Acta Adriatica 65 (2024): 75-121
https://doi.org/10.32582/aa.65.1.1

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REVIEW

Whales and dolphins of the Adriatic Sea: present knowledge, threats and conservation

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Abstract: The Adriatic Sea is one of the Mediterranean areas most exposed to cumulative human stressors. This semi-enclosed and largely shallow basin has been subjected to intensive exploitation and destructive fishing practices for decades, resulting in biodiversity decline and poor ecosystem health. Diversity of cetaceans is lower than in other parts of the Mediterranean, and the extant dolphins and whales have been facing threats that include the combined effects of habitat loss and degradation, prey depletion, incidental mortality and injury caused by fisheries, anthropogenic noise, chemical contamination and climate change. Here, we report information for the nine cetacean species known to occur in the basin (classified as either regular, visitor or vagrant), plus three species characterized by a single record. For these species, we review evidence from field research and other studies – with a bias towards the common bottlenose dolphin *Tursiops truncatus* (by far the most intensively-studied cetacean in this area). We also describe and characterize the main threats to cetaceans in the Adriatic, relying on recent literature as well as historical information that helps frame the present status of cetaceans in the context of past human impacts (particularly the extensive killing campaigns conducted until the 1960s). Finally, we provide management recommendations to inform and guide the action that must be taken in compliance with extant legislation, marine conservation directives and international commitments to protect marine biodiversity.
Keywords: Cetaceans; fisheries; human impact; management; marine mammals; Mediterranean Sea; mortality

Sažetak: KITOVI I DUPINI U JADRANSKOM MORU: SADAŠNJE SPOZNAJE, PRIJETNJE I OČUVANJE. Jadransko more je jedno od područja Sredozemnog mora koja su najizloženija kumulativnim ljudskim utjecajima. Ovaj poluzatvoreni i uglavnom plitki bazen je proteklih desetljeća bio izložen intenzivnom iskorištavanju i štetnim ribolovnim praksama, što je dovelo do smanjenja biološke raznolikosti i lošeg stanja ekosustava. Raznolikost kitova i dupina (Cetacea) ovdje je manja nego u drugim područjima Sredozemnog mora i postojeće vrste koje nastanjuju Jadransko more suočavaju se s prijetnjama koje uključuju kombinirane učinke gubitka i degradacije staništa, nedostatka plijena, slučajne smrtnosti i ozljeda uzrokovanih ribolovom, buke izazvane ljudskim aktivnostima, kemijskog zagađenja i klimatskih promjena. U ovom radu navodimo podatke o devet vrsta kitova i dupina za koje je poznato da se pojavljuju u Jadranu (klasificirani su kao redoviti, posjetioci ili skitnice) te tri vrste koje su zabilježene na ovom području samo jednom. Za ove vrste pregledali smo podatke iz terenskih istraživanja i drugih studija, među kojima ih je najviše za dobrog dupina *Tursiops truncatus* (koji je najintenzivnije proučavana vrsta u ovom području). U radu također opisujemo i navodimo značajke glavnih prijetnji kitovima i dupinima u Jadranskom moru, temeljem recentne literature kao i povijesnih podataka koji pomažu prikazu sadašnjeg stanja tih životinja u kontekstu prošlih ljudskih utjecaja (posebice opsežnih kampanja ubijanja provedenih do 1960-ih). Konačno, donosimo preporuke za upravljanje kako bi omogućili prijenos informacija i usmjeravanje aktivnosti koje se moraju poduzeti u skladu s postojećim zakonodavstvom, direktivama o očuvanju mora i međunarodnim obvezama u pogledu zaštite morske biološke raznolikosti.
Ključne riječi: Cetacea; ribarstvo; ljudski utjecaj; upravljanje; morski sisavci; Sredozemno more; smrtnost

INTRODUCTION

The Adriatic Sea is one of the Mediterranean areas most exposed to cumulative human stressors, resulting in biodiversity decline and poor ecosystem health (Coll *et al.*, 2007, 2009; Lotze *et al.*, 2011; Ferretti *et al.*, 2013; Fortibuoni *et al.*, 2017; Ramírez *et al.*, 2018; Sguotti *et al.*, 2022). With this review, we aim to provide a reference and a road map for anyone working on cetaceans (whales and dolphins) in this region. More specifically, we update and complement an early review on the cetacean fauna and human impacts in the north-

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Received: 24 November 2023, accepted: 5 January 2024
ISSN: 0001-5113, eISSN: 1846-0453

ern Adriatic Sea, which was published twenty years ago (Bearzi *et al*., 2004). We do so by 1) expanding the geographic scope to the entire Adriatic Sea, 2) reporting information for all the cetacean species known to occur or have occurred in the basin, and 3) reviewing evidence from field research and other studies conducted since the 1980's – with a focus on contributions that are formally published in scientific journals.

To frame this information in the context of past human impacts, we review historical and recent literature documenting the remarkable changes that have occurred in this part of the Mediterranean Sea during the past century, and we discuss the effects these changes had (or may have had) on cetacean populations. We also describe the main threats to cetaceans in the Adriatic today, and provide management recommendations intended to inform and guide actions in line with extant legislation, marine conservation directives and international commitments to protect marine biodiversity (e.g. EC, 1992, 2008, 2014; UNEP, 2019; accobams.org). We conclude that bringing the cetacean fauna of the Adriatic back to its original vibrancy would require restoring all the components of the marine ecosystem, and transitioning from a multi-decade phase of overexploitation and damage to responsible management.

STUDY AREA

The Adriatic Sea is a semi-enclosed basin encompassing 138,600 km², bordered by Italy to the west, and by Slovenia, Croatia, Bosnia and Herzegovina, Montenegro, and Albania to the east (Fig. 1). The northern sector is strongly influenced by the input of rivers (including the large river Po, one of the three Mediterranean rivers with the largest water discharge), with important effects on salinity, temperature and productivity (Orlić *et al*., 1992; Spillman *et al*., 2007; Campanelli *et al*., 2011; Malone and Newton, 2020). In the south, the Adriatic Sea connects to the Ionian Sea through the 72-km wide Strait of Otranto. The basin's average depth is 260 m, and its maximum depth is 1,233 m. However, its northern sector rarely exceeds depths of 100 m, with shallow western bottoms gradually deepening eastward. The Adriatic Sea is subject to strong oceanographic and trophic fluctuations, in part caused by human activities (Degobbis *et al.,* 2000; Russo *et al.,* 2002; Solidoro *et al.,* 2009; Fortibuoni *et al.,* 2010; Mozetič *et al.,* 2010; Lotze *et al.,* 2011). These wide fluctuations involve variations in prey availability that, in turn, can influence the abundance and local distribution of cetaceans (Bearzi *et al.,* 2008; Fortuna *et al.,* 2018).

In the scientific literature, the geographical subdivision of the Adriatic into northern, central or southern sectors can vary greatly, referring to areas with different extensions (Fig. 1). For instance, "northern Adriatic" (or "North Adriatic") can refer to the sector: a) north of Ravenna, Italy (e.g. Fortibuoni *et al*., 2017); b) north of the line connecting Ancona, Italy, and Zadar, Croatia

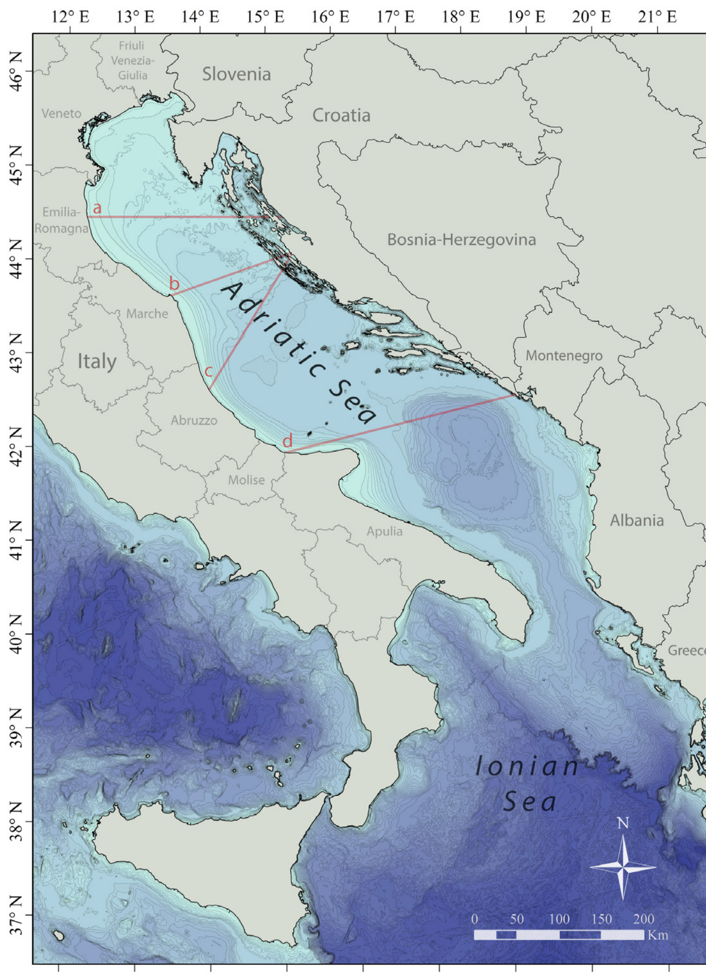

Fig. 1. The Adriatic Sea, showing the bordering countries, the bathymetry (from GEBCO 2023), and some examples of lines (a, b, c, d) used to delimit the basin's northern sector (see the Study area section).

(e.g. Bearzi *et al*., 2004); c) north of the imaginary line overlapping the 100 m isobath, approximately between Teramo, Italy, and Zadar (e.g. Artegiani *et al*., 1997a; UNEP-MAP-RAC/SPA, 2015); or d) north of the imaginary line linking the northern border of Apulia with the northern border of Montenegro (Geographical Sub Area 17, General Fisheries Commission for the Mediterranean). In this review, reference to northern, central or southern Adriatic is either generic, or it matches the subdivision by the cited authors.

METHODS

Our primary criterion for the inclusion of a given piece of information was formal publication in a peer-reviewed scientific journal. While we tried to bend towards inclusiveness, we simply might have failed to detect or retrieve a given contribution, for which we apologise to the authors. We also acknowledge that a relatively large body of information exists in the form of unpublished theses, technical reports, conference proceedings or abstracts etc. While such "grey literature" certainly can contain valuable information, it was not subject to formal peer-review, it may be difficult to retrieve, and the analyses or other contents could be meant to be preliminary. In addition, some authors simply may not want their unpublished reports or theses to be cited (and occasionally state so in their contribution). Interested readers may want to consider this body of unpublished information as a complement to what is being reported here.

In this review, exceptions to the "formally published" criterion have included final reports by authoritative international organizations (e.g. ACCOBAMS, FAO, IUCN, UNEP), limited information from relevant PhD dissertations or reports containing high-quality original data otherwise unavailable, as well as historical sources that may be difficult to retrieve and come from a time when the peer-review process was not in place. We also referred to, and cited, selected legislative instruments and conventions (e.g. European Community directives).

With respect to the reported stranding records, we note that in at least some cases the stranding locations of dead cetaceans (or a lack of strandings) may not reflect the actual occurrence of animals within a given area. Cetacean stranding records are known to be influenced by a variety of factors (Peltier *et al*., 2012). For instance, i) drifting carcasses can be transported unevenly because of the circulation of Adriatic Sea surface waters and currents patterns (Artegiani *et al.*, 1997a, b), ii) stretches of coast being less populated or more difficult to access tend to result in fewer stranding reports, and iii) geographical differences in monitoring effort, expertise, and awareness or interest by the general public, all affect the likelihood of reporting. Additionally, an animal may at least potentially be bycaught in fishing gear in a given area, kept on board a fishing boat during navigation, and discarded at sea in another area. In short, information on strandings can be extremely valuable but it must be assessed with caution, especially when it refers to carcasses in advanced decomposition that may have travelled long distances.

Following a recent cetacean status report (ACCOBAMS, 2021a), we used the following definitions to classify occurrence in the Adriatic Sea 1) "regular": a species represented by a population having its native distributional range within the region; 2) "visitor": a species represented by individuals found outside their native distributional range, which repeatedly, albeit irregularly, appear in a given region; and 3) "vagrant": a species represented by individuals found outside their native distributional range, appearing in a given region with high rarity.

CETACEAN SPECIES

A total of 25 species and subspecies of cetaceans have been reported in the Mediterranean Sea (ACCOBAMS, 2021a; Table 1). Eleven of these species occur in the Adriatic Sea (Table 1). Of these, only four species can be considered regular: the Cuvier's beaked whale *Ziphius cavirostris*, the Risso's dolphin *Grampus griseus*, the common bottlenose dolphin *Tursiops truncatus*, and the striped dolphin *Stenella coeruleoalba*. The common dolphin *Delphinus delphis* used to be abundant throughout the Adriatic, but the species declined in the first half of the 20th century, and it has not recovered. While groups of common dolphins were encountered in recent years off the eastern Adriatic coast, it is unclear whether the small extant groups are composed of immigrants (e.g. from the Ionian Sea; Genov *et al.*, 2012), or animals having their life cycle within the region. We have provisionally classified the common dolphin as visitor/regular. The fin whale *Balaenoptera physalus* and the sperm whale *Physeter macrocephalus* are classified as visitors, pending additional information on their abundance, movements and reproduction (especially in the southern basin). The humpback whale *Megaptera novaeangliae*, and the false killer whale *Pseudorca crassidens* are vagrant. Finally, three species – the minke whale *Balaenoptera acutorostrata*, the long-finned pilot whale *Globicephala melas* and the short-finned pilot whale *Globicephala macrorhynchus* – are each represented by a single Adriatic record (Table 1).

In the northern Adriatic, the common bottlenose dolphin (hereafter "bottlenose dolphin") is the only species that can be observed regularly. A greater variety of species can be found as one moves southward, towards the deeper waters of the central sector and the much deeper southern sector. The most abundant species in the Adriatic Sea is arguably the striped dolphin, but its range tends to be confined to the deep waters of the southern sector. Risso's dolphins and Cuvier's beaked whales are also regularly present in these waters, albeit in much lower numbers. Fin whales and sperm whales seem to occur in the southern Adriatic on occasional bases, and may roam to other portions of the basin. Common dolphins either survive in low numbers or occasionally move into the Adriatic from the south. Below, we summarise some of the available information on the cetacean species known to occur in the Adriatic Sea, including those that have made only sporadic appearances in this basin.

Fin whale *Balaenoptera physalus*

Fin whales are the only mysticete species regularly found in the Mediterranean Sea (Notarbartolo di Sciara *et al.*, 2003; Notarbartolo di Sciara, 2016). Fin whales have been reported to occur in the Adriatic Sea since the early 18th century (Notarbartolo di Sciara *et al.*, 2003), with sightings and strandings recorded since the 1960's being suggestive of a sporadic occurrence (e.g. Đulić and Tortić, 1960; Đulić and Mirić, 1967; Pilleri and Gihr, 1977; Kryštufek and Lipej, 1993; Podestà and Bortolotto, 2001). Information in more recent decades, when survey effort on cetaceans has been increasing, is scant. Aerial surveys conducted in 2010 and 2013

Table 1. Cetacean species and subspecies present in the Mediterranean Sea (based on ACCOBAMS, 2021a) and in the Adriatic Sea (based on this review's assessment). Approximate measures of relative abundance are based on information from basin-wide aerial surveys conducted in 2010, 2013 and 2018 (UNEP-MAP-RAC/SPA, 2015; ACCOBAMS, 2021a; Cañadas *et al.*, 2023), combined with other information included in this review.

Common name	**Scientific name**	**Suborder, Family**	**Presence in the Mediterranean**	**Presence in the Adriatic**	**Relative abundance in the entire Adriatic**
Fin whale	*Balaenoptera physalus*	Mysticeti, Balaenopteridae	Regular	Visitor in southern sector	Low
Sperm whale	*Physeter macrocephalus*	Odontoceti, Physeteridae	Regular	Visitor in southern sector	Low
Cuvier's beaked whale	*Ziphius cavirostris*	Odontoceti, Ziphiidae	Regular	Regular in southern sector	Medium-low
Risso's dolphin	*Grampus griseus*	Odontoceti, Delphinidae	Regular	Regular in southern sector	Medium
Common bottlenose dolphin	*Tursiops truncatus*	Odontoceti, Delphinidae	Regular	Regular	High
Common dolphin	*Delphinus delphis*	Odontoceti, Delphinidae	Regular	Visitor/Regular	Low
Striped dolphin	*Stenella coeruleoalba*	Odontoceti, Delphinidae	Regular	Regular in southern sector	High
Long-finned pilot whale	*Globicephala melas*	Odontoceti, Delphinidae	Regular in western Mediterranean, vagrant elsewhere	One record	
Rough-toothed dolphin	*Steno bredanensis*	Odontoceti, Delphinidae	Regular in Levantine Sea, visitor elsewhere	*No records*	
Black Sea harbour porpoise	*Phocoena phocoena relicta*	Odontoceti, Phocoenidae	Regular in northern Aegean Sea	*No records*	
Minke whale	*Balaenoptera acutorostrata*	Mysticeti, Balaenopteridae	Visitor	One record	
Humpback whale	*Megaptera novaeangliae*	Mysticeti, Balaenopteridae	Visitor	Vagrant	
Orca / killer whale	*Orcinus orca*	Odontoceti, Delphinidae	Visitor	*No records*	
False killer whale	*Pseudorca crassidens*	Odontoceti, Delphinidae	Visitor; possibly regular in Levantine Sea	Vagrant	
North Atlantic right whale	*Eubalaena glacialis*	Mysticeti, Balaenidae	Vagrant	*No records*	
Sei whale	*Balaenoptera borealis*	Mysticeti, Balaenopteridae	Vagrant	*No records*	
Grey whale	*Eschrichtius robustus*	Mysticeti, Eschrichtiidae	Vagrant	*No records*	
Dwarf sperm whale	*Kogia sima*	Odontoceti, Kogiidae	Vagrant	*No records*	
Northern bottlenose whale	*Hyperoodon ampullatus*	Odontoceti, Ziphiidae	Vagrant	*No records*	
Sowerby's beaked whale	*Mesoplodon bidens*	Odontoceti, Ziphiidae	Vagrant	*No records*	
Blainville's beaked whale	*Mesoplodon densirostris*	Odontoceti, Ziphiidae	Vagrant	*No records*	
Gervais' beaked whale	*Mesoplodon europaeus*	Odontoceti, Ziphiidae	Vagrant	*No records*	
Short-finned pilot whale	*Globicephala macrorhynchus*	Odontoceti, Delphinidae	Vagrant	One record	
Indian Ocean humpback dolphin	*Sousa plumbea*	Odontoceti, Delphinidae	Vagrant	*No records*	
Atlantic harbour porpoise	*Phocoena phocoena phocoena*	Odontoceti, Phocoenidae	Vagrant	*No records*	

resulted in only one encounter of a single fin whale, in the central Adriatic (UNEP-MAP-RAC/SPA, 2015). Aerial surveys in 2018 did not produce any sighting of balaenopterids; based on these surveys, fin whale / balaenopterid abundance was zero individuals according to design-based analyses, and 61 individuals according to model-based analyses (CV 0; 95% CI 45–248; ACCOBAMS, 2021b). A model-based estimate of fin whale density in the Adriatic Sea was 0.0005 animals/km^2 (CV 0.0000; Cañadas *et al*., 2023).

A total of 22 individuals were recorded from boats between 1979 and 2000 (Notarbartolo di Sciara *et al.,* 2003): 12 in the northern Adriatic (including one pair), two in the southern Adriatic and eight in the Otranto channel (connecting the Adriatic and Ionian Seas). Six additional individuals in the northern Adriatic (including one pair) were reported by Lipej *et al.* (2004) between 1990 and 2003. One individual was observed in August 2011 off Piran, Slovenia (Genov, 2011). One individual was observed in December 2011 in the Bay of Kotor, Montenegro, in waters only 5–7 m deep (Joksimović *et al.*, 2013). Examples of additional but unpublished observations include one pair of fin whales, estimated to be about 17 and 18 m long, filmed in August 2017 about 5 km west of Mali Lošinj, Croatia (tinyurl.com/4e58kdcb), one pair filmed in November 2020 in the Gulf of Trieste (tinyurl.com/yjzepna8), and five fin whales filmed in April 2023 near Komiža (island of Vis, Croatia; tinyurl.com/3fx4v24t and tinyurl.com/yhkkna7x).

A review of fin whale strandings in the Adriatic Sea (Pierantonio and Bearzi, 2012) reported a total of 17 records between 1728 and 2012: 11 in Italy, five in Croatia, and one in Slovenia. All these records involved single individuals, and three records, in 1728, 1771 and 1960, refer to animals that were deliberately killed (Pierantonio and Bearzi, 2012). In 2011 a fin whale hemi-mandible and one vertebra were found in the nets of a fishing boat operating off Porto Garibaldi, Italy, and acquired for use in museums (Minelli, 2014). A recent review on fin whale mortality along the Italian coast between 1624 and 2021 reported seven additional Adriatic records of single individuals from the region of Apulia (in 1872, 1894, 1949, 1963, 1977, 1988, and 2010), and these included two killings (Manfrini *et al*., 2022). One other individual was reported to have stranded in Italy in 2004 by Mazzariol *et al*. (2007). More recent unpublished reports from the northeastern Adriatic Sea include a 11.7-m long dead female that reportedly “got entangled” in a trawl net and was brought by a fisherman to the island of Male Orjule, Croatia, in January 2018 (tinyurl.com/juf62nkm); this was presumed to be the same individual observed alive near Rovanjska on an earlier date (tinyurl.com/2aemnke5).

The low number of fin whale records in the northern and central Adriatic can be related to absence of favourable deep-water habitat. Conversely, the southern basin – with depths of over 1,200 m – contains habitat that is potentially suitable for this species. In this area, the low occurrence of fin whales may be due at least in part to much lower numbers of fin whales in the eastern Mediterranean basin, as compared to the western basin (Notarbartolo di Sciara *et al.*, 2003, 2016; Stephens *et al.*, 2021), resulting in lower chances of animals entering the Adriatic Sea.

Based on age classes extrapolated from body lengths, only two (12.5%) of the 17 fin whales stranded in the Adriatic Sea between the years 1728 and 2012 were adults (Pierantonio and Bearzi, 2012). This information is consistent with the findings of Arrigoni *et al.* (2011), who described a higher mortality for young and immature fin whales based on strandings throughout the Mediterranean basin. The only genetic information on fin whales in the Adriatic Sea comes from one subadult female stranded in November 2002 near Ancona, Italy; genetic analyses revealed that her haplotype was typical from the Ligurian Sea (Caputo and Giovannotti, 2009).

Humpback whale *Megaptera novaeangliae*

A review of humpback whale occurrence in the Mediterranean Sea between the years 1990 and 2004 reported only one record in the Adriatic Sea (Frantzis *et al.*, 2004). More specifically, a humpback whale approximately 10 m long, described as being emaciated and weak, was observed off Fano and Senigallia, Italy, in August 2002 (Affronte *et al.*, 2003). Between February and April 2009, another humpback whale, 10–12 m long and considered a subadult, was observed repeatedly in the Gulf of Trieste (predominantly in Slovenian waters; Genov *et al.*, 2009a). This animal appeared in good condition and did not show evidence of illness or distress. It was observed in an area of approximately 27 km^2, between 200 m and 2.8 km from the coast, in waters 12–38 m deep, and the researchers suggested that the animal could be feeding on epipelagic fish that were unusually abundant in the area at that time (Genov *et al.*, 2009a).

Minke whale *Balaenoptera acutorostrata*

The minke whale is a visitor to the Mediterranean (Notarbartolo di Sciara and Birkun, 2010; ACCOBAMS, 2021a). There is a single historical record of a minke whale, based on the cranium of a young individual collected in 1771 in the fish market of Bologna, and preserved in the Comparative Anatomy Museum of that city (Capellini, 1877; Minelli, 2014; Minelli *et al.*, 2016).

Sperm whale *Physeter macrocephalus*

Single-animal and mass strandings of sperm whales have been recorded throughout the Adriatic Sea since historical times (for a review see Bearzi *et al.*, 2011). Of 36 records between 1555 and 2009, 21 were in Italy, 10 in Croatia, two in Albania, two in Montenegro and one in Slovenia. Most of these 36 records were of single individuals, but in six cases they involved between three and eight individuals. Overall, the strandings included a total of 67 individuals: 15 males, six females and 46 of unknown sex (Bearzi *et al.*, 2011). While sperm whale strandings in Croatia were spread along the entire coast, the majority (n = 12; 57%) of strandings in Italy were concentrated along a relatively short stretch of coast (about 90 km long) between Rimini and Ancona. Mortality events tended to be higher along gently sloping sandy beaches away from suitable sperm whale habitat (Bearzi *et al.*, 2011).

In addition to the cases reported above, there were two recent stranding events in the southern Adriatic, included in the Italian Strandings Database (mammiferimarini.unipv.it): the mass stranding of seven sperm whales near Vasto in 2014, and one individual stranded near Polignano a Mare in the same year.

The two most recent mass strandings, in 2009 and 2014, were particularly well studied. Between the 10th and the 11th of December 2009, a group of seven sperm whales stranded between Capoiale and Foce Varano, along the coast of the Gargano Peninsula (Apulia, Italy; Fig. 2). These animals, all subadult males 10.5–12.2 m long, were scattered along a 3.3 km stretch of sandy beach. All the animals were alive at the time of stranding, but only two had survived by December 12th, and all were dead by December 13th. On December 10th, before stranding, the group was observed in shallow coastal waters and it reportedly comprised nine animals, two of which managed to move away from the beach (Bearzi *et al.*, 2010). Complete necropsies suggested that these animals most likely died because of starvation, resulting in lipophilic chemical compounds entering blood circulation, and blood contamination, particularly from organochlorine contaminants, affecting the immune and nervous systems (Mazzariol *et al.*, 2011; Marsili *et al.*, 2014). In September 2014, another group of seven individuals stranded alive near Vasto, Italy: three of these animals died, while four were successfully refloated and returned to the sea; the three dead animals were genetically-related females, and one was pregnant (Mazzariol *et al.*, 2018a).

There have been few observations of live sperm whales in the Adriatic Sea. Two individuals, estimated to be 12 and 14 m long, were observed and filmed by a sport fisher approximately one nautical mile (1.852 km) off the island of Albarella, Italy, in March 2008 (Trombin and Verza, 2010). A group of five individuals was reported near the island of Vis, Croatia, on 7th of September 2014, and two days later in the Kornati Archipelago (Mazzariol *et al.*, 2018a). More recent and still unpublished observations include three adults repeatedly observed near Rovinj, Croatia, in August 2016, and a group of five repeatedly observed near the island of Korčula, Croatia, in August 2023 (tinyurl.com/bdhybvnx).

Aerial surveys conducted in 2010, 2013 and 2018 in the entire Adriatic Sea did not produce sightings of sperm whales (UNEP-MAP-RAC/SPA, 2015; Cañadas *et al.*, 2018; ACCOBAMS, 2021b). Sperm whale abundance was estimated as zero individuals according to design-based analyses of aerial survey data in 2018 (ACCOBAMS, 2021b).

Acoustic surveys with towed hydrophones conducted in 2007 in the southern Adriatic resulted in only

Fig. 2. One of the seven sperm whales *Physeter macrocephalus* stranded in the region of Apulia, Italy, in December 2009 (photo by S. Bonizzoni).

one detection of an estimated two individuals (Lewis *et al.*, 2018). The central and northern Adriatic were not surveyed acoustically as these areas were not considered to include potential sperm whale habitat (Lewis *et al.*, 2018). Finally, model-based analyses of acoustic detections of sperm whales via towed hydrophones, during surveys conducted in 2018 in the Mediterranean (not including Adriatic waters), resulted in no individuals being predicted to occur in the Adriatic Sea; these predictions, however, were environmentally extrapolated and should be taken with caution (Lerebourg *et al*., 2023).

Cuvier's beaked whale *Ziphius cavirostris*

Cuvier's beaked whales have been reported to occur only in the southern Adriatic Sea, consistent with the preference of this species for deep waters and steep slope habitats (Podestà *et al.*, 2006; Cañadas *et al.*, 2018). Based on habitat modelling analyses, Cañadas *et al.* (2018) identified the southern Adriatic as one of the species' hotspots in the Mediterranean Sea (the other five hotspots were Ligurian Sea, Alborán Sea, Hellenic Trench, northern Ionian Sea and northern Tyrrhenian Sea). According to this study, the southern Adriatic ranked fifth in terms of modelled density of this species.

Cuvier's beaked whale strandings in the southern Adriatic Sea, dating back to 1939, were reviewed by Podestà *et al.* (2006, 2016) and Holcer *et al.* (2007). Additional records can be found in the Italian Strandings Database (mammiferimarini.unipv.it), in Pino d'Astore *et al.* (2008), in Kovačić *et al.* (2010), and in Mazzariol *et al*. (2007). Based on this information, there were a total of 20 stranding records between 1939 and 2023, all in the southern section of the basin; two animals stranded in Italy (unknown location), 11 in the region of Apulia, Italy, six in Croatia, and one near Kavaje, Albania. An additional unpublished event concerns a 5-m long individual that washed ashore near Orebić, Croatia, in December 2017 (tinyurl.com/2p8kep49). All stranding records refer to single individuals, and no multiple-animal strandings were ever recorded in the Adriatic Sea.

One juvenile female Cuvier's beaked whale was observed between the 7th of March and the 11th of April 2001, in a shallow bay (maximum depth of 50 m) near Srebreno, Croatia; this individual was sometimes seen as close as 10 m to shore, and she closely approached the research boat. On the 12th of April, the animal was found dead floating adrift, possibly due to a stomach obstruction caused by plastic debris (Gomerčić *et al.*, 2006).

Live animals were observed on five occasions during aerial surveys conducted in 2010 and 2013; these encounters occurred in waters 700–1200 m deep, and had a mean group size of 2.6 individuals (UNEP-MAP-RAC/SPA, 2015). Aerial surveys conducted in 2018 resulted in one sighting of a single Cuvier's beaked whale in the southern Adriatic (Cañadas *et al.*, 2018; ACCOBAMS, 2021b); abundance was 66 individuals according to design-based analyses (coefficient of variation (CV) 1.0120; 95% confidence interval (CI) 13–343; ACCOBAMS, 2021b). Observations of groups composed of two-three individuals were made in 2013 during boat surveys off Albania, in waters 859–975 m deep adjacent to the Ionian Sea; two of these groups were mother-calf pairs (Bräger *et al.*, 2014). Observations from passenger ferries, conducted between 2013 and 2019 in the central and southern Adriatic Sea, totalled one sighting of Cuvier's beaked whale (Arcangeli *et al.*, 2023). A recent (October 2023) boat survey focusing on this species in southern Adriatic waters is expected to provide additional insight (tinyurl.com/mtap7cbw).

The population structure of Cuvier's beaked whales was investigated by Dalebout *et al.* (2005) using mitochondrial DNA, based on 87 samples obtained worldwide. Twelve of these samples were from individuals sampled in the Mediterranean: two from Croatia and 10 from Greece. Both of the Mediterranean haplotypes differed from those in the Eastern North Atlantic, and from non-Mediterranean samples generally. The authors suggested that the Mediterranean Cuvier's beaked whale population is isolated and relatively small (Dalebout *et al.*, 2005).

The stomach of a male Cuvier's beaked whale stranded on the island of Mljet, Croatia, in 2004 contained only cephalopods belonging to the family Histioteuthidae (n = 21, 34.7% of total weight), Octopoteuthidae (n = 19, 39.1%), Chiroteuthidae (n = 48, 17.7%), Cranchiidae (n = 10, 8.2%) and Sepiolidae (n = 1, 0.2%). An unsexed newborn stranded in Trstenica Bay, Croatia, in 2008 had only milk in its stomach (Kovačić *et al.*, 2010).

False killer whale *Pseudorca crassidens*

The few Adriatic Sea reports of false killer whales include one individual killed near the island of Korčula, Croatia, in 1936 (Hirtz, 1938), and three individuals from a pod of 30–40, that were killed off Ravenna, Italy, between 1959 and 1961 (Stanzani and Piermarocchi, 1992). One of these false killer whales was captured and swiftly put on display together with bottlenose dolphins in the inland channel Vena Mazzarini, in Cesenatico. However, the animal was soon considered dangerous for the captive bottlenose dolphins as well as for the people: it was tied to a jetty by its flukes, and subsequently transported to a slaughterhouse (Stanzani and Piermarocchi, 1992).

Between April and May 2021, a group of false killer whales was repeatedly observed by a professional diver near the Adriatic Gate Container Terminal in Rijeka, Croatia (Holcer *et al*., 2021). The diver provided a detailed description of the animals, as well as two photographs taken on May 21st, 2021, when the animals were observed in tight formation at about 300 m from shore. The photos portrayed at least five individuals including one calf (Holcer *et al*., 2021).

Long-finned pilot whale *Globicephala melas*

There are few reports of long-finned pilot whales in the Adriatic Sea. Two individuals were caught in a tuna trap near the island of Rab, Croatia (Hirtz, 1922): the larger individual escaped, while the smaller one, a male approximately 5.5 m long, was killed (Hirtz, 1922). One individual, about 3.5 m long and in advanced state of decomposition, stranded in Marina di Andrano, near Lecce, Italy, in June 2002. While this animal was recorded as long-finned pilot whale in official stranding reports (Centro Studi Cetacei, 2004) and in the Italian Strandings Database (mammiferimarini.unipv.it), the reliability of this identification is uncertain. Finally, a presumed/uncertain pilot whale found stranded near Porto Levante, Italy, in October 2006 (Trombin and Verza, 2010) is a likely misidentification (possibly a bottlenose dolphin based on the visible part of the skull).

Short-finned pilot whale *Globicephala macrorhynchus*

Based on a personal communication by Marco Affronte, Verborgh *et al.* (2016) mentioned that a group of three short-finned pilot whales was observed in the Adriatic Sea in 2010, and reported that "species identification was confirmed by photographs based on criteria developed by Rone and Pace (2012)". The original observation was reported in a blog by Marco Affronte (tinyurl.com/3jyn4bmf), who described three animals observed on May 23rd, 2010 and provided a link to three of the original photographs (tinyurl.com/2tpw8m92). While the photos may not allow for a certain identification of the species, they do seem to portray *G. macrorhynchus* based on the criteria in Rone and Pace (2012), as suggested by Verborgh *et al.* (2016).

Risso's dolphin *Grampus griseus*

Reports of Risso's dolphin (Fig. 3) occurrence in the Adriatic Sea date back to the 1860's (Giglioli, 1880; Brusina, 1889). Historical records are relatively few, and most authors concurred that the species was observed infrequently in the basin (Trois, 1874; Faber, 1883; Trois, 1883; Ninni, 1890; Trois, 1894; Valle, 1900; Ninni, 1901; Brunelli, 1932; Đulić and Mirić, 1967), though at the time there was limited information from the southern sector. Between 1860 and 1890, four Risso's dolphins were reportedly killed off the region of Veneto, Italy, four were killed near Zadar and one near Fažana, Croatia (Trois, 1894; Valle, 1900). In October 1936 a Risso's dolphin stranded alive and was killed on the island of Korčula, Croatia (Hirtz, 1938).

Recent sighting and stranding reports are indicative of a more regular occurrence (Storelli *et al.,* 1999; Podestà and Bortolotto, 2001; Zucca *et al.,* 2005; Bilandžić *et al.,* 2012; UNEP-MAP-RAC/SPA, 2015; Minoia *et al.*, 2023; and see tinyurl.com/y6x7z276). The Italian Strandings Database (mammiferimarini.unipv.it) has 23 Adriatic records of Risso's dolphins, totalling 37 individuals stranded between 1987 and 2023; 11 strandings occurred on the southern coast, nine on the northern coast and three on the central coast. Most cases involved single individuals, except four cases with two stranded

Fig. 3. A Risso's dolphin *Grampus griseus* photographed in the Gulf of Corinth, Greece (photo by G. Bearzi / Dolphin Biology and Conservation).

animals. Additional single records, not included in the Strandings Database, include seven strandings between 1996 and 2005, mostly in the region of Apulia (Storelli *et al.*, 1999; Mazzariol *et al*., 2007; Maio *et al.*, 2014). Along the coast of Croatia, at least 11 strandings of Risso's dolphins were recorded between 1905 and 2019 (UNEP-MAP-RAC/SPA, 2015; Đuras *et al.*, 2021).

A few of the Risso's dolphins stranded alive on the Italian coast were rescued. In 1996, a young female stranded in Grado was released offshore after surgical treatment to remove a hook in her upper jaw (Zucca *et al.*, 2005). One individual live-stranded near Ravenna in July 2000, and another one near Lignano in May 2001: both died after periods of attempted rehabilitation in a dolphin facility (Zucca *et al.*, 2005). Two individuals (a mother-calf pair) that entered the port of Ancona in June 2005 were transported to a dolphin facility for veterinary treatment: the mother died after three days, while the 6-month-old female calf was kept in a pool with bottlenose dolphins until her death seven years later (Favaro *et al.*, 2016; Mazzariol *et al*., 2018b).

Aerial surveys conducted in 2010 and 2013 resulted in seven sightings of Risso's dolphins, all in the southern Adriatic, in areas with a steep slope and depths of 600–900 m (UNEP-MAP-RAC/SPA, 2015). Group size during aerial surveys ranged between one and 12 individuals, with most groups being composed of four and six individuals (UNEP-MAP-RAC/SPA, 2015). Preliminary estimates of abundance based on the aerial survey in 2010 were 510 individuals (CV 0.781; 95% CI 124–2,089; UNEP-MAP-RAC/SPA, 2015). Aerial surveys conducted in 2018 resulted in three sightings (mean group size = 7.0; CV 0.46) in the southern Adriatic (ACCOBAMS, 2021b; Cañadas *et al*., 2023); estimated basin-wide abundance was 1,467 individuals according to design-based analyses (CV 0.7054; 95% CI 419–5,130), and 448 individuals according to model-based analyses (CV 0.7260; 95% CI 211–1,611; ACCOBAMS, 2021b). A model-based estimate of Risso's dolphin density in the Adriatic Sea was 0.0033 animals/km^2 (CV 0.7260; Cañadas *et al*., 2023). Observations from passenger ferries conducted between 2013 and 2019 in the central and southern Adriatic Sea totalled three sightings of this species (Arcangeli *et al.*, 2023).

Common bottlenose dolphin *Tursiops truncatus*

Much more information is available on bottlenose dolphins (Fig. 4) than on any of the other cetacean species occurring in the Adriatic Sea, owing primarily to the species' use of coastal habitats and widespread occurrence in the region. Bottlenose dolphins started being studied intensively in the Kvarnerić region, Croatia, in the late 1980's (Bearzi *et al.*, 1997, 1999): this study is still ongoing and it has been the longest-running in the Mediterranean Sea. Several other field studies of the same type have followed, generating substantial information on this species within portions of the Adriatic Sea. Meanwhile, aerial surveys and research on stranded animals have produced important information at the basin scale. Below, we summarize some of the main findings, subdividing them by topic.

Historical and present occurrence

In the Adriatic Sea, the bottlenose dolphin population suffered from massive killings until the 1960's (Bearzi *et al.*, 2004; Meliadò *et al.*, 2020), followed by habitat degradation and prey depletion. The bottlenose dolphin, however, is a highly resilient and opportunistic species known to adapt and survive in degraded environments (Bearzi *et al.,* 2019). It is therefore not surprising that the species has managed to persist, possibly also due to a lower predation by sharks, as well as a lower trophic competition resulting from the marked decline of other species. For instance, catches of elasmobranchs in the Adriatic have declined by more than 90% due to intensive fishing (Ferretti *et al.,* 2013; Barausse *et al.,* 2014).

The presence of bottlenose dolphins in the Adriatic Sea has been extensively documented since historical times (Nardo, 1853; Giglioli, 1880; Kolombatović, 1882; Faber, 1883; Kolombatović, 1894; Brusina, 1889; Trois, 1894; Kolombatović, 1896; Ninni 1901, 1904, 1917; Vatova, 1932; Đulić and Tortić, 1960; Đulić and Mirić, 1967; Pilleri and Gihr, 1969; Pilleri, 1970; Pilleri and Gihr, 1977; Pilleri and Pilleri, 1982, 1987). In the northern sector of the Adriatic, most historical reports also refer to the regular occurrence of common dolphins, but in recent decades the bottlenose dolphin has been the only cetacean species reported to occur regularly (Bearzi *et al.*, 2004). For instance, only bottlenose dolphins were encountered in this sector during cetacean surveys conducted from boats between 1986 and 1989 (Notarbartolo di Sciara *et al.*, 1993). Similarly, bottlenose dolphins were the only species observed during cetacean surveys, or reported in validated sightings between 1988 and 2007 (Bearzi *et al.*, 2008, 2009a).

Encounter rates, density and abundance

A summary of bottlenose dolphin encounter rates in various Adriatic Sea areas is given in Table 2. While encounter rates of cetaceans may provide valuable comparative insight, they tend to vary depending on a number of factors (sea state, survey platform, speed, observer skills etc.), and are therefore only loosely indicative of animal density and abundance. Based on aerial surveys conducted in 2018, a model-based estimate of bottlenose dolphin density in the entire Adriatic Sea was 0.0599 animals/km^2 (CV 0.2616; Cañadas *et al.*, 2023).

Baseline information on bottlenose dolphin abundance in the Adriatic Sea comes from aerial surveys carried out in the summers of 2010 and 2013 (Fortuna *et al.*, 2018), and 2018 (ACCOBAMS, 2021b). In addition to these estimates of basin-wide abundance, estimates of local abundance are available for parts of the Adri-

Fig. 4. A bottlenose dolphin *Tursiops truncatus* photographed off the region of Veneto, Italy (photo by S. Bonizzoni / Dolphin Biology and Conservation).

Table 2. Encounter rates of bottlenose dolphins in the Adriatic Sea, including information on Adriatic sector (N = northern, C = central, S = southern, E = eastern), geographic area, observation platform, years of sampling, units of sampling, mean encounter rate, annual minimum and maximum encounter rate, and literature source. SE - standard error, CI - confidence interval.

Adriatic Sea sector / Area	Observation platform	Years	Unit	Mean encounter rate	Annual minimum	Annual maximum	Source
N	Motor boat, ship	2001–2006	Groups / 100 km	–	0.42	1.67	Bearzi *et al.*, 2008
N	Ship	2003–2006	Groups / 100 km	1.57 (95% CI 0.84–2.30)	0.42 (SE = 0.031)	1.67 (SE = 1.107)	Bearzi *et al.*, 2009a
NE / Kvarnerić (Croatia)	Motor boat	1987–1994	Groups / 100 km	1.4	–	–	Bearzi *et al.*, 1997, 2004
NE / Kvarnerić (Croatia)	Motor boat	1995–2003	Groups / km within cell	0.016 (SE = 0.02)	0.009	0.022	Fortuna, 2007
NE / Kvarnerić (Croatia)	Motor boat	2007–2009	Groups / km within cell	–	0.01 (SE = 0.002)	0.02 (SE = 0.006)	Rako *et al.*, 2013a
NE / North Dalmatia (Croatia)	Motor boat	2016–2017	Groups / 100 km	1.50 (SE = 0.160)	1.16 (SE = 0.239)	1.94 (SE = 0.329)	Pleslić *et al.*, 2021
NE, CE / Kvarnerić, North Dalmatia, Vis-Lastovo (Croatia)	Motor boat	2013–2017	Groups / km within cell	Kvarnerić: 0.028 (SE = 0.003); North Dalmatia: 0.020 (SE = 0.002); Vis-Lastovo: 0.017 (SE = 0.002)	–	–	Pleslić *et al.*, 2019
SE / Montenegro	Motor boat	2013	Groups / km within cell	0.006 (SE = 0.002)	–	–	Miočić-Stošić *et al.*, 2020

atic, based on capture-recapture techniques applied to photo-identification data. The available information is reported in Table 3. None of the published studies in Table 3 reported significant differences in abundance across years, but some studies documented considerable shifts in abundance among months, consistent with dolphin movements in and out of the study area. For instance, estimates in a 3,000 km^2 area off the region of Veneto ranged between 121 dolphins in May 2019 (95% CI 20–721) and 494 dolphins in October 2019 (95% CI 378–645; Bearzi *et al*., 2021).

Distribution and habitat preferences

The aerial surveys conducted in 2010, 2013 and 2018 produced maps of bottlenose dolphin distribution based on predictions of relative density (Fortuna *et al.,* 2018; Cañadas *et al*., 2023). These maps show a generally higher density in the northern sector of the basin, and suggest that in these waters the density increases from the coast towards the open sea. As noted by Fortuna *et al.* (2018), surveys of this type can produce only temporal "snapshots" related to the period in which the study takes place, and variations in density and distribution certainly occur, as illustrated by different distributions in 2010 and 2013. The marked monthly variations in abundance observed off the region of Veneto, Italy (Bearzi *et al*., 2021), would be consistent with these distribution shifts.

Based on observations from oceanographic ships in the northwestern Adriatic, and early environmental modelling analyses, Bearzi *et al.* (2008) suggested that the distribution of bottlenose dolphins was affected by seasonal forcing and depended on complex interactions among hydrological variables, caused primarily by seasonal change and likely to result in shifts in prey distribution. This early study did not take into account the occurrence of trawling. However, operating trawlers can have important effects on bottlenose dolphin behaviour and distribution (Bearzi *et al*., 1999; Genov *et al*., 2008; Fortuna *et al*., 2010; Rako-Gospić *et al*., 2017; Genov *et al*., 2019a; Bonizzoni *et al.,* 2021, 2023). Observations from small boats in 2018–2021 indicated that dolphin occurrence in the northwestern Adriatic tends to be higher in offshore waters (Bonizzoni *et al*., 2023). This study, combining dolphin observations with remote sensing data and AIS information on trawlers, also indicated that distribution shifts were driven by bottom depth and the distribution of operating trawlers, with bottlenose dolphins making a remarkably different use of habitat in days with and without trawling. Overall, the spatial and temporal dimension of dolphin adaptations to foraging and scavenging in the proximity of trawlers (particularly bottom otter trawlers and midwater pair trawlers) indicated a major effect of the trawl fishery on bottlenose dolphin distribution (Bonizzoni *et al*., 2023).

Land- and boat-based surveys in Montenegro in 2016–2019 suggested that distribution hotspots for bottlenose dolphins were located within ~16 km from the coast, while a similar study conducted in Albania in 2018–2019 indicated a higher occurrence within ~6 km from the coast; in both areas dolphins were reported to prefer waters shallower than 200 m (Glarou *et al*., 2022).

As happens in other areas around the world, bottlenose dolphins in the Adriatic Sea can enter river estuaries and lagoons, sometimes travelling several kilometres upriver. For instance, bottlenose dolphins were observed in the Bojana/Buna river, between Albania and Montenegro, up to 9.5 km upstream (Sackl *et al.*, 2007). In 2004, a bottlenose dolphin live-stranded in the lagoon of Goro, Italy: after being rescued it swam up to 15 km upstream the Po river, and spent four days in that area. Nine days after being observed for the last time, a floating dead dolphin was found in the same area, but it is unknown whether it was the same individual (Manfrini *et al.*, 2020).

Population structure and movements

In most of the studied areas, Adriatic bottlenose dolphins displayed relatively high levels of site fidelity, though this fidelity may vary among individuals (Bearzi *et al.*, 1997; Genov *et al.*, 2008; Pleslić *et al.*, 2015; Rako-Gospić *et al.*, 2017; Genov *et al.*, 2019a; Pleslić *et al.*, 2019, 2021). Overall, local populations appeared to have limited movements across areas. For instance, Genov *et al*. (2009b) reported that no matches were found when dorsal fin catalogues from the Gulf of Trieste (Italy, Slovenia and Croatia) and the Kvarnerić region (Croatia) were compared. Similarly, Pleslić *et al*. (2019), reported no matches between dolphins in the Kvarnerić (Croatia) and those photo-identified in the waters off Ravenna (Italy), Vis-Lastovo (Croatia), and Montenegro. Comparisons between dolphins in the Kvarnerić region and in the Murter Sea (80 km to the south) revealed five matches out of 594 individuals catalogued (0.8%; Pleslić *et al*., 2015, 2019), suggesting limited exchange.

Long-distance movements, however, certainly can occur. One individual was observed alive off the Slovenian coast and, nine days later, it was found freshly dead near Goro, Italy, about 130 km from the first sighting location (Genov *et al*., 2016). A much longer movement was performed by an individual observed in July 2017 in the Aeolian archipelago (southern Tyrrhenian Sea), then in the Gulf of Trieste (northeastern Adriatic Sea) in February-March 2020, and finally off Imperia, Italy (northwestern Ligurian Sea) in September 2020, resulting in a minimum travel distance of 1,251 and 2,053 km, respectively, and a total round-trip of 3,304 km (Genov *et al*., 2022).

Genetic data based on stranded animals and biopsy samples of free-ranging individuals are largely consistent with findings from photo-identification. While an early study did not detect evidence of population struc-

Table 3. Abundance estimates of bottlenose dolphins in the Adriatic Sea, including information on observation platform, years of sampling, Adriatic Sea sector (N = northern, C = central, S = southern, E = eastern, W = western) and geographic area, surface area, model used for abundance estimates, number of groups, estimated abundance, standard error (SE), coefficient of variation (CV), 95% confidence interval (CI), and literature source.

Observation platform	Year	Adriatic Sea sector / Area	Surface area (km^2)	Model	*n* groups	Abundance	CV, SE	95% CI	Source
Plane	2010	N, C, S	~133,400	Halfnormal / Cosine	61	5,772	CV 0.257	3,467–9,444	UNEP-MAP-RAC/SPA, 2015
Plane	2010	N	-	Uniform / Cosine	35	3,608	CV 0.302	1,971–6,604	UNEP-MAP-RAC/SPA, 2015
Plane	2010	C, S	~73,900	Uniform / Cosine	23	1,786	CV 0.348	903–3,534	UNEP-MAP-RAC/SPA, 2015
Plane	2018	N, C, S	135,783	Design-based analyses	32	10,350	CV 0.2916	5,896–18,166	ACCOBAMS, 2021b
Plane	2018		135,785	Model-based analyses	31	8,134	CV 0.2616	5,356–13,824	ACCOBAMS, 2021b
Motor boat	2018	NW / Veneto (Italy)	3,000	Popan (open population)	193 (in years 2018–2019)	582	SE = 33	520–651	Bearzi *et al.*, 2021
Motor boat	2019		3,000	Popan (open population)		599	SE = 31	542–662	Bearzi *et al.*, 2021
Motor boat	2018		3,000	Closed population		562	SE = 59	458–689	Bearzi *et al.*, 2021
Motor boat	2019		3,000	Closed population		594	SE = 30	537–657	Bearzi *et al.*, 2021
Motor boat	2004–2008	NE / Gulf of Trieste (Slovenia, Italy, Croatia)	~550–1,400	Closed population	98 (in years 2004–2008)	38 (min) 108 (max)	CV 0.17 CV 0.24	34–47 84–163	Genov *et al.*, 2008
Motor boat	2013–2018	NE / Gulf of Trieste (Slovenia, Italy, Croatia)	~1,200	Pollock's Robust Design	392 (in years 2013–2018)	161 (min)	CV 0.03	153–170	Genov, 2021
Motor boat	2013–2018		~1,200			245 (max)	CV 0.06	219–273	Genov, 2021
Motor boat	1995–2003	NE / Kvarnerić (Croatia)	~2,000	Closed population	–	78 (min)	SE = 14.4; CV 0.18	59–119	Fortuna, 2007
Motor boat	1995–2003		~2,000			168 (max)	SE = 24.0; CV 0.14	132–229	Fortuna, 2007
Motor boat	2004–2011	NE / Kvarnerić (Croatia)	1,600	Closed population	440 (in years 2004–2011)	112 (min)	CV 0.16	94–150	Pleslić *et al.*, 2015
Motor boat	2004–2011		1,600			310 (max)	CV 0.12	265–392	Pleslić et al., 2015
Motor boat	2013–2017	CE / North Dalmatia (Croatia)	2,500	Pollock's Robust Design	284 (in years 2013–2017)	116 (min)	SE = 8.281; CV 0.071	107–133	Pleslić *et al.*, 2021
Motor boat	2013–2017		2,500			138 (max)	SE = 13.707; CV 0.099	121–165	Pleslić *et al.*, 2021
Motor boat	2010	CE / Vis-Lastovo (Croatia)	~5,000	Closed population	181 (in years 2007–2010)	474	SE = 102.15; CV 0.22	352–683	Holcer, 2012
Motor boat	2013	SE / Montenegro	~2,500	Closed population	21	90	SE = 14.92	71–152	Miočić-Stošić *et al.*, 2020

ture among Adriatic bottlenose dolphins (Galov *et al*., 2011), such finding could be due to small sample size and geographic limitations; a subsequent study suggested a general north-south and east-west split based on nuclear DNA, but not mitochondrial DNA (Gaspari *et al.*, 2015a). Additional work was consistent with the hypothesis of a north/central/south division, with samples from the Gulf of Trieste separating clearly from all other Adriatic samples, and instead clustering with samples from the Aegean Sea (Gaspari *et al.*, 2015b). More recent genetic analyses supported the notion of relatively well-defined communities with high site fidelity, as suggested by photo-identification, but also a clearly identified gene flow among them, suggestive of a metapopulation structure pattern (Gaspari *et al.*, 2023).

Social and community structure

Bottlenose dolphins live in fission-fusion societies, with frequent changes in group size and composition (Connor *et al.*, 2000; Wells, 2003). This pattern also applies to bottlenose dolphins in the Adriatic, with important differences among local populations. In the Kvarnerić region, Croatia, dolphins typically formed relatively small groups (see the Group size section), which changed frequently in size and composition (Bearzi *et al.*, 1997). Off the Croatian coast, bottlenose dolphins were considered to belong to three different communities (defined as "Kvarner", "North Dalmatia" and "Vis-Lastovo") based on ranging and association patterns suggestive of social and spatial segregation. However, the three communities were not isolated, as some individuals were observed in more than one community range (Pleslić *et al*., 2019). Dolphins in Kvarner, North Dalmatia and Vis-Lastovo had relatively low mean association indices (Pleslić *et al.*, 2019). Conversely, dolphins in the Gulf of Trieste and adjacent waters appeared to form larger groups, with much stronger and longer lasting associations, relatively infrequent changes in group composition, and no differences in the strength of associations between females and males (Genov *et al.*, 2019a). These differences may be due to habitat features, as well as spatial and temporal variability in prey distribution (Genov *et al.*, 2019a). The local population in the Gulf of Trieste also showed marked behavioural and temporal partitioning among two large social clusters, which overlapped spatially but not temporally and used the same area at different times of the day. The two clusters also differed in their behaviour related to fishing activity, with only one cluster regularly interacting with trawlers, though this factor alone failed to explain the observed temporal patterns (Genov *et al.*, 2019a). This local population also contained a third social cluster with weaker social bonds, and no clear pattern with respect to either temporal use of the area or interactions with trawlers (Genov *et al.*, 2019a).

Offspring were present in 14.8% of groups in the Kvarnerić region (Bearzi *et al*., 1997) and in 53.3% of groups in the Gulf of Trieste (Genov *et al.*, 2008). In Kvarnerić region, immatures (newborns, calves and juveniles) ranged between 11% and 20% (mean = 15.8; SE = 1.4) of the total number of individuals encountered annually in 2004–2011 (Pleslić *et al*., 2015). In North Dalmatia, based on data from 2013–2017, the fertility rate (defined as annual number of newborns divided by number of females alive in that year) ranged between 0.02 and 0.23, with a mean of 0.17 (SE = 0.038), while the inter-calving interval was estimated as 5.8 years (Pleslić *et al*., 2021).

Group size

A summary of bottlenose dolphin group size estimates in various Adriatic Sea areas is given in Table 4. Most information comes from the eastern and northern Adriatic, whereas there is limited information for central and southern areas off the coast of Italy. The mean size of groups observed from boats and vantage points on land varied between approximately four and nine individuals (Table 4). While groups tended to be small in some areas (Bearzi *et al.*, 1997; Pleslić *et al.*, 2015, 2021), aggregations of 40–70 individuals were not unusual in other areas (Genov *et al.*, 2008, 2019a; Bearzi *et al.*, 2021), and up to 120 individuals were observed within a single group in the northwestern Adriatic (Bearzi *et al.*, 2021). Groups sighted from planes appear to be smaller (with observed mean group sizes between three and five individuals; Table 4) than those encountered from boats, but it is unclear whether this difference could be an effect of sampling method.

It must be noted that definitions of what constitutes a dolphin "group" or "focal group" has often been hindered by uncertainty about actual group membership (Syme *et al.*, 2022). In addition, the size of groups that are large or widely scattered may be difficult to estimate visually, and sampling protocols and methods can differ substantially: these differences can hamper comparisons among studies and areas.

Dolphin group size is influenced by a number of factors, including habitat type, oceanographic and climate conditions, prey kind and availability, predation risk, presence of calves, social factors, behaviour, and noise (Bearzi *et al.*, 1997, 1999; Gygax, 2002; Genov *et al.*, 2019a; Pleslić *et al.*, 2021; La Manna *et al.*, 2023; Methion *et al.*, 2023). In the Kvarnerić region, Croatia, groups engaged in social activities were significantly larger than travelling groups, and these were larger than groups performing feeding dives (Bearzi *et al.*, 1999). Groups foraging in the proximity of trawlers were significantly smaller than those foraging in the presence of motor boats (Rako–Gospić *et al.*, 2021). Off the region of Veneto, Italy, groups observed during days of trawling were significantly (although slightly) larger than those observed in days without trawling (Bonizzoni *et al.*, 2023). In North Dalmatia, Croatia, the size of groups sighted within 200 m from fish farms was similar to those observed further away from these

Table 4. Information on bottlenose dolphin groups observed in the Adriatic Sea, including information on Adriatic sector (N = northern, C = central, S = southern, E = eastern, W = western) and geographic area, observation platform, years of sampling, sample size (n), mean group size, statistical error, group size range, and literature source. CV - coefficient of variation, SD - standard deviation, SE - standard error.

Adriatic Sea sector / Area	**Observation platform**	**Years**	**n**	**Mean group size**	**CV, SD, SE**	**Range**	**Source**
N, C, S	Plane	2018	31	4.7	CV 0.19	–	ACCOBAMS, 2021b; Cañadas *et al.*, 2023
N, C, S	Plane	2010	61	3.9	CV 0.207	–	UNEP-MAP-RAC/SPA, 2015
N	Plane	2010	35	2.8	CV 0.149	–	UNEP-MAP-RAC/SPA, 2015
C, S	Plane	2010	23	2.9	CV 0.185	–	UNEP-MAP-RAC/SPA, 2015
N	Ship	2003–2006	40	4.9	SD = 4.58	1–20	Bearzi *et al.*, 2008
NE / Gulf of Trieste (Slovenia, Italy, Croatia)	Motor boat, land	2002–2008	90	8	SD = 7.35	1–43	Genov *et al.*, 2008
NE / Istria (Croatia)	Motor boat	2016–2019	264	7.2	± 6.90	–	Ribarič and Clarkson, 2021
NE / Kvarnerić (Croatia)	Motor boat	1991–1994	12,916 3-min samples	7.4	SD = 7.15, SE = 0.06	1–65	Bearzi *et al.*, 1997
NE / Kvarnerić (Croatia)	Motor boat	1995–2003	339	6.2	SD = 6.0, SE = 0.3	1–45	Fortuna, 2006
NE / Kvarnerić (Croatia)	Motor boat	2004–2011	–	5.9–9.3	SE = 0.7–0.8	–	Pleslić *et al.*, 2015
NE / Kvarnerić (Croatia)	Motor boat	2007–2009	–	6.3	–	–	Rako *et al.*, 2013a
NE / Kvarnerić (Croatia)	Motor boat	2016–2017	25	–	SD = 13.6	2–47	Rako-Gospić *et al.*, 2021
NE, CE / North Dalmatia (Croatia)	Motor boat	2013–2017	–	5.7–7.5	SE = 0.42–0.88	–	Pleslić *et al.*, 2021
CE / Vis-Lastovo (Croatia)	Motor boat	2007–2010	211	6.3	SD = 5.42	1–40	Holcer, 2012
NE, CE / Kvarner, North Dalmatia, Vis-Lastovo (Croatia)	Motor boat	2013–2017	–	8.1	SE = 0.23	1–50	Pleslić *et al.*, 2019
NW / Veneto (Italy)	Motor boat	2018–2019	193	8.2	SD = 9.84	1–70	Bearzi *et al.*, 2021
NW / Veneto (Italy)	Motor boat	2018–2022 (trawling days)	225	8.8	–	1–70	Bonizzoni *et al.*, 2023
NW / Veneto (Italy)	Motor boat	2018–2022 (no trawling days)	101	6.5	–	1–60	Bonizzoni *et al.*, 2023
NW / Off Ravenna, Emilia-Romagna (Italy)	Motor boat	2001–2005	–	–	–	1–50	Triossi *et al.*, 2013
SE / Montenegro	Motor boat	2013	21	6.5	SE = 0.64	1–14	Miočić-Stošić *et al.*, 2020
SE / Montenegro	Land	2016–2017	51	4	–	1–9	Affinito *et al.*, 2019
SE / Delta of Bojana/Buna river (Montenegro and Albania)	–	2003–2004	4	–	–	1–6	Sackl *et al.*, 2007

facilities (Pleslić *et al*., 2021). Off Montenegro, groups engaged in surface feeding were significantly larger than travelling groups (Affinito *et al*., 2019). Finally, groups including immature individuals generally tended to be larger than those composed exclusively of adults (Bearzi *et al*., 1997; Pleslić *et al*., 2021).

Behaviour

Information on dolphin behaviour in the Adriatic Sea comes from a few studies conducted off eastern shores, either from small boats or from vantage points on land. An extensive boat-based study on the diurnal behavioural budget of bottlenose dolphins observed in the Kvarnerić region, Croatia, showed a strong prevalence (82%) of activities characterized by long dives, thought to be related to food search and foraging (including diving in the same area and diving while travelling; Bearzi *et al*., 1999). Travelling totalled 8% of the budget, socializing 6%, and the remaining 4% of the budget was related to resting and non-classified behaviour. Surface feeding was observed rarely. The high proportion of time spent in foraging-related activities, as compared to other areas, was thought to be indicative of low prey availability (Bearzi *et al*., 1999). Behavioural states did not vary significantly during daytime, but varied seasonally and annually, especially for feeding-related and travelling activities. Yearly variations in social behaviour seemed to be related to breeding cycles (Bearzi *et al*., 1999).

The behavioural budget of bottlenose dolphins in the Gulf of Trieste was assessed from boats based on behavioural states at the beginning of each sighting (n = 61). The most common state was "dive-travel" (34.4%), followed by "active trawler follow" (21.3%), "travel" (18.1%), "dive" (8.2%), "passive trawler follow" (3.3%), "socializing" (3.3%) and "social travel" (1.6%), with 9.8% being assessed as "mixed" (Genov *et al*., 2008).

Off the coast between Herceg-Novi and Ulcinj, Montenegro, travelling was the most common activity (55%), followed by diving (22%), socializing and resting (15%), and feeding at surface (8%) based on observations from land (Affinito *et al*., 2019). The behaviour did not appear to be influenced by time of day, but surface feeding and socializing increased in autumn and winter, suggesting seasonal variability (Affinito *et al*., 2019). A longer study (2016–2020; Rudd *et al*., 2022) based on observations from boats and from land in the same area confirmed that travelling and diving accounted for the majority of observed behaviour, respectively 43% and 33%, while socializing accounted for 10%, surface feeding 7%, and approaches to boats 4%. Socializing was reportedly higher in summer and autumn, while surface feeding was predominant in winter (Rudd *et al*., 2022). In a different study conducted from boats, the most frequent behaviour recorded at the beginning of each sighting was diving (57%), followed by the active following of a trawler (24%), while the remaining 19% included dive-travelling, travelling and resting (Miočić-Stošić *et al*., 2020).

Dolphin groups observed in proximity of offshore hydrocarbon platforms situated off the region of Emilia-Romagna, Italy, showed a slightly more frequent occurrence of feeding and milling behaviour compared to groups observed further away, and dolphins in the proximity of these facilities also showed more socializing and traveling (Triossi *et al*., 2013). As noted by the authors, these findings were based on a limited number of observations.

A study conducted off Istria, Croatia, between 2016 and 2019 suggested that bottlenose dolphins decreased foraging and travelling, and increased milling behaviour when dolphin watching and private boats were less than 50 m from the animals (Ribarič and Clarkson *et al*., 2021). Two studies in Montenegro focused on behavioural transitions in the presence of cruise ships and ferries (Clarkson *et al*., 2020), or commercial and artisanal fishing boats (Rudd *et al.,* 2022). When cruise ships and ferries were present, dolphins showed a lower occurrence of surface feeding and milling-socializing, they reduced diving and increased resting (Clarkson *et al*., 2020). When trawlers ("beam and pelagic") and purse seiners were present, there was a significant increase of surface feeding and diving, indicative of opportunistic foraging in the proximity of these fishing vessels. Conversely, artisanal fishing boats did not seem to have an influence, though bottlenose dolphins appeared to perform less surface feeding in the proximity of these boats (Rudd *et al.,* 2022).

In the Adriatic Sea, this species routinely follows different types of trawlers (Bearzi *et al*., 1999; Genov *et al*., 2008; Rako-Gospić *et al*., 2017; Genov *et al*., 2019a; Miočić-Stošić *et al*., 2020; Bonizzoni *et al*., 2021, 2023) and is also known to interact with other fishing gear. Information on the remarkable adaptations of bottlenose dolphins to foraging in the proximity of fishing gear is given in the following section.

Diet and interactions with fishing gear

Scant information on bottlenose dolphin diet in the Adriatic Sea comes from stomach content analyses on stranded or bycaught animals, as well as stable isotope analyses from biopsies of living animals, but most of this information has not been formally published. One published study refers to one individual bycaught in southern Croatia, whose stomach contained three species of demersal fish (European hake *Merluccius merluccius*, European conger *Conger conger*, common pandora *Pagellus erythrinus*) and one European squid *Loligo vulgaris* (Mioković *et al*., 1999). Moderately digested remains of an angler *Lophius piscatorius* about 15-cm long were found in the gastric chambers and oesophagus of a bottlenose dolphin stranded in the northwestern Adriatic (Genov *et al*., 2016). A young individual stranded in Pellestrina, Italy, in April 2019 had undigested remains of common octopus (*Octopus* *vulgaris*), as well as several octopod beaks and one ommastrephid beak; all other remains belonged to the poor cod *Trisopterus minutus*, with an estimated total of about 38 specimens (Corazzola *et al*., 2021). Results from stable isotopes analyses from 20 bottlenose dolphins biopsied in the eastern-central Adriatic Sea suggested foraging on small pelagics (predominantly sardines) and demersal species such as red mullets (*Mullus* sp.), with seasonal variations (Holcer, 2012; UNEP-MAP-RAC/SPA, 2015). All these findings would be consistent with the catholic diet habits of bottlenose dolphins documented in other Mediterranean areas (Bearzi *et al.*, 2009b).

Rare observations of surface feeding in the Kvarnerić region, Croatia (Bearzi *et al*., 1999), suggested that dolphins in these areas relied primarily on demersal or midwater prey. Conversely, regular observations of surface feeding in Montenegro, especially in winter months (Clarkson *et al.*, 2020), could reflect a higher reliance on epipelagic prey. In the Gulf of Trieste, surface feeding was observed during focal group follows in at least 17% of all sightings (Genov *et al*., 2008). In this area, observations of bottlenose dolphins catching mullets during surface feeding events, as well as frequent interactions with midwater pair trawlers that typically target anchovies and sardines, suggested that dolphin diet includes these epipelagic fish species (Genov *et al*., 2008). In the Gulf of Trieste, however, members of one social cluster in the local bottlenose dolphin community interacted regularly with midwater pair trawlers and bottom otter trawlers, whereas another social cluster did not (Genov *et al*., 2019a), and that might be indicative of further specialization and diet differences.

Off the coast of Veneto, Italy, during days of trawling bottlenose dolphins spent as much as 39% of their daily time in the proximity of trawlers, largely foraging and scavenging in their wakes (Bonizzoni *et al.,* 2023). Based on distribution modelling in the years 2018–2019, the odds of observing dolphins during trawling days was ~4.5 times higher if a bottom beam "rapido" trawler was present, ~16 times higher if a bottom otter trawler was present, and ~29 times higher in the presence of midwater pair trawlers (Bonizzoni *et al.,* 2021). Analyses on a larger dataset (2018–2021) confirmed that midwater pair trawlers and bottom otter trawlers had significantly more dolphins than expected, whereas bottom beam trawlers had fewer (Bonizzoni *et al.,* 2023), likely because dolphins could forage less effectively behind the latter gear. Chances of finding bottlenose dolphins behind bottom otter trawlers and midwater pair trawlers did not differ significantly (Bonizzoni *et al*., 2023).

Off the eastern and southern coasts of the Adriatic, commercial purse seining is intensive (Lucchetti *et al*., 2018) but information on potential interactions with this fishery is scant, possibly because most purse seining happens at night. In the inshore waters off southern Croatia, Zorica *et al*. (2018) conducted observations in 2013–2016 from a single purse seiner operating at night with fishing lights, and concluded that "dolphins" (most likely bottlenose dolphins) were present year-round, with a higher occurrence between July and October. On average, there were dolphins near the purse seiner 22% of the time. The authors contended that dolphins "help rounding up the school of small pelagic fish as no decrease in catches due to its appearance were noted, actually higher catches were realised in their presence" (Zorica *et al*., 2018). In Montenegro, bottlenose dolphin interactions with fishing boats including purse seiners were reported by Rudd *et al*. (2022), but no other information is available.

Postmortem examinations of bottlenose dolphins stranded along the coasts of Croatia between 1990 and 2019 provided clear, albeit indirect, evidence of interactions with passive fishing nets (see the Incidental mortality in fishing gear section). While the distribution of bottlenose dolphins in the Adriatic Sea frequently overlaps with small-scale fisheries deploying gill and trammel nets (e.g. in the northern Adriatic; Genov *et al.*, 2008, and in southern Montenegro and northern Albania; Glarou *et al*., 2022), information on these interactions is rarely based on direct observations.

Recent information on dolphin-fisheries interactions in the Adriatic Sea comes from interviews conducted by Li Veli *et al*. (2023) in July and November 2020; this dataset, however, also includes interviews along the western coast of Italy, as well as in Sardinia. Reported damage to fishing gear varied among areas and seasons, with passive nets (e.g. gill and trammel nets) being more affected than other gear (e.g. bottom trawls).

While bottlenose dolphins have habituated to foraging near aquaculture facilities in several areas around the world, including in parts of the Mediterranean Sea (for review see Bearzi *et al*., 2019), little is known about interactions with these facilities in the Adriatic Sea. Offshore mussel farms in the northwestern Adriatic did not appear to attract bottlenose dolphins (Bonizzoni *et al.,* 2021, 2023). In North Dalmatia, Croatia, 56 of 284 bottlenose dolphin sightings (20%) between 2013 and 2017 occurred within 200 m of a fish farm (Pleslić *et al*., 2021).

Acoustic communication

Most information on the acoustic behaviour of bottlenose dolphins in the Adriatic Sea, and the factors that may affect vocalizations, comes from the Kvarnerić region, Croatia (Rako-Gospić and Picciulin, 2016; Rako-Gospić *et al.*, 2021; Picciulin *et al.*, 2022; Falkner *et al.*, 2023). In this area, whistles and low-frequency narrow-band sounds were the most common vocalizations, while chirps were less frequent and burst pulse sounds were rare. There was no difference in the type of vocalizations between diurnal and nocturnal recordings (Falkner *et al.*, 2023). The acoustic repertoire could change depending on background noise, which in turn depended on time of day and season, suggesting vocal plasticity and strategies to avoid the masking of acoustic signals (Falkner *et al.*, 2023). Dolphins could also change whistle frequencies in response to high levels of ambient noise (Rako-Gospić and Picciulin, 2016). The foraging context reportedly affected whistle structure, with whistle characteristics such as start and end frequencies, maximal frequencies, and number of inflection points being significantly different between dolphins feeding in the proximity of trawlers and those feeding near motor boats, as well as between dolphins feeding near motor boats and those feeding when motor boats were absent (Rako-Gospić *et al.*, 2021).

Dolphin vocalizations recorded in the Kvarnerić region, Croatia, and in the Bay of Kotor, Montenegro, were compared with those recorded in other Mediterranean and extra-Mediterranean areas, to assess possible differences and analogies (La Manna *et al.*, 2017, 2020; Luís *et al*., 2021; Rako-Gospić *et al.*, 2021; La Manna *et al.*, 2022; Akkaya *et al.*, 2023). An additional study focused on bottlenose dolphin vocalizations recorded during interactions with trawlers (Di Nardo *et al*., 2023), and one study described the sounds produced by three bottlenose dolphins, including a pregnant female, simultaneously caught in midwater trawl gear with fatal consequences (Corrias *et al.*, 2021).

Common dolphin *Delphinus delphis*

Historically, common dolphins (Fig. 5) used to be abundant in the Adriatic Sea, including in its northern portion, but extensive killings (see the Intentional killings section) are thought to have substantially contributed to their eradication. The species declined in the first half of the 20th century, and its recovery was later compromised by prey depletion caused by overfishing, and by habitat degradation (Bearzi *et al.*, 2003, 2004; Bearzi and Genov, 2022). Below, we report some information on common dolphin occurrence in the Adriatic Sea published in the reviews by Bearzi *et al.* (2004) and Genov *et al.* (2021), with amendments and updates.

The presence of common dolphins in the northern Adriatic Sea until the 1970's is well documented (Giglioli, 1880; Đulić and Mirić, 1967; Pilleri, 1970; Pilleri and Gihr, 1977; Pilleri and Pilleri, 1982, 1983, 1987). In terms of relative occurrence, Nardo (1853) tentatively listed the common dolphin as the only regular cetacean species in the Adriatic, and De Marchesetti (1882) claimed that the most common Adriatic species was *Delphinus delphis*, and that "*Delphinus tursio*" (= *T. truncatus*) was less frequent[1]. Similarly, Faber (1883) regarded *D. delphis* as the most common cetacean species in the Adriatic, Brusina (1889) reported *D. delphis* and *T. truncatus* as the most common Adriatic cetaceans, and Trois (1894) reported that *D. delphis* was more abundant than *T. truncatus* in the northern Adriatic. Common dolphins were even reported to follow ships into ports (Kolombatović, 1882; Trois, 1894), and sold at the Venice fish market after being caught in the inner channels of the Venice lagoon (Trois, 1894). Ninni (1901, 1904) considered *D. delphis* very common in the Adriatic Sea compared with "*D. tursio*", which he thought was rare in the region. However, several inconsistencies and a report of a presumed "*D. tursio*" that was 6 m long (Ninni, 1901) suggest that some cetological accounts by this author should be taken with caution. Vatova (1928) listed *D. delphis* as common throughout the Adriatic, where the species was said to be present in large groups, while "*T. tursio*" was considered "very rare". However, the same author subsequently listed both species among the commonest marine animals to be found near Rovinj, Croatia (Vatova, 1932). *D. delphis* was the only cetacean listed as frequent in the catalogue of mammals of former Yugoslavia (Đulić and Tortić, 1960).

The catalogue of the Croatian Natural History Museum listed 16 dolphins collected between 1873 and 1935 along eastern Adriatic Sea coasts: 10 common dolphins (of which eight were from the northern Adriatic), five bottlenose dolphins (three from the northern Adriatic) and one Risso's dolphin caught near Zadar. Although the numbers seem to indicate that common dolphins were more abundant than other cetacean species, the methods and criteria used to collect this osteological material are unknown (Bearzi *et al.*, 2004).

Pilleri and Gihr (1977) noted that large groups of common dolphins could be easily encountered near the coast in the Gulf of Trieste in the 1940's, but by the late 1970's there was a noticeable decrease of the species in the northern Adriatic. By the 1980's and 1990's, common dolphins had almost completely disappeared from the region. For instance, based on boat surveys conducted between 1990 and 1995 in the Kvarnerić region, Croatia, Bearzi and Notarbartolo di Sciara (1995) reported a sighting frequency for common dolphins two orders of magnitude lower than that of bottlenose dolphins. Only one group of four common dolphins was sighted in 1991. One of those four common dolphins was then re-sighted, once in 1994 and once in 1995, in close association with groups of bottlenose dolphins (Bearzi and Notarbartolo di Sciara, 1995).

Since the 2000's, observations of common dolphins have been largely limited to stray individuals, typically found alone or in couples (often adult-subadult pairs, possibly mother-offspring), and occasionally entering industrial ports (Rako *et al.,* 2009; Boisseau *et al.,* 2010; Genov *et al.,* 2012, 2021). An adult female live-stranded in Lido degli Estensi, Italy, in October 2000, and was kept in captivity for 15 days until its death (Di Guardo *et al*., 2005). Unpublished observations include an adult-calf pair repeatedly observed in the Gulf of Trieste, including in the industrial ports of Koper, Slovenia,

[1] Scientific names in this section help avoid misunderstanding between a species' common name (e.g. "the common dolphin") and its reported abundance (e.g. "a very common dolphin"). Scientific names are also used to emphasize that the author(s) specifically referred to scientific names rather than common names.

Fig. 5. A common dolphin *Delphinus delphis* photographed in the Gulf of Trieste (photo by T. Genov / Morigenos).

and Trieste, Italy (tinyurl.com/4acuzcfj), and solitary individuals observed in 2023 in the bay of Rijeka and near Rab, Croatia (tinyurl.com/2s4z25h3). Observations of larger groups in Croatia include unpublished reports of about 20–30 common dolphins near Dugi Otok in the summers of 2015 and 2016, and over 50 near the islet of Mana in the Kornati Archipelago in July 2018 (tinyurl.com/yehfkjsk). While groups of common dolphins may be encountered occasionally, particularly off the basin's eastern shores, it remains uncertain whether these encounters imply any "comeback" of this species. Aerial surveys of the entire Adriatic Sea conducted in 2010, 2013 and 2018 did not report sightings of common dolphins (UNEP-MAP-RAC/SPA, 2015; ACCOBAMS, 2021b). The Italian Strandings Database (mammiferimarini.unipv.it) includes only nine individuals stranded in the Adriatic Sea across 38 years (i.e. between 1986 and 2023).

Striped dolphin *Stenella coeruleoalba*

The striped dolphin (Fig. 6) is the most common and abundant cetacean in the Mediterranean Sea (ACCOBAMS, 2021b; Notarbartolo di Sciara and Zanardelli, 2021; Cañadas *et al.*, 2023). In the Adriatic Sea, this pelagic, deep-water species tends to occur primarily in the deep southern sector of the basin, where groups may occasionally include hundreds of individuals (UNEP-MAP-RAC/SPA, 2015). Aerial surveys indicate that, in terms of total numbers, striped dolphins are the most abundant cetacean species in the Adriatic. Surveys in 2010 and 2013 resulted in no sightings of striped dolphins in the northern and central sectors, but reported a large number of sightings (100+) in the southern one, particularly in waters deeper than 300 m (UNEP-MAP-RAC/SPA, 2015). Estimates of abundance based on aerial surveys in 2010 were 15,343 individuals (CV 0.28; 95% CI 8,545–27,550; UNEP-MAP-RAC/SPA, 2015; Lauriano, 2022). Aerial surveys were also conducted in 2018, resulting in nine striped dolphin sightings (mean group size = 16.8; CV 0.44; Cañadas *et al*., 2023) in the central and southern Adriatic; based on these surveys, striped dolphin abundance was estimated at 10,264 individuals according to design-based analyses (CV 0.5427; 95% CI 3,772–27,932), and 13,138 individuals according to model-based analyses (CV 0.3075; 95% CI 8,093–24,026; ACCOBAMS, 2021b; Lauriano, 2022). A model-based estimate of striped dolphin density in the Adriatic Sea was 0.0968 animals/km^2 (CV 0.3075; Cañadas *et al*., 2023).

Other information includes visual and acoustic surveys conducted in the southern Adriatic in October 2007, resulting in four striped dolphin sightings, with a mean group size of five individuals (Boisseau *et al.*, 2010). Observations from passenger ferries, conducted between 2015 and 2018 in the central and southern sectors of the Adriatic, totalled 31 sightings of striped dolphins in waters 79–1,167 m deep (Azzolin *et al.*, 2020). Boat- and land-based surveys in the waters of Montenegro, between 2016 and 2019, totalled three sightings: one in waters shallower than 200 m and two in deeper waters (Glarou *et al.*, 2022).

In the shallower central and northern sectors of the Adriatic Sea, striped dolphins are encountered infrequently, normally as single individuals or very small groups that may be wandering north and away from deep Adriatic waters (Lapini *et al.,* 1995; Podestà and Bortolotto, 2001; Rako *et al.,* 2009, 2011; Nimak-Wood *et al.,* 2011). Records in the Gulf of Trieste between 1990 and 2007 totalled two observations of two individuals, and 10 of single individuals; one of these

Fig. 6. A striped dolphin *Stenella coeruleoalba* photographed in the Gulf of Corinth, Greece (photo by S. Bonizzoni / Dolphin Biology and Conservation).

stranded and died despite rescue attempts (Francese *et al*., 2007). A solitary individual was observed east of the Island of Lošinj, Croatia, in May 1996 (Bearzi *et al*., 1998). Another solitary individual was observed for five days in the harbour of Mali Lošinj, Croatia, in September 2008 (Nimak-Wood *et al.,* 2011), and a photographically-identified individual was observed seven times in Vinodol Channel, Croatia, between 2004 and 2009 (Rako *et al*., 2009). On two occasions, the Vinodol Channel individual was together with a common dolphin (Rako *et al*., 2009). In 2012, two adults were observed in the port of Koper and along a public beach in Portorož, Slovenia (tinyurl.com/2m743xh3). Two striped dolphins, an adult and a juvenile, entered the Grand Canal of Venice, Italy, on March 22nd, 2021 (tinyurl.com/yaj9u8ve); these might be the same individuals filmed in the Gulf of Trieste on March 5th, 2021 (tinyurl.com/3rppkapa). Given that striped dolphins are typically gregarious (Notarbartolo di Sciara and Zanardelli, 2021), encounters with single individuals in unsuitable shallow-water habitats are suggestive of unnatural conditions. However, most of the reported observations do not appear to refer to individuals in distress.

The Italian Strandings Database (mammiferimarini.unipv.it) includes 288 striped dolphins stranded on the Adriatic coasts between 1986 and 2023: 26 in the northern, 41 in the central and 221 in the southern sector. A similar geographic pattern of strandings was reported by Podestà and Bortolotto (2001) based on a smaller dataset (1986–1996). Additional records, not present in the Strandings Database, include: one stranding in Volano in November 1985 (Trabucco *et al.,* 2014), one in Marina di Massignano in September 1991 (Olivieri, 2014), one in Fossalon di Grado in April and one in Grado in May 1992 (Francese *et al*., 2007), one in Grado in October 1995 (Dall'Asta and Bressi, 2014), one in Grado in December 1995 (Francese *et al*., 2007), and one in Cattolica in March 2012 (Angelini, 2014).

Along the coast of Croatia, 15 striped dolphins were found dead between 1997 and 2007, with the majority of strandings being recorded in the south (Galov *et al*., 2009). Đuras *et al.* (2021) reported a total of 40 striped dolphins found dead between 1990 and 2019, but precise dates and locations are not provided and it would be difficult to match these with those reported by Galov *et al.* (2009).

Genetic analyses to investigate the population structure of striped dolphins in the Mediterranean Sea detected a significant difference between individuals sampled in the western (Tyrrhenian Sea) and the eastern (Adriatic Sea) side of Italy (Gaspari *et al*., 2007). Other analyses conducted on 15 striped dolphins stranded in Croatia did not find differences between the Croatian haplotypes and those from France and Spain, suggesting that striped dolphins may not be "resident" in Croatian waters (Galov *et al*., 2009).

Misidentified cetacean species

The Adriatic Sea literature contains reports of cetacean species that were misidentified or misnamed. These include the blue whale *Balaenoptera musculus*, the northern bottlenose whale *Hyperoodon ampullatus*, the rough-toothed dolphin *Steno bredanensis*, the white-beaked dolphin *Lagenorhynchus albirostris*, and the harbour porpoise *Phocoena phocoena*.

The blue whale does not occur in the Mediterranean Sea (ACCOBAMS, 2021a), the only partial exception being an individual stranded in the Tyrrhenian Sea in 2020, possibly a fin-blue whale hybrid *B. physalus* x *B. musculus* of North Atlantic origin (Fioravanti *et al.*, 2022). With reference to the Adriatic Sea, Bearzi *et al.* (2004) noted that reports of *B. musculus* (Brusina, 1889; Kolombatović, 1894; Parona, 1896; Ninni, 1901; Đulić and Tortić, 1960; Đulić and Mirić, 1967), often called "Mediterranean rorqual" in the historical literature, were the result of confused nomenclature and taxonomy rather than actual misidentifications.

The northern bottlenose whale record referred to a 5.35 m long animal weighing 2 t, that stranded alive in 1939 near Dubrovnik, Croatia (Hirtz, 1940). Holcer *et al.* (2007) concluded that this animal was a Cuvier's beaked whale based on the available photographs, descriptions and measurements.

The rough-toothed dolphin record refers to a female reported to be 2.89 m long and weighing 300 kg, that stranded in the region of Apulia, Italy, on September 22nd, 1991 and was estimated to have died ten days earlier (Marsili and Focardi, 1997). This animal, however, was included in the reports of Centro Studi Cetacei (1994) as a bottlenose dolphin (female, 2.89 m long, and reported to have stranded on the same date and in the same area).

The white-beaked dolphin record (Dathe, 1934) was corrected by Dathe (1972) himself, who re-identified the animal as a common dolphin. Finally, the skull of a presumed harbour porpoise collected in 1822 and preserved in the comparative anatomy museum of the University of Bologna, Italy, was long considered as the only Adriatic Sea record (Alessandrini, 1854; Cagnolaro, 1996). Bearzi *et al.* (2004) suggested it could be a case of confused nomenclature or misidentification. Subsequent osteological analyses confirmed that the skull did not belong to a harbour porpoise, but to a young bottlenose dolphin (Minelli, 2014).

THREATS TO CETACEANS IN THE ADRIATIC SEA

Threats to cetaceans can be subdivided into the broad categories described in Table 5. Most of these threats are at play in the Adriatic Sea, and have variously contributed to the status of cetaceans in this basin – either because of their direct effects (e.g. a bycatch event resulting in mortality), their impact on the ecosystem (e.g. human-driven changes in the availability of cetacean prey), or the impact these threats had in the past (e.g. extensive direct killings having potential influences on demographic trajectories).

The negative effects of human activities can be synergistic, and single practices may result in multiple threats. For instance, the trawl fishery can contribute to seafloor degradation, ecosystem disruption, prey depletion, and food-web contamination by resuspended contaminants, while also directly impacting cetacean communication and hearing (due to engine and gear noise), and resulting in occasional mortality and harm due to bycatch in trawl gear (Bonizzoni *et al.*, 2022). Below, we summarize information on past and extant threats to cetaceans in the Adriatic Sea, subdividing the available information into sections that reflect the regional context.

Intentional killings

In the Mediterranean Sea and Northeast Atlantic, dolphins were long considered as pests and the practice of killing them was common and widespread, largely as an attempt to reduce conflict with fisheries (Petitguyot *et al.*, in press). Historically, culling was promoted by the governments of several Mediterranean countries, including today's Algeria, Croatia, Italy, France, Greece, and Spain (Bearzi *et al.*, 2004, Gonzalvo *et al.*, 2015; Meliadò *et al.*, 2020; Petitguyot *et al.*, in press). For about a century, dolphin extermination was one of the main concerns of the authorities responsible for fisheries management (e.g. De Marchesetti, 1882; Del Rosso, 1905). In the Adriatic Sea, dolphin killings (Fig. 7) and systematic extermination campaigns were carried out for more than a century, until the 1960's. Culling began in the mid-1800's and is especially well documented in the northeastern portion of the basin, where thousands of common and bottlenose dolphins were killed (Bearzi *et al.*, 2004; Meliadò *et al.*, 2020). In today's Croatia (at the time Yugoslavia), dolphin killings were promoted through bounties since 1872, whereas in Italy bounties began in the 1930's. In Italy, these killings remained legal until 1979, whereas in Croatia they remained legal until 1995 (Bearzi *et al.*, 2004).

While it is difficult to compare the past and present abundance of dolphins in the Adriatic Sea, early 20th century reports are suggestive of extremely high dolphin densities, with numbers that greatly exceed those observed in recent decades. For instance, Italy's official data documenting the numbers of landed dolphins and the amount paid in bounties indicate that a total of 3,801 dolphins were killed between 1927 and 1937 off the Adriatic ports of Trieste, Venice, Chioggia, Ancona and Bari, as well as in the Kvarner region (Meliadò *et al.*, 2020). Bounty reports also suggest that 788 dolphins were killed in the district of Rijeka (a relatively small area of today's Croatia) between 1955 and 1960 (Bearzi *et al.,* 2004). The total number of dolphins killed was certainly higher, as wounded animals escaping capture and dying afterwards could not be reported and included in total counts, and not all killings were landed or reported to the officers (Bearzi *et al.,* 2004; Petitguyot *et al.*, in press). A more precise understanding of the magnitude of killings is currently hampered by the non-quantitative nature of most historical reports, by the fragmentary or defective study of the quantitative historical information (such as bounty reports; Meliadò *et al.*, 2020; Petitguyot *et al.*, in press), and by the fact that common and bottlenose dolphins were often lumped

Table 5. Main threats to cetaceans (based on Bearzi, 2017), and their relative importance in terms of potential impact on demography and population status and health in the Adriatic Sea (this study's assessment).

Threat	Description	Relative importance
Intentional and direct takes	Killing, acts of retaliation for actual or perceived damage to fish catches or gear, harming or capture to obtain products for human consumption, live capture for display facilities, killing for amusement and other reasons	High until the 1960s
Climate change	Human-induced changes in climate resulting in water heating and acidification, ecosystem change, shifts in prey availability (abundance or distribution), shifts in distribution of competitors or predators, altered trophic webs, ecology or productivity, exposure to novel diseases etc.	High
Habitat loss and degradation	Reduced habitat quality and loss of critical habitat caused by coastal and offshore development, marine engineering, port and dam construction, opening and closing of waterways, and exploitation of marine resources (e.g. resulting in sea floor modifications, changes in water quality, eutrophication, harmful algal blooms, alien species invasions)	High
Anthropogenic noise	Mortality, injury or chronic stressful disturbance from exposure to human-made sounds	High
Prey depletion	Depletion of food resources caused directly or indirectly by fishing (e.g. through exploitative competition, food web competition, and ecosystem damage caused by destructive fishing methods)	High
Incidental mortality and injury caused by fisheries	Mortality or injury from accidental entanglement (bycatch) in fishing gear of various types including passive and active nets, longlines, traps and discarded or lost nets and lines and illegal fishing practices (e.g. the use of dynamite)	Medium / High
Chemical contamination	Accumulation in the body tissues (mostly through the food web) of chemicals known to adversely affect mammalian functions and health	Medium / High
Ingestion of or entanglement in debris	Mortality or injury from the ingestion of foreign objects and materials (plastic, textiles, fishing gear etc.) obstructing part of the digestive tract, as well as entanglement in plastic, discarded and lost fishing gear and other debris, and chemical contamination secondary to the ingestion of microplastic particles with adsorbed pollutants	Low
Oil pollution	Mortality or health problems deriving from contamination, contact or ingestion of hydrocarbons deriving from oil spills and oil derivates at sea	Low
Vessel strikes	Accidental mortality or injury from contact with a vessel, particularly the hull or propeller	Low
Disturbance	Behavioural disruption through intentional or non-intentional approaches, likely or proven to induce long-term effects	Low

together (Bearzi *et al.,* 2004). Imprecise and incomplete as they may be, these figures clearly suggest a substantially higher abundance of dolphins before the 1960's.

Cetacean species other than common and bottlenose dolphins also used to be killed, and large cetaceans were routinely butchered when they live-stranded or approached the coast in apparent difficulty. Adriatic Sea cases involving sperm whales (Bearzi *et al.*, 2011) and fin whales (Pierantonio and Bearzi, 2012) are especially well documented. Starting from the 1980's, these butchering habits were replaced by efforts to rescue the animals and by a compassionate attitude (Bearzi *et al.*, 2010, 2011).

Nevertheless, intentional killings of small cetaceans can still occur, either as a retaliation measure resulting from perceived conflict or for "sport". In Croatia, Đuras *et al*. (2021) reported a gun shot injury as the cause of death of a bottlenose dolphin. Other examples include a harpooned bottlenose dolphin observed near the island of Olib, Croatia, in August 2013 (tinyurl.com/26w7zpdm), as well as a lone striped dolphin observed in the Vinodol Channel, Croatia, in June 2009 with a healed dorsal wound suggesting that the animal was injured with a five-pronged fishing spear (Rako *et al*., 2009). In Montenegro, intentional killing of bottlenose dolphins was reported by Đurović *et al*. (2016): two adults were killed in August 1999 in the Bay of Kotor (one with dynamite and one with firearms), a calf was killed with dynamite in February 2000 near Bigova, and an adult was found dead with two perforating gunshot wounds in October 2001 near Herceg Novi.

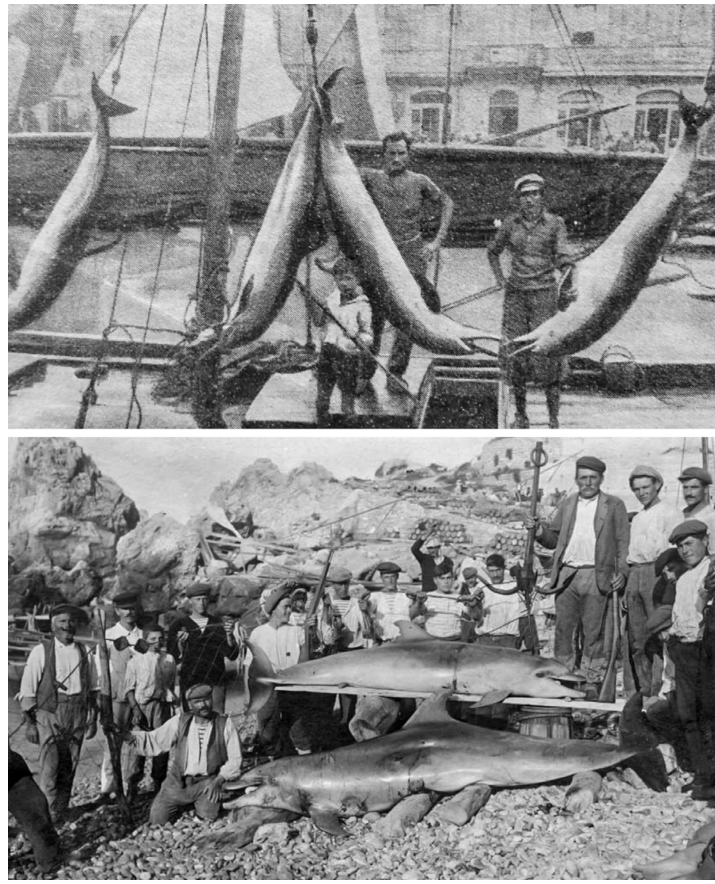

Fig. 7. Examples of dolphin killings in the Adriatic Sea. Top: four common dolphins *Delphinus delphis* killed in Cesenatico, Italy (source: La Domenica del Corriere, date unknown). Bottom: two bottlenose dolphins *Tursiops truncatus* killed in former Yugoslavia in 1913 (source: Museo del Mare, Trieste, Italy).

Incidental mortality in fishing gear (bycatch)

Foraging in the proximity of fishing gear is the most common and best-documented type of dolphin adaptation to human activities (Bearzi *et al.*, 2019). This opportunistic behaviour can result in incidental mortality, since it exposes the animals to a greater risk of getting caught in nets or hooked. Mortality in fishing gear is considered as the main direct threat to many odontocete populations, worldwide (Read *et al.*, 2006; Reeves *et al.*, 2013; Taylor *et al.*, 2017; Brownell *et al*., 2019).

In the central and northern Adriatic, systematic observations from trawlers were carried out in the context of the BYCATCH monitoring programme (Bonanomi *et al*., 2022), resulting in important information on the incidental capture of bottlenose dolphins by the Italian fleet of midwater pair trawlers. In 2006–2008 there were two bycatch events across 1,448 monitored hauls off the region of Veneto, and one bycatch event across 1,445 hauls off the region of Emilia-Romagna (Fortuna *et al.*, 2010). De Carlo *et al.* (2012) reported no bycatch events over 158 hauls between 2008 and 2009. In 2014–2015 there was one bycatch event of one bottlenose dolphin across 1,797 monitored hauls (Sala *et al.*, 2016), while in 2016–2017 there was one bycatch event involving the simultaneous capture of three bottlenose dolphins across 1,460 monitored hauls (Sala *et al.*, 2018; Corrias *et al.*, 2021). Between 2006 and 2019, 19 bottlenose dolphins were bycaught, ranging between zero and three animals per year, resulting in an estimated bycatch rate of 0.00075 individuals per haul (Bonanomi *et al*., 2022).

The BYCATCH initiative represents the only comprehensive study that sheds light on dolphin mortality in midwater trawl gear. Unfortunately, no other quantitative estimates of cetacean bycatch weighed on fishing effort (e.g. number of hauls) are available for any of the other fisheries with which dolphins are known to interact in the Adriatic Sea. These fisheries include large fleets of bottom otter trawlers, bottom beam trawlers, purse seiners, and boats deploying passive nets. Information on mortality in passive nets is limited to observations of stranded dolphins showing evidence of entanglement in fishing gear, or having ingested fishing gear. Of 253 bottlenose dolphins stranded along the coasts of Croatia between 1990 and 2019, 61 were considered as bycaught in fishing gear. These included 26% calves, 33% juveniles and 41% adults (Đuras *et al*., 2021). An additional 30 individuals, almost all adults, had signs of fisheries interactions including larynx strangulation resulting from the ingestion of net pieces, net remains in the stomach, and tail entanglement in fishing gear. Larynx strangulations were caused by gillnet pieces (Đuras Gomerčić *et al*., 2009), while fishing gear found in dolphin stomachs included “cotton and nylon net particles, nylon ropes and hooks” (Đuras *et al*., 2021). Of nine bottlenose dolphins stranded in Slovenia between 1996 and 2012, one reportedly died following bycatch in fishing gear (Gombač *et al.,* 2013). None of the seven bottlenose dolphins, three striped dolphins, three Risso’s dolphins, and one common dolphin stranded along the Italian coast of the Adriatic between 2000 and 2006 were reported to have bycatch lesions (Mazzariol *et al.,* 2007).

Effects of destructive and excessive fishing

The Mediterranean Sea has been characterized as one of the world’s most overfished areas (FAO, 2020). The Adriatic Sea, in particular, has been fished intensively since historical times, and is one of the most intensively trawled areas, globally (Eigaard *et al.*, 2017; Gissi *et al*., 2017; Amoroso *et al*., 2018; Ferrà *et al.*, 2018; Russo *et al.*, 2019; FAO, 2020). A recent assessment on the effects of bottom trawling in 24 areas around the world described the Adriatic Sea as the most intensively trawled, and the one having the worst seabed status (Pitcher *et al.*, 2022). Bottom trawling is known to cause mechanical damage to the seabed (Jones, 1992) as well as chemical alterations (Ferguson *et al.*, 2020), reducing the biomass and biological diversity of benthic ecosystems (Dayton *et al.*, 1995; Hall-Spencer *et al.*, 1999; Jennings *et al.*, 2001; Chuenpagdee *et al.*, 2003; Puig *et al.*, 2012; Oberle *et al.*, 2016). In the Adriatic Sea, trawling has long been an important driver of ecosystem change (Coll *et al.*, 2009; Fortibuoni *et al.*, 2010; Lotze *et al.,* 2011; Fortibuoni *et al.*, 2017) as well as a likely driver of demographic, ecological, or behavioural change for a number of marine vertebrates, including seabirds (Oro and Ruiz, 1997; Karris *et al.*, 2018), elasmobranchs (Ferretti *et al.,* 2013; Mitchell *et al.*, 2018; Sguotti *et al.*, 2022) and odontocete cetaceans (Bearzi *et al.*, 1999; Genov *et al.*, 2008; Rako-Gospić *et al.*, 2017; Bearzi *et al.*, 2019; Genov *et al.*, 2019a; Bonizzoni *et al.*, 2021, 2023).

Other fishing methods used in the Adriatic Sea are also known to have negative impacts, and they variously contributed to habitat degradation and overfishing in this region. These include hydraulic dredging off western Adriatic shores, and purse seining off eastern and southern shores. While direct impacts of dredging on marine mammals appear to be low (Todd *et al*., 2015), hydraulic dredging (e.g. for clam extraction) is known to alter seabed topography and microbenthic communities and can have adverse effects on marine ecosystems (Gilkinson *et al*., 2003; Morello *et al.,* 2005; Gilkinson *et al*., 2015; Ragnarsson *et al*., 2015; Wenger *et al*., 2017). Purse seining has been known to result in dolphin bycatch in other areas (e.g. Hamer *et al*., 2008; Marçalo *et al*., 2015).

Largely due to destructive and excessive fishing impacts, today’s Adriatic ecosystems are trophically simpler and less resilient than a few decades ago (Sguotti *et al.*, 2022). The relative composition of species has changed, several marine communities have suffered sharp declines (Eigaard *et al.*, 2017; Amoroso *et al.*, 2018; Russo *et al.*, 2019), and some long-lived vulnerable species have virtually disappeared. For instance, elasmobranchs declined by more than 94% across 60 years, and 11 of 33 studied species ceased to be detected (Ferretti *et al.*, 2013). Analysing the changes that have occurred since the 1940’s, Fortibuoni *et al.* (2017) documented declines in mean trophic level and other indicators, clearly highlighting a long-term fishing-down food web phenomenon (sensu Pauly *et al.*, 1998).

Fishing capacity in the Adriatic Sea increased enormously during the 1960’s and 1970’s regarding boat size, tonnage, horsepower, improved fishing gear and use of high-tech equipment. Total landings continued to increase until the mid-1980’s, but this favourable period for fishing was followed by a phase of lower nutrient intake from rivers, and by a very high and unsustainable fish harvest; the combination of these factors led to a collapse of marine biodiversity and a sharp decline in fish catches, with landings per unit of fishing capacity collapsing in 1986 (Degobbis *et al.*, 2000; Coll *et al.*, 2009, 2010; Fortibuoni *et al.*, 2010; Lotze *et al.*, 2011; Barausse *et al.*, 2014; Russo *et al.,* 2016; Fortibuoni *et al.*, 2017). In the past three decades, however, total landings have remained largely constant, likely due to a species turnover that helped maintain stable catches, possibly combined with changes in fishing behaviour and technology (Sguotti *et al.*, 2022). This phenomenon has been aptly described as “the illusion of plenty” (Erisman *et al.*, 2011). Reversing the major shift of the mid-1980’s would require a dramatic reduction in fishing capacity (Fortibuoni *et al.*, 2017; Sguotti *et al.*, 2022).

In the scenario summarized above, the fact that bottlenose dolphins have progressively adapted to foraging in the proximity of trawlers (Fig. 8) and other fishing gear (see the Common bottlenose dolphin section) indicates that this opportunistic and resilient species may be simply exploiting the resources that have remained available. However, any advantage gained is likely to be offset by the pervasive environmental impacts of fishing (for a review see Bearzi *et al.*, 2019 and Bonizzoni *et al.*, 2022).

Effects of anthropogenic noise

Underwater noise is a global threat to marine life (Lewandowski and Staaterman, 2020). More specifically, noise from human activities including shipping, geoseismic surveys, oil and gas exploration, marine

Fig. 8. Bottlenose dolphins *Tursiops truncatus* foraging at dawn in the proximity of a midwater trawler as the net is being hauled (photo by S. Bonizzoni / Dolphin Biology and Conservation).

construction, and the use of military or other sonars can have a variety of negative effects on cetaceans (Richardson *et al.*, 1995). Observed effects have included changes in vocalizations, respiration patterns, swim speed, diving and foraging behaviour, as well displacement, avoidance, shifts in migration path, stress, hearing damage, and strandings (Gordon *et al*., 2003; Nowacek *et al.*, 2007; Wright *et al*., 2007; Williams *et al.*, 2020).

Strandings induced by military sonars can result in mortality of beaked whales (Jepson *et al.*, 2003; Fernández *et al.*, 2005; Cox *et al.*, 2006). However, the possibility that noise can lead to strandings and mortality events exists well beyond naval sonars (Hildebrand, 2005). Seismic surveys, for instance, can dramatically raise background noise levels (Weilgart, 2007), with noise being recorded up to 4,000 km away from the source and, in some cases, for more than 12 consecutive months (Nieukirk *et al*., 2012). In the Mediterranean Sea, fin whale migration movements across the basin were found to be altered by seismic exploration (Castellote *et al*., 2009).

Responses of marine mammals to noise can often be subtle and barely detectable, and there are cases of apparent tolerance or habituation. Such tolerance, however, may express a need to remain in a particular location (e.g. for feeding or reproduction) despite exposure to noise, and long-term population impacts may occur without observable short-term reactions (Weilgart, 2007).

The Adriatic Sea is known to have high levels of anthropogenic noise. Human activities that use or result in impulsive noise sources are common off the Adriatic coast of Italy, and the northern sector, in particular, is characterized by intensive drilling for oil and gas (Maglio *et al*., 2016). The Adriatic Sea is also one of the Mediterranean areas most exposed to geoseismic surveys (Maglio *et al*., 2016). Such surveys have been conducted throughout the basin, including in very shallow waters, and noise emissions can be frequent and long-lasting (Carniel *et al*., 2012; De Santis and Caldara, 2016; Trobec *et al*., 2018; Brancolini *et al*., 2019; Giustiniani *et al*., 2020; Širović and Holcer, 2020), raising concern about their effects on cetaceans, particularly deep-diving species such as the Cuvier's beaked whale. Several military areas exist in the Adriatic, but risks related to the possible use of military sonars (that were linked to a mass stranding of Cuvier's beaked whales in western Greece; Frantzis, 1998) are unknown.

The shallow northern sector of the Adriatic also has high levels of underwater noise from vessel traffic (Codarin and Picciulin, 2015). In the Cres-Lošinj area, Croatia, the main source were recreational vessels, especially during the touristic season (Rako *et al*., 2013b, 2013c), whereas in the Gulf of Trieste, large ships were the main contributors and there were no seasonal variations (Codarin and Picciulin, 2015). In Croatian waters, noise caused by boat traffic is known to affect dolphin whistle frequencies (Rako-Gospić and Picciulin, 2016) and one study showed a significant seasonal displacement of dolphins from areas with intense traffic of leisure boats (Rako *et al*., 2013a). In recent years, extensive underwater acoustic data in the northern and central Adriatic Sea were recorded in the context of project SOUNDSCAPE, and this effort has provided baseline information on sound levels (Petrizzo *et al*., 2023; Picciulin *et al*., 2023), useful to assess acoustic threats to marine life including cetaceans.

Effects of marine traffic and oil spills

Apart from the effects of noise produced by propellers and engines, boat traffic and shipping can result in collisions and ship strikes that harm or kill cetaceans, particularly large species such as fin and sperm whales (Panigada *et al.*, 2006; Constantine *et al.*, 2015), but also, at least occasionally, smaller species such as bottlenose dolphins (Wells and Scott, 1997). Large cetaceans, however, are infrequent in the Adriatic Sea, and this may result in a lower occurrence of collisions compared to other parts of the Mediterranean. In the Adriatic, information is limited to one Cuvier's beaked whale stranded near Brindisi, Italy, in 2003. The animal's rear part of the body was entirely cut-off, possibly by a large propeller (Pino d'Astore *et al.*, 2008), but it was impossible to determine whether the animal was alive or it was a drifting carcass sucked in the propeller blades of a passing ship.

Operational and accidental spills of oil and other contaminants are another potential threat for cetaceans (Helm *et al*., 2014; Godard-Codding and Collier, 2018). In the Mediterranean Sea, the necessary tools to deal with accidental spills exceed the capacities of the different countries (Girin and Carpenter, 2017). That may be even more true in a semi-enclosed basin such as the Adriatic Sea, where legislation on chemical tankers does not seem to be strict enough (Perkovic *et al*., 2018) and oil spill accidents could have far-reaching consequences (Lončar *et al*., 2012). In addition to accidents, sources of oil pollution in the Adriatic include routine tank washing operations and illegal discharges (Morović *et al*., 2016), as well as corroding wrecks (Perkovic *et al*., 2018). The effects of these types of oil pollution on cetaceans in the Adriatic Sea are virtually unknown.

Effects of hydrocarbon platforms and wind farms

Off the Adriatic Sea coast of Italy, there are approximately 140 offshore hydrocarbon platforms (tinyurl.com/5fyndx89), of which some have been abandoned. Five additional platforms are located off the coast of Croatia (tinyurl.com/mrytrajy). These platforms and the associated activities can have strong environmental impacts, during either the construction phase or operational drilling. The seafloor around hydrocarbon platforms typically shows higher levels of pollutants such as hydrocarbons and heavy metals, as well as changes in sediment features. Negative effects of such pollutants on benthic assemblages vary depending on the local environmental and the specific type of platform, and can be found up to 3 km away, though the most severe effects tend to be within a 500 m radius (Terlizzi *et al*., 2008; Manoukian *et al*., 2010).

Apart from these negative effects, hydrocarbon platforms may provide substrate, shelter, or enhanced foraging opportunities for demersal and other fishes, sometimes inducing a greater diversity of fish assemblages and higher fish abundance (Fabi *et al*., 2004). In addition, strict fishing bans are typically implemented in the waters surrounding the platforms, and these bans have the advantage of creating de facto no-take areas where marine life has a chance of recovery. Possibly because of these effects, one study in the northwestern Adriatic suggested that hydrocarbon platforms off Ravenna, Italy, may attract bottlenose dolphins (Triossi *et al.*, 2013; and see Cremer *et al.*, 2009, for a related study in Brazil). This hypothesis, however, would need to be confirmed by weighted studies conducted near and away from the platforms, rather than primarily or exclusively in their proximity (Bearzi *et al.*, 2019). A recent model-based study (Bonizzoni *et al.*, 2023) found no evidence that bottlenose dolphins could be either attracted or deterred by a large regasification terminal situated 13 km off the coast of Veneto, Italy, which has been operating since 2009 (adriaticlng.it; Fig. 9).

Offshore wind energy offers a much-needed alternative to fossil fuels. However, the expansion of offshore renewables has raised concerns over potential disturbance to cetaceans. Primary acoustic impacts come from the pile driving required to install wind turbines (Best and Halpin, 2019), and such disturbance depends on the duration of pile driving (which may last between a few days and several years; Thompson *et al*., 2010). Once the wind turbines are in place, impacts on cetaceans may be lower. For instance, results from acoustic monitoring in Scotland suggested no dramatic long-term changes in the use of the area around the turbines by harbour porpoises, though there could be short-term responses within 1–2 km of the site (Thompson *et al*., 2010). In the Adriatic Sea, there is no information on the possible impact on cetaceans of either pile driving or operational wind turbines, though the use of wind energy is likely to increase in the future.

Effects of disturbance by boats

Several studies have shown that vessel traffic can affect dolphin behaviour, activity and energy budgets, habitat use and reproductive success, with effects that can include short-term displacement or long-term area avoidance (e.g. Lusseau, 2003, 2004; Bejder *et al*., 2006). Pirotta *et al*. (2015) showed that the physical presence of boats, and not just noise, plays a large role in disturbance. This effect increased for increasing number of boats and depended on boat type. Short-term behavioural responses to boat approaches were detected in several inshore dolphin populations from around the world. Long-term fitness effects, however, have only been clearly identified in a small number of these populations, characterised as being closed, small and food-limited (New *et al*., 2020). Therefore, the level of disturbance that could be tolerated depends on the characteristics of the population being disturbed. Closed populations are typically most sensitive, while large, open populations with no food limitation tend to withstand higher levels of disturbance (New *et al*., 2020).

Fig. 9. A bottlenose dolphin *Tursiops truncatus* surfaces by a large regasification terminal (adriaticlng.it), situated 13 km off the coast of Veneto, Italy (photo by S. Bonizzoni / Dolphin Biology and Conservation).

In highly touristic coastal areas of the eastern Adriatic Sea, recreational boats routinely approach cetaceans, particularly in the summer. That may result in various degrees of behavioural disruption (see the Common bottlenose dolphin section), thought to have a potential for displacing dolphins from critical habitat (Rako *et al.*, 2013a; Rako-Gospić *et al*., 2017). Model-based research off the region of Veneto, Italy, in 2018–2019 suggested that bottlenose dolphin occurrence may be lower near recreational fishing boats that engaged in sport angling while being anchored or adrift (often in the proximity of offshore mussel farms; Bonizzoni *et al*., 2021). In this area, however, direct disturbance by recreational boats was rare. In the Gulf of Trieste, preliminary analysis of summer distribution data suggested that dolphins avoided areas close to shore during times of day when the number of boats increased, and approached the coast in the early morning and late afternoon, when the number of boats was lower (Genov *et al.*, 2008).

Effects of contamination by xenobiotics

Cetaceans are long-lived mammals positioned at the top of marine food webs, making them susceptible to the accumulation and effects of chemical contaminants (Jepson *et al*., 2016; Williams *et al*., 2023). These effects can be either direct or indirect, and may result in impacts at the individual, community or population level (Reijnders *et al*., 1999). For instance, organochlorine contaminants such as polychlorinated biphenyls (PCB) and dichlorodiphenyltrichloroethane (DDT) have been shown to cause anaemia (Schwacke *et al*., 2012), immunosuppression (Tanabe *et al*., 1994) and the associated vulnerability to infectious disease (Aguilar and Borrell, 1994; Jepson *et al*., 2005), endocrine disruption (Tanabe *et al*., 1994; Vos *et al*., 2003; Schwacke *et al*., 2012), reproductive impairment (Schwacke *et al*., 2002), and developmental abnormalities (Tanabe *et al*., 1994; Vos *et al*., 2003). Below, we summarize some of the studies investigating persistent organic pollutants and heavy metals in Adriatic cetaceans, predominantly in stranded specimens.

Persistent organic pollutants — In early studies, Corsolini *et al*. (1995) and Marsili and Focardi (1997) assessed organochlorine contaminants in 10 bottlenose dolphins and seven striped dolphins stranded in Italy. Organochlorines were also assessed in Risso's, bottlenose and striped dolphins stranded in southern Italy (Storelli and Marcotrigiano, 2000, 2003; Storelli *et al*., 2007). On the Croatian coast, organochlorine contaminants were assessed in 13 bottlenose dolphins (Herceg Romanić *et al*., 2014) and one common dolphin (Lazar *et al*., 2012). Marsili *et al*. (2014) documented relatively high levels of organochlorine contaminants in the sperm whales that mass-stranded in Italy in 2009 (see the Sperm whale section), with strong responses of CYP1A1 and CYP2B biomarkers reflecting toxicological stress. High levels were also reported in the sperm whales stranded in Italy in 2014, and their contribution to the mass stranding could not be ruled out (Mazzariol *et al*., 2018a). Genov *et al*. (2019b) evaluated the levels of organochlorine contaminants in 32 live bottlenose dolphins in the Gulf of Trieste, and related them to demographic parameters known from long-term photo-identification. Sciancalepore *et al*. (2021) assessed per- and poly-fluorinated alkyl substances (PFAS) in livers of 20 bottlenose dolphins stranded in Italy between 2008 and 2020, and found no temporal trends or significant differences between sexes; calves had higher mean values than adults, suggesting that ability to eliminate PFAS may increase with age. The results also suggested that long-chain PFAS are widespread in bottlenose dolphins in the northeastern Adriatic (Sciancalepore *et al*., 2021). Finally, Minoia *et al*. (2023) assessed persistent organic pollutants in three Risso's dolphin stranded in Italy.

Comparing organochlorine levels across species, areas and studies is challenged by differences in compounds analysed, units and summary statistics used, sample sources and other factors (Genov *et al*., 2019b). Overall, PCB levels in bottlenose dolphins appeared higher in the northern Adriatic (Herceg Romanić *et al*., 2014; Genov *et al*., 2019b) than in the southern basin (Storelli and Marcotrigiano, 2003). Levels in Adriatic bottlenose dolphins were generally higher than those in the Ionian Sea and the eastern Mediterranean, but lower than those in the western Mediterranean (Genov *et al*., 2019b). Most studies in the Adriatic reported organochlorine concentrations exceeding toxicity thresholds (Storelli *et al*., 2012; Herceg Romanić *et al*., 2014; Genov *et al*.; 2019b). Hexachlorobenzene (HCB) levels were low across studies (Marsili and Focardi, 1997; Mazzariol *et al*., 2018a; Genov *et al*., 2019b). PCB congeners 153 and 138 were dominant in both bottlenose (Marsili and Focardi, 1997; Storelli and Marcotrigiano, 2003; Herceg Romanić *et al*., 2014; Genov *et al*., 2019b) and striped dolphins (Marsili and Focardi 1997; Storelli *et al*., 2012), as well as in one common dolphin (together with congener 170; Lazar *et al*., 2012). Accumulation patterns were relatively homogeneous across tissues (Storelli *et al*., 2007; Herceg Romanić *et al*., 2014). In studies with sufficient sample size, adult males had consistently higher concentrations than adult females (Marsili and Focardi, 1997; Storelli *et al*., 2012; Genov *et al*., 2019b), indicating maternal offloading of contaminants to the offspring. This was corroborated by Genov *et al*. (2019b), who showed that nulliparous females had significantly higher PCB concentrations than parous ones. Finally, Fortibuoni *et al*. (2013) assessed butyltin biomagnification in a variety of crustaceans, cephalopods, bony fish and elasmobranchs, as well as in six bottlenose dolphins stranded in the northwestern Adriatic, and found that bottlenose dolphins were the most contaminated species.

Heavy metals — Varying and sometimes high levels of heavy metals were found in cetaceans from the Adriatic Sea. Storelli *et al*. (1999) assessed Cd, Cr, Hg, Pb, Se and methylmercury (MeHg) in various organs and tissues of Risso's dolphins and Cuvier's beaked whales stranded in southern Italy. Levels in Cuvier's beaked whales were lower for all metals, except for Cd (Storelli *et al*., 1999). Zucca *et al*. (2005) reported high Hg concentrations in two Risso's dolphins in northern Italy, exceeding the limits over which hepatic damage occurs. Bilandžić *et al*. (2012) assessed As, Cd, Hg and Pb in bottlenose, striped and Risso's dolphins during 2000–2002, and Šuran *et al*. (2015) assessed Cd and Pb in bottlenose and striped dolphins stranded in Croatia during 1990–1999; together, these studies showed a progressive decrease in Pb between 1990 and 2002, but an increase in Cd levels. Risso's dolphins had the highest levels of heavy metals (Bilandžić *et al*., 2012). In a later study, Bilandžić *et al*. (2016) assessed Hg and Se in the same three species, as well as in three Cuvier's beaked whales and two fin whales, with the latter species containing the lowest concentrations of both elements. Bilandžić *et al*. (2016) also assessed Cu in bottlenose, striped and Risso's dolphins, whereas Đokić *et al*. (2018) assessed Mn in bottlenose, striped and Risso's dolphins stranded in Croatia. According to Mazzariol *et al*. (2018a), MeHg could not be ruled out as a potential factor contributing to the mass stranding of sperm whales in southern Italy in 2014. Sedak *et al*. (2022) assessed Hg and Se in 186 specimens of bottlenose, striped and Risso's dolphins stranded in Croatia: Hg and Se levels were higher in Risso's dolphins in all tissues. Overall, 64 individuals exceeded the lower critical level of 100 mg/kg Hg and 29 individuals exceeded the upper critical level of 400 mg/kg in the liver. The latter critical level was exceeded by 67% of Risso's dolphins, 15% of bottlenose dolphins, and one striped dolphin (Sedak *et al*., 2022).

To a degree, cetaceans can metabolize toxic organic MeHg into a less toxic inorganic mercury (Palmisano *et al*., 1995; Nigro and Leonzio, 1996), thereby alleviating some of the negative effects of these compounds (Bowles, 1999). While high concentrations of heavy metals may not necessarily imply toxicity (Bowles, 1999), toxicological risk will increase if levels exceed an animal's storage and metabolising capacity. However, unlike heavy metals, to which cetaceans have adapted to some degree due to their ubiquitous presence in nature, contaminants such as persistent organic pollutants represent an evolutionary novelty, and are therefore of greater concern.

Effects of marine debris

Obstruction of the digestive tract by ingested plastic and other debris (including discarded or lost fishing gear), as well as entanglement in such debris, is a known cause of marine mammal mortality (Baulch and Perry, 2014; Eisfeld-Pierantonio *et al*., 2022). Marine debris, particularly plastics, has become widespread in the marine environment (Laist, 1997; Derraik, 2002; Thushari and Senevirathna, 2020), especially in the Mediterranean Sea (Lambert *et al*., 2020). Cases of plastic ingestion in the Adriatic Sea are well documented, and have included several cetacean species (e.g. sperm whale: Mazzariol *et al.*, 2011, 2018a; Cuvier's beaked whale: Gomerčić *et al.*, 2006; bottlenose dolphin: Đuras *et al.*, 2021), but demographic impacts are unknown.

Effects of climate change

Rising temperatures and climate disruption caused by human activities have pervasive global consequences that have been amply documented, and can result in loss of biodiversity and catastrophic ecological changes (Cheng *et al*., 2019; Halpern *et al*., 2019; IPCC, 2019; Bradshaw *et al*., 2021; Georgian *et al*., 2022). Generally, climate change may have a lower impact on certain cetacean species (particularly those that are more resilient and mobile), while other species will be placed under extreme pressure by effects that may be largely indirect, and mediated via ecosystem and biodiversity changes, including changes in prey availability (Simmonds and Elliot, 2009; Sousa *et al*., 2019; van Weelden *et al*., 2021). Cetacean communities may reorganise in response to ocean warming, with shifts in distribution and losses of resilience (Lusseau *et al*., 2004; Learmonth *et al*., 2006; Whitehead *et al*., 2008; MacLeod, 2009).

Increased temperatures have long been observed in the Mediterranean Sea, both in surface and deep waters, and there is increasing evidence of biological responses to such warming, including disease outbreaks, faunal shifts and spreading of invasive species (Lejeusne *et al*., 2010). These effects can be predicted to become increasingly apparent in the coming decades, as water temperatures continue to rise and marine species are either displaced, replaced by more tolerant and tropical ones, or obliterated. Ocean acidification is also likely to affect marine biodiversity in ways that are poorly understood and difficult to predict for cetaceans (Whitehead *et al*., 2008; Lacoue-Labarthe *et al*., 2016).

Indirect negative effects on cetaceans can also result from extreme weather events, such as heavy rainfall causing extensive inland flooding and massive outflow of mud, debris and pollutants into the sea, leading to modifications in the basin's physical and chemical dynamics (e.g. Campanelli *et al*., 2011).

Pathogens and other mortality

Between 1990 and 1992, rapidly spreading dolphin morbillivirus outbreaks (Domingo *et al.*, 1990, 1995) caused thousands of striped dolphin deaths in the western Mediterranean Sea (Aguilar and Raga, 1993; Aguilar, 2000), also extending to the eastern basin (Van Bressem *et al.,* 1993). Another morbillivirus outbreak occurred in 2007 (Raga *et al.,* 2008), and more recent viral epizootics in the Mediterranean Sea have affected several marine mammal species (Mazzariol *et al.,* 2016; Centelleghe *et al.,* 2017; Giorda *et al*., 2022). The reasons behind these epizootics are still not understood, but considering the immunotoxic and other detrimental effects of environmental pollutants (Desforges *et al.*, 2016; Jepson *et al.*, 2016; Genov *et al.*, 2019b) anthropogenic factors cannot be ruled out. Epizootic phenomena have been related to compromised immune-system induced by exposure to xenobiotics and/or by stress from poor nutrition (Aguilar and Borrell, 1994; Calzada *et al.,* 1996; O'Shea and Aguilar, 2001). A few cases of morbillivirus were also detected in the Adriatic Sea, particularly along the Italian coast (Pautasso *et al.*, 2019). For instance, one individual stranded in Apulia in November 2016 was diagnosed with suppurative encephalitis associated to dolphin morbillivirus (Giorda *et al.*, 2022). One individual stranded in Molise in February 2019, and one stranded in Apulia in December 2020, showed a co-infection of dolphin morbillivirus and *Brucella ceti* (Grattarola *et al*., 2023). Three sperm whales from a group of seven that mass-stranded alive in September 2014 near Vasto (see the Sperm whale section) were infected by dolphin morbillivirus, and this was thought to have played a role in weakening the animals and affecting their orientation (Mazzariol *et al.*, 2018a).

Harmful algal blooms (favoured by oceanographic conditions and sometimes related to human-induced eutrophication) can result in cetacean mortality due to exposure to natural biotoxins (Van Dolah, 2005). Large-scale mortality events involving bottlenose dolphins have been associated with blooms of the marine alga *Karenia brevis* and the resulting exposure to the neurotoxins (brevetoxins) produced by this dinoflagellate (Fire *et al.,* 2007, 2011; Pierce and Henry, 2008), but no such cases were reported in the Adriatic Sea.

Some of the many parasites known to infect cetaceans (Geraci and St. Aubin, 1987; Dhermain *et al.*, 2002) can have serious health effects. For instance, infections with protozoan agents such as *Toxoplasma gondii* are common in the Mediterranean, especially in coastal areas, but only animals with compromised immune systems are at risk of becoming seriously ill (Cabezón *et* al., 2004).

Pneumonia was the most common pathology (n = 12) across 14 necropsies of well-preserved odontocetes stranded along the Italian coast of the Adriatic between 2000 and 2006, including seven bottlenose dolphins, three striped dolphins, three Risso's dolphins, and one common dolphin; other pathogens included parasites (*Halocercus* sp., *Crassicauda grampicola*, *Phyllobothrium delphini*, *Monorygma grimaldii*, *Pholeter gastrophylus*), bacteria (*Photobacterium damselae, Aeromonas hydrophyla*), and fungi *Cladosporium* spp. (Mazzariol *et al*., 2007). Bacterial infections were also found in several other cetaceans stranded in Italy. For instance, an adult male bottlenose dolphin stranded in the region of Abruzzo in 2014 had a bilateral pleuropneumonia and bacterial coinfections by *Ureaplasma* spp., *Photobacterium damselae* and *Actinomyces*-like species (Di Francesco *et al*., 2016). Seven of nine striped dolphins stranded in Abruzzo, Molise and Apulia between 2013–2021 had infections by the bacterial pathogen *Brucella ceti* (Grattarola *et al*., 2023). Pathogens including *Vibro parahaemolyticus* and *V. alginolyticus* were detected in a bottlenose dolphin stranded in Abruzzo in July 2016, and linked to a suppurative meningo-encephalitis (Di Renzo *et al*., 2017). Along the coast of Croatia, a bottlenose dolphin stranded in Poreč in 2015 had a *Brucella* spp. infection (Cvetnić *et al*., 2016), and a striped dolphin stranded in Vis in March 2002 had a *Clostridium tertium* infection, thought to have caused abscessation and osteomyelitis (Šeol *et al*., 2006). In

Slovenia, the cause of death in nine bottlenose dolphins stranded between 1996–2012 included verminous pneumonia caused by nematodes ($n = 5$), chronic ulcerative oesophagitis and gastritis ($n = 1$), endoparasitosis and emaciation ($n = 1$), and bycatch in fishing gear ($n = 1$), whereas the cause of death of one animal could not be established due to severe decomposition (Gombač *et al*., 2013).

Nematodes are commonly found in cetaceans (Aznar *et al*., 2002) and do not necessarily cause disease (Sweeney and Ridgway, 1975; Geraci and St. Aubin, 1987), although a heavy burden may indicate a health-compromised animal. Nematodes (*Anisakis* spp.) were found in 52 (29%) of 181 cetaceans stranded in Croatia between 1990 and 2012; these included 35 bottlenose dolphins, 13 striped dolphins, three Risso's dolphins and one Cuvier's beaked whale (Blažeković *et al*., 2015). Striped dolphins had a significant higher presence of nematodes compared to bottlenose dolphins, with differences seemingly related to ecology and diet (Blažeković *et al*., 2015). Nematodes (*Anisakis* spp.) were also found in one striped dolphin stranded in Opatija, Croatia, in June 2017, one stranded in Stari Grad, Croatia, in September 2017 (Mladineo *et al*., 2019), and in three of the six sperm whales that mass-stranded in the region of Apulia, Italy, in 2017 (Cipriani *et al*., 2022). An adult Risso's dolphin stranded in the region of Friuli Venezia-Giulia, Italy, in May 2001, had concretions near its tympanic bullae caused by nematodes *Crassicauda grampicola* (Zucca *et al*., 2004).

In marine ecosystems unaffected by human impacts, predation would represent one of the main sources of mortality for cetaceans. The Adriatic Sea, however, is far from pristine and natural predators have declined to the point of representing a rather insignificant threat. Large sharks, in particular, have declined dramatically (Ferretti *et al.*, 2008, 2013; Moro *et al.*, 2020) and their near-eradication must have substantially reduced predation pressure. Marine mammal species that potentially can prey on cetaceans, such as killer whales *Orcinus orca* and false killer whales, are either absent or rare in the Adriatic Sea. Finally, infanticide and violent inter- and intra-species interactions have involved bottlenose dolphins in some areas around the world (e.g. Patterson *et al.*, 1998; Robinson, 2014), but no such cases have been reported in the Adriatic.

CONSERVATION

The environmental conditions of the Adriatic Sea are highly compromised, due to the reasons described in previous sections. Transitioning from a multi-decade phase of overexploitation and damage to responsible management is therefore a difficult challenge, but not an impossible one (Micheli and Niccolini, 2013; Portman *et al.*, 2013). To restore the sea's health there is no shortage of effective policy tools, and a plethora of management initiatives were proposed at all scales and governance levels (national, regional, European and international).

Implementing the existing policy tools and management initiatives would positively affect the status of the Adriatic cetacean fauna. However, the conditions of a semi-enclosed, predominantly shallow sea such as the Adriatic, surrounded by different nations and subjected to an extreme intensity of human use, require a high degree of coordination and cooperation at the international level to achieve the desired results. The joining of several Adriatic coastal nations (Italy, Slovenia and Croatia) within the European Union, and the ongoing process of future accession by non-EU nations such as Bosnia and Herzegovina, Montenegro and Albania, can facilitate cooperation to achieve truly sustainable human activities, e.g. through the implementation of Council Directives 2008/56/EC (the "Marine Strategy Framework Directive") and 2014/89/EU (the "Maritime Spatial Planning Directive"). Until now, this has been an uphill process (e.g. Mackelworth *et al*., 2011), with regulatory frameworks operating at different scales and having largely uncoordinated objectives (Gissi *et al*., 2018).

Still, improving the conditions of the Adriatic Sea environment is an imperative widely recognised at all political levels, regardless of concerns specifically targeting the status of the region's cetaceans. International agreements such as the Convention on Biological Diversity (CBD), the Convention on Migratory Species (CMS), the Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean, and even the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic (ACCOBAMS) prescribe conducts that, unfortunately, are met with insufficient enforcement and compliance by the very individual nations that have approved them. Adopted resolutions often clash with the broad economic interests involved in the human uses of the marine environment, and these interests have invariably prevailed.

Notwithstanding the regrettable dearth of compliance with formal commitments made by the nations that are Parties to ACCOBAMS, it must be recognized that this Agreement helped raise institutional and public awareness on the need of mitigating pressures on the region's cetaceans, and it provided a strong and invaluable stimulus to cetacean research in a context of international cooperation. Such stimulus has resulted *inter alia* in coordinated efforts to increase scientific knowledge and, in recent years, unprecedented assessments of cetacean abundance and density throughout the Mediterranean Sea (ACCOBAMS, 2021b; Cañadas *et al*., 2023; Panigada *et al*., in press). Information generated by ACCOBAMS partners was used profusely in this review on Adriatic cetaceans.

Recommended actions

Describing the complex of initiatives to manage human uses of the Adriatic Sea (including fisheries, transportation, tourism, hydrocarbon extraction and wind farms), and the ways to prevent environmental degradation and biodiversity loss caused by such uses, is beyond the scope of this review. Here, the focus is on marine management and conservation initiatives that can positively affect cetaceans, and what recommendations can be made to make cetacean conservation more effective. The prospect of bringing back the cetacean fauna of the Adriatic to its original vibrancy can only be a dream, until all the components of the marine ecosystem have been restored from their current status of depletion.

In an effort to propose actions that have a chance of being effective, we have adhered to the following principles:

A) actions should concentrate, at least initially, within specific areas known to contain habitat that is especially important for cetaceans;
B) management action should not be limited to the conservation of the status quo, but must aim at restoring the status to previous, more favourable conditions, thus leaving room for ecosystem and biodiversity recovery;
C) management action should not be limited to population conservation and restoration, but attention should also be dedicated to the quality of life of cetaceans.

A) Place-based management and conservation

Various international organisations have highlighted areas within the Adriatic Sea that are important for cetaceans. These comprise:

- the Cres-Lošinj bottlenose dolphin habitat, included by ACCOBAMS in the list of areas to be protected (Resolution 3.22; ACCOBAMS, 2007);
- two Ecologically or Biologically Significant Marine Areas (EBSAs), that include a "Northern Adriatic EBSA" justified in part by the presence of bottlenose dolphins, and a "Southern Adriatic/Ionian Strait EBSA" justified by its importance for Cuvier's beaked whales and striped dolphins (Convention on Biological Diversity, 2016);
- the "Northern and Central Adriatic Important Marine Mammal Area" identified for bottlenose dolphins by the IUCN Marine Mammal Protected Areas Task Force (IUCN, 2017), justified by criteria including B2 (aggregations), C1 (reproductive areas), and D1 (population distinctiveness).

All of the above, however, are areas that have been singled out because they contain important habitat for Adriatic cetaceans, based on scientific criteria. Such evidence-based designations do not contain, by themselves, management implications but serve the purpose of highlighting the presence of areas that deserve conservation action.

By contrast, and on a more limited scale, a variety of marine protected areas (MPAs) declared by the Adriatic nations formally protect portions of their coastal waters (Sovinc, 2021; and see map at tinyurl.com/4d5hsmsu). Regrettably, these areas are extremely small and were not established specifically to protect wide-ranging cetacean populations. In addition to these MPAs, several Natura 2000 sites of community importance under the Habitats Directive (Council Directive 92/43/EEC) have been established off the Adriatic coasts of Italy and Croatia (see map at natura2000.eea.europa.eu). Such sites, once converted into Special Areas of Conservation (SAC) based on European law, will be subjected to management and could become potentially effective cetacean conservation tools.

Even assuming that cetacean conservation actions are effectively implemented within all the waters delimited by the complex of existing Natura 2000 sites and nationally established MPAs, a mismatch is evident between the relatively small sea surface covered by the sum of all the MPAs and Natura 2000 sites, and the much larger area covered, for instance, by the Important Marine Mammal Area identified by the IUCN (IUCN, 2017). Such mismatch indicates that the spatial extent of protection could be insufficient to satisfy the conservation needs of cetaceans.

Still, achieving cetacean conservation goals should not rely exclusively on the formal establishment of "traditional" marine protected areas. When it comes to the management of fisheries impacts, a straightforward and powerful tool is represented by Fisheries Restricted Areas (FRAs), created under the General Fisheries Commission for the Mediterranean (GFCM). These are geographically-defined areas where all or certain fishing activities are temporarily or permanently banned or restricted. In the Adriatic Sea, the Jabuka/Pomo Pit FRA, and the GFCM ban on trawling and dredging in waters deeper than 1,000 m are important examples of management measures that benefit both the marine environment (cetaceans included) and the fisheries. Similarly, the establishment of large fishery reserves such as the one proposed by Fouzai *et al*. (2012), coinciding to a large extent with an area of high bottlenose dolphin occurrence identified by Bonizzoni *et al*. (2023), would be consistent with biodiversity recovery (Demestre *et al*., 2008; Fouzai *et al.,* 2012; Micheli *et al*., 2013; Bastari *et al*., 2016) and long-term cetacean conservation.

These considerations bring to the foreground a basic consideration: present knowledge on the spatial occurrence, movements and conservation needs of Adriatic cetaceans (as reviewed in this study) needs to be fully and timely incorporated into management strategies and actions. Concurrently, appropriate support should be given to continued field monitoring, both at the local and basin-wide scale, while also encouraging the development of new projects on cetaceans in poorly-researched portions of the basin. Updated science-based evidence is essential for management (Taylor *et al*., 2000), and it allows for the monitoring of conservation outcomes. Additionally, research in the fields of historical ecology and environmental history (Holm *et al*., 2001) can provide historical baselines of cetacean diversity, abundance and distribution (Brito and Vieira, 2010; van den Hurk *et al.*, 2023; Petitguyot *et al.*, in press). This information sheds light on population trends, viability, and potential for recovery, and it can help set meaningful baselines for conservation.

In many cases, cetacean conservation can be ensured without resorting to the lengthy, costly and often uncertain process of MPA establishment, by simply phasing out human activities known to either have direct negative impacts on cetaceans (e.g. geoseismic surveys) or result in pervasive environmental degradation and loss of biodiversity (e.g. destructive fisheries). In other cases, effective results can derive from case-by-case efforts and negotiations with stakeholders to resolve conflicts.

B) Restoration and recovery

The Kunming-Montreal Global Biodiversity Framework, adopted in 2022 by the parties to the Convention on Biological Diversity (and therefore by all the nations surrounding the Adriatic Sea), clearly refers to the need to "take urgent action to halt and reverse biodiversity loss" and "put nature on a path to recovery" (Convention on Biological Diversity, 2022). Reference to this imperative is contained throughout the document, and is particularly emphasised under Target 2: "Ensure that by 2030 at least 30% of areas of degraded terrestrial, inland water, and coastal and marine ecosystems are under effective restoration, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity". It is noteworthy that policy language referring to the restoration of nature is progressively replacing that of simple conservation, even when simple conservation is a target that is still largely unattained in the global arena.

That cetacean conservation should go beyond just avoiding further population decline or warding off the extinction of single species has been argued repeatedly (e.g. Notarbartolo di Sciara and Würsig, 2022). As noted by Bearzi and Reeves (2021):

Allowing only the most opportunistic and resilient species to persist, often by merely attempting to mitigate direct mortality (e.g., bycatch in fishing gear), should not pass for actual cetacean conservation. We should strive instead for the full recovery of multiple species throughout their historical ranges.

In previous sections of this review, we have emphasized that the Adriatic cetacean fauna in historical times was more diverse and richer, and this is where conservation efforts should aim, in a fight against ever-shifting baselines. Species and population recovery must include the preservation of their connectivity within the Adriatic, and in some cases over the wider Mediterranean Sea. Important areas that are often represented as nodes scattered across the marine expanse should instead be connected within networks reflecting the movements of the species using them, and those linkages need to be protected just like the nodes (Reisinger *et al.*, 2022).

C) Preserving the quality of cetacean life

True conservation should aim even higher than obtaining the recovery of the historical ranges of the full complement of species of the Adriatic Sea. The ability of a group of animals to counter a declining trend is greatly impaired if their habitat becomes difficult to live, if not unliveable. Difficulties involve not only physical well-being, but also psychological health. In other words, mere survival is not enough: cetaceans require a healthy environment where they can exist free of harassment by ubiquitous human presence (Notarbartolo di Sciara and Würsig, 2022). Requirements will also include preservation of their cultural landscape. Many, and perhaps all, cetaceans exist in cultural units characterized by unique behaviour, vocalizations, feeding habits, and social-sexual strategies (Rendell and Whitehead, 2001; Whitehead and Rendell, 2014). These traits are integral to the populations' survival. Therefore, the conservation of these cultural entities should be central to conservation efforts. Brakes *et al*. (2019, 2021) provide a convincing link between our understanding of animal cultures and mechanisms to enhance conservation efforts. Ultimately, conservation efforts should strive to allow cetacean populations to flourish in an environment where marine food webs are revived and ocean health and richness are restored as much as possible to pre-industrial times (Notarbartolo di Sciara and Würsig, 2022).

We are fully aware that we are far from attaining any of the goals described above, anywhere in today's world's oceans, let alone in a basin as degraded as the Adriatic Sea. However, we hope that our considerations will provide an even stronger stimulus to try. Building a new narrative with all available means – reports, movies, books, articles, conferences, social media – can help create in the broader public the needed level of awareness of the real costs of environmental degradation, and the benefits of regaining a balanced relationship with nature, which can lead people to exert stronger pressure on decision makers and stimulate change.

ACKNOWLEDGEMENTS

We are grateful to the journal's Editor-in-Chief and to three anonymous reviewers for their valuable feedback and constructive comments. Tommaso De Lorenzi kindly retrieved and shared the photo of bottlenose dolphin in Fig. 7.

Author contributions

Giovanni Bearzi: Supervision; Conceptualization; Investigation; Methodology; Writing - original draft; Visualization. Silvia Bonizzoni: Investigation; Writing - original draft. Tilen Genov: Investigation; Writing - original draft. Giuseppe Notarbartolo di Sciara: Conceptualization; Writing - original draft.

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