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Acoustic deterrent devices as mitigation tool to prevent dolphin-fishery interactions in the Aeolian Archipelago (Southern Tyrrhenian Sea, Italy)

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Abstract

In a test-control study conducted in the Aeolian Archipelago (Southern Italy), acoustic deterrent devices (pingers) were applied to four gear types typical of local artisanal fisheries to assess their effectiveness in mitigating dolphin-fishery interactions. In this area ecosystem degradation and overfishing have been increasing bottlenose dolphin (*Tursiops truncatus*) and striped dolphin (*Stenella coeruleoalba*) conflict with fishers. Banana Pingers were applied to *Spicara maena* gillnets, trammel nets, “lampara” nets and hand-operated squid jig lines (“totanara”) in trials conducted from April to September 2017. Dolphin depredation events were greatly reduced in the gillnet (100%) and the “lampara” net (86%), resulting in a strong increase in catch weight (kg) and revenue (€). In the squid hand-jig line trials, severe depredation events (60%) markedly reduced catch and revenue. In the trammel net, catch weight and revenues were not significantly different in the test and control nets. Despite the absence of dolphin damage, the fish species that are part of the dolphin diet were more abundant in the test net. Our findings suggest that pinger effectiveness may be influenced by a variety of factors including dolphin species, season, habitat and fish species distribution. Notably, the discards of trammel nets account for nearly 50% of the catch and include potentially valuable bycatch species, like *Sparisoma cretense*, which however commands a low price on the local market. We suggest that together pingers and the local sale of non-target species could mitigate the economic loss due to dolphin damage, although this requires appropriate planning.

Keywords: Conservation; Mediterranean Sea; small-scale fishery; socio-economic impact; *Stenella coeruleoalba*; Southern Tyrrhenian Sea; *Tursiops truncatus*.

Introduction

Dolphin-fishery interactions in the Mediterranean Sea are a growing problem (Geraci *et al*., 2019) and a source of concern for several cetacean species, whose survival is threatened by the risk of capture (Brotons *et al.,* 2008a; Read, 2008; Lauriano *et al.,* 2009), injuries sustained while plundering the gear (Gomerčić *et al.,* 2009) and behavioural/biological changes (Bearzi, 2002; Crosti *et al.*, 2017). Although conflict with fisheries has been reported worldwide (Gearin *et al.*, 1994; Barlow & Cameron, 2003; Powell & Wells, 2011; Reeves *et al.,* 2013; Rechimont *et al.*, 2018), a vast literature suggests that the problem is severe throughout the Mediterranean area, including the Tyrrhenian Sea (Díaz-López, 2006; Buscaino *et al.*, 2009; Lauriano *et al.,* 2009; Rocklin *et al.,* 2009; Maccarrone *et al.*, 2014; Blasi *et al.,* 2015; Pennino *et al.,* 2015), the Balearic Sea (Brotons *et al.,* 2008a; Gazo *et al.,* 2008), the Ionian Sea (Gonzalvo *et al.,* 2015), the Adriatic Sea (Gomerčić *et al.,* 2009), the Aegean Sea (Aydi *et al.,* 2013; Snape *et. al*., 2018) and the Black Sea (Gönener & Özdemir, 2012; Bengil *et al.*, 2020). According to several reports bottlenose dolphin have developed opportunistic feeding behaviours, plundering the nets, especially in areas characterized by high fishing pressure (Pace *et al.*, 2003; Díaz-Lòpez, 2006; Bonizzoni *et al.*, 2016). Furthermore, the depletion of fish stocks due to overfishing (Colloca *et al.*, 2017) involves that fishers and dolphin now compete for the same resources (Blasi & Boitani, 2012; Blasi & Boitani, 2014; Leone *et al.*, 2019, Blasi *et al.*, 2020). Since the dolphin and the fishers are both threatened by the situation, the issue should urgently be addressed (Read, 2008; Bearzi *et al.*, 2019).

The Aeolian Archipelago (Southern Tyrrhenian Sea, Italy; Fig.1) is a geomorphologically varied area of volcanic origin surrounded by extensive neritic and oceanic habitats (Favalli *et al.,* 2005). It hosts a variety of characteristic Mediterranean cetacean species such as the striped dolphin (*Stenella coeruleoalba*) and the bottlenose dolphin (*Tursiops truncatus*) (Blasi & Boitani, 2012; Blasi & Boitani, 2014; Blasi *et al.*, 2015). In this area, both dolphin species interact with local small-scale fisheries, especially gillnet, trammel net and purse seine fisheries targeting small pelagic species ("lampara" nets) and hand-operated squid jig lines ("totanara") (Battaglia *et al.*, 2010; Blasi *et al.*, 2015; Di Natale & Navarra, 2019). These gear types capture numerous species of commercial interest that are also part of the dolphin diet (*Spicara maena, Trachurus* spp., *Oblada melanura, Boops boops, Loligo vulgaris, Engraulis encrasicolus, Sardinella aurita, Sardina pilchardus, Scomber scombrus, Auxis rochei* and *Todarodes sagittatus*; Blanco *et al.*, 2001; Santos *et al.*, 2007). The bottlenose dolphin population in the Aeolian Archipelago has been declining dramatically (Blasi & Boitani, 2014; Leone *et al.*, 2019, Blasi *et al.*, 2020), in part because their favourite prey is often found in areas that overlap with fishing grounds (Blasi & Boitani, 2012; Blasi & Boitani, 2014; Blasi *et al.*, 2015). Moreover, some male bottlenose dolphins have specialized in attacking trammel nets in small groups (Blasi & Boitani, 2012; Blasi & Boitani, 2014; Blasi *et al.,* 2015). Such attacks damage the gear and injure the catch, which can no longer be sold, besides hindering fishing operations. The resulting economic damage is huge as it includes gear repair, lost sales and loss of fishing time. Italian fishers do not receive compensation for such damage, or else compensation is difficult to obtain. Not surprisingly, fishers' attitudes towards cetacean conservation have changed for the worse. In 2017, the tensions due to the threats to their livelihoods escalated, leading to a massive strike by Aeolian fishers. Retaliation events also seem to have increased, as demonstrated by skin injuries, seen on some specimens, that are clearly the result of deliberate human action (Leone *et al.*, 2019).

Several attempts have been made to mitigate dolphin-fisheries interactions in the Mediterranean Sea (Gazo *et al.*, 2008; Buscaino *et al.*, 2009; Maccarrone *et al.*, 2014; Vella, 2016; Bilgin & Kose, 2018; Snape *et al.*, 2018). Acoustic deterrent devices (ADDs), or pingers, are considered as an effective tool (Buscaino *et al.*, 2009; Waples *et al.*, 2013; Maccarrone *et al.*, 2014; Snape *et al.*, 2018). Several studies have demonstrated the ability of different pinger models to reduce dolphin damage (Vella, 2016) or inhibiting cetacean activity (Crosby *et al.*, 2013), especially in Italy (Buscaino *et al.,* 2009; Maccarrone *et al.,* 2014) and the Balearic Islands (Brotons *et al.,* 2008b; Gazo *et al.,* 2008). However, ADDs do not always provide the expected results (Pirotta *et al.,* 2016). Moreover, the fact that in some cases the pingers actually seemed to attract bottlenose dolphin (Aydi *et al.*, 2013) suggests an adaptation to their sound, which may in fact alert groups of dolphins to the presence of fishing gear ("dinner-bell" effect) (Richardson *et al.*, 1995; Cox *et al.*, 2004; Carretta & Barlow, 2011). The phenomenon is likely related to the highly adaptive foraging behaviour of the species (Cox *et al.*, 2004; Brotons *et al.*, 2008b), which makes it hard to predict how a population will react to the device (Leeney *et al.*, 2007; Gazo *et al.*, 2008). The severe threat against fishers' livelihoods therefore calls for additional/alternative mitigation tools suitable to the socio-economic context of each affected area.

Discarding unmarketable fish is a common practice in most fisheries worldwide (Rochet *et al.*, 2002; Sánchez *et al.*, 2004; Catchpole *et al.*, 2005; Hall & Mainprize, 2005;

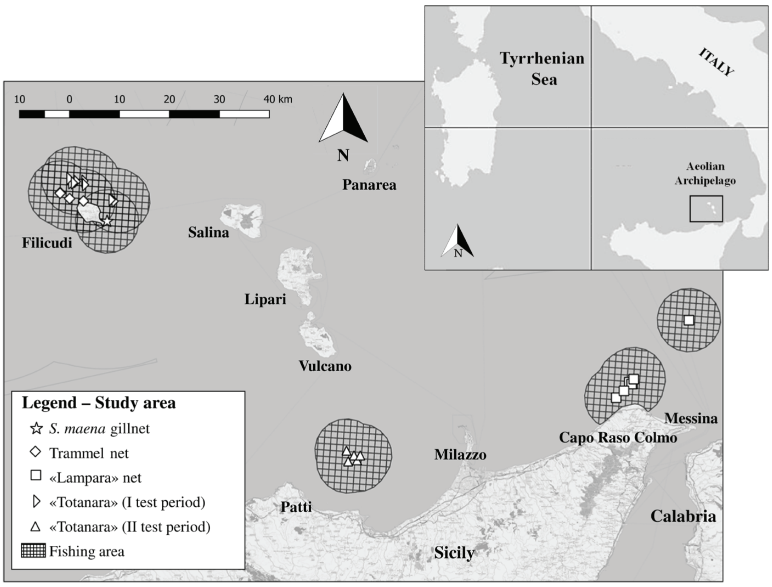

Fig. 1: Aeolian Archipelago (Southern Tyrrhenian Sea, Italy) and the fishing grounds where the trials with the *S. maena* gillnet, the trammel net, the "lampara" net and the squid hand-jig line (I and II test periods) were conducted. Scale: 1:10000 (QGIS 2.18).

Walmsley *et al.*, 2007), but it wastes valuable resources, ultimately leading to stock overexploitation (Hall *et al.*, 2000; Hall & Mainprize, 2005; Bellido *et al.*, 2011). The decision to retain or discard certain species largely depends on local traditions and market demand (Tiralongo *et al.*, 2018). Nevertheless, some abundant species that are commonly discarded have potential economic value (Stergiou *et al.*, 2006; Gonçalves *et al.*, 2007; Batista *et al.*, 2009) and could play a role in marine conservation if they replaced overexploited target species. For instance, *Sparisoma cretense* (Mediterranean parrotfish), the most abundant discard species in the Aeolian Archipelago (Di Natale & Navarra, 2019), has become a target species in other countries due to the decline of the principal fish stocks (Wan & Shao, 2005).

We conducted a pilot investigation to assess the ability of Banana Pingers (FishTek Marine Ltd) to reduce dolphin-fishery interactions in the Aeolian Archipelago. To test their effectiveness, four local gear types were deployed with and without pingers to assess a) signs of dolphin depredation; b) catch composition; c) total and relative catch weight; and d) total and relative revenues. Additionally, the catch of each haul was divided into target species (the more valuable species the fishers wanted to catch, which however are often part of the dolphin diet) and non-target species (commercial bycatch and discards, namely the species with little or low commercial value), to establish whether the sale of the latter fraction could be used to offset the economic loss due to dolphin damage.

The dwindling resident dolphin population, the risks associated with their frequent interactions with fisheries and the threat to fishers' livelihoods require urgent mitigation measures. Our findings provide insights that can help resource management and conservation efforts in the area and promote a shared use of the environment by cetacean populations and small-scale fisheries.

Materials and Methods

Pinger trials were carried out from April to September 2017 in the coastal waters of the Aeolian Archipelago and on the north-eastern coast of Sicily (Fig. 1). Altogether, 36 test-control trials were conducted on four gear types employed by local artisanal fishers: the species-specific *S. maena* gillnet, the trammel net, the "lampara" net and the hand-operated squid jigging line ("totanara"). The test gear was fitted with pingers and compared to the control gear.

The sound source level of Banana Pingers is 145 dB; high-frequency pings (50-120 kHz for 300 ms) are emitted at randomized intervals of 400-1200 ms (EC Regulation 812/2004 of 26 April 2004). The minimum distance preventing interference between pingers is 50 m and the minimum depth for their automatic activation is 1 m.

All trials were performed at night and ranged from a few hours (8:00 p.m. to 12 p.m. for the *S. maena* gillnets and the trammel nets) to the whole night ("lampara" nets and squid hand-jig lines). The pingers were set as shown in Figure 2.

Preliminary interviews with fishers allowed collecting information on the socio-economic situation of local fisheries and the severity of dolphin depredation on the different gear types. The sale price of each species caught (€/kg) was recorded directly at the fish market (Table S1), to calculate the revenue (€) generated by each trial and estimate the pingers' economic effect.

Economic, legal, technical aspects and local traditions are major drivers of the market value of each species (Rochet & Trenkel, 2005) and of fishing effort distribution in given areas or periods. We categorized each fish species found in the catch according to three criteria: a) being the target of one of the gear types, b) being part of the dolphin diet, and c) market value; in turn, the latter is

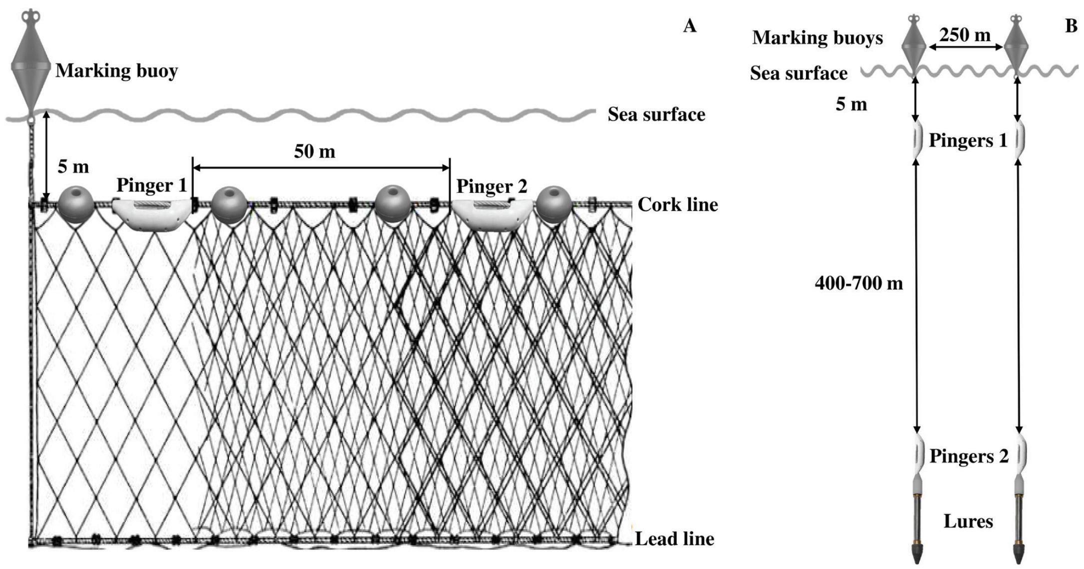

***Fig. 2**:* Pinger setup. A) Fishing nets and B) fishing lines.

the result of a combination of sale price (€), catch weight (kg), and occurrence (%).

The following data were collected for each test and control gear: a) total catch weight (kg); b) occurrence (%) and relative weight (kg) of each target and non-target species; and c) occurrence (%) and severity of dolphin damage (number of holes and/or weight of the damaged fish) as determined by the fishers (Díaz-Lopez, 2006).

Based on a recent report (Di Natale & Navarra, 2019) which described peaks of bottlenose dolphin depredation events in early summer, the study was conducted in early summer (April-May), midsummer (June-July) and late summer (September), to document any seasonal differences in depredation events (%).

Catch weight and revenues are reported as mean ± standard deviation (SD) and occurrence as percentage. The Kruskal-Wallis and Mann-Whitney tests were applied to assess differences in catch, weight, revenues and dolphin damage between the test and the control gear using R software 4.03.

Pinger trials

S. maena *gillnet*

This gillnet – whose mesh opening depends on target species size – is widely used to catch *S. maena* (blotched picarel) especially in their breeding grounds (*Posidonia* meadows; depth, 5-20 m). The *S. maena* gillnets used in the trials were 400 m long and 3 m high; mesh opening was 35.6 mm (Fig. 3A). The average setting depth was 15.2 m.

Six trials were performed in the coastal waters of Filicudi Island (Fig. S1) in May, the peak of the reproduction period of *S. maena*. Test nets (n=4) with 7 pingers and control nets (n=2) without pingers (Fig. 2A; Fig. 3A) were set on consecutive days, to account for the natural variation of fish distribution in the area (~1 km^2) and avoid correlating variations to dolphin depredation.

Trammel net

Trammel nets are fixed gear consisting of three netting panels with different mesh size. Their setting depth ranges from 20 to 80 m, to catch a wide range of coastal demersal species such as *Phycis phycis O. melanura, S. maena, B. boops, Diplodus* spp., *Sepia officinalis, Epinephelus marginatus* and *Pagellus bogaraveo*, all of which are part of the bottlenose dolphin diet (Blanco *et al.*, 2001). Since these species are commonly caught at night, the nets were left to soak overnight.

The experimental trammel nets were 350 m long and 5 m high; the mesh size of the internal and external panels was 44.2 and 180 mm, respectively (Fig. 3B). The average setting depth was 21.8 m.

Ten trials were performed around Filicudi Island from May to July (Fig. S1). The test and control nets were set 400 m apart, a sufficient distance to prevent the pingers to exert effects on the control net but sufficiently close to have similar habitat characteristics. Five pingers were mounted on each test net (Fig. 2A).

Fig. 3: Experimental fishing gears: A) *Spicara maena* gillnet; B) trammel net; C) “lampara” net (setting and hauling operations); D) squid hand-jig line.

"Lampara" net

This is a purse seine that relies on lamps ("lampara") to aggregate schools of small pelagic fish, mainly anchovy, at night. Multiple vessels are commonly involved. A rowing boat (length overall > 4 m) carrying the lamps attracts and aggregates the fish schools; then, one or more smaller vessels set the net (450 m long, 45 m high, mesh size ~14 mm) around them (Fig. 3C). The entire purse seine is commonly set in less than 10 min. The net is then closed by hauling in the purse line. Hauling usually lasts < 1 h. The operation can be performed several times in the same night, usually at sites 2 to 9 km apart. In our trials the interval between operations was ~160 min, which was felt to be sufficient to prevent any dolphin swimming close to the net or following the boat from one fishing site to the next from correlating the test and the control nets. All fishing operations were conducted in habitats with similar characteristics at an average depth of ~50 m, to catch target species like *Trachurus mediterraneus, E. encrasicolus, S. aurita, S. pilchardus, S. scombrus* and *A. rochei*, which are part of the bottlenose dolphin diet (Santos *et al.*, 2007). Seven trials were carried out in June between the Aeolian Archipelago and the north-eastern coast of Sicily (Fig. 1). Ten pingers were mounted on the test nets (Fig. 2A; Fig. 3C).

Hand-operated squid jig line ("totanara")

The hand-operated squid jig line ends with a cone-shaped tip ~10 cm long that is equipped with one or more hook crowns. Since the line is controlled manually from the boat, gear efficiency is closely related to operator skill. The body of the gear is a light-emitting pole ~50 cm in length that lures the target species – the European flying squid, *T. sagittatus* – to the hooks. The devices are set ~250 - 500 m apart and are lowered to between 400 and 700 m. At sunset, they are hauled to a depth of ~70 m, where a baited "totanara" has previously been set (Fig. 3D).

The jig line trials were performed in two periods. Eight trials were conducted off Filicudi Island (Fig. S1) between June and July (I test period). They involved deploying 10 lamps simultaneously (total, n=80). Pingers were randomly applied on 38 of them (Fig. 2B), to avoid statistical bias. In the absence of published protocols, 5 different pinger setups were tested (Fig. S2). In September (II test period), 5 trials were conducted in the area between Vulcano Island and the Sicilian coast, off the town of Patti (Fig. 1). Four lamps were deployed simultaneously; however, at variance with the early summer trials, the test (n=12) and control (n=8) lamps were used on different days. The 6 pingers employed in each trial were mounted as shown in Fig. 2B, to observe whether they exerted any effect on dolphin movement patterns (emerging, patrolling) near the jig line.

Results

Pinger trials

S. maena *gillnet*

The total commercial catch obtained with the *S. maena* gillnets was ~86.10 kg (commercial value, € 516.60), of which 80.03% (69.15 kg, € 414.90) was caught with the test nets. Catch weight varied widely and ranged from 8.45 to 32 kg (17.49 ± 11.01 kg) in the 4 test nets and from 1.95 to 15 kg (8.48 ± 9.23 kg) in the 2 control nets (p-value = 0.03). Accordingly, revenues ranged from € 103.73 (± 66.08; range, € 50.7 - 192) in the test nets to € 50.85 (± 55.37; range, 11.7 - 90) in the control nets. No dolphin damage was observed in the test nets. In contrast, both control nets (100 % occurrence) were damaged (9 holes), reducing catch weight (75%) and revenues (€ 313.20). Non-target species (*Scorpaena scrofa, Sphyraena sphyraena*), which were found only in 3 test nets and in small quantity, were considered negligible for the scope of the study.

Trammel net

Even though different groups of bottlenose dolphin were sighted in the trial area, no dolphin damage was detected either in the test or the control nets. Total catch weight was 207.52 kg (€ 2156.38), of which 58.4% (102.43 kg, € 1258.53) was in the test nets. The difference between the test and the control nets was not significant either in terms of weight (10.24 ± 6.99 kg and 10.49 ± 14.67 kg, respectively; p-value = 0.96) or in terms of revenues (€ 125.85 ± 96.35 and € 89.64 ± 91.00, respectively; p-value = 0.40). In contrast, their catch composition differed, since the target species, which are also part of the bottlenose dolphin diet, were more abundant in the test nets (Table 1). Also, several non-target species, which accounted for 49.2 % (102.05 kg) of the total catch were consistently found in both nets (Table 1).

"Lampara" net

The sea trials caught 7304 kg (€ 11,742) of fish, of which 52.6% (3844 kg, € 5707€) was caught in the test nets. The differences between the test and control nets were therefore not significant, either in term of catch weight (549.14 ± 267.92 kg and 494.29 ± 312.78 kg, respectively; p-value = 0.73) or of revenue (€ 815.29 ± 497.78 and € 862.14 ± 497.73, respectively; p-value = 0.86). Dolphin, which were sighted in proximity of the vessel in test #5, plundered only the control net (14.2 % occurrence), dramatically reducing catch weight (91.6%) and revenues (€ 250). The bycatch species of commercial interest (*S. sphyraena*) occurred only once and was considered irrelevant for the study. The species catch composition showed little variation among trials (Table 2).

Table 1. Catch composition of each trial with the trammel nets. Weight and revenue Sum, Mean, SD and 95% CI are reported for each trial. Target species in bold. (*) Part of the dolphin diet.

Trial	Test net	Control net				
	Species	Weight (kg)	Revenue (€)	Species	Weight (kg)	Revenue (€)
1	***Boops boops****	0.20	1.40	*Chromis chromis**	2.67	9.35
	Muraena helena	4.50	22.50	*Muraena helena*	1.50	7.50
	Phycis phycis*	1.95	39.00	***Scorpaena scrofa***	0.50	12.50
	Scorpaena scrofa	0.95	23.75	***Serranus scriba****	0.09	0.90
	Sepia officinalis*	0.20	3.00			
	Sum	7.80	89.65	**Sum**	4.76	30.25
	Mean	1.56	17.93	**Mean**	1.19	7.56
	± SD	1.79	15.77	**± SD**	1.15	4.90
	± 95%CI	0.05	0.44	**± 95%CI**	0.04	0.15
2	***Oblada melanura****	0.20	1.80	***Phycis phycis****	1.60	32.00
	Phycis phycis*	0.80	16.00	***Serranus scriba****	0.20	2.00
	Sparisoma cretense	3.60	7.20			
	Sum	4.60	25.00	**Sum**	1.80	34.00
	Mean	1.53	8.33	**Mean**	0.90	17.00
	± SD	1.81	7.17	**± SD**	0.99	21.21
	± 95%CI	0.07	0.26	**± 95%CI**	0.04	0.94
3	***Boops boops****	0.40	2.80	***Oblada melanura****	0.65	5.85
	Loligo vulgaris*	0.10	2.00	***Phycis phycis****	1.50	30.00
	Mullus surmuletus*	7.58	151.60	***Scorpaena scrofa***	0.20	5.00
	Pagellus bogaraveo*	0.80	20.00	*Sparisoma cretense*	0.90	1.80
	Phycis phycis*	6.70	134.00			
	*Trachurus trachurus**	1.00	6.50			
	Sum	16.58	316.90	**Sum**	3.25	42.65
	Mean	2.76	52.82	**Mean**	0.81	10.66
	± SD	3.42	70.22	**± SD**	0.54	13.01
	± 95%CI	0.09	1.80	**± 95%CI**	0.02	0.41
4	***Boops boops****	2.00	14.00	***Boops boops****	25.45	178.15
	Mullus surmuletus*	5.10	102.00	***Mullus surmuletus****	0.20	4.00
	Phycis phycis*	1.60	32.00	*Order: Torpediniformes*	0.50	0.00
	Zeus faber	1.50	30.00	***Scorpaena scrofa***	0.30	7.50
				Synodus saurus	1.20	0.00
	Sum	10.20	178.00	**Sum**	27.65	189.65
	Mean	2.55	44.50	**Mean**	5.53	37.93
	± SD	1.71	39.17	**± SD**	11.14	78.45
	± 95%CI	0.05	1.23	**± 95%CI**	0.31	2.20
5	*Muraena helena*	1.50	7.50	***Boops boops****	0.25	1.75
	Order: Torpediniformes	2.40	0.00	***Serranus scriba****	0.15	1.50
	Phycis phycis*	1.20	24.00	*Trachurus trachurus**	45.63	296.56
	Scorpaena scrofa	1.70	42.50			
	Scyllarides latus	0.20	0.00			
	Sparisoma cretense	3.90	7.80			
	Trachurus trachurus*	1.00	6.50			
	Sum	11.90	88.30	**Sum**	46.03	299.81
	Mean	1.70	12.61	**Mean**	15.34	99.94
	± SD	1.18	15.43	**± SD**	26.23	170.28
	± 95%CI	0.03	0.37	**± 95%CI**	0.95	6.16
6	***Boops boops****	0.35	2.45	*Muraena helena*	1.20	6.00
	Epinephelus marginatus*	0.20	5.00	***Oblada melanura****	2.60	23.40
	Phycis phycis*	2.80	56.00	***Octopus vulgaris****	1.50	22.50
	Scorpaena scrofa	2.30	57.50	*Scyllarides latus*	1.00	0.00

Continued

Table 1 continued

Trial	Test net Species	Control net Weight (kg)	Revenue (€)	Species	Weight (kg)	Revenue (€)
6	***Sepia officinalis****	0.30	4.50	*Sparisoma cretense*	2.80	5.60
	Sparisoma cretense	8.30	16.60			
	*Sphyraena sphyraena**	3.15	31.50			
	Spicara maena*	6.65	39.90			
	Sum	24.05	213.45	**Sum**	9.10	57.50
	Mean	3.01	26.68	**Mean**	1.82	11.50
	± SD	3.03	22.86	**± SD**	0.83	10.72
	± 95%CI	0.07	0.51	**± 95%CI**	0.02	0.30
7	***Phycis phycis****	4.80	96.00	***Diplodus****	0.50	12.50
	Scorpaena scrofa	2.70	67.50	***Epinephelus marginatus****	0.30	7.50
	Serranus scriba*	1.60	16.00	***Palinurus elephas***	1.00	70.00
				Phycis phycis*	2.00	40.00
				Sepia officinalis*	0.30	4.50
				Sparisoma cretense	0.90	1.80
	Sum	9.10	179.50	**Sum**	5.00	136.30
	Mean	3.03	59.83	**Mean**	0.83	22.72
	± SD	1.63	40.55	**± SD**	0.64	26.98
	± 95%CI	0.06	1.47	**± 95%CI**	0.02	0.69
8	***Scorpaena scrofa***	1.00	25.00	***Scorpaena scrofa***	1.00	25.00
	*Sphyraena sphyraena**	1.00	10.00			
	Spicara maena*	0.40	2.40			
	*Symphodus tinca**	0.15	1.50			
	Sum	2.55	38.90	**Sum**	1.00	25.00
	Mean	0.64	9.73	**Mean**	1.00	25.00
	± SD	0.43	10.87	**± SD**		
	± 95%CI	0.01	0.34	**± 95%CI**	0.00	0.00
9	***Diplodus****	0.20	5.00	***Boops boops****	0.60	4.20
	Loligo vulgaris*	0.20	4.00	***Phycis phycis****	0.20	4.00
	Mullus surmuletus*	0.40	8.00	***Scorpaena scrofa***	0.80	20.00
	Muraena helena	1.25	6.25	***Serranus scriba****	0.60	6.00
	Oblada melanura*	0.20	1.80			
	Palinurus elephas	0.05	3.50			
	Phycis phycis*	0.20	4.00			
	Scorpaena scrofa	0.40	10.00			
	Spicara maena*	0.20	1.20			
	Synodus saurus	0.80	0.00			
	*Trachurus trachurus**	9.75	63.38			
	Uranoscopus scaber	1.10	11.00			
	Sum	14.75	118.13	**Sum**	2.20	34.20
	Mean	1.23	9.84	**Mean**	0.55	8.55
	± SD	2.71	17.19	**± SD**	0.25	7.69
	± 95%CI	0.05	0.31	**± 95%CI**	0.01	0.24
10	***Mullus surmuletus****	0.10	2.00	***Mullus surmuletus****	0.45	9.00
	Scorpaena scrofa	0.10	2.50	***Phycis phycis****	1.00	20.00
	Serranus scriba*	0.50	5.00	***Serranus scriba****	0.45	4.50
	Spicara maena*	0.20	1.20	***Spicara maena****	2.25	13.50
				Uranoscopus scaber	0.15	1.50
	Sum	0.90	10.70	**Sum**	4.30	48.50
	Mean	0.23	2.68	**Mean**	0.86	9.70
	± SD	0.19	1.64	**± SD**	0.84	7.34
	± 95%CI	0.01	0.05	**± 95%CI**	0.02	0.21

Table 2. Catch composition of each trial with the "lampara" nets. The contribution (%) of total weight and revenue of each species is shown. (*) Depredation event. Weight and revenue Sum, Mean, SD and 95% CI are reported for each trial. The catch consisted exclusively of target species. All species are part of the dolphin diet.

Trial	Test net Species	Control net Weight (kg)	Revenue (€)	Species	Weight (kg)	Revenue (€)
1	*Boops boops*	100.00	200.00	*Auxis rochei*	130.00	650.00
	Sardinella aurita	200.00	100.00	*Sardinella aurita*	360.00	180.00
	Scomber scombrus	320.00	640.00	*Scomber scombrus*	250.00	500.00
	Trachurus mediterraneus	100.00	200.00			
	SUM	720.00	1140.00	**SUM**	740.00	1330.00
	Mean	180.00	285.00	**Mean**	246.67	443.33
	± SD	104.56	241.32	**± SD**	115.04	240.07
	± 95%CI	3.28	7.57	**± 95%CI**	4.16	8.69
2	*Boops boops*	80.00	160.00	*Boops boops*	180.00	360.00
	Sardinella aurita	224.00	112.00	*Sardinella aurita*	320.00	160.00
	Scomber scombrus	240.00	480.00	*Scomber scombrus*	300.00	600.00
	Trachurus mediterraneus	80.00	160.00	*Trachurus mediterraneus*	100.00	200.00
	Sum	624.00	912.00	**Sum**	900.00	1320.00
	Mean	156.00	228.00	**Mean**	225.00	330.00
	± SD	88.00	169.52	**± SD**	103.76	199.67
	± 95%CI	2.76	5.32	**± 95%CI**	3.25	6.26
3	*Sardinella aurita*	20.00	10.00	*Auxis rochei*	60.00	300.00
	Scomber scombrus	50.00	100.00	*Boops boops*	90.00	180.00
				Sardinella aurita	150.00	75.00
				Scomber scombrus	80.00	160.00
				Trachurus mediterraneus	120.00	240.00
	Sum	70.00	110.00	**Sum**	500.00	955.00
	Mean	35.00	55.00	**Mean**	100.00	191.00
	± SD	21.21	63.64	**± SD**	35.36	84.88
	± 95%CI	0.94	2.82	**± 95%CI**	0.99	2.38
4	*Boops boops*	120.00	180.00	*Auxis rochei*	30.00	150.00
	Engraulis encrasicolus	160.00	320.00	*Engraulis encrasicolus*	100.00	200.00
	Oblada melanura	80.00	240.00	*Sardinella aurita*	100.00	50.00
	Sardinella aurita	80.00	40.00	*Scomber scombrus*	130.00	260.00
	Scomber scombrus	320.00	640.00			
	Trachurus mediterraneus	60.00	120.00			
	Sum	820.00	1540.00	**Sum**	360.00	660.00
	Mean	136.67	256.67	**Mean**	90.00	165.00
	± SD	96.68	211.06	**± SD**	42.43	88.88
	± 95%CI	2.48	5.40	**± 95%CI**	1.33	2.79
5*	*Sardinella aurita*	500.00	250.00	*Scomber scombrus*	40.00	80.00
	Trachurus mediterraneus	40.00	80.00			
	Sum	540.00	330.00	**Sum**	40.00	80.00
	Mean	270.00	165.00	**Mean**	40.00	80.00
	± SD	325.27	120.21	**± SD**		
	± 95%CI	14.42	5.33	**± 95%CI**	0.00	0.00
6	*Boops boops*	80.00	120.00	*Scomber scombrus*	200.00	400.00
	Sardina pilchardus	80.00	160.00			
	Scomber scombrus	80.00	160.00			
	Trachurus mediterraneus	80.00	160.00			
	Sum	320.00	600.00	**Sum**	200.00	400.00

Continued

Table 2 continued

Trial	Test net Species	Control net Weight (kg)	Revenue (€)	Species	Weight (kg)	Revenue (€)
6	**Mean**	80.00	150.00	**Mean**	200.00	400.00
	± SD	0.00	20.00	**± SD**		
	± 95%CI	0.00	0.63	**± 95%CI**	0.00	0.00
7	*Boops boops*	120.00	180.00	*Engraulis encrasicolus*	250.00	500.00
	Sardinella aurita	350.00	175.00	*Sardina pilchardus*	120.00	240.00
	Scomber scombrus	200.00	400.00	*Sardinella aurita*	100.00	50.00
	Trachurus mediterraneus	80.00	320.00	*Scomber scombrus*	250.00	500.00
	Sum	750.00	1075.00	**Sum**	720.00	1290.00
	Mean	187.50	268.75	**Mean**	180.00	322.50
	± SD	119.27	110.33	**± SD**	81.24	219.15
	± 95%CI	3.74	3.46	**± 95%CI**	2.55	6.87

Hand-operated squid jig line ("totanara")

The total catch in the first test period was 324.70 kg (n=743 specimens) and was worth € 3008. *T. sagittatus,* the target species, accounted for 97.7% (€ 2938). Specimens > 2 kg are considered as commercial bycatch, due to their low market value (€ 5/kg vs € 13/kg). However, their occurrence was limited (1.9 %, n=14). The differences between the test (14.25 ± 5.93 kg, € 185.25 ± 77.13) and the control (14.00 ± 5.43 kg, € 182.00 ± 70.55) gear were not significant. There were no dolphin sightings during the trials, suggesting a natural distribution of *T. sagittatus*.

In contrast, dolphins were sighted in 3/5 (60%) trials of the second test period (Fig. S2). Compared with the first period, total catch weight (19.80 kg) and revenues (€ 257.40) were significantly lower (p-value = 0.007 and 0.0002, respectively), whereas the difference between gears was not significant (test, 2.67 ± 1.26 kg, € 34.67 ± 16.36; control, 5.90 ± 0.85 kg, € 76.70 ± 11.03). Finally, *T. sagittatus* > 2 kg did not occur in this period and striped dolphin plundered all the lamps of the 3 test jig lines (83.3% occurrence). We also found differences in the occurrence of depredation events between midsummer (0.93%; n=1) and early/late (63.16%; n=12) summer.

Discussion

Our study is the first to evaluate the effectiveness of pingers in mitigating dolphin depredation in the Aeolian Archipelago, which is characterized by severe dolphin-fishery interactions (Blasi & Boitani, 2014; Blasi *et al*., 2015).

The Banana Pingers have been tested in different areas of the world, but their inconsistent effect in avoiding bycatch (Akande, 2018; Björklund Aksoy, 2020; Omeyer *et al*., 2020) has prevented their widespread adoption in marine resource management. We assessed their ability to prevent dolphin poaching of four gear types. The effect was strongest for the *S. maena* gillnets and the "lampara" nets – the most widely used gear types in these coastal areas – through reduced gear depredation (by 100% and 85.7%, respectively), potential losses per haul (€ 50-250 due to plundering of the marketable catch) and gear damage (€ 390).

Poaching events were more frequent in early and late summer than in midsummer, despite the fact that most trials took place in the latter period. This finding is consistent with similar studies describing a seasonal peak of bottlenose dolphin depredation events between February and June in the area (Battaglia *et al*., 2010; Blasi *et al.,* 2015; Di Natale & Navarra, 2019). Nevertheless, further data are required, since poaching of "lampara" and trammel nets is more frequent in the periods for which we have no data (Battaglia *et al*., 2010; Blasi *et al*., 2015).

The effect of the Banana Pingers on the depredation of squid hand-jig lines was variable. This is consistent with studies of depredation occurrence (Lapiccirella *et al.,* 2018) and of the effectiveness of pingers emitting sound continuously on pelagic cetaceans (Cruz *et al.,* 2014); in particular, this gear is poached by several dolphin species, including *T. truncatus, S. coeruleoalba, Grampus griseus* and *Globicephala melas*, regardless of pinger presence. In the Southern Tyrrhenian Sea, striped dolphin attack squid hand-jig lines throughout the year, disturbing fishing operations and plundering the catch (Di Natale & Navarra, 2019). According to our data, the mean economic loss for this gear was € 132.15 per fishing session and ~€ 2700 per fishing season. In the first test period, in the trials around Filicudi Island – where striped dolphin interacts less with this gear in summer (Caserta *et al.*, 2019) – the test lamps were not plundered. In the second test period – when trials were performed between Vulcano Island and Sicily, which is highly frequented by striped dolphin as well as fishers (Fortuna *et al.*, 2007) – the pingers not only failed to keep the dolphin away, but they actually appeared to attract them. Cruz *et al.* (2014) have reported that two pinger models emitting sound continuously had no effect on Risso's dolphin interactions with the squid fishery, neither scaring them away nor attracting them. Despite the limited literature on squid hand-jig lines, it cannot be excluded that some physical features of pelagic habitats may affect pinger emissions (Cruz *et al.*, 2014). Although pingers have clear effects on coastal marine mammals (Battaglia *et al.*, 2010; Akande, 2018;

Björklund Aksoy, 2020), several studies have described failures due to the interference of background noise or to starving-driven depredation due to habitat degradation (Hardy & Tregenza, 2010; Carretta & Barlow, 2011; Snape *et al.*, 2018).

Different types of pingers should be tested. Interactive pingers should not involve habituation, because they are activated by dolphin whistles (Marçalo *et al.* 2019); however, even these ADDs may be ineffective, even though they do not seem drive striped dolphins outside their usual feeding habitats or to induce dramatic changes in behaviour (Cruz *et al.,* 2013). Further work is also required to establish whether dolphin may develop habituation or attraction ("dinner bell" effect) to the sound (Carretta & Barlow, 2011; Akande, 2018).

Furthermore, after the swordfish driftnet fishery was banned in 1998 (Council Regulation (EC) no. 1239/98 and Council Reg. no. 809/2007), fishers in the Aeolian Archipelago had to convert their pelagic fishing gear to coastal gear, which involved a dramatic increase in squid catches. Yet, current legislation does not regulate the sustainability of this fishery, since Art. 4 of Coast Guard's Order no. 40/2013 only limits the number of lamps that can be deployed. Moreover, lack of knowledge of the biology and current stock status of *T. sagittatus*, which is considered by the International Union for the Conservation of Nature (IUCN) as a "least concern" species (Barratt *et al.*, 2014), hampers the adoption of a management plan. We found squid of all sizes in the catch, although large specimens (> 2 kg), for which demand is limited, accounted for only 1.9% (€ 112) with seasonal peaks (87.5 % in summer) that are unrelated to dolphin presence. It cannot be excluded that the occurrence of large squid is seasonal and that their scarce presence in our trials was the result of overfishing of non-reproductive specimens the previous year. According to Lapiccirella *et al.* (2018), fishing success is largely related to the number of squid that have been attracted to the surface, which in turn depends more on environmental and operational conditions than on dolphin depredation. From an economic standpoint, taking large squid to the fish market would increase revenues by 38.5 % per fishing session. However, we feel that the introduction of such mitigation measure might further increase the fishing effort, depleting the residual reproductive stock of *T. sagittarius*. Further studies are needed to explore striped dolphin interactions with this fishery (Fortuna *et al.*, 2007) and guide effort distribution measures.

As regards the trammel nets, the period when the trials were conducted did not allow assessing pinger effectiveness. Although bottlenose dolphin was sighted throughout the study period, neither the test nor the control net exhibited signs of dolphin damage. It is unclear whether the difference in the catch composition of the target species that are also part of the dolphin diet (Table 1) was due to natural variation in fish distribution or to the pingers. However, the trammel net trials provided a unique opportunity to study species distribution and assess the potential economic value of target and bycatch species. Bycatch accounted for nearly 50% of the total weight of the trammel net catch, consistent with published data of between 10% and 66% (Kelleher, 2005; Tzanatos *et al.,* 2007). Considering that 98.8% of the bycatch has no market value and 1.2% cannot be sold (*Scyllarides latus* and *Order: Torpediniformes*), the landing success is halved. The low value of non-target species results in a mean economic loss of € 27.85 € per fishing session, more in case of dolphin depredation (Di Natale & Navarra, 2019). The sale of species that are particularly abundant but have little or no commercial value, such as *T. trachurus* (Di Natale & Navarra, 2019), could go some way towards offsetting the economic loss caused by dolphins (Fig. 4).

Even though in areas such as the Aeolian Archipelago *T. trachurus* is not viewed as a target species, its major contribution to the catch weight and its high demand by consumers on other islands make it potentially valuable. Therefore, since it is part of the dolphin diet (Santos *et al.*, 2007), its depredation can cause considerable economic loss. In contrast, the low market value of *S. cretense* and *Muraena helena* – the most abundant non-target species in the area – prevents their being considered as compensation for dolphin damage, as in the case of other remote fish markets. As noted by Di Natale & Navarra (2019), *S. cretense* and *M. helena* sell respectively for 10 €/kg and 6-10 €/kg on Lipari and Salina Islands, whereas on Filicudi Island they sell for as little as €2/kg (-80%) and €5/kg (-37.5%). If a similar price could be obtained on Filicudi, the respective revenue would rise to € 27.20 and € 5.97 per fishing session. Moreover, since neither species is part of the dolphin diet, the potential revenue would not be at risk. Altogether, promoting the sale of non-target species would involve a fairer sharing of marine resources, distributing the fishing effort over a wider range of species (Pet-Soede *et al.,* 2001), most of which are not part of the dolphin diet (Santos *et al.,* 2007). Clearly, adequate public outreach (Nuñez *et al.,* 2012) is a precondition for the generation of consumer demand.

Conclusion

Our study provides novel data about dolphin-fishery interactions including their severity, seasonality and distribution. Despite its short-term nature, the study outlines a severe ecological and socio-economic situation due to the fact that the widespread presence of fishing gear has generated an unexpected dependence of dolphin on a food source that is very easy to plunder. Although pingers and the sale of non-target species can provide some mitigation, they are insufficient by themselves. Increasing our understanding of cetacean and fish population dynamics and seasonality could help guide environmental protection actions and improve fishery efficiency. However, total fishing bans would not be socially or economically sustainable. Reducing the number of active vessels could be another way to limit the fishing pressure on both dolphin and fish populations. Offering incentives for converting to non-fishing activities (e.g., dolphin watching as a tourist attraction) or retirement plans would also provide a contribution. Appropriate awareness campaigns

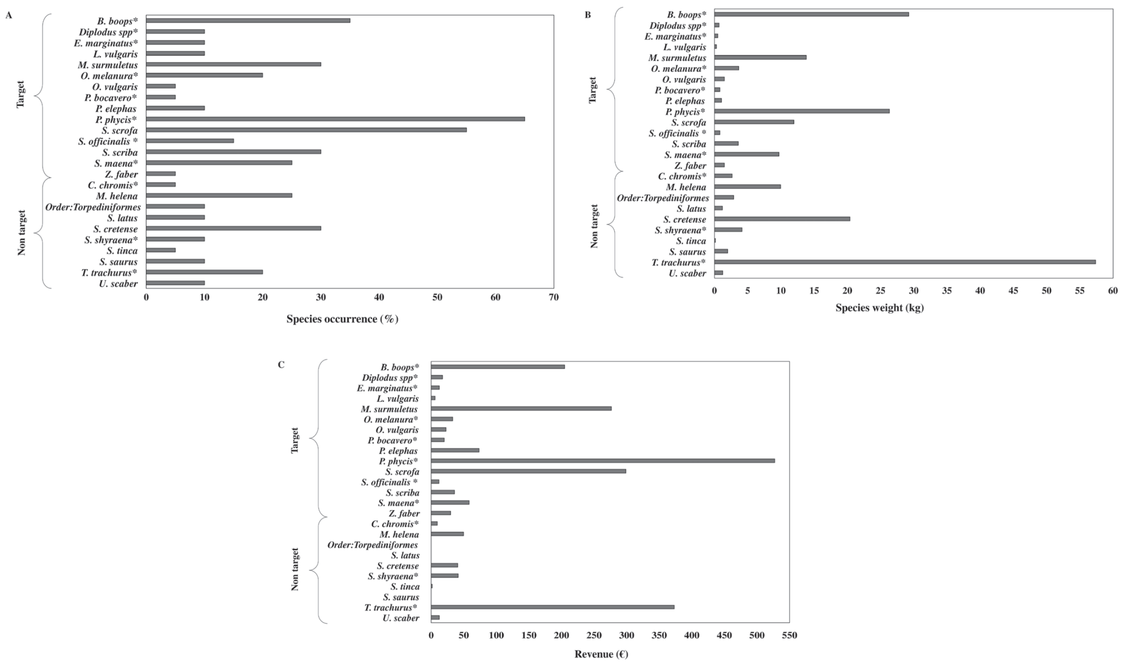

Fig. 4: Target and non-target species found in the trammel net trials. A) Species occurrence (%), B) Species weight (kg) and C) revenue (€) in the test and control nets (n=20). (*) Part of the dolphin diet.

would also help generate the demand for sustainable activities involving cetaceans and would encourage the authorities to implement marine protected areas and a code of conduct for the conservation of cetacean species.

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Supplementary data

The following supplementary information is available online for the article:
Table S1. Market price of all target and non-target species caught by each fishing gear.
Fig. S1: Distribution of fishing trials around Filicudi Island. Scale 1:1000 (QGIS 2.18). Aeolian Archipelago, test period.
Fig. S2: The five-pinger setup combinations used on squid hand-jig lines in the first test period. The fishing line starts from the leftmost buoy.