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Impact of Plastic Pollution on Marine Biodiversity in Italy

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Abstract: Plastic litter is a global threat affecting all marine ecosystems. Utilizing digital media platforms like Google, Facebook, and Instagram we assessed the detrimental effects of marine plastic litter on the biodiversity of the Italian marine ecosystem. We noted that marine plastic litter had adverse consequences on marine reptiles, mammals, sea birds, fish, crustaceans, and mollusks, including endangered and vulnerable marine species. The loggerhead sea turtle (*Caretta caretta*) was the most recorded species found entangled in plastic litter. Our investigation revealed that abandoned, lost, or otherwise discarded fishing gear are the primary contributors to the entanglement of numerous marine species. The current study represents a preliminary step towards establishing databases that document records of entanglement, which may be useful in adopting new conservation measures in the Mediterranean geographical subareas. Our results emphasize the critical need for collaborative efforts among all stakeholders and policymakers to effectively manage marine plastic litter.

Keywords: plastic pollution; biodiversity; entanglement; ingestion; endangered species; digital media

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1. Introduction

Marine litter is becoming increasingly recognized as a major threat to marine wildlife. Plastics constitute most of the marine litter, and they have become ubiquitous in ocean basins [1]. Plastics are known for their durability and low recycling rates, making them a persistent and pervasive problem in marine ecosystems, with profound implications for marine biodiversity [1]. The increasing accumulation of plastic waste in our seas is posing a grave threat to this delicate ecological balance [2]. The impact of plastic debris on marine fauna is growing in marine ecosystems, with adverse effects being documented for over 900 species [3,4] and across food webs [5]. The ingestion of plastic can lead to numerous adverse effects, including physical blockage or perforation of the gastrointestinal tract, a reduction in growth, and mortality [6–8]. The presence of plastic pollution in the marine ecosystem may result in the entanglement of wild species, potentially causing physical deformities in juvenile animals due to prolonged entanglement or leading to death in cases where individuals are unable to eat or breathe [9,10].

Abandoned, lost, or otherwise discarded fishing gear (hereafter ALDFG) is a major threat to marine biodiversity [9]. The presence of ALDFG is responsible for the entanglement of various organisms, including fish, birds, turtles, and mammals [11–14]. Entanglement refers to the interaction between marine life and anthropogenic debris that entraps animals or entangles their appendages within the loops and openings of the debris [15]. Examples of such items include strapping bands, ropes, or plastic bags that may encircle or create a loop around an animal [16], resulting in lacerations, mutilations, infections, and ultimately, mortality [17]. Furthermore, fragments of fishing nets and other plastic

debris can be ingested by several marine animals [4,18]. Marine animals often mistake plastic fragments for a specific prey, and they may ingest plastic pieces that align with their anatomy and foraging strategy [19]; for example, plastic bags are mistaken as jellyfish by marine turtles [20].

The Mediterranean Sea is considered one of the areas most polluted by plastic [21,22]. This is worrying considering that the Mediterranean Sea is a hotspot for marine biodiversity, hosting 4% to 18% of the world's marine species [23]. Italy, a country in south-central Europe, occupies a peninsula that juts deep into the Mediterranean Sea. With almost 8000 km of coasts, the Italian waters are some of the Mediterranean's most biodiverse, and host an estimated 14,000 marine species, of which 10% are unique to the area [23]. Until now, 32 marine protected areas have been established in Italy, covering 57,181 km^2 (10.1%) [24]. Italian coastal marine ecosystems are currently under great pressure from marine litter. In Italy there are 57 major rivers that contribute significantly to plastic pollution in the Mediterranean Sea. A study carried out on 12 Italian rivers highlighted that approximately 87% of the waste dispersed in Italian rivers contains macroplastics and more than 38% is single-use plastic [25]. Among the factors that most influence the presence of waste in the terminal sections of river environments is the proximity of urban settlements. Most of the objects for which identification was possible derive from activities related to the production and consumption of food [26]. Among the rivers studied, the Sarno (Campania), which flows into the Tyrrhenian Sea, presented the highest amount of waste transported to the sea, on average almost 66 objects/hour. The annual loading of the Tiber River, which flows into the Tyrrhenian Sea, was estimated to be 4 $\times$ 105 items/year at the main mouth [27], while the Po River, which flows into the Adriatic Sea, contributes about 145 tons of plastics into the Mediterranean Sea annually [28]. The Italian coasts are characterized by a large presence of plastic debris on the seafloor at different depths, with accumulation zones reported in many different areas [29–35], as well as on the sea surface, within the water column [36], on beaches [37–40], and in costal ponds [41]. In the last decade, many studies on plastic ingestion by marine mammals [42], reptiles [43], teleost [44,45], elasmobranchs [46,47], shellfish [48], and crustaceans [49] along the coasts of Italy have been conducted.

In this era of huge plastic production and consumption, it is crucial to understand the multifaceted impact of plastic on marine biodiversity [50,51]. There seems to be variation in plastic ingestion among different taxonomic groups and species, as indicated by Kühn and van Franeker [4]. Moreover, studies have underscored the spatial variability in the impacts of marine plastics on marine wild species [9,51]. These studies highlighted the significance of monitoring plastic ingestion and entanglement on a regional scale and across taxonomic groups [51]. Citizen science has emerged as a potent resource for gathering data on the presence of marine litter and its effects on marine biota [14,52]. Citizen science has the potential to address the growing global issue of marine litter through various means, such as gathering data and involving diverse stakeholders [53]. Moreover, it offers a hopeful path to enhance involvement and initiatives in global marine conservation [54].

In this context, social media has evolved into a valuable tool for investigating the consequences of various activities on biodiversity, encompassing the influence of marine litter on marine biodiversity [14]. Over the past decade, information concerning the plastic–wildlife interactions along the Italian coasts has been disseminated through digital and social media. This research aims to identify, by the collection and analysis of data from digital and social media: (1) the species affected by plastic litter and (2) the hotspots for plastic–wildlife interactions. In this study, for the first time, the entanglement and ingestion cases were analyzed considering the geographical subarea (GSA) in which the records fell. As the ALDFGs are often involved in plastic–wildlife interactions, knowledge about impacts at the GSA level could be useful for implementing management measures.

2. Materials and Methods

2.1. Data Collection

For this study, we selected the predominant digital and social media platforms in Italy, namely Google, Instagram, and Facebook. The authors used these platforms as data sources to investigate the effects of marine litter on marine biodiversity along the coasts of Italy. Information available from public posts up to October 2023 was included in this study. To conduct our search, we employed a set of combined keywords, including: "marine plastic + Italy"; "ghost fishing net + Italy"; "fishing net + marine animals"; "fishing net + entangled marine animals"; "ingestion of plastic + Italy"; fishing lines + marine animals + Italy; "entanglement + plastic + Italy"; "conservation + plastic + Italy"; stranding + marine animals + plastics; findings + marine animals + plastics; entanglement + marine fish + Italy; ingestion + marine fish + Italy; entanglement + sharks + Italy; ingestion + sharks + Italy; entanglement + rays + Italy; ingestion + rays + Italy; entanglement + marine invertebrates + Italy; ingestion + marine invertebrates + Italy; entanglement + marine turtles + Italy; ingestion + marine turtles + Italy; entanglement + seabirds + Italy; ingestion + seabirds + Italy; entanglement + cetaceans + Italy and finally; ingestion + cetaceans + Italy. We employed searches on Google, Instagram, and Facebook to identify pages associated with organizations or communities dedicated to marine pollution and conservation, and to find news in local newspapers. Every report was meticulously reviewed and documented in our database (see Table S1, Supplementary Material). All reported species were recognized by photos and videos. The cases in which it was not possible to trace the species or have information on the place of discovery, date, and type of incident were discarded. We classified "ingestion" as the presence of material in the digestive tract and "entanglement" as the presence of material around or within a part of the body. For each record, we documented the species, the geographic location, the litter type, and the type of litter interaction. Additional information is shown in Table S1. The species were identified using field guides and general morphological characteristics. In case of doubt about the identity of the species, photographs were sent to scientists for confirmation. We used specific literature to assess the conservation status of the species [55].

2.2. Data Analysis

The frequency of occurrence (FO%) was calculated for each marine species and taxonomic group. The Spearman test was applied to evaluate temporal trend in entanglement cases. Additionally, data were analyzed considering the GSAs in which the report fell. There are seven Italian GSAs recognized within the General Fisheries Commission for the Mediterranean framework, namely GSA 9—Ligurian and Northern Tyrrhenian Sea; GSA 10—Central and Southern Tyrrhenian Sea; GSA 11—Sardinia; GSA 16—Southern Sicily; GSA 17—Northern Adriatic Sea; GSA 18—Southern Adriatic Sea; GSA 19—Western Ionian Sea (Figure 1). Data were tested for homoscedasticity and normality using the Levene and Shapiro–Wilk tests. Since the data did not meet the assumptions required for conducting a parametric analysis of variance (ANOVA), even after log transformation, the Mann–Whitney test was used to assess differences between Italian GSAs. GraphPad Prism 8.4.2.3. was used for statistical analyses and graphs. All results were considered significant when $p < 0.05$.

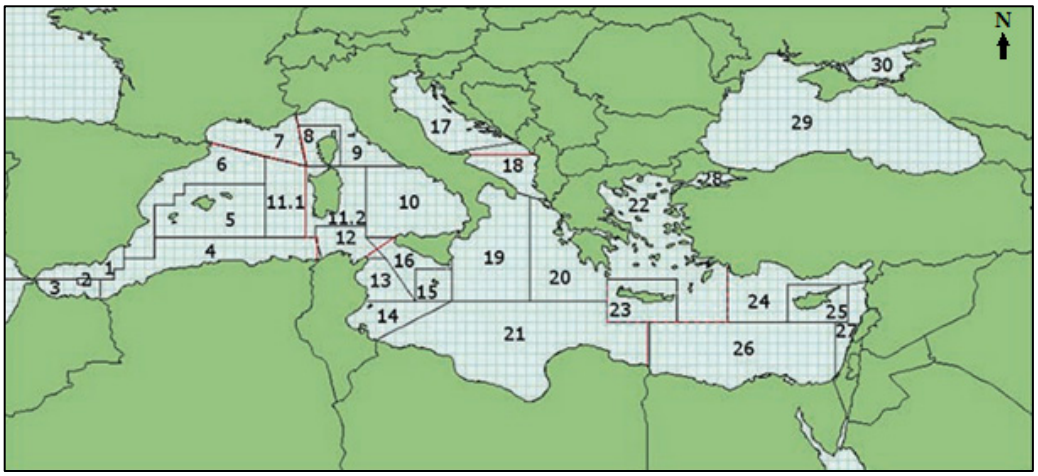

Figure 1. Mediterranean Geographical Sub-Areas (GSAs www.fao.org/gfcm/data/gsas/en/, accessed on 20 October 2023).

3. Results

A study conducted during the last fifteen years (2009–2023), showed that the major information source was Google (52%), followed by Facebook (32%), and Instagram (16%). A total of 127 cases involving interactions between marine species and marine litter were documented along the Italian coasts. A significant positive trend (rs = 0.88, $p < 0.01$) was observed starting from 1% in 2009 and reaching 24% by 2021 (Figure 2A). Most of the cases were reported in the autumn (38%), followed by the summer (26%), spring (23%), and winter (13%). GSA 10 emerged as the area with the highest number of cases (34.6%), followed by GSA 11 (15%), GSA 9 (11.8%), GSA 16 (11%), GSA 17 and 19 (9.4%), and GSA 18 (8.7%) (Figure 2B). However, no significant differences between GSAs were detected ($p > 0.05$).

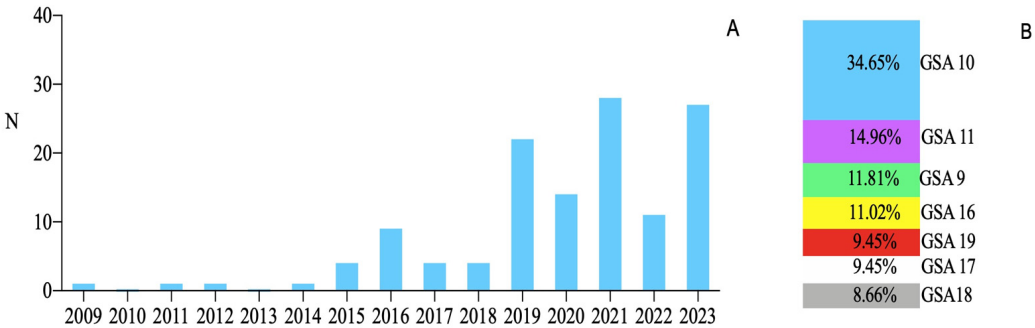

Figure 2. Temporal trend in the number of entanglement and ingestion records reported by digital media between 2009 and 2023 in Italy (**A**); Percentage of records found in Italian GSAs (**B**).

Out of these recorded cases of interaction with marine litter, 16 distinct species were identified (the species are listed in Table S1, Supplementary Materials). Our results showed that 61% of cases were entanglement and 39% were plastic ingestion. Additionally, a single record of concurrent entanglement and ingestion was observed. Marine turtles (78%) were the most affected marine animals, followed by cetaceans (9%), seabirds (5%), elasmobranchs (4%), teleost (2%), and invertebrates (2%) (Figure 3).

Among the three reported turtle species, the loggerhead sea turtle *Caretta caretta* (Linnaeus, 1758) was the most frequently recorded (ninety-four records) followed by the leatherback sea turtle *Dermochelys coriacea* (Vandelli, 1761) (three records), and the green sea turtle *Chelonia mydas* (Linnaeus, 1758) (two records) (Table S1; Figure 4).

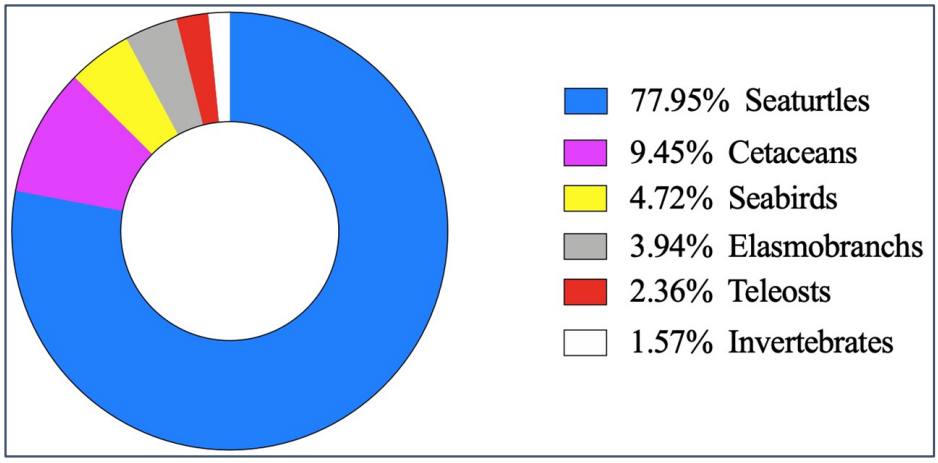

Figure 3. Percentage of records in marine species.

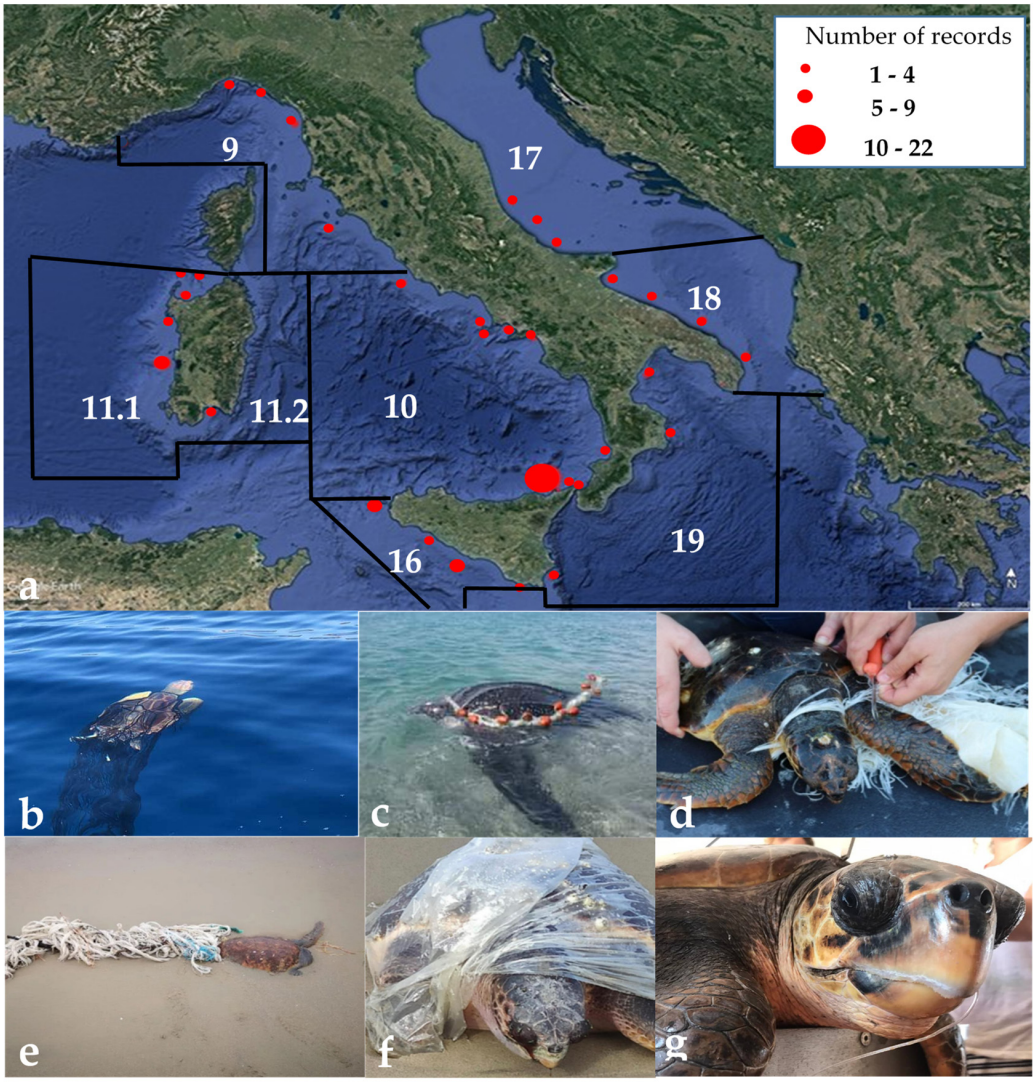

Figure 4. Map of records of marine turtles in Italian GSAs. Small dot from 1 to 4 reported cases, medium dot from 5 to 9 and large dot from 10 to 22 registerd cases. (**a**). *Caretta caretta* and *Dermochelys coriacea* entangled in fishing nets (**b**,**c**) [56], *C. caretta* entangled in plastic packaging (**d**) [57], in fishing net and ropes (**e**) [58], in a plastic sheet (**f**) [59], and *C. caretta* with fishing line and hook within the digestive tract (**g**) [60].

Cetaceans constituted the second largest group found in this study. Most of the records were regarding the sperm whale *Physeter macrocephalus* (*Linnaeus*, 1758) (seven records), followed by the common bottlenose dolphin *Tursiops truncatus* (Montagu, 1821) (three records), and the striped dolphin *Stenella coeruleoalba* (Meyen, 1833) (two records) (Table S1, Figure 5).

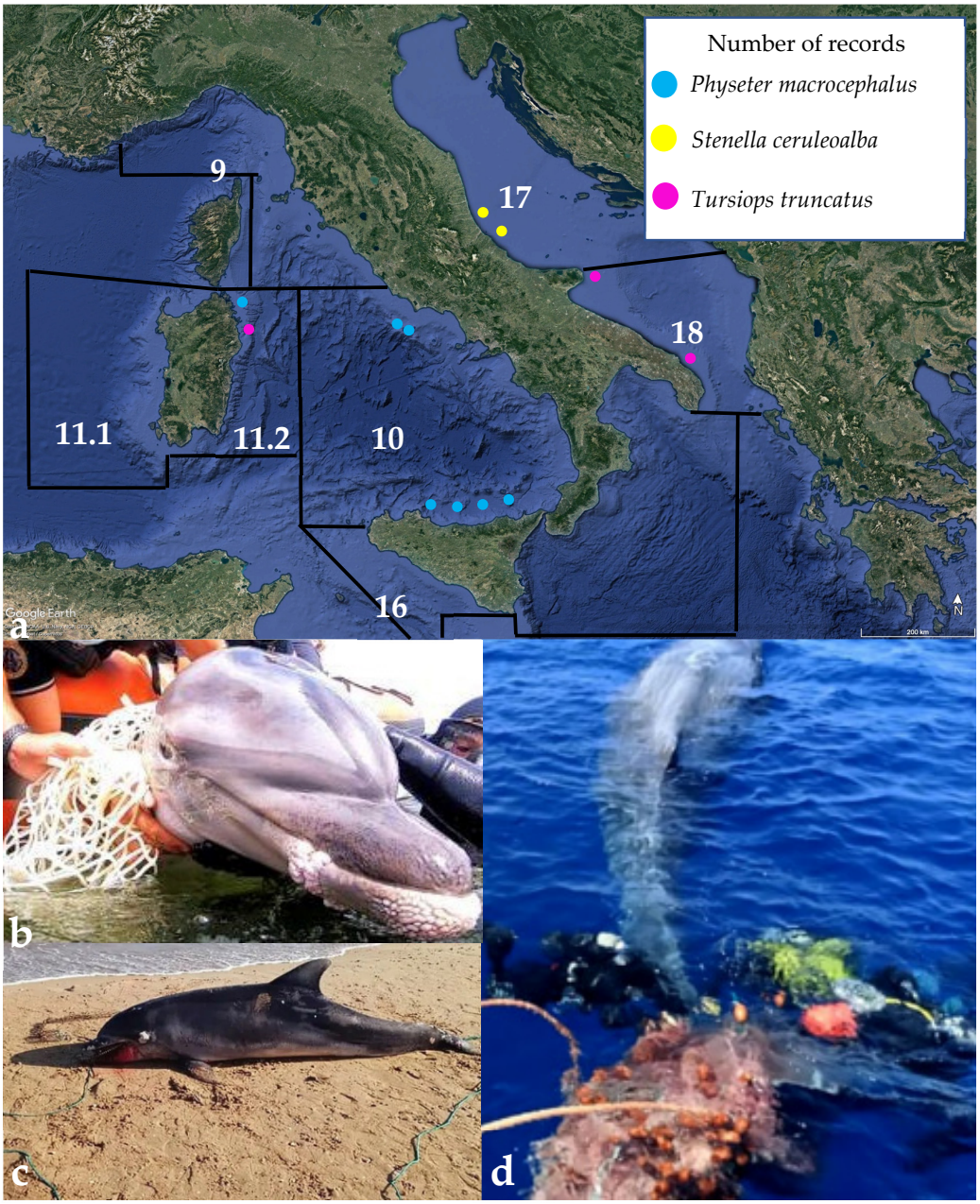

Figure 5. Map of records of cetaceans in the Italian GSAs (**a**). Examples of plastic entanglement of cetaceans in fishing nets: *Tursiops truncatus* (**b**), *Stenella coeruleoalba* (**c**), and *Physeter macrocephalus* (**d**) [61–63].

Concerning seabirds, three different species were recorded: the yellow-legged gull *Larus michahellis* (Naumann, 1840), the greater flamingo *Phoenicopterus ruber* (Linnaeus, 1758), and the levantine shearwater *Puffinus yelkouan* (Acerbi, 1827). *L. michahellis* (four records) and *P. ruber* (one record) were entangled in fishing lines, while *P. yelkouan* (one record) was trapped with its legs in a surgical mask (Figure 6).

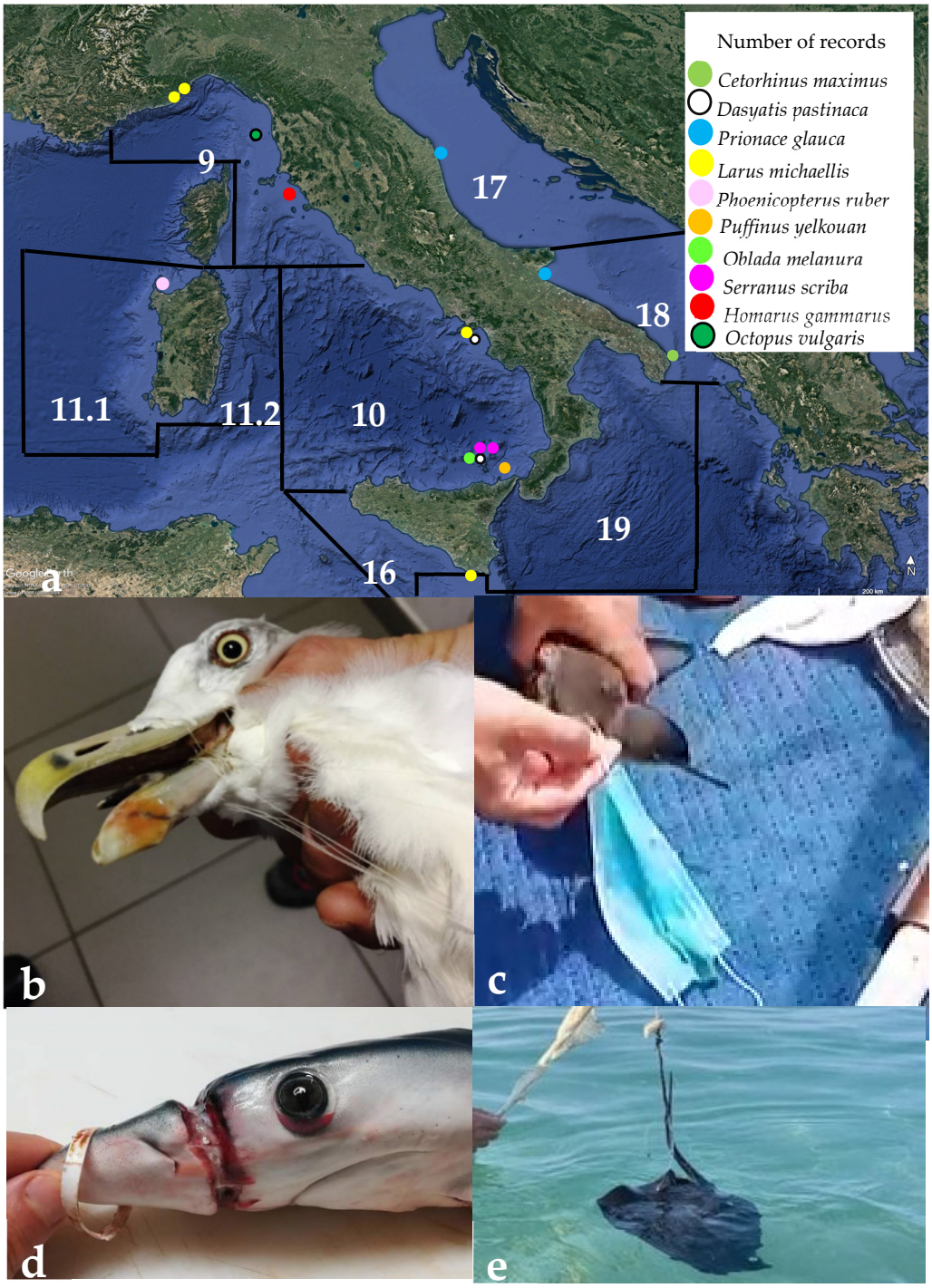

Figure 6. Map of records of seabirds, elasmobranchs, teleost, and invertebrates (**a**). *Larus michahellis* entrapped in fishing lines (**b**), *Puffinus yelkouan* entrapped in a surgical mask (**c**), *Prionace glauca* entangled by a plastic ring (**d**), *Dasyatis pastinaca* entangled by fishing lines, and plastic bag (**e**) [64–67].

Regarding elasmobranchs, a specimen of basking shark *Cetorhinus maximus* (Gunnerus, 1765) was entangled in a fishing net, and two specimens of common stingray *Dasyatis pastinaca* (Linnaeus, 1758) were entangled in plastic bags and fishing lines. The blue shark *Prionace glauca* (Linnaeus, 1758) was entangled in a plastic ring (two records); the first one, a juvenile specimen, was found dead with the ring around its snout, while the second was an adult specimen with a plastic ring around its body (Figure 6).

Two fish species, that is the saddled seabream *Oblada melanura* (Linnaeus, 1758) and the painted comber *Serranus scriba* (Linnaeus, 1758), were found entrapped in a ghost net (pot). The European lobster *Homarus gammarus* (Linnaeus, 1758) and the common octopus *Octopus vulgaris* (Linnaeus, 1758) were entangled in a ghost net and in a plastic bottle, respectively (Table S1).

When focusing exclusively on entanglement cases, the predominant litter type was fishing nets, accounting for 46% of the cases, followed by fishing lines at 23%, and plastic debris (15%, mostly consisting of plastic floats, plastic bottles, plastic sheets, and plastic rings) (Figure 7A). Regarding the records of macroplastic ingestion, the dominant category of plastic litter consisted of 75% of plastic debris, which included items such as cups, bottles, filters, food packages, balloons, and balloon strings (Figure 7B).

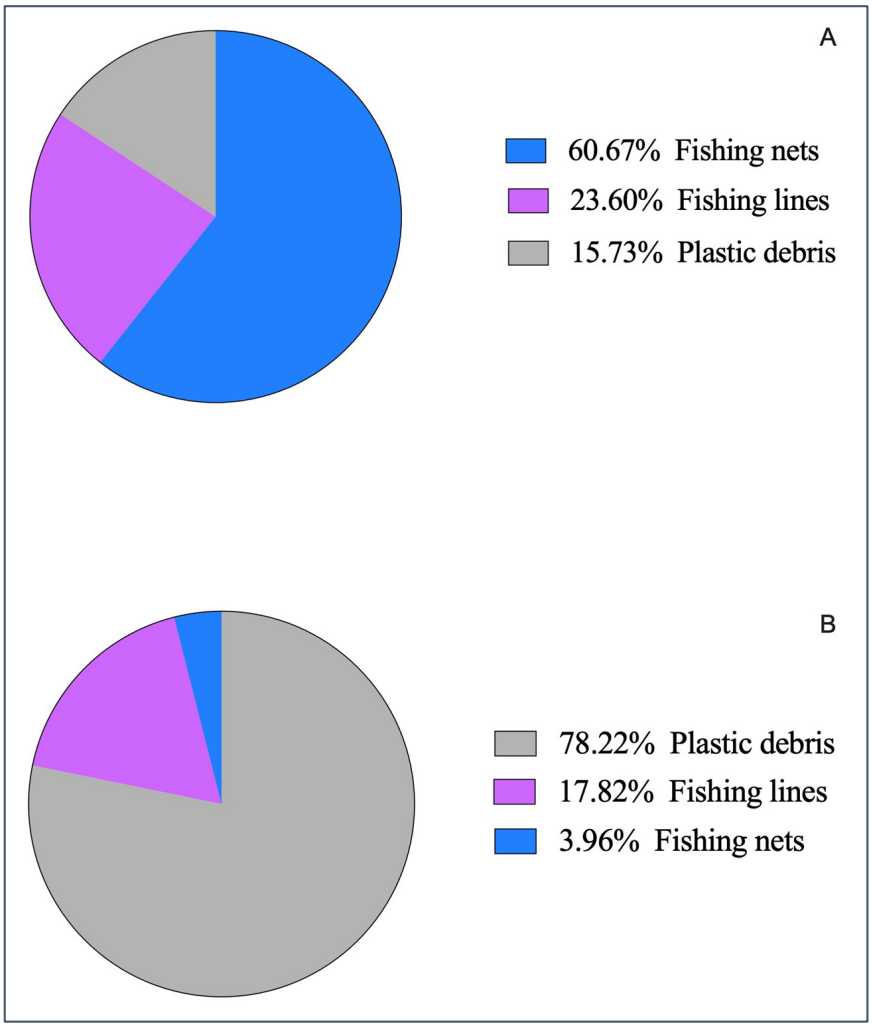

Figure 7. Percentage of entanglement (**A**) and ingestion (**B**) cases by litter type in Italy.

Regarding the health status of the species, 74% of marine animals survived the impact of plastic waste and 24% died, while the health condition of 2% marine animals could not be confirmed. Finally, regarding the environment in which marine animals were found, 72% of cases were found in the sea, while the remaining 28% were on the beach. In Figure 8 the percentage of the type of litter in the studied cases is shown. Fishing nets appear to be the main source of entanglement for cetaceans and teleost; fishing lines are the main source of entanglement for seabirds.

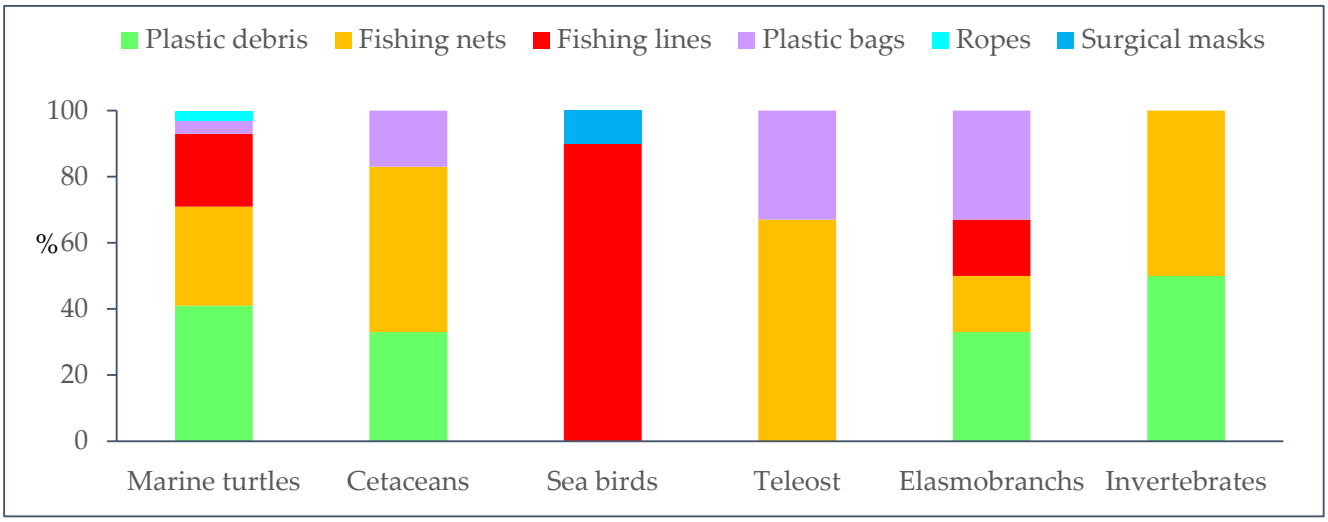

Figure 8. Percentage of the type of litter in cetaceans, seabirds, marine turtles, teleost, elasmobranchs, and invertebrates between 2009 and 2023.

4. Discussion

The worldwide problem of marine litter, primarily consisting of plastic, poses a significant environmental concern, leading to adverse effects on marine biodiversity and ecosystems. This study was performed using social media to establish a comprehensive database of observations and incidents related to marine animals interacting with plastic, especially ALDFGs. The method is opportunistic, and the publication of entanglement sightings depends heavily on the motivations of media users, sensitivity to this issue, population density and, finally, preference for sharing images of specific species such as sea turtles or large marine animals compared to others such as fish or invertebrates. It is also possible that many cases are not reported on social media, so one can only draw a snapshot of the interaction between plastic waste and marine species along Italian coasts. Despite its limitations, this study effectively demonstrates the importance of using citizen science and social media for data collection along the Italian coasts. Our study identified the earliest documented case, dating back to 2009. The positive temporal trend in the records, with a peak in findings in 2021, suggested that there was an increase in the number of interactions and/or in posting on social media.

4.1. Taxonomic Groups

Our results suggest that marine turtles are the group most impacted by plastics in Italian waters. The loggerhead sea turtle was the most impacted species both for entanglement and plastic ingestion (56% and 44%, respectively). *C. caretta* is the most abundant sea turtle species in the Mediterranean Sea and, according to the International Union for Conservation of Nature (IUCN), is listed as a vulnerable species. *C. caretta* has been involved in several entanglement cases in the Mediterranean Sea also and globally [9,68]. The ingestion of plastic debris is common in the Mediterranean loggerhead sea turtle [69–73]. In our study, fishing lines, plastic debris, and plastic bags were the main plastic items found. Mrosovsky et al. [74] and Schuyler et al. [75] reported that plastic bags were often mistaken for gelatinous prey by several species of marine turtles. The green sea turtle and leatherback sea turtle were involved in a limited number of cases of plastic ingestion and entanglement. The importance of our findings is, however, noticeable as *C. mydas* is an endangered species and *D. coriacea* is a vulnerable species [55].

The cetaceans constituted the second largest group found, exhibiting both plastic ingestion and entanglement. Sperm whale, common bottlenose dolphin, and striped dolphin were the impacted cetacean species in Italian waters. The sperm whale is listed as a vulnerable species [55], for which entanglement and plastic ingestion have often been

reported in the scientific literature [6,8]. *P. macrocephalus* has been proposed as an indicator of ocean health, showing the impact of macro- and micro-litter at the global scale [76]. In our study, fishing nets and lines and ropes associated with this gear appear to be the main source of entanglement for cetaceans, as reported by [77].

Concerning seabirds, the findings exclusively unveiled incidents of entanglement involving the yellow-legged gull, the greater flamingo, and the yelkouan shearwater. Yellow-legged gull cases were linked to fishing lines, as documented by Mghili et al. [52] along the Moroccan Atlantic and Mediterranean coasts, and by Costa et al. [78] for the Portuguese coasts. The entanglement of the greater flamingo, to the best of our knowledge, represents the first reported entanglement case. In the case of the yelkouan shearwater, entanglement was caused by a surgical mask, mirroring a similar incident reported by Karris et al. [79] in Cyprus, highlighting the unfortunate global repercussions of the COVID-19 pandemic.

Among the various categories of marine animals that were entangled, we observed a limited number of cases involving elasmobranchs, specifically the basking shark, common stingray, and blue shark. The entanglement of these organisms has been documented in the scientific literature by Parton et al. [10], Wegner and Cartamil [80], and Mucientes and Queiroza [80]. This study marks the first report of entanglement for the basking shark. Plastic bags and fishing lines were identified as the cause of the entanglement of another vulnerable species, the common stingrays. Previous entanglement records were reported along the French Mediterranean coasts by Parton et al. [10]. The entanglement of the blue shark was linked to plastic rings, consistent with previous findings by Colmenero et al. [81]. Similar instances of sharks becoming entangled in circular plastic debris have been detected in various species, including tiger sharks (*Galeocerdo cuvier*, [82]), mako sharks (*Isurus oxyrinchus*, [80]), and Galapagos sharks (*Carcharhinus galapagensis*, [83]). Parton et al. (2019) [10] emphasized that fishing gear is the primary cause of shark entanglements. The circular plastics, sourced predominantly from fisheries, result from plastic straps from bait boxes used by longliners [78], components of plastic barrels common in industrial fisheries (Thiel et al. 2018) [83], or detachable sections of bottle lids likely discarded by fishing or recreational boats [84].

Our study represents the first report of entanglement for both *O. melanura* and *S. scriba*. However, it is important to note that these data are likely underestimated, as Mghili et al. [52] pointed out the challenges in accurately assessing the true extent of entangled fish due to their rapid cadaver decomposition. Perroca et al. [85] documented over 40 fish species entangled in ghost fishing in the Mediterranean Sea, emphasizing the widespread issue. Additionally, larger marine mammals and turtles are more commonly reported on social media compared to fish entanglements.

Our findings include the entanglement of the European lobster and the common octopus. This study represents the first evidence of such entanglement.

A recent report [86], highlights that loggerhead sea turtles, common fin whales, and Cory's shearwaters, are the most impacted by floating waste and plastic pollution in the marine environment. Our research confirms that *C. caretta* is the most damaged species, and underlines for the first time the impact of plastic on other marine species. This study provides a complementary framework that further defines a dramatic situation.

4.2. Geographical Distribution

The impacts of plastic pollution frequently exhibit spatial variability and are specific to populations and species, necessitating that research be undertaken across various spatial scales [51]. Italian coasts are potentially hotspot for plastic-wildlife interactions between marine litter and marine wildlife, in particular, the western GSAs seem to experience more significant impacts compared to the eastern ones. The GSAs are geographic divisions used for the management of Mediterranean fisheries resources, with the aim of promoting sustainable fishing and the conservation of marine ecosystems. International organizations, such as the General Fisheries Commission for the Mediterranean (GFCM), may use these

subdivisions to implement specific management measures in certain areas of the Mediterranean Sea. GSA 10 emerges as the most severely affected area, with a high number of reports, especially in the Aeolian Islands.

4.3. Marine Plastic Governance

In 2021, Italy was the tenth highest country in EU in terms of fishery production (https://www.eumofa.eu, accessed on 21 October 2023). With almost 12,000 vessels, the Italian fleet is among the largest in the Mediterranean Sea. The Italian fishing fleet uses several types of gear such as demersal and pelagic trawlers, beam trawlers, dredgers, purse seiners, long liners, and passive polyvalent gear [87]. The Italian fleet contributed to the pollution of the marine environment by dumping fishing equipment. Fishing waste is inadequately handled by fishermen, often discarded or lost at sea, posing a significant threat to marine wildlife. Until now, information regarding abandoned fishing gear in the seas around Italy remains sparse and fragmented in terms of the number, weight, and geographical location [31,88–90]. Nevertheless, fishing materials contribute to the mortality of numerous marine species, as demonstrated in studies by Pace et al. [91], Perroca et al. [85], and the current investigation.

Reducing the influx of ALDFG is crucial for minimizing the mortality of marine biota [92]. Strategies to address this issue involve minimizing equipment losses by either discarding them in port or repairing them, instead of releasing them into marine environment. Authorities should promote the repair of fishing gear in various Italian ports. Another approach is the use of "Biodegradable Fishing Gear" to reduce potential harm to marine wildlife without reduction in fishing performance [93].

Changing fishermen's behavior is essential for effectively addressing the environmental challenges associated with ALDFG. To achieve this goal, education and awareness programs for fishers are necessary, as well as their involvement in collecting waste captured in their nets and depositing it in ports (Fishing For Litter), and encouraging them to report animal entanglements to create a database for developing management solutions. Continuous monitoring of entanglements is necessary to assess the impact of ALDFG on wild species. Collaboration with all stakeholders, including local communities, fishermen, citizens, social scientists, and resource managers, is essential for mitigating the threat of ALDFG to marine wildlife. To provide a comprehensive understanding of the extent of marine wildlife entanglement in Italy, a systematic collection of sightings through targeted surveys focusing on highly sensitive species. Additionally, the collection of sightings from citizens will contribute to understanding the impact of plastic on wildlife. The variety and quantity of entangling materials highlight the imperative for immediate management interventions in Italy and in Mediterranean areas.

5. Conclusions

Our study highlighted that digital media can be a valid aid in evaluating the impacts of plastic litter on marine animals and in devising new strategies to mitigate the problem of ghost fishing. Our findings suggest further research into the effects of ghost nets on wildlife. We set out to study the species affected by plastic litter and we discovered that sea turtles, in particular, *Caretta caretta* is heavily impacted. We also noted that GSA 10 is the most severely affected area. Our results underscore the fundamental importance of reducing plastic waste production, as well as initiating programs for the collection and disposal of such waste, especially ghost nets. The present study represents an important first step towards the creation of a database that can document cases of ingestion and entanglement along the Italian coastlines. Furthermore, the results obtained can be useful in encouraging conservation measures to be adopted in the geographical sub-areas of the Mediterranean. Further research is needed to understand the scope of this problem across Italy, also with the help of citizen science.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w16040519/s1, Table S1: Plastic interactions and marine species found in Italy an according to digital media.

Author Contributions: Conceptualization, T.B.; funding acquisition T.B. and M.M.; data analysis T.B.; review and editing, T.B., B.M. and M.M.; Investigation, M.M.; writing—original draft, T.B. and M.M.; formal analysis, K.G. and M.M.; project administration, T.B. and M.M.; data and writing curation, B.M. and K.G.; formal analysis, supervision, K.G. and M.M. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Original data are available as Supplementary Materials.

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Conflicts of 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.

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