 5°C for 6 h and left at room temperature overnight. Subsequently, the sample was filtered through fiberglass filters (pore size 1.6 μm, GF/A Whatman) using a vacuum system. After the filtration, 40 mL of 20% nitric acid (HNO_3) was added to the clogged filters. The solution remained in contact with the filter for 60 min at room temperature before being removed by filtration. Then, the filters were gently cleaned with ultrapure water and were placed in Petri dishes for subsequent observations under the stereomicroscope.

2.3. Preventing contamination

To avoid contamination during laboratory analysis, rigorous precautions were carried out according to Schirinzi et al. (2020). The samples were processed in a room with restricted access, to prevent any accidental external contamination. Glassware was used and all instruments and equipment (including tweezers and scissors) were rinsed thoroughly with ultrapure water. Additionally, cotton coats were worn by operators. All procedures were conducted under the fume hood and the beakers were covered with paper or aluminium foil between each step to limit airborne contamination. Procedural blanks without tissue were also run concurrently with samples in order to contamination control. Blank sample consisted of 20 mL of 10% KOH and of 20 mL of 20% NHO_3. To avoid fibre overestimation, moist filters in Petri dishes were exposed to the laboratory air and put under the fume hood and near the stereomicroscope. All particles fixed on these filters were recorded and photographed. All particles found in the samples presenting the same shape and colour of those in blank samples were excluded from the results, as they were considered airborne contamination.

2.4. MPs identification

The filters obtained from the digestion were observed under a stereomicroscope (Zeiss Discovery V.8). All particles were counted, measured (length and width, mm) and photographed using the AxioVs40 version 4.8.2.0 digital image processing software.

Fourier transform infrared (FT-IR) spectroscopy was used to identify plastic polymers. The plastic identification was carried out with an Agilent Cary 630 spectrometer in ATR (Attenuated Total Reflection) mode (spectrum matching over 70%). Because of the instrumental limit of detection, only particles with a size > 100 μm were examined; specific libraries (Agilent Polymer Handheld ATR Library, Agilent Elastomer Oring and Seal Handheld ATR Library, Clear Polymers, POLY_D, ATR Demo Library) were used to identify the polymer composition. Identified plastic items were classified based on their size (small-micro: 0.1–1 mm; large-micro: 1–5 mm; meso: 5–25 mm; macro: > 25 mm), shape (pellet, fibre, foam, fragment, sheet and sphere) and colour according to the protocol of the MSFD (Galgani et al., 2013). For each LC, the average number of plastic items found in the GITs was calculated based on the total number of individuals (number of plastic items/number of all examined individuals).

2.5. Statistical analysis

The relative condition factor (Kn) was chosen as general indicator of health of fish, according to Sbrana et al. (2020). Kn is more reliable than Fulton's condition factor when comparing fish with different length (Froese, 2006). Kn was calculated by comparing the observed weight of the fish (TW) to an expected weight based on the fish's observed lengths

(TL; Bottari et al., 2014).

Length and weight data were log-transformed and the linearised relationships were fitted by least squares regression to estimate "a" (intercept) and "b" (allometry) coefficients. The isometric condition (H_0: b = 3) was tested by Student's *t*-test. The relative condition factor (Kn) was calculated for each LC according to the expression:

$$Kn = TW / (a' \times TL^b)$$

where a' (antilog of a) and b are the power length-weight relationship parameters (Le Cren, 1951).

Kendall's rank correlation has been performed to assess the correlation between: i) MPs abundance *vs.* fish body size; ii) MPs abundance *vs*. fish weight; iii) MPs abundance *vs.* Kn; iv) MPs size *vs*. fish body size.

Plastic particle length data were tested for homoscedastiticy and normality by the Levene and Shapiro–Wilk test's using the PAST software (Hammer et al., 2001). Because the data did not satisfy the supposition required to perform a parametric analysis of variance (ANOVA), even after log transformation, the Kruskal–Wallis non-parametric test was used to test whether there were any significant differences in the plastic particles size among the four LC (LC_15; LC_20; LC_25; LC_30). Differences were considered significant at $p < 0.05$ (Fig. 1).

3. Results

A total of 65 adult specimens of *B. boops* was analysed, they measured from 15.6 to 34 cm in TL and from 31.6 to 383.2 g in TW (Table 1).

3.1. Plastic ingestion

A total of 180 plastic elements (2.8 items/specimens) was detected in the bogue GITs, mainly belonging to small MPs (59%) and large MPs (40%) (Fig. 2a). Of them, fragments and fibres (63% and 30%, respectively) were the predominant shape categories, followed by sheets (7%). No plastic pellets, foams or spheres were observed (Fig. 2b). Fig. S-3 shows the length and width ranges of plastic particles, varying from 0.04 to 11.39 mm and from 0.01 to 3.84 mm, respectively.(Fig. 3) Transparent (27%), black (15%), blue (13%) and yellow (10%) were the most common colours observed, but brown, white, green, red, grey and other colours were also found (Fig. 4). The main polymer types identified by FT-IR analysis were polypropylene (PP, 25%), polyethylene (PE, 24%), both low density (LDPE) and high density (HDPE), ethylene-propylene rubber (EPR, 19%), polyvinyl chloride (PVC, 9%) and nitrile butadiene rubber (NBR, 9%), followed by polybutylene terephthalate (PBT, 5%), polychloroprene (CR, 5%), ethylene-propylene diene monomer (EPDM), polyisobutylene rubber (PIB), polytetrafluoroethylene (PTFE) and, finally, styrene-butadiene rubber (SBR), representing 1% (Fig. 5). Fig. S-6 reports images of the main isolated polymers.

Finally, only 0.8 fibres per specimen were identified, but their characterisation was not achieved by FT-IR because they were too thin. The ingested fibres were mainly green (16%), blue or red (15%) and transparent or black (11%), even though brown, grey, yellow and "other color" category were also found.

3.2. Data analysis

Table 1 provides Kn data for each LC; Kn was very similar in the LCs with small fluctuations between 0.99 in the LC_15 and 1.04 in the LC_30 and a mean value equal to 1.00.

Plastic particles were found in all four LC; their number per specimen increased from 1 (LC_15) to 5.8 (LC_30) (Table 1). A positive correlation (Tau = 1; $p < 0.05$) has been found between the MPs abundance and the fish body size. Similarly, a positive correlation was found between the MPs abundance and the fish body weight (Tau = 1; $p < 0.05$). No significant correlation between MPs abundance and Kn was evident (Tau = 0.6; $p > 0.05$).

The plastic particle length for each LC was assessed. As shown in the Fig. S-7, there was a significant difference among the sample medians ($H = 17.3, p < 0.01$). No significant correlation was found between the MPs size and the fish body length (Tau = 0.0; $p > 0.05$).

Overall, PE was the only polymer present in all groups, with a percentage ranging from 4% to 38%. The other main types of polymers found in LC_15 were EPR (43%) and PP (29%). The latter one was also the most frequent synthetic polymer (46%) in LC_20, followed by PE (27%) and PVC (21%). PE and NBR were predominant in LC_25, with a percentage of 38% and 34%, respectively. Finally, EPR (55%) and PBT (21%) were mainly observed in LC_30 (Fig. 8).

4. Discussion

The present study reported information on the MPs ingestion in *B. boops* species collected during experimental trawl fisheries in the southern Tyrrhenian Sea in 2010. The presented data represent, chronologically, the first record of MPs ingestion in this benthopelagic species and also provide additional information on marine litter pollution in

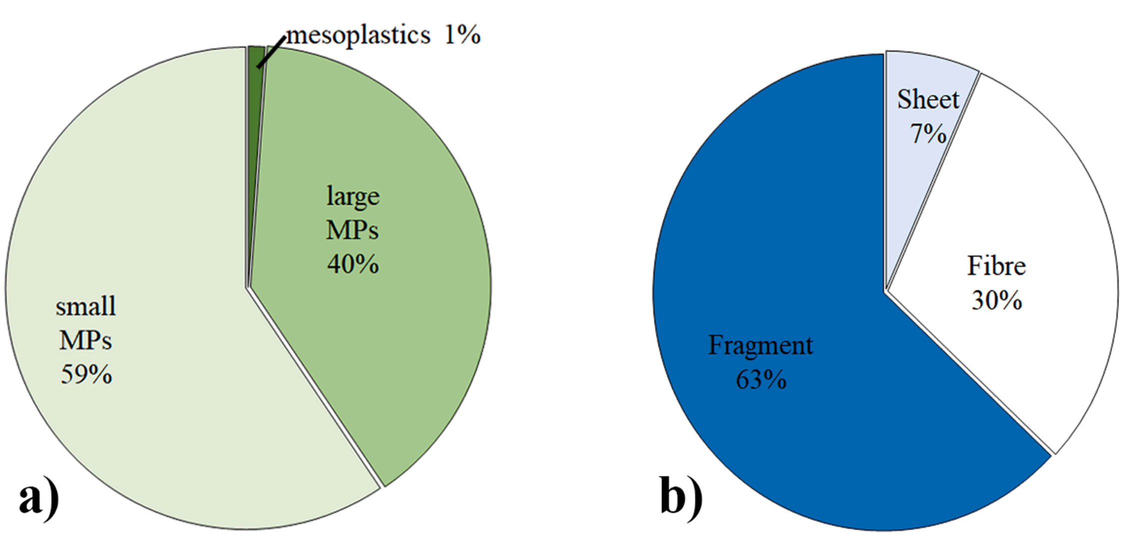

Fig. 1. Categorisation (%) by a) size (small-MPs: 0.1–1 mm; large-MPs: 1–5 mm; meso: 5–25 mm; macro: > 25 mm) and b) shape (pellet, fibre, foam, fragment, sheet and sphere) of plastics isolated from *Boops boops*.

Table 1
Number (n) of *B. boops* specimens for length class (LC), mean, standard deviation (SD) and ranges of total length (TL, cm) and total weight (TW, g), relative condition factor (Kn) and the numerical abundance of ingested plastic particles.

Length class	Sample size	TL (cm)		TW (g)		Kn	N. plastic items	N. plastic items/N. all examined individuals
	n	range	mean ± SD	range	mean ± SD			
LC_15	8	15.6–17.3	16.7 ± 0.6	31.6–56.2	44.75 ± 8.5	0.99	8	1.0
LC_20	34	17.7–22.5	20.1 ± 1.4	46–115.7	77 ± 19.8	1.01	66	1.9
LC_25	12	22.8–27.5	25.2 ± 1.8	103.8–229.5	156.7 ± 36.4	1.00	42	3.5
LC_30	11	28–34	30.3 ± 1.9	200.8–383.2	271.2 ± 53.1	1.04	64	5.8
Total	65	15.6–34	22.4 ± 4.6	31.6–383.2	120.6 ± 82.2	1.00	180	2.8

$Kn = TW / (a \bullet TL^b)$

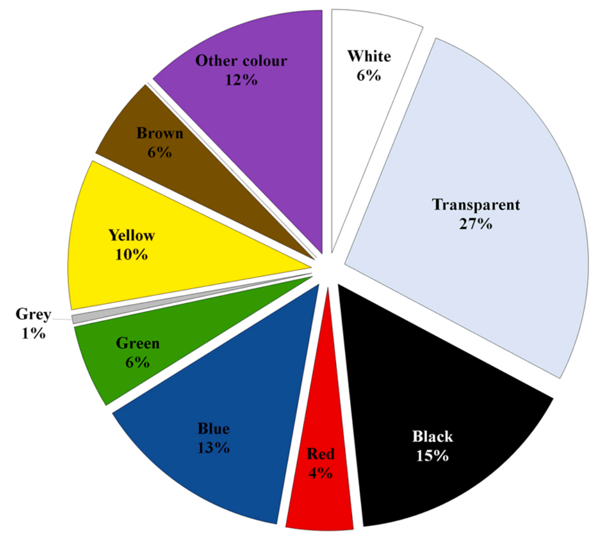

Fig. 2. Distribution percentage of plastics colour (%) ingested by *Boops boops*.

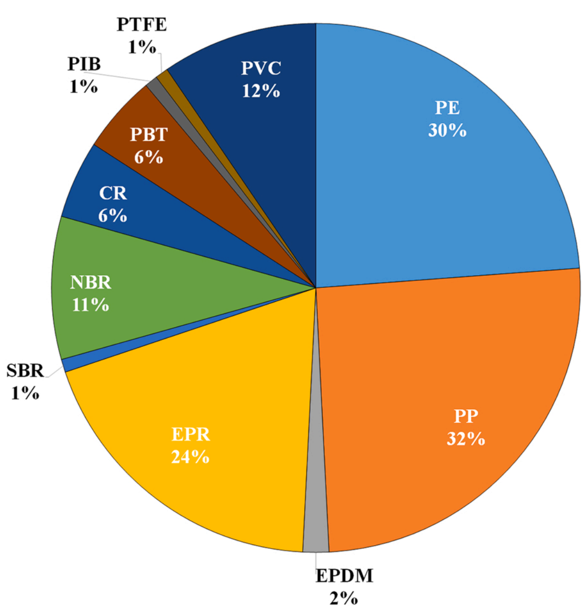

Fig. 3. Composition percentage of polymers found in GITs of *Boops boops*.

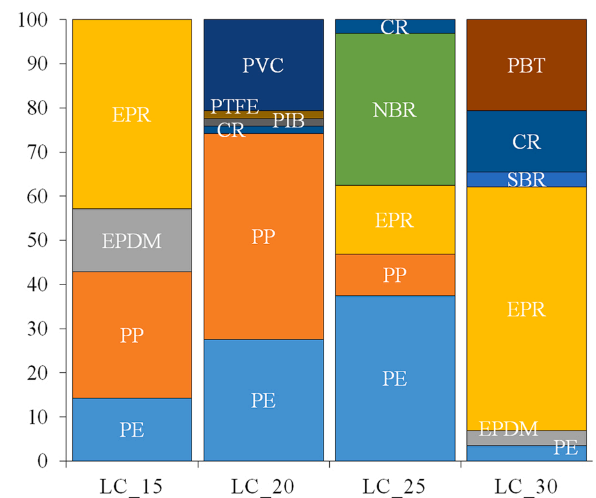

Fig. 4. Frequency of occurrence (FO %) of plastic polymers for each length class (LC, cm).

the study area, showing evidence of plastic litter as early as 2010.

About the results on MPs ingestion, our value of abundance (2.8) was higher than other Mediterranean areas, though it falls within the range (3.19 – 0.19) reported by Tsangaris et al. (2020). This result confirms an important occurrence of MPs in bogues from the Mediterranean basin as well as a high variability on spatial scale, how emphasized by Tsangaris et al. (2020). This result seems to be closely linked to the characteristics of the Gulf of Patti. In fact, as reported by Bottari et al. (2019), this is a highly urbanised coastal area strongly affected by several anthropic activities (e.g. tourism, fishing and mariculture activities, shipbuilding and boating). The introduction of marine litter could also be due to the runoff processes of neighbouring watercourses with different flow rates. In addition, the study area has been closed to trawl fishing since 1990 (Battaglia et al., 2017). These conditions, together with low water circulation levels, may make it a highly vulnerable site. Indeed, a recent study on the distribution of seabed macrolitter identified a high density of plastic in samples from 2013 to 2015 in the southern Tyrrhenian Sea, including the Gulf of Patti (Spedicato et al., 2019).

MPs (small and large) were the main size class of ingested litter. This finding in the GITs of bogues could be due to the feeding habits as also suggested by other authors (Nadal et al., 2016; Fossi et al., 2018). Indeed, the bogues are opportunistic predators, occupy an intermediate position in the marine pelagic trophic web (Cardona et al., 2012), thus they may accidentally or intentionally ingest the MPs but also eat plastics contaminated prey (secondary ingestion). For instance, bogues might confuse plastics with potential preys such as small crustaceans or feeding on the organisms attached to plastics, indirectly ingesting MPs items (Nadal et al., 2016). MPs ingestion by bogues could also occur in part during predation on gregarious prey (Fossi et al., 2018).

Furthermore, evidences of MPs ingestion were observed in other species, demersal and benthopelagic, from the same study area (Mancuso et al., 2018; Bottari et al., 2019; Capillo et al., 2020, Pedà et al., 2020).

Fragments and fibres, were the most abundant MPs shape categories observed, consistent with the finding reported in bogues from the northern coasts of Catalonia and South Sardinia (Tsangaris et al., 2020). This result may be related to different land and sea-based pollution sources in the study area (Rochman et al., 2015), although these shape categories, were also observed by different authors in other Mediterranean areas (Nadal et al., 2016; Tsangaris et al., 2020).

Another feature that differentiates these results from those obtained in other studies concerns the colour of the plastic. In fact, the most common colour for plastic items was transparent, followed by black and white. The prevalence of light-coloured MPs in the examined bogues could be due to a possible likeness to their potential preys. For instance, the exoskeleton of some crustacean's species and gelatinous planktonic organisms are transparent, translucent or white (Nadal et al., 2016). Tsangaris et al. (2020) reported different colours based on Mediterranean geographical regions. For example, black was the main colour observed in French coasts, Lazio and Liguria, whereas in Spanish coasts it was green and blue. These differences are probably due to the different sources of contamination in the areas as well as the feeding habits of bogue species.

The FT-IR analyses highlighted the presence of 11 polymer types in the GITs of the bogue coming from the southern Tyrrhenian Sea and collected in 2010. The polymer types detected in the current study were more varied than other Mediterranean areas in which the number of polymer types ranged from 2 to 5 (Tsangaris et al., 2020). The most recurring polymer in the analysed organisms were PP (25%) and PE (24%), followed by EPR (19%). PP and PE are widely used for packaging or single-use products; thus, they have a relatively short lifetime and they are also the most common polymers in the Mediterranean waters (Andrady, 2011; Rochman et al., 2013; Suaria et al., 2016). The occurrence of these polyolefins (PE and PP) have already been widely reported in demersal (*Scyliorhinus canicula*), benthopelagic (*Galeus melastomus* and *Zeus faber*), mesopelagic (*Lepidopus caudatus*) and pelagic species (*Coryphaena hippurus*, *Sardina pilchardus* and *Engraulis encrasicolus*) from the southern Tyrrhenian Sea (Bottari et al., 2019; Capillo et al., 2020; Pedà et al., 2020; Savoca et al., 2020; Schirinzi et al., 2020) and it could be also linked to the degradation of lost or abandoned fishing gears due to the intense fishing activity carried out in the study area (Pedà et al., 2020), while we may exclude they came from the net employed in our sampling, since we recorded mainly fragments and sheets. Regarding the bogue, most of the information on plastic ingestion has come from the western Mediterranean basin (Tsangaris et al., 2020), confirming PP and PE as the most common polymer type in this species from different geographical subareas (GSA 6 – Northern Spain; GSA 9 – Ligurian Sea and Northern Tyrrhenian Sea; GSA 10 – Central and southern Tyrrhenian Sea; GSA 11 – Sardinia; GSA 20 – Eastern Ionian Sea). Nevertheless, other synthetic polymers of the elastomer class (e.g., EPR, NBR, EPDM, PIB and SBR) were found in this study. In particular, EPR was the third most abundant polymer (19%) and it was observed in three of the four LC. It is used in the automotive and road construction industry such as tyres, automotive components, tubes, O-rings, gaskets, accumulator bladders, wire and cable connector manufacturing (Qi, 2015). Generally, the presence of all these elastomers is closely linked to motorway-related pollution and they enter the marine environment through runoff processes. This is consistent with the fact that the coastal area near the Gulf of Patti is subject to a lot of traffic along the coast. Considering that the bogue does not carry out extensive movements, the MPs were probably ingested in the sampling area (Sbrana et al., 2020; Tsangaris et al., 2020). Therefore, the types of ingested plastics may reflect the marine contamination in situ.

There was a positive correlation between the abundance of plastic particles and specimen's size and weight consistently with several studies on MPs ingestion in fish (Beer et al., 2018; Park et al., 2018; Pegado et al., 2018; Capone et al., 2020). Instead, to date, no relation between MPs abundance and fish size has been reported for the Mediterranean bogue by Tsangaris et al. (2020).

Assessment of a general health status of fish through the use of indirect biological parameters is suggested in the studies on MPs ingestion (Morgana et al., 2018; De Vries et al., 2020; Tsangaris et al., 2020). Some studies assessed the impact of MPs on the health status of fish using Fulton's condition factor (Garcia-Garin et al., 2019; Tsangaris et al., 2020). This parameter assumes that mass and length increase isometrically, but we are conscious that the different methodological analyses could be limited to compare data. In our study, Kn value, used as a proxy for fitness, was equal to 1.00 despite the presence of MPs in the gastrointestinal tract. This value was slightly higher than value reported for bogue in the same period (October 2010) in southern Tyrrhenian Sea ($Kn = 0.9$; Bottari et al., 2014). Moreover, MPs abundance was not related to Kn consistently with Sbrana et al. (2020) who examined bogues from GSA 9 (Ligurian Sea and Northern Tyrrhenian Sea) and GSA 11 (Sardinia). Probably MPs ingested were too few and/or small and did not retain long enough to influence the general health status of examined bogue. Indeed, this parameter provides information for a first assessment of health status but further studies are needed to better deepen this aspect.

Correlation between plastic size and fish size was not found in agreement with Rios-Fuster et al. (2019), who analysed plastic pollution in *B. boops* from western Mediterranean Sea. Conversely, Tsangaris et al. (2020) reported a weak but significant correlation between plastic size and fish size.

To understand the temporal variability of plastic pollution, it is useful to compare our data with data from the same area. Of note, the fibres could not be identified because of their thickness and the technical limitation of our instrument. The fibre abundance index was calculated to compare our record with Savoca et al. (2019), the only other study on the bogue in the Gulf of Patti. In fact, they observed only the presence of anthropogenic microfibres (viscose, cellulose and rayon). From this comparison, we noted an increase in fibre abundance over time. Moreover, we also found a greater variability in colour then Savoca et al. (2019), even if dark fibres were the most abundant.

The highlighted difference can be both linked to the different isolation method employed (visual sorting) as well to the temporal variability. In fact, 7 years had passed between the two investigations, during which time the abundance and composition of MPs in the sea could have changed, as suggested by recent studies highlighting the increase in anthropogenic textile microfibres in the Mediterranean Sea (Musso et al., 2019; Avio et al., 2020; Rodríguez-Romeu et al., 2020; Pedrotti et al., 2021).

5. Conclusion

Our data represent the oldest record of MPs in *B. boops* and they can be considered the first picture of MPs ingestion by this benthopelagic species. This finding can be useful to better understand changes in marine litter pollution over time, especially in the Gulf of Patti (southern Tyrrhenian Sea), with its peculiar environmental features, fishery management and anthropic pressure.

The increase in marine litter in the study area has been strongly influenced by the closure of the Gulf of Patti to trawl fishing since 1990. The absence of these activities and the limited seabed mixing combined with the confluence of different watercourses and the presence of several human activities, including roads, make it a 'waste disposal site'. This condition has arguably influenced the trend of plastic occurrence in the GITs of the bogue during the time. Our results confirm the suitability of *B. boops* to monitor the plastic ingestion, in a view of spatial-temporal variability. To this end, it would be useful to establish a connection network to retrieve older samples from different areas of the Mediterranean; to plan an annual monitoring using the bogue as a target species; to promote mitigation actions.

CRediT authorship contribution statement

Teresa Bottari: Formal analysis, Writing - Original Draft. **Monique Mancuso**: Resources, Writing - original draft. **Cristina Pedà**: Formal analysis, Investigation, Data curation, Writing - Review & Editing. **Francesca De Domenico**: Investigation, Writing - Review & Editing.

Federica Laface: Investigation, Writing - Review & Editing. **Gabriella F. Schirinzi**: Investigation, Writing - Review & Editing. **Pietro Battaglia**: Investigation, Supervision. **Pierpaolo Consoli**: Investigation, Supervision. **Nunziacarla Spanò**: Resources, Supervision. **Silvestro Greco**: Resources, Supervision. **Teresa Romeo**: Conceptualization, Writing - Review & Editing, Project administration, Funding acquisition, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jhazmat.2021.127669.

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