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Assessment of the bycatch level for the Black Sea harbour porpoise in the light of new data on population abundance

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Incidental catch in fishing gear (often known as bycatch) is a major mortality factor for the Black Sea harbour porpoise (*Phocoena phocoena relicta*), an endemic subspecies listed as Endangered in the IUCN Red List. The primary gear, responsible for porpoise bycatch in the Black Sea are bottom gillnets and trammel nets targeting turbot (*Scophthalmus* spp.), the most valuable commercial fish species in the Black Sea. From 2019 to 2021, a study was conducted in Bulgaria, Romania, Türkiye and Ukraine, to estimate the bycatch level in light of new information on porpoise distribution and abundance obtained from aerial surveys (CeNoBS) undertaken in 2019 as part of ACCOBAMS Survey Initiative (ASI). Bycatch data were collected by independent observers onboard turbot fishing boats (Bulgaria and Romania), complemented by questionnaire surveys and examination of stranded carcasses (in all countries). Some 48 monitoring trips took place (63 hauls by 11 different vessels). Cetaceans were caught on just over half of the trips (55%): 182 harbour porpoises, 4 bottlenose dolphins and 3 common dolphins. The median number of porpoises bycaught per trip was 1 (maximum 41) and the number of porpoises per km of net varied between 0 and 3.66 (median 0.1). Bycatch rates showed seasonal variation with marked increase in summer, compared to spring. The total annual bycatch of harbour porpoises in the Black Sea was roughly estimated as between 11 826 and 16 200 individuals. These numbers were the product of median values for effort (days/trips and vessels) and bycatch rate. Given the new estimates of porpoise abundance based on the CeNoBS survey of 2019 and reconciling abundance and bycatch estimates, harbour porpoise bycatch in the Black Sea represents between 4.6% - 17.2% of the estimated total population, depending on assumptions used. Even the most conservative estimate is among the highest worldwide and far exceeds the probable sustainable levels of around

1.0-1.7%. This study confirms that bycatch poses the most serious threat to the Black Sea harbour porpoises and that all riparian countries engaged in turbot fisheries must implement urgent measures to reduce it immediately, if the population is to survive in the long-term.

KEYWORDS

Black Sea, harbour porpoise, bycatch, gillnets, on-board observation, Phocoena phocoena

1 Introduction

Three species of cetaceans are found in the Black Sea that are designated as endemic subspecies: the Black Sea harbour porpoise (*Phocoena phocoena relicta* Abel, 1905); the Black Sea bottlenose dolphin (*Tursiops truncatus ponticus* Barabash-Nikiforov, 1940); and the Black Sea common dolphin (*Delphinus delphis ponticus* Barabash, 1935) (Figures 1–3). All of them are considered as vulnerable or endangered due to several historical and current adverse factors affecting their populations (Birkun et al., 2014). Among these factors, the primary one was the commercial hunting of cetaceans in the Black Sea which was highly intensive between 1929 and 1966 when a ban was adopted by the USSR, Bulgaria and Romania. It continued in Turkish waters until 1983 (Kleinenberg, 1956; Tonay and Öztürk, 2012). Additionally, a genetic study indicated a strong reduction in the population size of Black Sea harbour porpoise (approximately 90%) in the second half of the 20th century, possibly due to massive dolphin fisheries and bycatch (Fontaine et al., 2012).

Nowadays, Black Sea cetaceans are protected in the riparian countries at both national and international levels. They are listed in the IUCN Red List, national Red Data Books, and (in EU waters) annexes II and IV of EU Habitats Directive 92/43/EEC and in Descriptor 1 (D1, Biodiversity) of EU Marine Strategy Framework Directive (MSFD) 2008/56/EC.

Incidental catch in fishing gear (henceforth referred to as bycatch) is a major threat for populations of small cetaceans in European seas, and the greatest source of non-natural mortality for many (Dolman et al., 2016; Amaha Öztürk, 2021). In Europe, cetacean bycatch is considered under the above-mentioned EU Directives, the EU Common Fisheries Policy (CFP) and the two regional CMS (Convention for Migratory Species) agreements on the conservation of cetaceans: ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas) and ACCOBAMS (Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area) - the latter one covering the Black Sea. Bycatch mortality is specifically identified as criterion D1C1 assessed in the current cycle of EU MSFD implementation for 'good environmental status' (GES) for cetaceans.

A quantitative understanding of the effect of bycatch on affected populations is key to being able to undertake (and later evaluate) effective bycatch mitigation measures (e.g. Moore et al., 2021; Wade et al., 2021). Determining an 'acceptable' removal rate (taking into account inevitable uncertainty) for a cetacean population is not easy and several suggestions have been put forward. For example, ASCOBANS agreed to a 'limit' of 1.7% of the harbour porpoise abundance as appropriate for the GES (Moffat et al., 2011; ASCOBANS, 2015). Other approaches are used elsewhere such as the estimated potential biological removal (PBR) used in the USA – this has been parameterised to be equal to 1% of the minimum

FIGURE 1
Bycaught Black Sea harbour porpoise.

FIGURE 2
Bycaught Black Sea bottlenose dolphin.

FIGURE 3
Bycaught Black Sea common dolphin.

abundance estimate for cetaceans (Wade, 1998). More recently, Manlik et al. (2022) proposed an approach they called sustainable anthropogenic mortality in stochastic environments (SAMSE): this method gives an estimate of sustainable bycatch level for bottlenose dolphins to be not more than 0.5% of abundance estimate.

Historically, several kinds of fisheries have been identified as primary sources of cetacean bycatch in the Black Sea including:

- turbot (*Scophthalmus* spp.) gillnet/trammel fishery (Vasiliu and Dima, 1990; Pavlov et al., 1996; BLASDOL, 1999; Anton et al., 2010; Radu and Anton, 2014; Tonay, 2016; Bilgin et al., 2018);
- sturgeon (Acipenseridae) trammel net fishery (Pavlov et al., 1996; Vishnyakova and Gol'din, 2015a);
- dogfish (*Squalus acanthias*) gillnet fishery (Birkun et al., 2009);
- pound net fishery (Vasiliu and Dima, 1990);
- purse seining (Birkun et al., 2014); and
- pelagic trawling (Özdemir and Erdem, 2011; Birkun et al., 2014).

By far the largest bycatch (90 to 98% by number) reported by the above studies was that of the Black Sea harbour porpoise. Most cetacean bycatch was due to illegal, unreported and unregulated (IUU) fishing operations - this makes estimation of deaths difficult to obtain from the preferred method – direct observations. A previous estimation of cetacean bycatch numbers in the Black Sea (Birkun et al., 2014), based on historical data and extrapolation, suggested an annual catch of at least 20 000 animals (of which over 11 000 were in gillnets for turbot) – probably greatly exceeding any sustainable level. Tonay (2016), based on onboard observations of part of the fleet, estimated the annual bycatch of harbour porpoises to be around 2 000 animals (CV=0.37) in the Turkish western Black Sea which is the most precise sub-regional bycatch estimate available. Vishnyakova (2017) undertook a demographic study of the harbour porpoise population in the Azov Sea. It showed that bycatch was the main mortality factor for the Azov population, which declined by 60% over 13 years (2000-13). Clearly, this could be applicable to some other parts of the Black Sea.

The present study focused on developing and applying a standard approach to bycatch monitoring in the Black Sea with a view to filling the existing gaps on distribution, levels and effects of bycatch pressure on cetaceans in the region. The research was undertaken across several Black Sea riparian countries and the objective was to identify and evaluate patterns of cetacean interactions with fisheries. The methodological framework was developed for collecting field data and bycatch assessment, and the field surveys were conducted in Bulgaria, Romania, Türkiye and Ukraine between 2019 and 2021. The estimated bycatch level of the Black Sea harbour porpoise as the most affected species was compared to the most up-to-date abundance estimate derived from the summer 2019 aerial survey of the basin (Paiu et al., 2021a), which is the most comprehensive until now.

2 Material and methods

The study included information collected by questionnaire surveys and data from onboard observers, supplemented by data from cetacean stranding records and fishing effort (fleet size, annex 1). All these data were used to estimate total bycatch that was compared to total abundance estimated by the 2019 aerial survey (Paiu et al., 2021a) This approach using several sources of information is broadly following the recommendations of Wade et al. (2021). Each step is described below.

2.1 Questionnaire development and application

The questionnaire developed was based upon a review of similar exercises throughout the world and the experiences of the authors (Zappes et al., 2018; Filgueira dos Santos et al., 2021). Special attention was devoted to the aspects of fishing operations which are often concealed and missing in reports. Since cetaceans are legally protected in the Black Sea countries, fishermen have a tendency to deny or under-report bycatch, even if it occurs during legal fisheries operations. Therefore, the questionnaire was designed with indirect indicators to understand the bycatch potential of certain fishing practices, net types and operations. The final questionnaire was largely based upon that developed for the coast of the northwestern Spain (Goetz et al., 2014) supplemented with questions used in published studies from the Black, Mediterranean, Caspian Seas and the Persian Gulf (Dmitrieva et al., 2013; Jabado et al., 2015; FAO, 2019). Taking into account the completeness and comprehensiveness of the questionnaire developed by Goetz et al. (2014), its structure and principles of the interview were used in this survey. These included close-ended questions prevalence together with open-ended, 'don't know' answer options, understandability and anonymity. The list of variables used here followed Goetz et al. (2014) and Table 1 therein. Included questions were on fleet segment (vessel and gear types), number of vessels, frequency and duration of operations, net types, target and main discard species, cetacean behaviour near the fishing operations, personal attitude of fishermen to cetaceans, depredation by cetaceans, all kinds of bycatch (including fish and birds), survival of bycaught animals, intensity and dynamics of interactions with fisheries. Voluntary interviews covering the broadest scale of the fisheries types, company sizes and port sizes across the area were conducted using local languages, in an informal environment. No personal data were collected during the interviews. Analysis of interviews followed qualitative approach such as that used by Carruthers and Neiss (2011) and Mustika et al. (2021). Mann-Whitney U tests were used for detecting statistically significant differences between samples and sub-samples when necessary.

2.2 Onboard data collection on cetacean bycatch

Onboard observers monitored catch and bycatch during regular fishing operations of gillnet fisheries targeting turbot species (*Scophthalmus maeoticus, S. maximus, S. rhombus*), the most valuable commercial fish in the Black Sea. In Bulgaria approximately 3% of turbot fishing fleet was monitored on basis of willingness of shipmasters to accept observers, and in Romania 2.4% of the active vessels able to fish with stationary nets or bottom trawling were covered by the study. Standard protocols provided by the General Fisheries Commission for the Mediterranean (GFCM) were adopted for collecting standardized information on fishing operations and bycatch of cetaceans by onboard observers (FAO, 2019). These included general data on the vessel, data on fishing operations for each vessel; general information on fishing trip (number of hauls, location, duration, catch data) and general information on bycatch of vulnerable species and existence of marine litter for each onboard observation; biological data on bycaught marine mammals. For several small-size boats that could not accommodate independent observers, data were collected by fishermen.

During the onboard data collection, 27 (43%) of the observed 63 hauls included strings fitted with acoustic deterrent devices (ADDs or pingers) as a mitigation measure: therefore, use of pingers hypothetically might have caused reduction of bycatch level. Pinger trials included two types of configurations. In 2019 mixed sets of nets were used combining active and control parts. In 2020 and 2021 trials were using pair of sets - active and control - that were situated at minimum distance of 500 m.

2.3 Cetacean stranding surveys

Strandings can be used as supplementary source of data on the cause of death, as well as demographic data, for subsequent population and health analyses (Vishnyakova and Gol'din, 2015b). During the current study, cetacean stranding data were collected as supplementary evidence for the occurrence of bycaught cetaceans ashore during the seasons of observations. Surveys were conducted by some of the authors and information from existing databases was used (Bulgaria: Popov and Meshkova, 2022; Ukraine: Vishnyakova et al., 2021; Romania: Paiu et al., 2022; Türkiye: Paiu et al., 2021b and İÜ-TUDAV, unpubl. data).

2.3.1 Bulgaria and Ukraine

Overall data on strandings were collected by field surveys and opportunistically through citizens' reports verified by photographs. In addition, in Ukraine, specific monitoring routes, 4 km each, located near the fisheries facilities (Kurortne, Sasyk, Shagany, Lebedivka-Burnas, Chornomorsk, Odesa, Tendra, Zalizny Port, Dzharylhach), were checked for presence of cetaceans and signs of bycatch.

2.3.2 Romania

The area between Corbu and Vama Veche was under surveillance both in 2019 and 2020. The surveys were done mainly on foot and when possible, by all-terrain vehicle. Surveys were conducted by Mare Nostrum NGO-coordinated National Monitoring Network that includes volunteers and partner institutions (Dobrogea Littoral Water Basin Administration, National Agency for Fishery and Aquaculture, Dobrogea Inspectorate for Emergency Situations, Police and Coast Guard).

2.3.3 Türkiye

Data was collected through local stranding surveys, citizens' and media reports by İÜ-TUDAV Cetacean Stranding Network.

2.4 Fishing effort assessment

The most robust measure used for fisheries assessment in the Black Sea is the fleet size (the number of vessels licensed for turbot fishery) where fishing effort is quantified as the number of trips (Gómez-Munõz, 1990; McCluskey and Lewison, 2008). These data are the most consistent and the best quantified across a region with diverse practices and regulations and frequent IUU fishing (Gómez-Munõz, 1990). Each trip is equal to a fishing day and may involve one or more hauls depending on length of strings of nets that were set. It is specific for the Black Sea turbot fishery that usual soaking time of nets is longer – from 7 to 20 days. That is taken into account by the unit of effort described in part 3.2. The fishing fleet structure was analysed using GFCM reports (FAO, 2020; STECF, 2020). Additionally, the national assessments of the fleet in Bulgaria, Romania, Türkiye and Ukraine were obtained from the competent authorities upon requests or from open access sources. In view of the comparability of the estimates obtained, the GFCM reports were used as the main data source for the fleet structure assessment for Bulgaria, Romania and Ukraine. For Türkiye, the national assessment was used as the best primary source due to its more complete and detailed analysis of fleet (TUIK, 2019). Also, in Ukraine, the numbers of vessels involved in turbot fishery was assessed on site during the questionnaire survey, since the data on the number of currently operating small vessels were not included into official statistics.

2.5 Total bycatch assessment

Total bycatch for Bulgaria, Romania, Türkiye and Ukraine, which comprised the major part of observable fishing operations in the Black Sea was estimated only for the harbour porpoise. The two other cetacean species were not assessed due to the low numbers of observed bycatch which precluded the development of robust estimates. Given the inevitable uncertainty of data on fishing effort and bycatch reporting, the assessment was based on the assumptions listed below.

1. Bycatch occurs exclusively in gillnets: although different type of fishing gear, including static nets set or pelagic trawls can cause bycatch of harbour porpoises, their impact seems to be minor in comparison with the gillnets (Radu and Anton, 2014). In the past, the use of three-walled trammel nets in turbot fishery was reported (Radu et al., 2003; Samsun and Kalaycı, 2004; Tonay, 2016), but since the use of these nets is prohibited in turbot fishery, they are considered as limited to some IUU operations (Gol'din, personal data) and were not considered here.
2. All the gillnets of the mesh size 160 to 200 mm have equal potential for bycatch: historically it was suggested that nets of 120-140 mm mesh size were especially dangerous for cetaceans (Birkun et al., 2009). However, at the time of this study they are not used in the sea.
3. Most bycatch are not reported by fishermen, regardless of the fishing being legal or IUU, due to the protected status of cetaceans under national legislation; uncertainty in legal definitions of incidental catch; the absence of a code of conduct for incidental catch situations; and fear of prosecution.
4. No other vessels than members of the fishing fleet are involved in IUU operations: the well-developed legal and regulatory framework in all the countries of this study leaves little room for unregistered fishing vessels. However, the effort and scope of IUU operations, especially turbot fishing during the annual closed season, is large but difficult to estimate (Shlyakhov, 2013). Even if only a few vessels are really involved in IUU fishing, their IUU effort during the closed season of prohibition is believed to be high enough that makes it comparable to that of the legal operations.
5. Bycatch is independent of local differences in effort: large scale IUU fishing is practiced in all the countries of study, and it includes considerable effort in shelf waters of exclusive economic zones. An inevitable consequence of this practice is extensive hauling and the loss of many 'ghost' nets at sea. It is estimated that over 1 500 gillnets and entangling nets are lost annually in Turkish Black Sea alone (Dagtekin et al., 2019), the loss of turbot nets in the Istanbul region was estimated to be around 70 km in 2008-2009 (Yıldız and Karakulak, 2016). Clearly, ghost nets in remote open sea areas continue to catch fish and cetaceans.
6. There are no seasonal differences in effort as proscribed closed seasons are fully utilised by IUU operations. Although there are legal closed seasons (between 30 and 60 days, depending on the country) for turbot in all the riparian Black Sea countries during spawning, this season is the most commercially profitable (turbot form the largest aggregations during this period) and the IUU effort is at least as intensive as the legal effort during other seasons.
7. There is a season of porpoise bycatch largely limited to four months, from April to July. This assumption is based on considerable published evidence of bycatch seasonality (Vishnyakova and Gol'din, 2015a; Paiu et al., 2017; and references therein), which was additionally confirmed by the results of this study. Importantly, this season coincides with the reproductive season of the Black Sea harbour porpoise peaking from May to July and, consequently, can be explained by aspects of its life history (Vishnyakova and Gol'din, 2015a).
8. Bycatch is linearly proportional to seasonal porpoise abundance (density): this assumption is based on assumptions 2 and 5-7. If the gillnet fishing effort is high during all the season of high bycatch rate, and the bycatch coincides with biologically important season for the Black Sea harbour porpoise (summer), the bycatch rate can be presented as a function of porpoise density.
9. Observed bycatch could be possibly lower than usual due to tested pingers as mitigation measure on 27 of 63 hauled strings of nets. Despite significant reduction of bycatch levels was observed only for 6 hauls (10% of all) that involved PAL pingers there is underlying possibility that use of pingers generally may have introduced negative bias in normal bycatch levels.

Mean values and variance were evaluated as part of the general statistics considered (Northridge and Fortuna, 2008). However, median values were considered preferable to arithmetic means as they better correspond to the non-parametric nature of bycatch events and uncertainty of the underlying distribution. Median values show less bias due to outliers – cases of extremely high bycatch events shifting the mean values. Resultant estimates of bycatch based upon the use of median values might thus be considered 'conservative'. Interquartile ranges were used for estimation of confidence intervals.

Given the data limitations and uncertainties that preclude a more sophisticated analysis, bycatch numbers are estimated solely as a function of number of vessels, bycatch per trip and number of trips during the bycatch season:

$$Nbyc = f(\text{number of vessels; bycatch per trip; number of trips})$$

$$N_{byc} = N_v B_t N_t$$

where N_{byc} is total bycatch level per year; N_v is number of vessels; B_t is bycatch per trip and N_t is annual number of trips per vessel.

The basis for the calculations came from the onboard bycatch study in Bulgaria and Romania conducted from 2019 to 2021, supported by questionnaire surveys in four riparian countries.

Limitation to this time and sub-region concurred with the aerial survey in summer 2019 (Paiu et al., 2021a).

3 Results

3.1 Questionnaire survey

In total, 63 interviews were conducted, 23 in Bulgaria, 15 in Romania, 8 in Türkiye and 17 in Ukraine, covering the main segments of the fleet (Table 1 and Figure 4). The individual respondents reported data from 1 to 20 boats each. No significant differences were found between countries in the statistical characteristics of samples and numerical results of the survey (Mann-Whitney U test, $p<0.05$). The interviewees were aged between 28 and 74 years (median 47 years) and had 2-60 years of experience (median 25 years) indicating a high level of expertise and good institutional memory. Besides, 37% originated from families traditionally involved in fishing. Most of the interviewed fishermen (81%) were flexibly involved in multi-target fisheries (target species distribution is shown at the Figure 5), and 17% switched between fisheries practices within a year due to catch seasonality. Almost half (48% of all the responses) of the fishing gears reported as being in use were gillnets (Figure 6); these included nets used among multiple gears. The soaking time for gillnets involved in turbot fisheries varied from 1 to 91 days (median 12 days). In addition, the number of small vessels currently used in the north-western Black Sea sector of Ukraine for turbot fishery was specially assessed on site and estimated as 180 vessels.

In 50 of 63 interviews (79%) bycatch was reported, and 30 (48%) of respondents reported cases of cetacean bycatch: 25 of them (40% of the total sample) mentioned the harbour porpoise as the bycaught species; eight respondents (13%) mentioned the cases of bottlenose dolphins and four (6%) reported common dolphins; seven respondents mentioned bycatch of more than one cetacean species. Cetacean bycatch was reported for gillnets (24 respondents, 80% of those who reported cetacean bycatch), other stationary nets (3 respondents), purse seine nets (2 respondents) and mid-depth trawls (1 respondent). In Türkiye, it was reported that cetacean survival rate in trammel nets was higher than in the other types of stationary nets or gillnets as animals could be released alive.

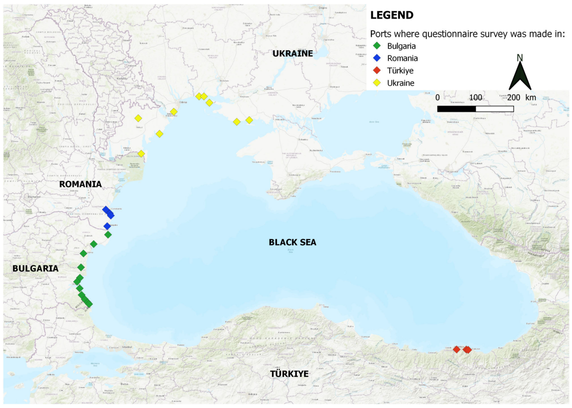

FIGURE 4
Map of the Black Sea ports covered by the questionnaire surveys.

Several respondents who did not report cetacean bycatch in turbot or bluefish fisheries mentioned the bycatch of species that are usually bycaught together with cetaceans, indirectly indicating possible cetacean bycatch: the great cormorant (*Phalacrocorax carbo*), whiting (*Merlangius merlangus*), sturgeons (Acipenseridae), dogfish (*Squalus acanthias*) and rays (*Raja clavata, Dasyatis pastinaca*). Therefore, it can be assumed that a considerable part of respondents concealed cetacean bycatch cases. In particular, in Ukraine none of the respondents reported cetacean bycatch during the current fishing season, while in Romania no cetacean bycatch was reported at all. This situation was mirrored in official records by fisheries authorities where cetacean bycatch records were missing. However, many of the respondents reported bycatch as 'historical' (at least, one or two years before the interview). Overall attitude of interviewed fishermen towards cetaceans was mostly positive or neutral. None of the respondents reported cases of intentional killing of cetaceans.

3.2 Onboard observations

Bycatch monitoring aboard fishing vessels licensed for turbot fishing was undertaken in Bulgaria from 2019 to 2021 and in Romania in 2020 (Figure 7). In total, 48 monitoring missions were made that covered 63 hauls by 11 different vessels (eight for Bulgaria

TABLE 1 Fishermen interviews by country and fishing port.

Country	Ports	Vessel type/fishery	No. interviews
Bulgaria	Balchik, Varna, Byala, Nessebar, Pomorie, Sozopol, Primorsko, Tsarevo, Ahtopol, Krapets, Sinemorets	fishing vessels 6-20 m	23
Romania	Constanta, Mangalia, Agigea, Eforie	beam trawler and small boats (4.5-10 m long)	15
Türkiye	Çarşıbaşı, Akçaabat, Faroz (Trabzon Prefecture)	purse seiners and small boats (5-10 m long)	8
Ukraine	Vylkove, Lebedivka, Bilhorod-Dnistrovskyi, Chornomorsk, Rybakivka, Ochakiv, Pokrovka, Lazurne, Skadovsk	mid-depth trawlers and small boats (4-10 m long)	17

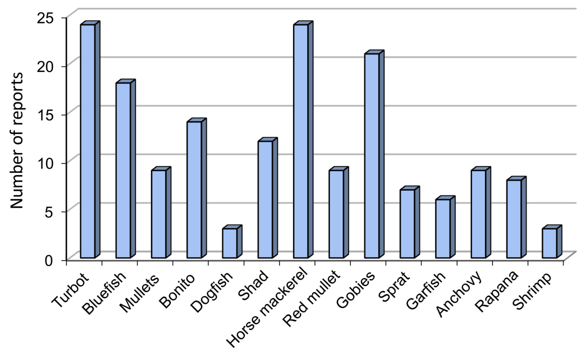

FIGURE 5
Target species reported by interviewed fishermen.

and three for Romania) during two main turbot fishing campaigns: spring and summer (Table 2). For seven of the missions (12 hauls), data were reported by fishermen who agreed to report (i.e., no observers were present). Bycatch was reported for some of these missions without observers, suggesting no bycatch was hidden by fishermen that agreed to report. Consequently, potential bias is minimal and relates more to species identification and biological data rather to bycatch level. Observations in Bulgaria were concentrated between April and July with just few hauls in October and November in line with turbot fishing effort. In Romania observations spanned between March and July. No significant differences were found between the countries and years of study (Mann-Whitney U test, $p>0.05$). The gillnet strings observed during the hauls were between 840 and 11 760 m long (median 4 300 m) with soaking times from 7-31 days (median 16 days). In two exceptional cases, soaking time was extremely long (up to 91 days) due to bad weather.

In 36 (57.1%) of 63 hauls there were records of bycaught cetaceans. Harbour porpoises (in total, 182 individuals) were recorded in 32 hauls. In addition, bottlenose dolphins (total four individuals) were recorded in four hauls, and common dolphins (total three individuals) in three hauls. The median number of porpoises bycaught per haul was 1, the mean number was 2.89, and the maximum number was 41. The number of bycaught porpoises per km of net varied between 0 and 3.66 (median 0.1).

Standardized bycatch per unit of effort (BPUE) was calculated using the following formula:

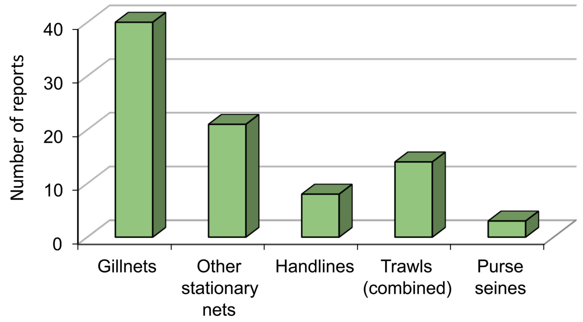

FIGURE 6
Gear types reported by interviewed fishermen.

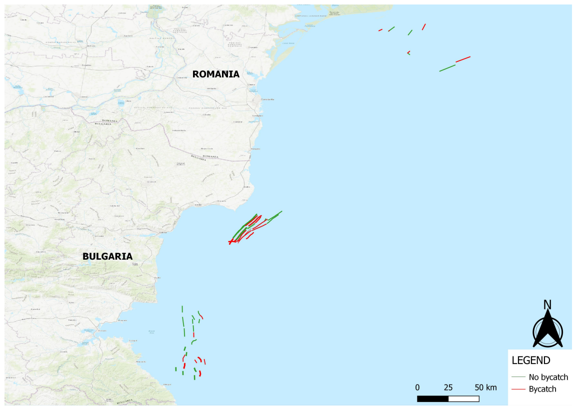

FIGURE 7
Geographic distribution of onboard bycatch observations in the Western Black Sea.

$$BPUE = \frac{individuals}{day \cdot km^2}$$

Soaking time is measured in days (1 day = 24 hours) while surface of nets was calculated in km^2 as product of length and height. In this way different height of used nets (that varied between 2 and 4 m) was taken into account.

Besides, an average bycatch rate as individuals per km of nets (ind./km) was 0.37 ind./km (SD = 0.67)

Bycatch showed strong seasonality with the high risk during the four months April to July. Most of the cases (70%) exceeding the median number of bycaught porpoises per haul were recorded in summer, between June 27 and July 29, whereas the proportion of hauls exceeding median number per km and BPUE were respectively 45% in spring and 55% in summer. BPUE was significantly higher in summer compared to spring (Mann-Whitney U test: $U=316$, $p<0.05$). No significant difference in BPUE between years was found (Kruskal-Wallis test: $H=1541$, $p>0.05$). The total annual bycatch per vessel varied between 0 and 95 porpoises.

Importantly, the general statistical characteristics of the cetacean bycatch, such as high variance (54.4), skewness (4.1) and kurtosis (17.7) were comparable to that of an average target fish species rather than of marine mammal bycatch usually observed in fisheries (Curtis and Carretta, 2020).

Another feature was that cetacean bycatch did not correlate to fish catch. However, both fish catch (CPUE) and cetacean bycatch (BPUE) positively correlated to net length at statistically significant levels (r was respectively 0.50 ($p < 0.05$) and 0.32 ($p < 0.001$)) and reached a maximum at 10 000 – 11 500 m length of the strings.

3.3 Stranding surveys

3.3.1 Bulgaria

Collected data on stranded cetaceans in Bulgaria for 2019 revealed 58 stranded cetaceans while at the same time onboard

TABLE 2 Results from bycatch onboard monitoring.

Boat	Country	Date	Bycatch (ind.)	Bycatch (ind./km)	BPUE	Soak time, days	Length, m	Depth, m	Type of sampling	Species		
										Dd	Pp	Tt
1	Bulgaria	8.4.2019	0	0.00	0.00	23	3 640	71	observer		0	
1	Bulgaria	12.4.2019	1	0.13	1.70	26	7 560	71	observer		1	
1	Bulgaria	10.4.2019	2	0.17	2.27	25	11 760	71	observer		2	
1	Bulgaria	11.4.2019	0	0.00	0.00	25	10 920	65	observer		0	
2	Bulgaria	10.4.2019	1	0.22	4.75	18	4 500	70	observer		1	
3	Bulgaria	12.4.2019	1	0.24	4.28	19	4 100	88	self-report		1	
3	Bulgaria	13.4.2019	1	0.23	0.00	20	4 300	88	observer		0	1
4	Bulgaria	13.4.2019	0	0.00	0.00	7	3 500	80	observer		0	
1	Bulgaria	27.6.2019	1	1.19	56.69	7	840	65	observer		1	
1	Bulgaria	1.7.2019	14	1.31	43.57	10	10 710	65	observer		14	
1	Bulgaria	2.7.2019	36	3.21	97.40	11	11 200	65	observer		36	
1	Bulgaria	6.7.2019	41	3.66	76.26	16	11 200	73	observer		41	
2	Bulgaria	6.7.2019	2	0.44	10.68	16	4 500	67	observer		2	
3	Bulgaria	6.7.2019	5	0.96	16.03	20	5 200	65	observer		5	
5	Bulgaria	8.7.2019	0	0.00	0.00	19	2 000	75	self-report		0	
6	Bulgaria	21.10.2019	0	0.00	0.00	77	2 000	60	self-report		0	
6	Bulgaria	4.11.2019	0	0.00	0.00	91	4 000	80	self-report		0	
9	Romania	5.3.2020	0	0.00	2.83	22	3 000	50	observer		0	
10	Romania	20.3.2020	1	0.25	0.00	14	4 000	70	observer		1	
10	Romania	20.3.2020	0	0.00	2.64	14	4 000	71	observer		0	
11	Romania	4.4.2020	0	0.00	2.42	21	1 500	45	observer		0	
11	Romania	10.4.2020	1	0.17	0.00	21	6 000	35	observer		1	
11	Romania	10.4.2020	1	1.25	0.00	29	800	45	observer		1	
1	Bulgaria	10.4.2020	2	0.36	0.00	21	5 600	74	observer	1	1	
1	Bulgaria	10.4.2020	0	0.00	0.00	21	5 600	74	observer		0	
1	Bulgaria	12.4.2020	2	0.17	0.00	22	11 480	65	observer		2	
1	Bulgaria	13.4.2020	2	0.17	0.00	24	11 480	76	observer		2	
2	Bulgaria	12.4.2020	0	0.00	0.00	14	8 800	65	observer		0	
2	Bulgaria	12.4.2020	1	0.13	0.00	14	8 000	83	observer	1	0	
7	Bulgaria	13.4.2020	0	0.00	4.68	17	4 200	65	self-report		0	
7	Bulgaria	13.4.2020	0	0.00	0.00	17	6 100	65	self-report		0	
7	Bulgaria	13.4.2020	0	0.00	14.88	17	6 000	65	self-report		0	
7	Bulgaria	13.4.2020	0	0.00	0.00	17	3 000	75	self-report		0	
7	Bulgaria	13.4.2020	0	0.00	32.18	17	4 000	75	self-report		0	
7	Bulgaria	13.4.2020	1	0.33	9.92	17	3 000	75	self-report		0	1
3	Bulgaria	10.4.2020	1	0.43	27.55	31	2 300	80	self-report		1	
3	Bulgaria	12.4.2020	0	0.00	6.87	15	3 200	82	observer		0	
1	Bulgaria	28.6.2020	6	0.54	0.00	12	11 200	80	observer		6	

(Continued)

TABLE 2 Continued

Boat	Country	Date	Bycatch (ind.)	Bycatch (ind./km)	BPUE	Soak time, days	Length, m	Depth, m	Type of sampling	Species		
										Dd	Pp	Tt
2	Bulgaria	28.6.2020	0	0.00	0.00	12	3 100	81	observer		0	
1	Bulgaria	4.7.2020	14	1.35	7.09	14	10 360	68	observer		14	
1	Bulgaria	16.7.2020	4	0.36	4.36	12	11 200	77	observer		4	
11	Romania	21.7.2020	1	0.20	5.13	13	5 000	55	observer		1	
11	Romania	22.7.2020	0	0.00	0.00	14	1 100	55	observer		0	
11	Romania	22.7.2020	2	0.67	15.87	14	3 000	55	observer		2	
1	Bulgaria	23.7.2020	10	0.91	2.20	11	11 000	76	observer		10	
1	Bulgaria	29.7.2020	3	0.27	0.00	13	11 200	75	observer		3	
1	Bulgaria	2.8.2020	1	0.09	0.00	10	10 640	70	observer	1	0	
2	Bulgaria	14.10.2020	0	0.00	26.67	7	3 100	45	observer		0	
1	Bulgaria	10.4.2021	4	0.40	17.81	14	10 080	80	observer		3	1
1	Bulgaria	13.4.2021	3	0.26	7.04	13	11 760	80	observer		2	1
1	Bulgaria	11.4.2021	1	0.10	20.25	15	10 080	78	observer		1	
2	Bulgaria	11.4.2021	0	0.00	0.00	15	2 500	82	observer		0	
8	Bulgaria	12.4.2021	0	0.00	0.00	16	2 700	86	observer		0	
5	Bulgaria	13.4.2021	2	1.00	6.06	15	2 000	70	self-report		2	
1	Bulgaria	2.7.2021	7	0.64	0.00	12	10 920	80	observer		7	
1	Bulgaria	3.7.2021	3	0.27	0.00	13	10 920	80	observer		3	
1	Bulgaria	4.7.2021	10	0.85	0.00	14	11 760	80	observer		10	
2	Bulgaria	4.7.2021	0	0.00	0.00	14	2 600	80	observer		0	
8	Bulgaria	15.7.2021	0	0.00	5.95	25	3 000	81	observer		0	
8	Bulgaria	15.7.2021	1	0.30	0.00	25	3 300	87	observer		1	
8	Bulgaria	15.7.2021	0	0.00	0.00	25	3 000	77	observer		0	
8	Bulgaria	15.7.2021	0	0.00	2.65	26	2 200	83	observer		0	
8	Bulgaria	15.7.2021	0	0.00	14.37	26	2 500	81	observer		0	
									TOTAL	3	182	4

bycatch data reported 104 bycaught cetaceans from only six vessels (3% of all licensed vessels for turbot fishing). This suggests that the portion of bycaught animals reaching the coast is small. At least two freshly dead stranded cetaceans were observed with clear evidence of bycatch (missing tail flukes) during the closed turbot fishing season in Bulgaria providing evidence of IUU fishing.

3.3.2 Romania

Between 2019 and 2020, a total of 154 cetaceans were recorded stranded on Romanian beaches. In 2019 the peak was reached in June and in 2020 in August. Of the 53 recorded cases in 2019, 16 of them indicated possible cetacean-fisheries interaction, 28 unidentifiable causes. While of the 101 recorded cases in 2020, only 8 could be assigned to bycatch. The large number of unidentified causes of death recorded in 2020 (84 cases) was because the state of decomposition was too advanced to establish cause of death realistically.

3.3.3 Ukraine

No bycatch evidence was discovered during dedicated cetacean stranding surveys conducted in Ukraine near the fisheries sites. That concurred with the data from interviews, as well as with the low density of cetaceans at sea during the season of the survey. From 137 cetacean stranding cases recorded in overall in 2019-20 along the Ukrainian Black Sea coast (including all the data coming from opportunistic sources), only 20 (18 harbour porpoises and two bottlenose dolphins) indicated possible cetacean-fisheries interaction. Most cases of stranded animals with bycatch signs were recorded between May and July but they also occurred from March to November.

3.3.4 Türkiye

Between 2019-2020, a total of 73 cetaceans were recorded stranded on Türkiye coast by İÜ-TUDAV Cetacean Stranding Network, local surveys and media. Strandings of harbour porpoises were observed at high rate during spring and summer (especially in June and July) and half of them were neonates. This may be related with turbot fishery's indirect effect, which was reported before in the Black Sea. Because of the death of lactating and nursing mothers in turbot nets, neonates may have starved to death and stranded ashore (Tonay et al., 2017). The number of strandings of common dolphins was high in winter and early spring. Bycatch signs were found in six common dolphins, one bottlenose dolphin and one harbour porpoise.

The harbour porpoise represented 96% of recorded bycatch in onboard survey and 65% in stranding records and was present in all the months when bycaught cetaceans were recorded (Figure 8).

3.4 Total bycatch estimates

Total Black Sea bycatch numbers were estimated by multiplying the following parameters:

- Median bycatch of porpoises per trip (based on onboard observations): 1 (interquartile range 0-2.5)
- Median number of trips per bycatch season: based on onboard observations 7.3 (interquartile range 5.65-9.42); based on questionnaires 10 (interquartile range 6-16)
- Number of turbot fishing vessels in the Black Sea (except Georgia) (data sources: FAO, 2020; this study): 1 620

Using this simple approach that is generally conservative for the reasons given above, estimates for annual bycatch of harbour porpoises by the Black Sea fleet involved in turbot catch is either 11 826 (interquartile range 0 – 38 200) assuming trip information from onboard observers or 16 200 (interquartile range 0 – 64 800) assuming trip information from questionnaires (Figure 9).

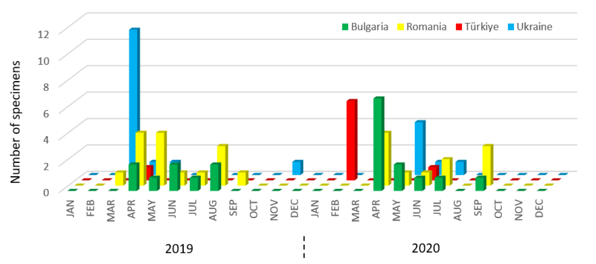

FIGURE 8
Seasonal distribution of records of stranded cetaceans with bycatch signs by Black Sea countries, 2019-2020.

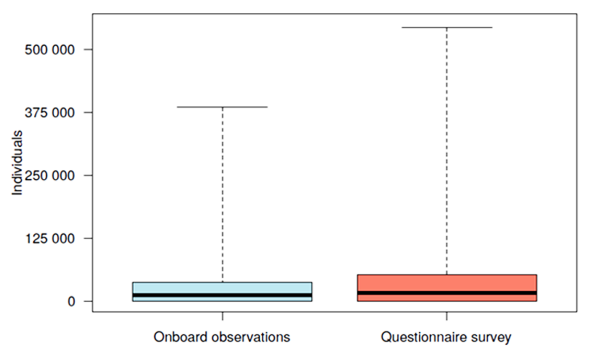

FIGURE 9
Estimates of annual bycatch of the harbour porpoise by Black Sea fleet involved in turbot fishery. Median values are shown as bold lines, and interquartile ranges are shown as boxes.

4 Discussion

Overall basin wide bycatch rate of harbour porpoises in turbot gillnet fisheries found in this study in spite of the conservative assumptions used is apparently very high. Most previous studies of harbour porpoise bycatch in the Black Sea reported an average bycatch rate as individuals per km of nets (ind./km). The comparable statistic from the present study was 0.37 ind./km – similar to a previous 2014-2018 study in Bulgarian waters when 0.31 ind./km was reported (Zaharieva et al., 2022). Older studies conducted in different regions of the Black Sea reported a wide range of bycatch rates – these are summarised here for information without any comparison of methods and assumptions (e.g. how net height and soaking time were taken into account): 0.09 ind./km in Ukraine (Pavlov et al., 1996), 1.53 ind./km in Ukraine (Birkun et al., 2009), 0.22 ind./km in Bulgaria (Mihaylov, 2011), 0.33 and 0.19 ind./km in western Türkiye (Tonay, 2016), 4.14 ind./km in central Türkiye (Gönener and Bilgin, 2009) and 0.43 ind./km in eastern Türkiye (Bilgin et al., 2018).

Strandings can be a supplementary source of monitoring bycatch. In the current study, there were some carcasses indicating the evidence of bycatch in Bulgaria, Romania and Ukraine. Besides, between January 2019-May 2020, 50 stranded cetaceans (common dolphins 58%, harbour porpoises 36%, bottlenose dolphins 4%, and unidentified delphinids 2%) were reported in Turkish Black Sea coast, of which one harbour porpoise and six common dolphins indicated the evidence of bycatch (Paiu M. et al., 2021b). Strandings of common dolphins were in winter-early spring and not related to turbot fisheries but possibly to purse seines or midwater trawls. This implies that the interaction with fishing gears other than turbot gill nets needs further investigation. Besides, the result of Bulgaria indicated that it was not possible to robustly estimate the annual bycatch from the stranding record due to the low number of strandings compared to the data obtained through onboard observations. The advanced stage of decomposition also makes it impossible to determine the cause of death. As a result, it was understood that strandings themselves can indicate the occurrence of bycatch but hardly provide quantitative data without demographic modelling (Moore and Read, 2008).

During the current study pingers have been tested as mitigation measure in 27 of the hauls in Bulgaria. Three models of pingers have been tested: Future Oceans 10 kHz, Future Oceans 70 kHz and Porpoise Alerting Devices (PAL), frequency 10 kHz. Observed differences in bycatch levels in strings fitted with Future Oceans pingers and those without pingers were not significant in 2019 (Popov et al., 2020). The only model which showed significant decrease in bycatch (86%, p<0.05) was the PAL pinger deployed on six strings. These accounted for 10% of all observed hauls with resultant overall negative bias of 8% in recorded bycatch rate. Larger scale trials in terms of coverage and duration are needed to confirm these results and test potential habituation effect.

The bycatch estimates provided here concur with the overall bycatch in turbot gillnet and trammel net fisheries (including IUU fishing) calculated for the western Turkish Black Sea coast of 2 011 and 2 294 porpoises per year in 2007 and 2008, respectively, based on bycatch per haul and the total net amount in the area (Tonay, 2016). Using an earlier value of the number of active vessels in that area as 185 (Tonay and Öztürk, 2003), the average annual bycatch of harbour porpoises per boat varied between 10.9 and 12. These mean values are a little higher than those from this study (7.3-10 depending on data source). The differences probably reflect normal interannual and interregional variation, and the rough combined estimate of annual bycatch as 10 harbour porpoises per vessel can be assumed to be a robust estimate for further monitoring, given the consistency in values despite the different approaches. Widening sub-regional coverage, i.e. further research in the eastern Black Sea is important for enhancing the accuracy of scaling or further stratified modelling (Authier et al., 2021), since most of the data for both studies come from the western Black Sea. However, the estimates from the western subregion are particularly important due to the summer concentration of the major part of the Black Sea harbour porpoise population in this area (Paiu et al., 2021a).

The data obtained during this study from several independent lines of evidence corroborate earlier suggestions on bycatch seasonality and the potentially strong impact of IUU as well as legal fisheries. They also provide similar rough estimates of overall bycatch per vessel. However, the data presented here are somewhat limited due to the relatively small sample size of observed trips/hauls. Based on the calculator of Curtis and Carretta (2020), it can be suggested that the coverage by onboard observers needed to obtain abundance estimates with a CV value of about 0.3, is at least 220 trips for the whole Black Sea. The relatively small sample size (48 trips, 63 hauls) might have affected precision of the obtained result. However, unlike many situations elsewhere when bycatch sampling effort is considered low due to the rarity of bycatch events (Authier et al., 2021), bycatch frequency in the Black Sea is high (57.1% observed occurrence rate, 95% probability of observing bycatch is achieved at 0.2% observation effort: Curtis and Carretta, 2020), and here the high variance of cetacean bycatches is observed, which is due to outliers – extremely high bycatch events. Moreover, the highest bycatch incidents could be missed and thus increasing the observation effort would only increase the variance. Also, most part of the eastern Black Sea was not covered by this survey, data from that area are limited and probably more vessels involving bycatch are falling out of the GFCM statistics. Therefore, given the whole bulk of available evidence, despite the high figure obtained from this study, our estimates can be even underrated (rather than overrated).

Despite the small sample of observation effort, these results concurred with two previous independent studies (Birkun et al., 2014; Tonay, 2016). Birkun et al. (2014) provided a total estimated annual bycatch of porpoises in the Black Sea of 20 000 for all fishing gear types or 11 000 for gillnets, mostly based on surveys conducted in 2006-08 and 2012-13. Applying our method to the data of Birkun et al. (2014) increases the total for all gear to 25 000 porpoises. Alternatively, if we use the annual bycatch rate per vessel in 2007-08 calculated for western Turkish Black Sea fleet (after Tonay, 2016) for the whole basin' turbot fleet, the annual bycatch estimate will be around 20 100 individuals. Therefore, assuming a stable bycatch rate during the last 15 years, the upper range of total bycatch estimate which can be taken into consideration is at least 20 000 individuals per year.

The earlier high overall porpoise bycatch estimates for the Black Sea (Birkun et al., 2009; Birkun et al., 2014) seemed incompatible with the data on overall abundance (65 000) of the Black Sea population of the harbour porpoise. That abundance though was based on an aerial survey that covered only the northwestern Black Sea (29% of total area). However, the CeNoBS aerial survey conducted in summer 2019 as part of ACCOBAMS Survey Initiative (ASI) has covered more than 60% of the basin. It is the most comprehensive basin survey so far providing an overall abundance estimate (uncorrected for g(0)) of 94 219 (CV=0.07) porpoises with the highest density in the southwestern part of the Black Sea (Paiu et al., 2021a). Using the correction factor for g(0) of 0.364 for good sighting conditions, calculated for the harbour porpoise in SCANS-III aerial survey of European Atlantic waters (Hammond et al., 2017), the abundance in the Black Sea would be some 258 900 porpoises. Thus, the bycatch rate is between 4.6% and 21.3% of the total abundance estimation, depending on the sources and methods of population and bycatch assessment (Table 3). We consider the lower end of this range as quite a realistic estimate on basis of previous demographic study for the Black Sea harbour porpoise. Therefore, the new data obtained under the ASI have been crucial for reconciling bycatch and abundance estimates.

A previous demographic study (Vishnyakova, 2017) that suggested a long lifespan (23 years) and generation time (7.5 years) for Black Sea harbour porpoises was consistent with a relatively low bycatch rate, which indirectly supports the lower limit of estimates presented here. In terms of assessing impacts of

TABLE 3 Bycatch rate calculation.

Bycatch estimation	Abundance estimation	Bycatch rate
11800	94200	12,5%
20100	94200	21,3%
11800	258900	4,6%
20100	258900	7,8%

bycatch on the Black Sea harbour porpoise populations, this suggests that if a PBR approach is to be considered, a review of the 'traditionally' used parameter values with respect to reproduction and recovery must be undertaken given the demographic information available for the Black Sea population which is known for its early maturation and high reproductive rates (Gol'din, 2004; Vishnyakova, 2017). However, it is clear that the information presented, even for the most conservative estimates of total bycatch, reveals population bycatch rates among the highest in the world (Read et al., 2006; Nelms et al., 2021), and greatly exceeds present agreed thresholds for sustainable levels (c.f. 1.7%, ASCOBANS, 2015) and thus poses a significant threat for this endemic subspecies.

5 Conclusions and future work

Despite being a species of high conservation concern and under strict protection, conservation of harbour porpoise is failing in Europe (Carlen et al., 2021) including the Black Sea. The conservative estimates of bycatch levels for the Black Sea harbour porpoise in this paper raise serious concerns about the survival of this subspecies. Whilst there is a scientific need to continue to improve monitoring of bycatch and refining bycatch estimates in the light of abundance estimates and population assessment, it is quite clear that the available data are already sufficient to demand that the primary focus must be on establishing effective mitigation measures (see below) and ensuring that these are implemented and monitored for effectiveness (that will also entail population abundance monitoring). Cooperation with fishermen and fisheries authorities for enhancing bycatch reporting is crucial to increase the sample size and robustness of the estimate and to evaluate the effectiveness of mitigation approaches. More effective implementation of existing regulations and recommendations (ex. EU Habitats Directive, ACCOBAMS Recommendations 2.13, 4.9 and 7.11) is needed to minimize IUU and ghost fishing. Accurate and standardized spatio-temporal recording of fishing effort should be conducted, and spatio-temporal closure of fishing should be considered when necessary (this can be evaluated *via* population dynamics modelling approaches). Further aerial surveys on density, abundance and distribution of cetaceans in the Black Sea are needed to detect trends in population development and seasonal distribution patterns. Support of all Black Sea states for realization of recently adopted ACCOBAMS Resolution 8.10 on implementation of Long-Term Monitoring Strategy is crucial to achieve that. The retrieval of bycaught animals from fishing vessels should be encouraged by the authorities to obtain biological data for population structure assessment.

Thus, as a matter of urgency, bycatch mitigation measures should be further tested and introduced in the Black Sea. Elsewhere, acoustic approaches such as ADDs (pingers) have been used (Dawson et al., 2013). A few models have been tested in Türkiye, Romania and Bulgaria, some showing good results while others not (Gönener and Bilgin, 2009; Bilgin and Köse, 2018; Popov et al., 2020). In the current study, use of PAL pingers showed promising results. The sample size was small; thus, a large-scale trial is required to confirm these provisional results. Dolphin-safe fishing gears and technology are worth attention e.g., modified nets with acrylic glass spheres to improve acoustical detectability were tested in the Turkish Black Sea (Kratzer et al., 2021). In the implementation of mitigation measures and testing their continued effectiveness, in addition to common problems (habituation, habitat exclusion), local specific features should be considered carefully (e.g., assessment of effectiveness of pingers for the endemic Black Sea harbour porpoises). In conclusion, bycatch poses such a serious threat to the Black Sea harbour porpoises that all riparian countries engaged in turbot fisheries are required to implement urgent measures to reduce it immediately (ACCOBAMS, 2019; CMS, 2020).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the animal study because No disturbance of animals occured.

Author contributions

DP, KV, MPai, AT and PG planned the study. DP, GM, KV, JI, MPai, CT, ED and PG collected data. PG led the analysis. DP, KV and PG analyzed data with input from GM, MPan, AAO, AT and ED. DP, GM, KV and PG wrote the initial manuscript draft with input from all the authors. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2023.1119983/full#supplementary-material

References

ACCOBAMS (2019). "Resolution 7.11 interactions between fisheries and cetaceans," in *ACCOBAMS-MOP7/2019/Doc38/Annex15/Res.7.11. 3*.

Amaha Öztürk, A. (2021). "Bycatch: A serious threat for cetaceans in Europe," in *Under pressure: The need to PROTECT whales and dolphins in European waters. an OceanCare report*, 78–95.

Anton, E., Nicolaev, S., Radu, G., Maximov, V., and Dumitrache, C. (2010). Fisheries impact on dolphin populations in the Black Sea Romanian sector. *Cercetări Marine: Recherches Marines* 2010, 281–292.

ASCOBANS (2015). *ASCOBANS workshop on further development of management procedures for defining the thresholds of unacceptable interactions* (Bonn, Germany: ASCOBANS), 17.

Authier, M., Rouby, E., and Macleod, K. (2021). Estimating cetacean bycatch from non-representative samples (i): a simulation study with regularized multilevel regression and post-stratification. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.719956

Bilgin, S., and Köse, Ö. (2018). Testing two types of acoustic deterrent devices (pingers) to reduce harbour porpoise, *Phocoena phocoena* (Cetacea: Phocoenidae), by catch in turbot (*Psetta maxima*) set gillnet fishery in the Black Sea, Türkiye. *Cahiers Biol. Mar.* 59, 473–479.

Bilgin, S., Köse, Ö., and Yesilcicek, T. (2018). Incidental catches of endangered (*Phocoena phocoena*) and vulnerable (*Delphinus delphis*) cetaceans and catch composition of turbot bottom gillnet fisheries in the southeastern Black Sea, Türkiye. *Cahiers Biol. Mar.* 59 (6), 571–577.

Birkun, A., Krivokhizhin, S., Masberg, I., and Radygin, G. (2009). *Cetacean by-catches in the course of turbot and spiny dogfish fisheries in the northwestern Black Sea* (Istanbul: 23rd Annual Conference of the European Cetacean Society), 194 pp.

Birkun, A.Jr., Northridge, S. P., Willsteed, E. A., James, F. A., Kilgour, C., Lander, M., et al. (2014). *Studies for carrying out the common fisheries policy: Adverse fisheries impacts on cetacean populations in the Black Sea* (Brussels: European Commission), 347p.

BLASDOL (1999). *Estimation of human impact on small cetaceans of the Black Sea and elaboration of appropriate conservation measures: Final report for EC inco-Copernicus (contract no. ERBIC15CT960104)*. Ed. C. R. Joiris (Georgia. Brussels: Free University of Brussels, Belgium; BREMA Laboratory, Ukraine; Justus Liebig University of Giessen, Germany; Institute of Fisheries, Bulgaria; and Institute of Marine Ecology and Fisheries), 113 p.

Carlen, I., Nunny, L., and Simmonds, M. (2021). Out of sight, out of mind: how conservation is failing European porpoises. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.617478

Carruthers, E. H., and Neiss, B. (2011). Bycatch mitigation in context: using qualitative interview data to improve assessment and mitigation in a data-rich fishery. *Biol. Conserv.* 144 (9), 2289–2299. doi: 10.1016/j.biocon.2011.06.007

CMS (2020) *Concerted action for the harbour porpoise (Phocoena phocoena)*. Available at: https://www.cms.int/en/document/proposal-concerted-action-harbour-porpoise-phocoena-phocoena.

Curtis, K. A., and Carretta, J. V. (2020). ObsCovgTools: Assessing observer coverage needed to document and estimate rare event bycatch. *Fish. Res.* 225, 105493. doi: 10.1016/j.fishres.2020.105493

Dagtekin, M., Ozyurt, C. E., Misir, D. S., Altuntas, C., Cankaya, A., Misir, G. B., et al. (2019). Rate and causes of lost gillnets and entangling nets in the Black Sea coasts of Turkey. *Turkish J. Fish. Aquat. Sci.* 19 (8), 699–705.

Dawson, S., Northridge, S., Waples, D., and Read, A. (2013). To ping or not to ping: the use of active acoustic devices in mitigating interactions between small cetaceans and gillnet fisheries. *Endangered Species Res.* 19, 201–221. doi: 10.3354/esr00464

Dmitrieva, L., Kondakov, A., Oleynikov, E., Kydyrmanov, A., Karamendin, K., Kasimbekov, Y., et al. (2013). Assessment of Caspian seal by-catch in an illegal fishery using an interview-based approach. *PloS One* 8 (6), e67074. doi: 10.1371/journal.pone.0067074

Dolman, S., Baulch, S., Evans, P. G., Read, F., and Ritter, F. (2016). Towards an EU action plan on cetacean bycatch. *Mar. Policy* 72, 67–75. doi: 10.1016/j.marpol.2016.06.020

FAO (2019). Monitoring the incidental catch of vulnerable species in Mediterranean and Black Sea fisheries: Methodology for data collection in *FAO fisheries and aquaculture technical paper no. 640* (Rome: FAO).

FAO (2020). *The state of Mediterranean and Black Sea fisheries 2020* (Rome: General Fisheries Commission for the Mediterranean). doi: 10.4060/cb2429en

Filgueira dos Santos, C. H. M., Zappes, C. A., Vidal, M. D., and Nunes, J. L. S. (2021). Traditional knowledge of artisanal fishers and *Sotalia guianensis* (Van bénéden 1864) (Cetacea, Delphinidae) in the extractive reserve baía do tubarão (Brazilian Amazon coast). *Ocean Coast. Manage.* 210, 105700. doi: 10.1016/j.ocecoaman.2021.105700

Fontaine, M. C., Snirc, A., Frantzis, A., Koutrakis, E., Öztürk, B., Öztürk, A. A., et al. (2012). History of expansion and anthropogenic collapse in a top marine predator of the Black Sea estimated from genetic data. *Proc. Natl. Acad. Sci.* 109 (38), E2569–E2576. doi: 10.1073/pnas.1201258109

Gómez-Munõz, V. M. (1990). A model to estimate catches from a short fishery statistics. *Survey Bull. Mar. Sci.* 46, 719–722.

Gönener, S., and Bilgin, S. (2009). The effect of pingers on harbour porpoise, *Phocoena phocoena* bycatch and fishing effort in the turbot gill net fishery in the Turkish Black Sea coast. *Turkish J. Fish. Aquat. Sci.* 9 (2), 151–157.

Goetz, S., Read, F. L., Santos, M. B., Pita, C., and Pierce, G. J. (2014). Cetacean–fishery interactions in Galicia (NW spain): results and management implications of a face-to-face interview survey of local fishers. *ICES J. Mar. Sci.* 71 (3), 604–617. doi: 10.1093/icesjms/fst149

Gol'din, P. E. (2004). Growth and body size of the harbour porpoise, *Phocoena phocoena* (Cetacea, Phocoenidae), in the Sea of Azov and the Black Sea. *Vestnik Zoologii* 38 (4), 59–73.

Hammond, P. S., Lacey, C., Gilles, A., Viquerat, S., Börjesson, P., Herr, H., et al. (2017). *Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys* (Wageningen, The Netherlands: Wageningen Marine Research), 39 p.

Jabado, R. W., Al Ghais, S. M., Hamza, W., and Henderson, A. C. (2015). The shark fishery in the united Arab Emirates: an interview based approach to assess the status of sharks. *Aquat. Conservation: Mar. Freshw. Ecosyst.* 25 (6), 800–816. doi: 10.1002/aqc.2477

Kleinenberg, S. E. (1956). *Mammals of the Black Sea and the Sea of Azov: an experience of biological and fisheries research* (Moscow: Izdatelstvo ANSSSR), 288 pp.

Kratzer, I. M. F., Brooks, M. E., Bilgin, S., Özdemir, S., Kindt-Larsen, L., Larsen, F., et al. (2021). Using acoustically visible gillnets to reduce bycatch of a small cetacean: first pilot trials in a commercial fishery. *Fish. Res.* 243, 106088. doi: 10.1016/j.fishres.2021.106088

Manlik, O., Lacy, R. C., Sherwin, W. B., Finn, H., Loneragan, N. R., and Allen, S. J. (2022). A stochastic model for estimating sustainable limits to wildlife mortality in a changing world. *Conserv. Biol.* 36 (4), e13897. doi: 10.1111/cobi.13897

McCluskey, S. M., and Lewison, R. L. (2008). Quantifying fishing effort: a synthesis of current methods and their applications. *Fish Fish.* 9 (2), 188–200. doi: 10.1111/j.1467-2979.2008.00283.x

Mihaylov, K. (2011). Development of national network for monitoring the Black Sea cetaceans (stranded and by-caught) in Bulgaria and identifying relevant measures for mitigation the adverse impact of fisheries. *Final report. MoU ACCOBAMS, N° 01/2010. IFR - Varna, Bulgaria*. 70 p.

Moffat, C., Aish, A., Hawkridge, J. M., Miles, H., Mitchell, P. I., McQuatters-Gollop, A., et al. (2011). "Advice on United Kingdom biodiversity indicators and targets for the Marine Strategy Framework Directive," in *Report to the department for environment, food and rural affairs*, vol. 207. (London: H. a. BDSE Group).

Moore, J. E., and Read, A. J. (2008). A Bayesian uncertainty analysis of cetacean demography and bycatch mortality using age-at-death data. *Ecol. Appl.* 18, 1914–1931. doi: 10.1890/07-0862.1

Moore, J. E., Heinemann, D., Francis, T. B., Hammond, P. S., Long, K. J., Punt, A. E., et al. (2021). Estimating bycatch mortality for marine mammals: concepts and best practices. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.752356

Mustika, P. L. K., Wonneberger, E., Erzini, K., and Pasisingi, N. (2021). Marine megafauna bycatch in artisanal fisheries in Gorontalo, northern Sulawesi (Indonesia): An assessment based on fisher interviews. *Ocean Coast. Manage.* 208, 105606. doi: 10.1016/j.ocecoaman.2021.105606

Nelms, S. E., Alfaro-Shigueto, J., Arnould, J. P., Avila, I. C., Nash, S. B., Campbell, E., et al. (2021). Marine mammal conservation: over the horizon. *Endangered Species Res.* 44, 291–325. doi: 10.3354/esr01115

Northridge, S., and Fortuna, C. (2008). *Protocol for data collection on bycatch and depredation in the ACCOBAMS region* (Rome, Italy: International Workshop Bycatch within the ACCOBAMS Area), 60 pp.

Özdemir, S., and Erdem, E. (2011). "Incidental catch in the pelagic trawl fishery of the Black Sea (Turkey-Samsun): Sturgeons and dolphins," in *3rd Bi-annual BS Scientific Conference and UP-GRADE BS-SCENE Project Joint Conference*, Odessa, Ukraine. 1–4.

Paiu, M., Tonay, A. M., Timofte, C., Gheorghe, A.-M., Cândea, M. M., Paiu, A., et al. (2021b). *ANEMONE deliverable 4.3. citizen science - a tool to assess cetacean population status* (Romania: CD Press).

Paiu, R. M., Paiu, A. I., Mirea Candea, M. E., and Gheorghe, A. M. (2017). Cetaceans strandings between 2010-2016 at the coast of Romania. *Cercetări Mar. / Mar. Res.* 47, 222–231.

Paiu, R. M., Paiu, A., Mirea-Candea, M., Gheorghe, A. M., and Timofte, C. (2022). "Cetacean strandings along Romanian Black Sea coasts 2010-2022," in *Mare nostrum cetacean monitoring and conservation program - annual report* (OBIS-SEAMAP). Available at: http://seamap.env.duke.edu/dataset/899.

Paiu, R. M., Panigada, S., Cañadas, A., Gol`din, P., Popov, D., David, L., et al. (2021a). "Deliverable 2.2.2. detailed report on cetacean populations distribution and abundance in the Black Sea, including proposal for threshold values," in *CeNoBS project - contract no 110661/2018/794677/SUB/ENV.C2*(Constanta, Romania: Mare Nostrum NGO), 96 pages.

Pavlov, V., Artov, A., and Zhuravleva, T. (1996). "Impact of fishing on Black Sea dolphins off the Crimea coasts. pp. 41-43," in *Proceedings of the first international symposium on the marine mammals of the Black Sea*. Ed. B. Öztürk (Istanbul: ACAR Matbaacilik A.Ş.), 120 p.

Popov, D., and Meshkova, G. (2022). "Cetacean strandings along Bulgarian Black Sea coast 2010-2022," in *Green balkans NGO cetacean monitoring and conservation program* (Plovdiv, Bulgaria: OBIS-SEAMAP). Available at: http://seamap.env.duke.edu/dataset/824.

Popov, D. V., Meshkova, G. D., Hristova, P. D., Gradev, G. Z., Rusev, D. Z., Panayotova, M. D., et al. (2020). Pingers as cetacean bycatch mitigation measure in Bulgarian turbot fishery. *Acta Zool. Bulgarica* S15, 235–242.

Radu, G., and Anton, E. (2014). Impact of turbot fishery on cetaceans in the Romanian Black Sea area. *Scientia Marina* 78, 103–109. doi: 10.3989/scimar.04029.27A

Radu, G., Nicolaev, S., Anton, E., Maximov, V., and Radu, E. (2003). "Preliminary data about the impact of fishing gears on the dolphins from the Black Sea Romanian waters," in *Workshop on demersal resources in the Black Sea & Azov Sea*. Eds. B. Öztürk and S. Karakulak (TUDAV Publications), 115–129.

Read, A. J., Drinker, P., and Northridge, S. (2006). Bycatch of marine mammals in US and global fisheries. *Conserv. Biol.* 20 (1), 163–169. doi: 10.1111/j.1523-1739.2006.00338.x

Samsun, N., and Kalaycı, F. (2004). The determination of turbot tangle nets and trammel nets features, catch per unit effort (CPUE) and turbot fishing in middle Black Sea (Sinop). *J. Eğirdir Fish. Faculty* 12 (2), 99–108.

Scientific, Technical and Economic Committee for Fisheries (STECF) (2020). *The 2020 annual economic report on the EU fishing fleet (STECF 20-06), EUR 28359 EN* (Luxembourg: Publications Office of the European Union), 2020, ISBN: . doi: 10.2760/500525

Shlyakhov, V. A. (2013). "Ukraine. in nature and extent of the illegal, unreported and unregulated (IUU) fishing in the Black Sea," in *Background paper for the workshop joint GFCM-BSC workshop on illegal, unreported and unregulated fishing in the Black Sea*. Ed. B. Öztürk (Istanbul: BSC Headquarters), 37–43, 58 pp.

Tonay, A. M., and Öztürk, B. (2003). "Cetacean bycatches in turbot fishery on the western coast of the Turkish Black Sea," in *International symposium of fisheries and zoology*. Eds. I. K. Oray, M. S. Çelikkale and G. Özdemir (Istanbul: Istanbul University, Fisheries Faculty), 131–138.

Tonay, A. M., and Öztürk, A. A. (2012). Historical records of cetacean fishery in the Turkish seas. *J. Black Sea/Mediterr. Environ.* 18 (3), 388–399.

Tonay, A. M. (2016). Estimates of cetacean by-catch in the turbot fishery on the Turkish Western Black Sea coast in 2007 and 2008. *J. Mar. Biol. Assoc. United Kingdom* 96 (4), 993–998. doi: 10.1017/S0025315416000060

Tonay, M. A., Dede, A., and Öztürk, A. A. (2017). "Marine mammals in the Turkish coast of the Black Sea," in *Black Sea marine environment: The Turkish shelf*, vol. 46 . Eds. M. Sezgin, I. Bat, D. Ürkmez, E. Arıcı and B. Öztürk (Istanbul, Türkiye: Turkish Marine Research Foundation), 269–288.

TUIK (2019). *Fisheries statistics 2018* (Ankara, Türkiye: The Turkish Statistical Institute (TURKSTAT).

Vasiliu, F., and Dima, L. (1990). "Quelques considerations sur la presence et la mortalite des dauphins sur le littoral roumain de la mer noire. pp. 171-176," in *Recherches marines*, vol. 23. (IRCM, Constanta: Proc. Romanian Marine Research Institute), 200 p.

Vishnyakova, K. A. (2017). *The harbour porpoise (Phocoena phocoena) in the Sea of Azov and the northeastern Black Sea: population morphology and demography* (Kyiv: Schmalhausen Institute of Zoology).

Vishnyakova, K., and Gol'din, P. (2015a). Seasonality of strandings and bycatch of harbour porpoises in the Sea of Azov: the effects of fisheries, weather conditions, and life history. *ICES J. Mar. Sci.* 72 (3), 981–991. doi: 10.1093/icesjms/fsu192

Vishnyakova, K., and Gol'din, P. (2015b). Cetacean stranding rate correlates with fish stock dynamics: research of harbour porpoises in the Sea of Azov. *Mar. Biol.* 162 (2), 359–366. doi: 10.1007/s00227-014-2600-x

Vishnyakova, K., Gol'din, P., and Golubiev, O. (2021) *Cetacean strandings on the Ukrainian coast of the Black Sea and the Sea of Azov*. Available at: https://seamap.env.duke.edu/dataset/2162.

Wade, P. R. (1998). Calculating the limits to the allowable human-caused mortality of cetaceans and pinnipeds. *Mar. Mammal Sci.* 14 (1), 1–37. doi: 10.1111/j.1748-7692.1998.tb00688.x

Wade, P. R., Long, K. J., Francis, T. B., Punt, A. E., Hammond, P. S., Heinemann, D., et al. (2021). Best practices for assessing and managing bycatch of marine mammals. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.757330

Yıldız, T., and Karakulak, F. S. (2016). Types and extent of fishing gear losses and their causes in the artisanal fisheries of Istanbul, Turkey. *J. Appl. Ichthyol.* 32 (3), 432–438. doi: 10.1111/jai.13046

Zaharieva, Z., Racheva, V., and Simeonevska-Nikolova, D. (2022). Cetacean bycatch in turbot gillnets by Bulgarian fisheries in the Black Sea. *Acta Zool. Bulgarica* 74 (1), 95–102.

Zappes, C., Gama, R., Domit, C., Gatts, C., and Di Beneditto, A. (2018). Artisanal fishing and the franciscana (*Pontoporia blainvillei*) in southern Brazil: Ethnoecology from the fishing practice. *J. Mar. Biol. Assoc. United Kingdom* 98 (4), 867–877. doi: 10.1017/S0025315416001788