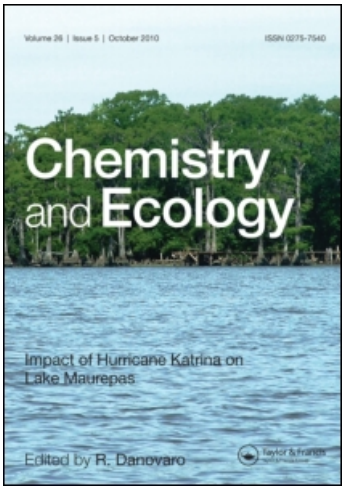

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455114

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Online publication date: 20 May 2010

To cite this Article Fortuna, Caterina M. , Vallini, Carola , Filidei Jr., Elio , Ruffino, Marco , Consalvo, Ivan , Di Muccio, Stefano , Gion, Claudia , Scacco, Umberto , Tarulli, Enrico , Giovanardi, Otello and Mazzola, Antonio(2010) 'By-catch of cetaceans and other species of conservation concern during pair trawl fishing operations in the Adriatic Sea (Italy)', Chemistry and Ecology, 26: 1, 65 — 76
To link to this Article: DOI: 10.1080/02757541003627662
URL: http://dx.doi.org/10.1080/02757541003627662

Chemistry and Ecology
Vol. 26, Supplement, June 2010, 65–76

Taylor & Francis
Taylor & Francis Group

By-catch of cetaceans and other species of conservation concern during pair trawl fishing operations in the Adriatic Sea (Italy)

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(*Received 18 May 2009; final version received 14 December 2009*)

By-catch is one of the main sources of anthropogenic mortality in marine species of conservation concern worldwide. Between 2006 and 2008, the Consorzio Nazionale Interuniversitario per le Scienze del Mare (CoNISMa) coordinated a monitoring programme of cetacean by-catch in Italian pelagic trawlers, funded in compliance with European Regulation 812/2004. Sixteen independent observers monitored a total of 3141 hauls. The observation coverage ranged between 0.9 and 6.3% of the regional fishing effort. Almost all by-catch events were recorded in the northern Adriatic Sea. By-catch rates of bottlenose dolphins (*Tursiops truncatus*) and loggerhead turtles (*Caretta caretta*) were 0.0006 and 0.0255 individuals per haul, respectively. Given the low number of observed deaths, reliable estimates of total mortality for these two species were not obtained. The annual number of by-caught turtles was 863 (CV = 0.15), with 99% released alive. A 'hotspot' for turtle captures was found off Goro (south Venice). The existence of lethal interactions makes it important to understand whether the scale of this mortality is sufficient to pose a threat at population level. Finally, annual by-catch estimates for rays and sharks were 5436 (CV = 0.08) and 5414 (CV = 0.15), respectively. Thintail threshers (*Alopias vulpinus*), piked dogfish (*Squalus acanthias*) and smooth-hounds (*Mustelus mustelus*), which are both commercial and vulnerable to overfishing, were taken in large numbers.

Keywords: Regulation (EC) 812/2004; by-catch; cetaceans; sea turtles; elasmobranchs

1. Introduction

By-catch during fishing operations is one of the main sources of anthropogenic mortality in protected species and species of conservation concern worldwide. For some species or populations this represents a significant conservation threat [1,2]. Not all forms of fishing gear have the same impact, and the threat represented by a given type of fishing gear may depend on how that gear is used.

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ISSN 0275-7540 print/ISSN 1029-0370 online

DOI: 10.1080/02757541003627662
http://www.informaworld.com

In order to be applicable in terms of management, estimates of annual by-catch levels and rates need to be compared with the total number of animals in the population or species affected, taking into account the general population structure. Only then it is possible to assess whether the scale of mortality caused by fishing activities is likely to pose a real conservation threat, and then whether management actions are required [3].

Cetaceans, sea turtles and elasmobranchs are known as K-selected species (K refers to the environmental carrying capacity). In terms of population dynamics, K-selected species are characterised by slow population growth, long generation time and, generally, low dispersal capabilities [4]. Because of these features, most such species play a fundamental role in shaping the structure of marine ecosystems, but are highly vulnerable when subjected to anthropogenic mortality [5]. Those K-selected species that are commercially exploited and depleted by excessive removals require longer periods to recover when compared with most other marine organisms, and can generally be harvested sustainably only at rather low rates.

All cetaceans and most sea turtles are protected by European legislation. In particular, the Habitats Directive lists them in Appendix IV (*Animal and plant species of Community interest in need of strict protection*) and imposes that Member States establish a system to monitor accidental captures. Member States are also required to ensure that these captures do not have a significant impact on the species concerned.

Despite being K-selected species, elasmobranchs are generally considered commercial species, except for the basking shark (*Cetorinhus maximus*) and the white shark (*Carcharodon carcharias*), which are fully protected from all fisheries (Regulations (EC) 40/2007, 41/2007). Other species such as the bluntnose sixgill shark (*Hexancus griseus*), thresher sharks (*Alopiidae* spp.), whale shark (*Rhincodon typus*), requiem sharks (*Carcharhinidae* spp.), hammerhead, bonnethead and scoophead sharks (*Sphyrnidae* spp.) and mackerel sharks (*Isuridae* and *Lamnida*) are protected from driftnetting (Regulation (EC) 894/97 amended). Under Regulation (EC) 43/2009 quotas are set for other species of elasmobranchs in some northern European fishing areas. Nevertheless, there is an increasing interest, at the European level, in stricter protection and management for these taxa (2937th Agriculture and Fisheries Council Meeting, Luxembourg, 23 April 2009).

Between July 2006 and December 2008, the Consorzio Nazionale Interuniversitario per le Scienze del Mare (CoNISMa) coordinated, in cooperation with the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) and the Italian nongovernmental organisation ARCHÈ, a monitoring programme of accidental catches of cetaceans by Italian pelagic and mid-water trawlers. The programme was funded by the Italian Ministry of Agriculture, Food and Forestry, in compliance with Regulation (EC) No. 812/2004. Under this regulation, 'Member States shall design and implement monitoring schemes for incidental catches of cetaceans using observers on board [vessels . . .] with an overall length of 15 m or over' for selected fisheries listed in its Annex III. In the European Mediterranean region this translates into a monitoring programme only targeting pelagic and mid-water trawl fishing operations. This article is intended to give an overview of data collected during this monitoring programme and its results on by-catch rates and annual estimates.

1.1. *Pelagic/midwater trawlers*

Italian pelagic trawlers, called 'volanti', are licensed to operate in pairs. Twin boats, usually of overall length (LOA) >18 m and nominal power between 150 and 900 kW, mainly operate in the open sea, trawling a net ∼ 150 m long, with a mouth opening of ∼15–18 m width and 6–10 m height. The cod-end diamond mesh size is 10 mm (not stretched). The speed and relative distance of the boats, and the size and depth of the net mouth can be altered. Hauls last between 30 min and 1 h, depending on the bottom depth [6]. It should be noted that in the northern Adriatic Sea,

given the relatively shallow waters (<50 m) as well as net sizes, these pair trawlers end up fishing very close to the bottom.

The target species for this fishery is the anchovy (*Engraulis encrasicolus*), which accounts for over 66% of the biomass of the total catch, and over 80% in terms of the number of individuals. The second most abundant species is the European sardine (*Sardina pilchardus*), totalling 21% of biomass and 14% of the total number of individuals. The discard rate is rather low, around 6% of biomass [6].

During the study period, between 349 and 363 annual fishing licences were recorded on the National Fishing License Register of the Ministry of Agriculture, Food and Forestry. Almost all of the boats had multipurpose licences and about half, given their size and engine power, were actually operating singly as bottom trawlers or purse seiners. It is believed that the real number of pair trawlers currently operating is <78 [7]. Of these, ∼69 are operating in the Adriatic Sea, with the others operating in the Sicilian Channel. According to the official statistics produced by IREPA [7,8], fishing effort in the Adriatic Sea represented 100 and 85% of the total national fishing effort for this fishing system in 2006 and 2007, respectively. In 2007, the remaining effort was carried out in the Sicilian Channel (15%). In the northern Adriatic Sea (Veneto and Emilia Romagna), fishing effort in 2006 and 2007 represented 67 and 61%, respectively, of the total effort in the Adriatic Sea; whereas in the central Adriatic the corresponding figures were 33 and 39%. Most Italian pair trawlers operate all the year round, but some work only seasonally (one or two months). In terms of the regulation of fishing effort, Italian pair trawlers must respect the following temporal closures: weekends, bank holidays, and a 30 day closure in mid-summer (usually shifting between the end of July and the end of September, according to different schemes in different areas), with a one day closure every Friday for the following eight weeks. In addition, 60% of the boats must respect a closure every Thursday for eight weeks following the 30 day mid-summer closure.

1.2. *Cetacean species in the Adriatic Sea*

Many species of cetaceans have been observed in the Adriatic Sea [9], including the fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera novaengliae*), sperm whale (*Physeter macrocephalus*), Cuvier's beaked whale (*Ziphius cavirostris*), false killer whale (*Pseudorca crassidens*), Risso's dolphin (*Grampus griseus*), striped dolphin (*Stenella coeruleoalba*), common dolphin (*Delphinus delphis*) and common bottlenose dolphin (*Tursiops truncatus*). However, most of these species now occur in the region only rarely or occasionally. The exceptions are the bottlenose dolphin, which is regularly recorded throughout the entire Adriatic [9], and the striped dolphin, which is considered a regular resident of the central and southern Adriatic Sea [10]. In the northern Adriatic, the distribution of bottlenose dolphins appears to be widespread [11], and long-term photo-identification monitoring studies exist in a few restricted areas: for example, in Istria [12], Kvarneric [13], Kornati Islands [14] and Vis Island [15].

2. Materials and methods

The Adriatic Sea is the northernmost arm of the Mediterranean Sea. It is a semi-enclosed basin located between Italy and the Balkan Peninsula. It has a roughly rectangular shape oriented in a NW–SE direction, stretching for ∼800 km with a width of ∼200 km. Based on its physiographic characteristics, it can be divided into three sub-basins: (1) a northern shallow basin generally <50 m deep, reaching a maximum of 100 m in the Croatian archipelago; (2) a central basin with a maximum depth of 280 m; and (3) a deep southern basin, separated from the central basin by the 170 m deep Palagruza Sill, with a maximum depth of ∼1200 m in the centre.

Between July 2006 and December 2008 independent observers monitored all fishing operations of a subset of pair trawlers with an LOA >15 m. Based on the available official information on fishing effort for 2005 [8], all observations were planned in the Adriatic Sea (Figure 1). Data collection was stratified to account for the difference between the fishing effort in the north and in the central Adriatic Sea. Logbook data was not made available. As an initial measure of fishing effort, we used the officially estimated fishing days reported by IREPA [7,16]. IREPA estimate the annual total and regional fishing effort based on a multivariate analysis of sampled fishing effort, stratified by gear, vessel size, region and basin. Strata are selected based on the information contained in the National Fishing Licences database, using the Bethel procedure and the Hanurav–Vijayan algorithm [7,8,16]. In the absence of an official estimate of fishing effort for 2008, we used the 2007 estimate as a proxy; however, we believe that fishing effort of pair trawlers in 2008 decreased because of the drastic increase in fuel price. We estimated by-catch in the entire fleet by first estimating the total number of hauls made. Fishing days from Veneto, Emilia Romagna and Puglia were scaled to the total hauls by using the average number of hauls recorded in each region. For Marche, where no observations were carried out, an overall average of all observed hauls was used.

During daylight the presence/absence of dolphins and other species of conservation concern around the vessel was assessed by each observer by eye throughout the duration of all fishing operations, including net deployment, towing, hauling and discard. During night hours observations were limited to hauling and discarding procedures. Opportunistic observations were also carried out during transits to/from fishing grounds.

In fishery terminology, the word 'by-catch' is used loosely to refer to the capture of any nontarget species (dead or alive), although more properly to the capture of nontarget species that have

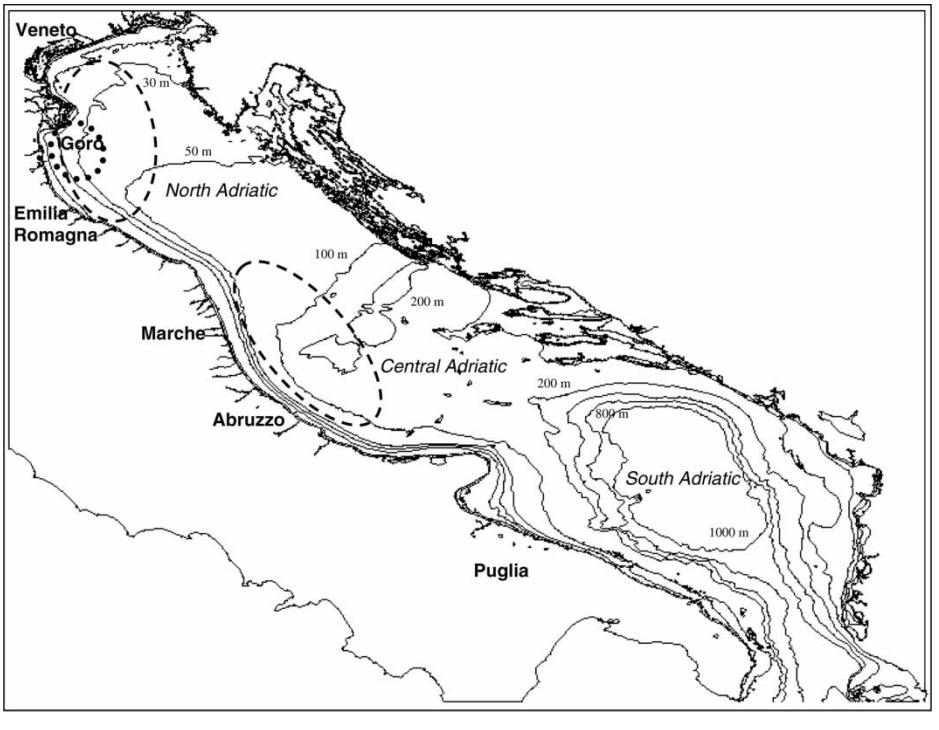

Figure 1. Monitored fishing areas (dashed circles), sea turtle hotspot (small dotted circle) and names of the Italian regions.

some commercial value. It is often also now applied to the unwanted take of protected species even though the more proper term for this would be 'accidental catch' or 'accidental take'. For simplicity, in this article we use the term 'by-catch' in both cases, as this term and meaning are now widely used in the literature. The total by-catch rate ($\hat{T}$) for species of conservation concern was calculated as follows:

$$\hat{T} = \frac{\sum t_h}{H_{\text{obs}}},$$

where t_h is the number of animals taken (by-caught) in the h_{th} haul, and H_{obs} is the number of hauls observed in a given period. The estimate of $\hat{K}$, the total by-catch in a given year, with its estimated coefficient of variation (CV), is:

$$\hat{K} = \hat{T} \times H_{\text{tot}} \quad \text{and} \quad CV_K = (U \times SE_T)/\hat{K}$$

where H_{tot} is the total number of hauls in a given period and $U \times SE_T$ is the estimated standard error, given by the total number of unobserved hauls multiplied by the total standard error. The log-normal 95% confidence limits were calculated after Bravington and Bisack [17] as:

$$\sum t_h + U \times \exp(\mu \pm 1.96\sqrt{\sigma^2}),$$

where

$$\mu = 1/2 \ln\left(\frac{\hat{T}^2}{(1 + CV_K^2)}\right) \quad \text{and} \quad \sigma = \ln(1 + CV_K^2).$$

Two different types of annual estimates were calculated, one referring to the total fishing operations and one to the northern Adriatic Sea only. Only estimates with CVs <30% were considered acceptable.

Concerning elasmobranchs, here we present only estimates of those species currently considered to be highly vulnerable, that is with a Vulnerability Index >0.70, as given in FISHBASE (http://www.fishbase.org, calculated after Cheung et al. [5]).

Observers on board the northern Adriatic vessels were also trained to tag sea turtles. Each turtle was tagged with two 1005-681 Monel tags (National Band & Tag Company) on the first scute of both front flippers.

3. Results

3.1. *Monitoring operations*

Fishing operations of a subset of 27 boats were monitored during 24 different months, totalling 759 days at sea, 745 successful fishing trips and 3141 hauls. Sixteen independent observers participated in this monitoring programme. Additional details of the monitoring programme, stratified by region, are given in Table 1.

Figure 1 shows the fishing areas of pair trawlers. Boats registered in the regions of Veneto and Emilia Romagna operated in the northern Adriatic Sea, whereas those registered in Puglia were active in the central Adriatic Sea.

Our observations covered between 1.8 and 6.3% of the total fishing effort of those boats registered in Veneto, between 1.8 and 4.2% of those registered in Emilia Romagna, and between 0.9 and 1.7% of those registered in Puglia [7,16].

Table 1. Summary of the monitoring programme parameters.

Region and harbour	Year	Months	Monitored boats	No. of trained observers	Successful daily fishing trips	Hauls observed	Mean hauls per fishing trip
Veneto (Chioggia, Pila)							
	2006	Jul–Dec	4	3	82	468	5.7
	2007	Sep–Dec	6	2	51	233	4.6
	2008	Jan–Jun, Sept–Dec	8	2	154	747	4.8
Emilia Romagna (Porto Garibaldi)							
	2006	Jul–Dec	4	1	35	162	4.6
	2007	Jan–Mar, Jul, Sep–Dec	6	6	133	517	3.9
	2008	Jan–Oct, Dec	11	4	212	766	3.6
Abruzzo (Giulianova)							
	2006	Nov–Dec	2	5	13	37	2.8
	2007	Jan–Mar, Nov	4	4	22	74	3.4
	2008	Jan–Oct	4	3	43	137	3.2

3.2. *Species of conservation concern*

A total of 609 groups of bottlenose dolphins were sighted close to the net in over 30% of fishing operations, often interacting with the fishing operation (e.g. persistently following trawlers during tows, entering the net and swimming around the cod-end during the final part of hauling operations, or feeding on discarded fish). Dolphins were also observed opportunistically during transit to/from fishing grounds on 83 occasions. The bottlenose dolphin was the only species of cetacean recorded

Table 2. List of species of conservation concern by-caught in pair trawlers and their by-catch rates.

	Northern Adriatic Sea		Central Adriatic Sea	By-catch rate	
	Veneto	Emilia Romagna	Abruzzo	Individuals per haul	Vulnerability Index[a]
Cetaceans					
Bottlenose dolphins (*Tursiops truncatus*)	2	1		See text	NA
Sea turtles					
Loggerhead turtle (*Caretta caretta*)	13	67		See text	NA
Elasmobranchs					
Thintail thresher (*Alopias vulpinus*)	10	3		0.0041	76.66
Sandbar shark (*Carcharhinus plumbeus*)		1		0.0003	86.16
Piked dogfish (*Squalus acanthias*)	280	92	2	See text	87.49
Starry smooth-hound (*Mustelus asterias*)	15			0.0048	52.41
Smooth-hound (*Mustelus mustelus*)	57	23		0.0256	73.09
Blackspotted smooth-hound (*Mustelus punctulatus*)	18			0.0057	54.02
Blue shark (*Prionace glauca*)			1	0.0003	67.21
Small-spotted catshark (*Scyliorhinus canicula*)	1	2		0.0010	34.27
Bull ray (*Pteromylaeus bovinus*)	131	12		See text	72.29
Common eagle ray (*Myliobatis aquila*)	208	19	1	0.0726	61.07
Common stingray (*Dasyatis pastinaca*)	1	3	1	0.0016	64.45
Pelagic stingray (*Pteroplatytrygon violacea*)	51	67	3	0.0384	65.68
Thornback ray (*Raja clavata*)		10		0.0032	52.51
Starry ray (*Raja asterias*)		1		0.0003	49.97
Spotted torpedo (*Torpedo marmorata*)		1		0.0003	68.79

Note: [a]After Cheung et al. [5], see http://www.fishbase.org. NA, not available.

Table 3. Summary of monthly by-catch data by region.

Region Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
North Adriatic Sea												
Sea turtles by-catch rate	0.0	0.005	0.0	0.0	0.025	0.006	0.032	0.049	0.053	0.037	0.025	0.063
Elasmobranch by-catch rate	0.212	0.283	0.109	0.270	0.264	0.356	0.822	0.195	0.435	0.211	0.343	0.384
Veneto												
Fishing trips	19	13	6	13	20	15	33	4	40	54	46	24
Hauls	71	52	19	65	122	88	200	26	223	270	227	78
Cetacean catches							1*				1	
Sea turtles catches					2(1†)	1	4		2	1	2	1
Sea turtles by-catch rate	0.0	0.0	0.0	0.0	0.016	0.011	0.020	0.0	0.009	0.004	0.009	0.013
Elasmobranch catches	45	39	6	27	50	57	239	7	93	64	91	54
Elasmobranch by-catch rate	0.634	0.750	0.316	0.415	0.410	0.648	1.195	0.269	0.417	0.237	0.401	0.692
Emilia Romagna												
Fishing trips	40	34	30	23	26	23	38	3	49	51	32	31
Hauls	151	135	110	87	79	92	143	15	170	214	137	112
Cetacean catches										1*		
Sea turtles catches		1			3		7(2†)	2	19(1†)	17(2†)	7(1*)	11
Sea turtles by-catch rate	0.0	0.007	0.0	0.0	0.038	0.0	0.049	0.133	0.112	0.079	0.051	0.098
Elasmobranch catches	2	14	8	14	3	7	43	1	78	38	34	19
Elasmobranch by-catch rate	0.013	0.104	0.073	0.161	0.038	0.076	0.301	0.067	0.459	0.178	0.248	0.170
Abruzzo/Puglia = Central Adriatic Sea												
Fishing trips	11	10	12	6	4	4	3	–	6	8	5	8
Hauls	38	33	41	25	16	15	8	–	15	21	20	20
Cetacean catches								–				
Sea turtles catches								–				
Sea turtles by-catch rate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	0.0	0.0	0.0	0.0
Elasmobranch catches	1	1		4		1	1	–				
Elasmobranch by-catch rate	0.026	0.030	0.0	0.16	0.0	0.067	0.125	–	0.0	0.0	0.0	0.0

Notes: For the protected species only the following notation is used: *specimen dead in the net; †comatose specimens released after recovery. Please note that because of the 30 day summer closure, no observations were made in the central Adriatic in August.

by the observers in the northern Adriatic, whereas in the central Adriatic two groups of striped dolphins were also sighted during transit to the fishing area.

Two bottlenose dolphins were recorded as dead by-catch, yielding an observed mortality rate of 0.0006 individuals per haul (the by-catch rate was 0.0010 individuals per haul). The by-catch rate of loggerhead turtles was much higher, 0.0255 individuals per haul, and mostly concentrated during fishing operations around the Goro area (Figure 1). For this species the mortality rate was 0.0003 individuals per haul and the rate of by-caught comatose animals was 0.0019 individuals per haul.

In general, by-catch events were concentrated in the northern Adriatic fishing grounds. Boats registered in Veneto accidentally caught 2 bottlenose dolphins (1 died, 1 was partially entangled during the final part of hauling and promptly released), 13 sea turtles (1 comatose was released after full recovery; 4 were tagged before release) and 772 elasmobranchs of 11 different species (Table 2). Boats registered in Emilia Romagna accidentally caught 1 bottlenose dolphin (dead), 67 sea turtles (1 died and 5 comatose were released after recovery; 61 were caught alive and released, 33 of these were tagged) and 261 elasmobranchs of 12 different species, including 13 unspecified sharks and 14 unspecified rays and skates (Table 2). In the central Adriatic Sea, only 8 elasmobranchs of 5 different species were by-caught. In general, all by-caught sharks and skates were marketed, whereas pelagic stingrays (*Pteroplatytrygon violacea*), common stingrays (*Dasyatis pastinaca*), bull rays (*Pteromylaeus bovinus*) and common eagle rays (*Myliobatis aquila*) were discarded at sea.

The data on monthly changes in by-catch events and by-catch rates for species of interest are summarised in Table 3. Loggerhead turtles showed an apparent overall increasing trend in the monthly by-catch rate during the year. Rates were very low in the first quarter, increased strongly towards the end of the second quarter and remained relatively high until December.

By-catch rates of elasmobranchs by boats registered in Veneto seemed to show a more complex cycle: a strong peak in the summer, a lower peak in the winter, with low levels in spring and autumn.

Table 4. Annual by-catch estimates: Northern Adriatic Sea and all pair trawlers fishery.

	Total hauls	Observed hauls	Total by-catch	By-catch rate	Annual estimate	CV	95% CI
North Adriatic Fishing Effort							
Loggerhead turtle (captured)	78,010	2899	80	0.0276	863	0.15	817–891
Loggerhead turtle (dead)	78,010	2899	1	0.0003	–	–	2–27
Loggerhead turtle (comatose)	78,010	2899	6	0.0021	65	0.39	46–79
Bottlenose dolphins	78,010	2899	2	0.0007	–	–	9–37
Rays	78,010	2899	504	0.1739	5436	0.08	5360–5482
Pteromylaeus bovinus	78,010	2899	143	0.0493	1542	0.18	1434–1611
Sharks	78,010	2899	502	0.1732	5415	0.15	5124–5595
Alopias vulpinus	78,010	2899	13	0.0045	140	0.23	124–151
Squalus acanthias	78,010	2899	372	0.1284	4012	0.20	3654–4242
Mustelus mustelus	78,010	2899	80	0.0276	863	0.15	818–891
Total Fishing Effort							
Loggerhead turtle (captured)	148,205	3147	80	0.0254	1510	0.15	1426–1562
Loggerhead turtle (dead)	148,205	3147	1	0.0003	–	–	4–50
Loggerhead turtle (comatose)	148,205	3147	6	0.0019	113	0.40	79–140
Bottlenose dolphins	148,205	3147	2	0.0006	–	–	15–66
Rays	148,205	3147	509	0.1617	9607	0.08	9467–9691
Pteromylaeus bovinus	148,205	3147	143	0.0454	2699	0.18	2500–2825
Sharks	148,205	3147	505	0.1605	9531	0.16	9001–9861
Alopias vulpinus	148,205	3147	13	0.0041	245	0.29	202–276
Squalus acanthias	148,205	3147	374	0.1188	7059	0.20	6403–7480
Mustelus mustelus	148,205	3147	80	0.0254	1510	0.15	1427–1561

Notes: Acceptable estimates are those with CVs <0.30. Estimates with CVs ⋙30 are considered unacceptable.

3.3. *Annual by-catch estimates*

Two average annual estimates – one for the total Italian Adriatic pelagic/mid-water trawl fishing and the other only for the Italian pelagic/mid-water trawling in the northern Adriatic – were derived for each taxonomic order/species and for those marine species considered more vulnerable. These are presented in Table 4. Estimates of the total annual by-catch, with CVs $<30\%$, were obtained for the loggerhead turtle and four species of elasmobranchs considered relatively vulnerable. The two by-catch estimates of bottlenose dolphins had CVs of $\sim$68–69% and were, therefore, considered unreliable. Simple simulations of increased observer coverage indicated that with the same capture rate and single captures per haul, the observation effort would need to be increased fivefold in order to obtain an annual estimate (assuming the true annual capture were to be 22 dolphins, as predicted by these observations) with an acceptable coefficient of variation ($CV = 0.26$) for the northern Adriatic Sea alone.

4. Discussion

This article presents an overview of data collected during an extensive programme to monitoring by-catch of cetaceans and other species of conservation concern during commercial fishing operations. Despite the fact that Regulation (EC) No. 812/2004 obliges Member States to monitor only accidental captures of cetaceans, observers collected important data on a number of other species of conservation concern. This programme effectively contributes to regional knowledge on this phenomenon by providing additional information on loggerhead turtle and elasmobranch distribution, seasonality, by-catch rates and biology.

Fishing operations made by boats registered in Veneto and Emilia Romagna took place more or less in the same region, the northern and shallower Adriatic Sea, whereas boats registered in Puglia operated in the central and deeper Adriatic Sea. There was a large variability in the occurrence of observed by-catch events for all species of conservation concern in these two fishing areas. In particular, there was a greater diversity and occurrence of species, both pelagic and benthic, in the northern Adriatic compared with the central Adriatic, where by-catch was rare and included only pelagic species. Such a difference is not surprising given the physiographic characteristics of these two areas and current knowledge on the ecology of the species in the region. The literature suggests that elasmobranchs have undergone a dramatic decline in the Mediterranean Sea as a result of overfishing and by-catch [2,18]. In the Adriatic Sea this decline has been observed in terms of both abundance and number of species [18]. The results of this study highlight areas of concern for pair trawlers fishing operations in the northern Adriatic Sea and suggest that further work is needed to evaluate the real impact that they could pose to a number of species classified as vulnerable [5]. Even though the pelagic/mid-water pair trawl fishery does not target sharks and skates, these are considered a very valuable by-catch, given their high market price and, therefore, are never released. Concerning the large number of by-caught pelagic and epibentic species of rays, they were all immediately released. If any mitigation measures are to be adopted then geographical differentiation and seasonality of the by-catch rates will need to be taken into account. Should further studies show that the total by-catch has an impact at the population level for some species, mitigation measures for this type of fishery should focus on the northern Adriatic fishing grounds first.

The bottlenose dolphin was the only cetacean species observed in the fishing areas. This finding is not surprising and reflects current knowledge on presence and distribution of cetaceans in the Adriatic Sea [9,10,19]. It also reflects the opportunistic nature of bottlenose dolphins in terms of their capability to take advantage of fishing operations for feeding purposes [20]. The low by-catch rate for bottlenose dolphins is not an indication of low densities in the region or the lack of overlap between fishing grounds and areas of dolphin presence. In fact, dolphins were frequently

sighted during our observations, and often interacting with fishing operations. These dolphins have probably developed the capacity to take advantage of this fishery while minimising their risk of entanglement. However, some degree of lethal interaction was observed and there is an urgent need to determine whether the scale of this mortality is sufficient to threaten bottlenose dolphins at the population level. The basic information required to make a robust assessment of population status consists of: (1) a robust estimate of the number of bottlenose dolphins in the area of concern (the entire Adriatic Sea); and (2) the population structure of bottlenose dolphins inhabiting this sea and adjacent areas. At present, this information does not exist. Data on abundance of bottlenose dolphins is limited to rather small sub-areas of the Adriatic [19]. Concerning the genetic evidence on the potential existence of a Mediterranean bottlenose dolphin meta-population, a preliminary study indicates that there is gene flow within the Adriatic and adjacent areas, with some degree of structure within the Mediterranean (e.g. eastern vs. western basin) [21]. However, these are still partial indications and both of these aspects will need to be considered in the next monitoring programmes.

The same reasoning, in terms of need for population status assessment, applies to loggerhead turtles using this region, which showed a by-catch rate 26 times higher than that of the bottlenose dolphin. Even though their mortality rate was extremely low, it was possible to obtain a good estimate of the annual total by-catch in the northern Adriatic Sea, which appears to be quite high: almost 900 specimens per year. However, only ∼1% of these turtles were dead, with an additional 7.5% potentially debilitated (those released after recovering from a comatose state). However, at present it is impossible to quantify the real rate of recaptures, of the 37 tagged turtles during this study none was recovered after release.

A previous study carried out in this region, based on numbers of by-caught turtles reported by fishermen, estimated a much lower annual by-catch (∼160 specimens) in pair pelagic trawlers [22]. However, this form of estimate, based on indirect observation, should always be considered with caution, and our results seem to confirm this. In adition, direct onboard observations on bottom trawlers, also as part of this study, estimated that annually ∼4200 loggerhead turtles are accidentally caught in the same area, 9% of which are dead [22]. Based on all these indications, it seems important to carefully investigate the overall mortality caused by all trawling activities in the entire Adriatic Sea. In addition it is fundamental to assess whether the stress caused by nonlethal capture followed by release can have a negative impact at the population level. This is certainly not a trivial task, as turtles frequenting this area belong to at least three different populations, nesting in Greece, Turkey and Cyprus [23]. Regardless, given the fact that loggerhead turtles and bottlenose dolphins are protected species, no further evidence should be required to begin testing mitigation measures and start robust population abundance assessments. Mitigations measures could include the use of pingers, excluder devices (i.e. turtle excluder devices), or geographical and temporal closures of fishing activities, especially in the 'turtle hotspot' south of Goro.

The observed trend in sea turtle by-catch rate seems consistent with what is known about the regional geographic movements of this species. Generally, nonadult specimens use the northwestern Adriatic area for feeding purposes from the end of spring onwards [24]. They appear to initially stay in open waters and gradually approach the coast, moving off again in late summer. In early winter they start migrating southward [24].

It was not possible to obtain a reliable estimate of annual lethal captures of bottlenose dolphins because of the very low by-catch rate and current level of observer coverage. However, our basic simulation on how much effort would be needed to obtain acceptable CVs highlight that, for species with very low lethal by-catch rates, such as the bottlenose dolphin and the loggerhead turtle, obtaining reliable estimates of annual deaths would imply huge costs. Given the current pair/mid-water trawl fishing effort and assuming the same logistic arrangements for observers, increasing the observation coverage to the required level would cost over one million Euros. This considerable amount of money would be devoted to obtain a robust estimate of by-catch, without

addressing any underlying conservation issue. On the other hand, given that we know that lethal interactions involving protected species are occurring, it would be more prudent and efficient to invest in at least three synergistic activities. These are: (1) the testing and implementation of mitigation measures that promise to increase the survival of species of conservation concern, in particular sea turtles, making fishing operations more selective; (2) the gathering of data on population sizes and structures, for those species affected by the by-catch; and (3) the evaluation of different coverage targets for programmes of direct observation of by-catch, through ad hoc stratifications.

4.1. *Potential limitations of this study*

Given the extent of the Italian pair pelagic and mid-water trawl fishing operations, the observation programmes were unable to achieve average observation coverage higher than 2% of the total hauls at the national level, and 4% in the northern Adriatic Sea. At regional level, within the northern Adriatic area, these observations achieved a maximum of 6.3%. In the central Adriatic monitoring was unsatisfactory and will be increased in future. The gap in onboard monitoring of pair trawlers operating from the Marche harbours – representing ∼15% of the total fishing effort – will be also covered in the next programme. However, based on our results we believe that, given the Adriatic Sea and pair trawler operations' characteristics, the by-catch of species of conservation concern will likely be lower in the central and southern fishing areas.

The available fishery statistics, which represent the best available source of information, need to be considered with care in relation to total by-catch estimates. The official effort data, in fact, does not reflect fishing effort accurately. At present, the estimates of total fishing days are based on standard sampling procedures, applied to the total number of boats owning a *volante* license, combined to landings data and logbooks. However, all of these boats have multipurpose licenses and can switch from one gear to another, targeting the same species (e.g. from pair trawling to purse seining or bottom trawling). Obviously this can affect the estimation of real fishing effort if gear type is not correctly recorded in the landings statistics. In addition, seasonal fluctuation in the economic value of target species, and the increasing cost of fuel in 2008, could have resulted in an overestimation in the extrapolations of fishing effort based on 2007 data. Unreliable fishing effort data would obviously affect both the effective observation coverage and the estimate of total by-catch events. In order to provide robust advice for management, it would be best to use more reliable real-time indicators of fishing effort, stratified as necessary. This may become possible, in the near future, with the full application of the EU regulations on real-time electronic submission of fishing effort data.

Acknowledgements

This study was financed by the Italian DG Fishery within the Italian obligations to the Council Regulation (EC) 812/2004 and comprises data collected during two consecutive monitoring programmes: BY-CATCH I & II. Special thanks to our observers Dario Beneventi, Simonetta Boscolo, Davide Grazi, Domenico Enrico Marcon, Liberata Morra, Edoardo Mostrarda, Federica Osellatore, Nicoletta Palmegiani, Giorgia Panizio and Francesca Vannini for carrying out the onboard observations and to the crews of *Audace*, *Augusta Zennaro*, *Balena Bianca*, *Bruno Zennaro*, *Cisky*, *Flipper*, *Fratelli Zennaro*, *Freccia Del Sud*, *King II*, *Mario Terenzi*, *Nadia*, *Nonno Milio*, *Nonna Guerrina*, *Nuova Rebecca*, *Nunzia*, *Odissea*, *Olinda*, *Ornitorinco*, *Palma II*, *Profeta*, *Raffaella*, *Santa Chiara II*, *S. Mazzola*, *Samuele I* and *Stella Zennaro* for facilitating the work of our observers. We would also like to thank the Harbour Masters of Chioggia and Porto Garibaldi for their kind cooperation. We finally thank Peter Mackelworth, Simon Northridge, Randy Reeves and two anonymous reviewers for greatly improving the early drafts of this manuscript with their useful suggestions and language revisions.

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