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The conservation of the endangered Mediterranean common dolphin (*Delphinus delphis*): Current knowledge and research priorities

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Abstract

1. Preservation of endangered species is now recognized as a relevant component of regional and global conservation actions achieved through the maintenance of the remaining populations in a favourable conservation status. The Mediterranean common dolphin (*Delphinus delphis*) is listed as an Endangered subpopulation in the International Union for Conservation of Nature Red List, with declining numbers in some of the areas where it has been studied for numerous years. Prey depletion, fisheries bycatch, pollution, health risks, and climate change are among the recognized threats that the species is facing in the region.
2. The existing national, regional, and international legislation pertinent to Mediterranean countries should aid greater science–policy–management integration and support innovative research and monitoring towards effective conservation. The challenges inherent in studying the pelagic *D. delphis* should not preclude the use of long-term, year-round, multiplatform surveys, side by side with the latest molecular tools, which aid our understanding of its populations' genetic diversity, resistance to diseases, and resilience in a semi-enclosed fast-changing sea.
3. Addressing the multiplicity of problems confronting the species requires collaborative effort at all levels to share and merge resources, data, and expertise more efficiently. In this review, we provide an overview of the current knowledge on the Mediterranean common dolphin, the main threats, and knowledge gaps that are priorities for addressing its conservation, while providing clear recommendations for effectively safeguarding the species and its habitat at both local and regional levels.

KEYWORDS

common dolphin, conservation, *Delphinus delphis*, Mediterranean

1 | INTRODUCTION

At a global level, the short-beaked common dolphin (*Delphinus delphis*, Linnaeus, 1758) is listed as Least Concern by the International Union

for Conservation of Nature (IUCN) Red List (Hammond et al., 2008) owing to its widespread and abundant distribution in tropical and cool temperate waters (Perrin, 2018). However, at a regional level, the IUCN status for the Mediterranean subpopulation has been listed as

Endangered since 2003 due to its decline since the 1960s (Bearzi et al., 2003, 2008; Piroddi, Bearzi, Gonzalvo, & Christensen, 2011).

Establishing demographically distinct management units within cetacean populations is critical for targeting their effective conservation (Giménez et al., 2017). Identifying and characterizing such units for *D. delphis* may be achieved through consideration of the various developing insights, disciplines, and research outcomes, with the latter targeting phenotypic, genotypic, acoustic characteristics, foraging and habitat preferences, site fidelity information, life history, and demographic requirements for long-term survival of the species. Additionally, for highly mobile marine mammal species, it has been reported that, despite no obvious barrier exist to gene flow, historical environmental processes and ecological specializations may lead to complex genetic differentiation and ecotypes as a result of niche specializations and/or social organization (Louis et al., 2014).

Delphinus delphis sampling from the Mediterranean Sea, Black Sea, and eastern North Atlantic ($n = 118$) has revealed a weak but significant population genetic structure between the eastern and western Mediterranean, when using nine microsatellite nuclear loci and 428 bp of the mitochondrial DNA (mtDNA) control region (Natoli et al., 2008). Additionally, analyses of whistle characteristics also indicate differentiation between the western and the eastern Mediterranean, as a possible consequence of geographical separation that leads to genetic differences (Azzolin et al., 2021) (see Section 2.3).

Another genetic study, using 15 microsatellite nuclear loci from three areas in the Mediterranean Sea ($n = 43$) and eight areas from the North-East (NE) Atlantic ($n = 449$), still did not find evidence of strong genetic population structure in European waters, possibly due to low analytical power or incomplete sampling (Moura, Sillero, & Rodrigues, 2012). A more recent study, using 366 bp of the mtDNA D-loop fragments from common dolphin sampled from the Black Sea, Turkish Straits, and Aegean Sea ($n = 37$), and then compared with previous stored GenBank genetic data for 100 Mediterranean and Black Sea samples and 250 East Atlantic Ocean samples, reiterates previous outcomes by indicating the sampling limitations that hinder complete understanding of the genetic population structure of *D. delphis* in the Mediterranean Sea (Tonay et al., 2016, 2020). In the meantime, the first complete mtDNA genome and resultant phylogeny of *D. delphis* has clearly distinguished it from the long-beaked form *Delphinus capensis* while revealing that these two species are closely related to *Stenella coeruleoalba* (Lee et al., 2018). These results, and more so the developed molecular tools, may be applied to further investigate the genetic diversity and structure of *D. delphis* in the Mediterranean in more detail and with the required sampling protocols. In fact, apart from having a wider coverage of the sampling locations from the whole of the Mediterranean Sea, sample sizes would usually need to be 25 samples or more for each of the sampling locations through the region in order to detect most of the genetic variation present (Hale, Burg, & Steeves, 2012; Leberg, 2008; Yan & Zhang, 2004).

Just as genetic diversity may shed light on population structure, phenotypic diversity may also reveal distinguishing features possibly shaped by directional selection or phenotypic plasticity (Ben Cohen & Dor, 2018). Spatial distinction in skull morphology of *D. delphis*

between southern Sicily and the Tyrrhenian Sea was found after cranial morphometric analyses of museum specimens (Nicolosi & Loy, 2021). The ones from the Tyrrhenian Sea were found to be characterized by a slender skull and a narrower occipital region, suggesting adaptations to different foraging resources and potential ecological separation from the dolphins found in southern Sicilian and North African waters. In fact, evidence is emerging on disparate foraging ecology among *D. delphis* found within and outside the Mediterranean, based on stable isotopes and stomach contents (Giménez et al., 2017; Marçalo et al., 2018; Silva, 1999) (see Section 3.2).

As a pelagic species, the common dolphin is usually found in large groups inhabiting coastal to offshore waters, exhibiting long-distance dispersal, and possibly concealing the existence of fragmented populations with some site fidelity (Ball, Shreves, Pilot, & Moura, 2017). Photo-identification at local to regional level in the Mediterranean Sea would allow consideration of ecological population structuring through investigations of the extent of individuals' site fidelity versus distribution shifts (see Section 2.1).

To achieve holistic and effective protection of the endangered Mediterranean *D. delphis*, consideration of both the latest research findings and current knowledge in a fast-changing marine environment is essential. The latter will increasingly challenge the species resilience and test the effectiveness of conservation management provisions, including the designation of conservation areas (such as the Cetacean Critical Habitat by the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic Area (ACCOBAMS) and the Important Marine Mammal Areas (IMMAs) by the IUCN-Task Force (IUCN Marine Mammal Protected Areas Task Force, 2017)). The limitations in knowledge may be overcome by the greater involvement of researchers from around the Mediterranean Sea studying and monitoring the species as part of marine biodiversity and cetacean conservation requirements (Convention on Migratory Species, Bern Convention, ACCOBAMS, Habitat Directive, Marine Strategy Framework Directive), further supported by a closer collaborative science-policy-management conservation approach.

The following sections, therefore, explore the scientific progress made in the various biological research aspects on *D. delphis* species in a Mediterranean context, paving the way to stronger research networking and focused conservation science-policy-management integration, from a local to a regional scale.

2 | ECOLOGY

2.1 | Density estimates

Long-term research and monitoring on *D. delphis* in the Mediterranean have provided some local abundance estimates. These include the Alboran Sea (Cañadas & Hammond, 2008; Cañadas & Vázquez, 2017; Forcada & Hammond, 1998), the waters around the Maltese islands (Central Mediterranean; Aissi & Vella, 2015; Vella, 2005, 2016), the Inner Ionian Sea Archipelago (Bearzi et al., 2003, 2005, 2008), the

Thracian Sea (Milani et al., 2021), and more recently the eastern Aegean Sea, south of Samos island (Inch, Pietroluongo, & Hepburn, 2018; Pietroluongo et al., 2020). The first estimates of common dolphin aerial densities in the Mediterranean Sea were of 0.16 km^{-2} in the Alboran Sea (Forcada & Hammond, 1998) and 0.14 km^{-2} in Maltese waters (Central Mediterranean; Vella, 2005). It has also been recently estimated off Samos island (Greece) to be 0.15 km^{-2} (Pietroluongo et al., 2020). Common dolphin encounter rate measures were reported for the Alboran Sea (1.74 km^{-1}) (Cañadas & Hammond, 2008), the Gulf of Vera (0.36 km^{-1}), the North Aegean (0.015 km^{-1}) (Milani et al., 2021), the island of Ischia with declining encounter rates between 2000 and 2015, from 0.31 km^{-1} to 0 km^{-1} (Mussi, Vivaldi, Zucchini, Miragliuolo, & Pace, 2021). Decline was also reported in Kalamos island, with numbers decreasing between 1993 and 2002 from 0.11 km^{-1} to 0.04 km^{-1} (Bearzi et al., 2003, 2005, 2008). This decline in numbers continued, with first reports of long-distance transfers between areas by Gonzalvo and Costa (2016).

The common dolphin was recently reported to be rare in the middle latitudes of the Western Mediterranean after a study that used both non-designed longitudinal transect line surveys across the Mediterranean between 2003 and 2007 and a designed zigzag transect survey from 2018 to 2019 (Karamitros et al., 2020). However, small-boat dedicated surveys carried out between 1988 and 2012 described the distribution of common dolphins in five French maritime regions and three southern regions of the western basin, thus providing observations of this species in the Western Mediterranean, beyond the Alboran Sea (Gannier, 2021). In the central Tyrrhenian Sea, *D. delphis* presence was confirmed through long-term monitoring undertaken since the early 1990s (Arcangeli, Marini, & Crosti, 2012; Arcangeli, Campana, & Bologna, 2017). A latitudinal gradient in the frequency of mixed-species groups with striped dolphins (*S. coeruleoalba*) was also reported (Arcangeli et al., 2017; Pace et al., 2015). In the southern Tyrrhenian Sea, including the Strait of Messina, the species occurrence is reported to be higher (Pace et al., 2015, 2016; Santoro et al., 2015), but no abundance estimates are available. Records of *D. delphis* have been documented in other Italian waters (Mussi et al., 2016; Pace et al., 2016, 2019), in the Pelagos Sanctuary (Pace et al., 2015), Ischia Island (Mussi et al., 2021; Mussi & Miragliuolo, 2003, 2005), near Lampedusa Island (Pace et al., 2015), off western Sardinia (IUCN, 2017), at Cap Bon, north-east Tunisia (Aissi & Vella, 2015; Benmessouad, Chérif, Bradai, & Bejaoui, 2012), in the eastern Ionian Sea (Frantzis & Herzing, 2002), in the Aegean Sea (Dede & Öztürk, 2007; Giannoulaki et al., 2017; Ryan et al., 2014), in the Levantine Sea (Boisseau et al., 2010; Brand et al., 2021; Kerem et al., 2012), in Libyan waters (Benamer, 2016), and along the Algerian west coast (Larbi Doukara, 2021; Larbi Doukara, Bouslah, Bouderbala, & Boutiba, 2016) and the Moroccan coast (Masski & De Stephanis, 2015). In the Adriatic Sea, common dolphins appear to be extremely rare in recent times (Genov, Kotnjek, & Centrih, 2021), despite historically well-documented presence (Bearzi, Notarbartolo di Sciarra, Reeves, Cañadas, & Frantzis, 2004). From this overview, to accurately understand the distribution of the common dolphin in the Mediterranean, it is clear that long-term small-scale

studies that include a seasonal component and which are ideally supplemented by various platforms of observations (marine and aerial) should be considered throughout the full range of the species in the region (Pace et al., 2019; Stockin & Vella, 2005).

2.2 | Photo-identification and social structure

Dolphin individuals can be recognized using photographic identification techniques, which has conventionally been dependent on natural-occurring, unique markings on their dorsal fin (Mariani et al., 2016). For some species, like the short-beaked common dolphin, individuals may be difficult to identify as they are generally scarcely marked. This species is reported to have the second lowest mark ratio of any delphinid (Hupman, 2016; Neumann, Leitenberger, & Orams, 2002; Stockin & Vella, 2005) that is found in highly mobile, large pelagic aggregations. These difficulties may explain the limited number of studies dealing with photo-identification that have been published on this species worldwide (Pawley, Hupman, Stockin, & Gilman, 2018; Stockin & Vella, 2005). In fact, only 16 peer-reviewed works have been found including those by Neumann et al. (2002); Bearzi et al. (2005, 2008); Bearzi, Bonizzoni, Agazzi, Gonzalvo, and Currey (2011); Bearzi, Bonizzoni, Santostasi, Eddy, and Gimenez (2016); Genov, Bearzi, Bonizzoni, and Tempesta (2012); Bamford and Robinson (2015); Hupman (2016); Mason, Salgado Kent, Donnelly, Weir, and Bilgmann (2016); Santostasi, Bonizzoni, Bearzi, Eddy, and Gimenez (2016); Inch et al. (2018); Pawley et al. (2018); Santostasi, Bonizzoni, Gimenez, Eddy, and Bearzi (2021); Bouma, Pawley, Hupman, and Gilman (2018); Mussi et al. (2021); and Genov et al. (2021).

Nine of the published studies were conducted in the Mediterranean Sea (Table 1), where short-beaked common dolphins form smaller aggregations in more coastal habitats than in pelagic open waters. Some of these photo-identification studies were focused on estimating abundance in the Eastern Mediterranean (Ionian Sea, Gulf of Corinth, Aegean Sea), demonstrating the decline of the species in some of the areas investigated over the years. These studies also revealed some level of site fidelity in different locations with spatio-temporal variation related to feeding opportunities (e.g. Bearzi et al., 2005; Mussi et al., 2021).

In addition, Bruno et al. (2004) and Pace, Mariani, Miragliuolo, Venier, and Mussi (2009) reported preliminary investigations on social structure in the Ionian Sea (1996–1999) and in the Tyrrhenian Sea (2003–2008), using mark–recapture analysis on photo-identified individuals (Table 1). Different indices were used to describe the association patterns in these two locations, for which differing results were noted. In the Ionian Sea, membership of groups was reported as highly fluid, with little evidence of long-term social bonds found. The latter suggests a complex social network in a fission–fusion social structure, possibly reflecting local ecological characteristics (unpredictable and patchy prey distribution; Bruno et al., 2004). In the Tyrrhenian Sea, however, several individuals formed lasting associations, and a core of 12 females

TABLE 1 Common dolphin photo-identification, mark-recapture and social structure studies in the Mediterranean Sea

| Mediterranean region | Location | Study period | Photo-ID encounters | Avg. group size (\pm SD) | No. individuals identified | Abundance estimate | Matching with other areas | References |
|----------------------|-------------------------|--------------|---------------------|-----------------------------|----------------------------|--|---------------------------|---|
| Eastern | Ionian Sea | 1993–2003 | 428 | 6.8 (\pm 4.16) | 72 | – | No | Bearzi et al. (2005) |
| Eastern | Ionian Sea | 1995–2007 | 400 | – | 143 | Different values over years | No | Bearzi et al. (2008) |
| Eastern | Gulf of Corinth | 2009 | 23 | – | – | 28 (95% CI = 11–73) | No | Bearzi et al. (2011) |
| Eastern | Gulf of Corinth | 2011–2015 | 468* | 45 (\pm 31.1)* | – | 22 (95% CI = 16–32) | No | Bearzi, Bonizzoni, Santostasi, Furey, et al. (2016); Santostasi et al. (2016, 2021) |
| Eastern | Aegean Sea | 2015–2017 | 7 | – | 76, 78 | 147 (95% CI = 109–212), 180 (95% CI = 106–323) | No | Inch et al. (2018) |
| Eastern | Adriatic Sea | 2012 | 1 | 1 | 1 | – | No | Genov et al. (2021) |
| Eastern | Ionian Sea–Adriatic Sea | 2010–2011 | – | 1 | 1 | – | Yes | Genov et al. (2012, 2021) |
| Eastern | Ionian Sea | 1996–1999 | 253 | – | 47**/61 | – | – | Bruno, Politi, & Bearzi (2004) |
| Central | Tyrrhenian Sea | 2003–2013 | 31 | 43.57 (\pm 36.54) | 94 | – | No | Mussi et al. (2021) |
| Central | Tyrrhenian Sea | 2003–2008 | 17 | – | 38**/91 | – | – | Pace, Mariani, Miragliuolo, Venier, & Mussi (2009) |

*Mixed groups of common and striped dolphins.

**Number of identified individuals used for social structure analysis. CI: confidence interval.

was sighted together nine times in five different years (Mussi et al., 2021). This preferred companionship indicated durable social patterns and strong association levels among females at different reproductive states (females from late pregnancy to the first year of their calves' life; females from early pregnancy to parturition of their calves and the period thereafter; females with older calves or without calves). It was suggested that several selective pressures, including ecological features of the area (e.g. distribution of prey resources) and e-to-ecological constraints (e.g. the overlap with the striped dolphin, *S. coeruleoalba*, in habitat use and distribution), may be of importance in determining such associations.

The Bay of Algeciras has been identified as an important breeding and feeding area for common dolphins (Giménez et al., 2011). Animals are found year-round in this bay, but especially during the summer, where a large number of individuals tend to concentrate to feed and breed. Mark-recapture models estimate an open population of 1,966 common dolphins (CV = 0.11, 95% confidence interval (CI) = 1,590–2,414) using the bay in summer (CIRCE, 2010, unpublished data). Movements between the bay and the Strait of Gibraltar have been detected through photoidentification (Giménez et al., 2009).

Short-beaked common dolphin photo-identification efforts have been analysed for Italian waters (Pace et al., 2016), through consideration of more than 20,000 photographs collected in 67 photo-identification encounters between 2004 and 2015. The distribution of marks within dolphin groups in different locations (Ligurian Sea, Tyrrhenian Sea, Sicily Channel) was assessed using a precise protocol for the classification of the dorsal fin features, and for estimating movements between different areas by matching known individuals. As part of the long-term research effort for the species in the Central Mediterranean (Mannocci et al., 2018; Vella, 1998, 2005, 2014, 2015; Vella & Vella, 2016), unpublished photo-identification work is also in progress. For the identification of short-beaked common dolphin individuals, other researchers have used a combination of white patch patterns and long-term natural markings on the dorsal fins, but it was recently demonstrated that the majority of images could be manually matched to the correct individual based on distinctive pigmentation patterns alone (Pawley et al., 2018). The unique position and shape of the dorsal edge marking and white patches of these dolphins highlighted low to medium distinctiveness of the classified dorsal fins in Italian waters, with indented mark types in the upper part of the dorsal fin and diffuse/basal white patches being the most prevalent patterns. Such techniques and criteria were applied to classify images (e.g. photographic quality), to identify individuals (e.g. marks categorization) and their degree of distinctiveness offers a baseline for photo-identification work in the Mediterranean. This would increase the number of individuals identified in each location, at the same time facilitating matching between contiguous areas, improving population size estimates, social structure, and site fidelity studies. In fact, a reported observation by Genov et al. (2012, 2021) of *D. delphis* long-distance movement between the Ionian and Adriatic seas may support recent findings highlighting that common dolphin dispersal from a natal area may likely involve long-distance movements of females (Ball et al., 2017).

2.3 | Acoustics

As with other odontocetes, the common dolphin is a highly vocal species (Au, 1993; Caldwell & Caldwell, 1968; Moore & Ridgway, 1995), being able to generate:

1. Clicks; that is, short-duration, broadband-pulsed calls used in echolocation and navigation, ranging from 0.2 to 150 kHz and lasting 50–150 μ s, with a peak frequency of 23–67 kHz (Au, 1993; Erbe et al., 2017; Moore & Ridgway, 1995; Richardson, Greene, Malme, & Thomson, 1995).
2. Burst pulses; that is, series of rapidly produced clicks perceived as tonal sounds and emitted both for echolocation and communication (Erbe et al., 2017; Richardson et al., 1995); depending on sampling frequency, each click may last 39–130 μ s, with a peak frequency of 16–52 kHz (Papale et al., 2021).
3. Whistles; that is, frequency-modulated, long-duration, tonal calls of generally 3–24 kHz, lasting 0.5–0.9 s, used for communication (Erbe et al., 2017; Papale et al., 2014; Petrella, Martinez, Anderson, & Stockin, 2012; Richardson et al., 1995).
4. Buzzes (Moore & Ridgway, 1995) and other non-whistle pulsed sounds, mentioned as barks, chirps, yelps, or squeals (Caldwell & Caldwell, 1968).

Further research is required to improve knowledge on common dolphin clicks and burst pulses, as studies focusing on these signals are still rare and contradictory (Ceraulo et al., 2015; De Vita, 2016; Erbe et al., 2017; Papale et al., 2021). Limited work on the characterization of short-beaked common dolphin whistles has been conducted worldwide, with to date an emphasis on the modulation of the acoustic parameters in connection with behavioural contexts and group size (Ansmann, Goold, Evans, Simmonds, & Keith, 2007; De Vita, 2016; Griffiths, 2009; Petrella et al., 2012; Silvestri, 2017), as well as genetic, morphological, environmental, and cultural differences (Papale et al., 2014).

The limited literature available on the acoustic repertoire of the short-beaked common dolphin in the Mediterranean Sea is presented in Table 3. Only two studies have been published to date: one study on clicks (Ceraulo et al., 2015) and one on burst pulsed signals (Papale et al., 2021). The latter encompasses the first analysis for the species on burst pulsed signals' transmission through the environment and highlighted how the sampling frequency and the distance from the source affect the temporal and spectral properties of the burst pulsed sounds (Table 2). It also revealed which features of the signal are more involved in such alteration in relation to the recording scenarios. These findings provide valuable insights on the communicative use of burst pulses, emphasizing the need of investigating this kind of signal as calls between individuals in social contexts, and the necessity of improving the accuracy and duty cycle duration of passive acoustic monitoring systems.

The majority of the available knowledge on the short-beaked common dolphin acoustic signals in the Mediterranean Sea is related to the structural characteristics of whistles (Table 3), their emission

TABLE 2 Acoustic characteristics and geographic location of short-beaked common dolphin burst-pulses recorded and analysed in the Sicily Strait, Central Mediterranean Sea

| Sampling frequency (kHz) | Single click peak frequency, average (SD) (kHz) | Single click duration, average (SD) (μ s) | Reference |
|--------------------------|---|--|----------------------|
| 300 | 52.73 (9.75) | 39.27 (6.22) | Papale et al. (2021) |
| 192 | 43.87 (9.22) | 51.76 (6.72) | Papale et al. (2021) |
| 96 | 28.87 (4.39) | 61.85 (12.02) | Papale et al. (2021) |
| 48 | 19.69 (2.18) | 123.70 (13.91) | Papale et al. (2021) |
| 44.1 | 16.36 (1.97) | 130.39 (10.47) | Papale et al. (2021) |

Data from Papale et al. (this issue).

TABLE 3 Acoustic characteristics and geographic location of short-beaked common dolphin whistles recorded and analysed in the Mediterranean Sea

| Frequency range, average (SD) (kHz) | Duration, average (SD) (s) | Mediterranean region | Location | Reference |
|-------------------------------------|----------------------------|----------------------|---|---|
| 8.06 (2.95) | 0.95 (0.40) | Western | Alboran Sea | Azzolin et al. (2021) |
| 6.88 (3.27) | 0.90 (0.47) | Western | Sardinia Channel, Tyrrhenian Sea | Azzolin et al. (2021) |
| 4.6 (2.74) | 0.47 (0.29) | Western/Central | Alboran Sea, Sardinia Channel, Tyrrhenian Sea | Gannier, Fuchs, Quebre, & Oswald (2010) |
| 11.02 (3.26) | 0.35 (0.23) | Central | Tyrrhenian Sea | Venier (2007) |
| 7.41 (2.74) | 1.10 (0.50) | Central | Tyrrhenian Sea | Silvestri (2017) |
| 7.90 (3.39) | 1.10 (0.64) | Central | Sicily Strait | Azzolin et al. (2021) |
| 8.32 (3.72) | 0.97 (0.50) | Central | Sicily Strait | De Vita (2016) |
| 7.76 (3.33) | 0.67 (0.29) | Eastern | Ionian Sea | Azzolin et al. (2021) |

pattern associated with various behavioural states, and their geographic variation within the basin (Azzolin, 2008; Azzolin et al., 2014, 2021; De Vita, 2016; Gannier et al., 2010; Papale et al., 2014; Silvestri, 2017; Venier, 2007). Updated information on the variability of whistle structure in different locations within the Mediterranean is reported in Azzolin et al. (2021). The authors presented data collected from 1994 to 2012 throughout the basin, identifying distinct geographical units of whistle parameters (e.g. duration, frequency). By including the Sicilian whistle sample within the Western Mediterranean data set, a significant difference was observed with the whistle structure of dolphins in the Eastern Mediterranean ($P < 0.001$), and 70% of whistles were classified correctly. Further analysis assessed variability in whistle parameters among four Mediterranean sub-basins (Alboran Sea, Central Western Mediterranean, Sicily Strait, and Ionian Sea), and a significant difference was also observed ($P < 0.001$), with whistles being correctly assigned to sub-basins in 43% of cases.

Genetic isolation is suggested as a possible cause of this geographic variance, as it seems to reflect genetic diversity and structuring (i.e. whistles differentiation may reflect the geographical separation and genetic differences in the basin; Natoli et al., 2008; Natoli, Moura, & Hoelzel, 2016; Tonay et al., 2016). In addition, the effect of evolutionary adaptations to particular ecological conditions or the by-product result of morphological evolution are suggested as further drivers of differentiation. Considering the results, which added new insights on the short-beaked common dolphin whistle variability in the Mediterranean Sea, the authors proposed the use of acoustic

information in combination with other sources of data (such as genetic, morphological, and others) as a promising tool to identify geographic areas where discrete management units occur, in order to better address conservation needs.

2.4 | Habitat preferences

The Mediterranean Sea, covering approximately 2,500,000 km², has, with few exceptions, narrow continental shelves and large areas of open water, with an average depth of 1,460 m (Coll et al., 2011). In this region, few studies have estimated the geographic distribution of the common dolphin, characterizing suitable environmental conditions, and identifying features influencing changes over time. Long-term field research that considers the common dolphin's distribution and activities through four different seasons of each year provides the ideal basis on which to elaborate species habitat preferences in different parts of the Mediterranean Sea.

Different parameters used to investigate habitat preferences for this species include static environmental (water depth, bottom slope, distance to shore, distance to continental shelf break) and geographic (longitude and latitude) variables, time-varying conditions (sea surface temperature, chlorophyll, sea level anomaly, salinity, euphotic depth, sea surface current speed), biotic interactions (probability of prey presence), and anthropogenic factors (e.g. distance from fish farms, distance from fishing ports, encounter rate with trawlers, index of

summer acoustic pollution, distance from mud deposits). Most of these parameters have been and continue to be modelled against common dolphin presence and distribution in Mediterranean research areas, with increasing publications in recent years (Bonizzoni et al., 2019; Cañadas & Hammond, 2008; Cañadas & Vázquez, 2017; Gannier, 2021; Giannoulaki et al., 2017; Giménez et al., 2017; Giménez, Cañadas et al., 2018; Karamitros et al., 2020; Moura et al., 2012).

In Greek waters, a large-scale assessment integrating environmental variables and biotic factors during summertime revealed a strong correlation between dolphins and prey presence (sardine; Giannoulaki et al., 2017). In early and late summer, the northern Aegean and Ionian seas appeared to be the most suitable areas to support common dolphin presence, as well as extended coastal portions of the Cyclades Plateau and the Dodecanese Islands (Giannoulaki et al., 2017). Other studies (Cañadas & Hammond, 2008; Gannier, 2021) reported that common dolphin presence and distribution are significantly influenced by the depth and the distance to the shelf edge (slope waters). The different results documented in the Gulf of Corinth, where common dolphins seemed to prefer deeper waters, is consistent with the hypothesis of common dolphins having modified their behaviour and extended their distribution to associate with larger striped dolphin (*S. coeruleoalba*) groups (Bonizzoni et al., 2019).

It has been suggested that the striped dolphin (*S. coeruleoalba*) currently occupies the ecological niche of the common dolphin in almost all regions of the Mediterranean Sea (Viale, 1985), except in the Alboran Sea and some relict areas (Bearzi et al., 2003). Indeed, recent studies in the Alboran Sea showed that the 'replacement hypothesis' seems plausible because their isotopic niches were found to be very similar and their preferred habitats were contiguous in the study areas (Giménez et al., 2017; Giménez, Cañadas, et al., 2018). These studies suggested that the replacement may have occurred when conditions favoured striped dolphins but not common dolphins (Jefferson & Schiro, 1997; Kenney, Payne, Heinemann, & Winn, 1996; Palka, Read, & Potter, 1997; Shane, 1994). However, more research needs to be undertaken to fully understand the extent to which competition or ecological niche differentiation prevails between these two similar species in the Mediterranean.

As for time-varying conditions, the chlorophyll concentration has been indicated as a possible factor affecting the distribution of the common dolphin, where it has been examined in the Mediterranean (Cañadas & Hammond, 2008; Karamitros et al., 2020; Moura et al., 2012). The rich chlorophyll concentration may result in a higher incidence of zooplankton, possibly influencing the amount of pelagic schooling fish which also constitute common dolphins' prey (Solanki, Mankodi, Nayak, & Somvanshi, 2005; Ware & Thomson, 2005). Nevertheless, primary production and prey distribution may be altered by the increasing sea surface temperature (SST) as a consequence of climate change, hence affecting cetacean distribution in the Mediterranean (Gambaiani, Mayol, Isaac, & Simmonds, 2009; Reeves, Smith, Crespo, & Notarbartolo di Sciara, 2003). In the Alboran Sea, a two-decade-long data set with a time series of environmental changes

accounted for the potential effect of climate change on common dolphins at local level, revealing an inverse relationship between animal density and sea surface temperature (Cañadas & Vázquez, 2017). An increase in sea surface temperature will potentially yield a reduction in suitable habitat for common dolphins, with a progressive density decrease towards the west.

The identification of significant habitats for highly mobile marine vertebrates is essential for their conservation (Pace et al., 2018). Habitat suitability modelling can help visualize habitat preferences and their alterations through time (Cañadas & Vázquez, 2017) and assist with the marine protected area (MPA) selection and its adaptation in the Mediterranean Sea (Bonizzoni et al., 2019; Pace et al., 2018). Knowledge on the suitable habitat of the common dolphin over extended areas can improve our ability to monitor, detect, and respond to shifts in species distribution.

3 | STRANDINGS

Stranding records of *D. delphis* have been reported throughout the Mediterranean and are often affected positively by the presence and implementation of stranding protocols that enable local scientists to be called on site to gather relevant information of each stranding case. Figure 1 shows that strandings, although found along most of the Mediterranean coastline, are scarcer where such protocols are missing or ineffective, and where reports are not accessible (e.g. south-east Mediterranean). On the other hand, the very dense number of strandings close to the Strait of Gibraltar is concerning and may be indicative of lethal interactions with anthropogenic activities, such as fishing (Bearzi et al., 2003; Bellido et al., 2012; Ridoux, 2005).

3.1 | Life history and body size

In the last three decades, strandings of common dolphins have been reported along the Mediterranean coastlines of Algeria, Croatia, France, Greece, Italy, Israel, Libya, Malta, Morocco, Slovenia, Spain, and Tunisia (Figure 1). However, little information has been published on their life history in the region. There is also a disparity of information from historical strandings and bycatches. Some published historical data suggested maximum body length of 222 cm for both male ($n = 35$) and female ($n = 35$) for Mediterranean common dolphins (Heyning & Perrin, 1994; Perrin, 1984; Perrin & Reilly, 1984). Perrin (1984) noted that they were of an intermediate size between those in the NE Atlantic population, with maximum lengths of 250 cm for males and 252 cm for females reported in recent years (Murphy, Pinn, & Jepson, 2013; Read, 2016), and the Black Sea sub-species *D. delphis ponticus*, with maximum lengths of 219 cm for males and 200 cm for females (Amaha, 1994; Perrin, 1984). As in other geographic regions, common dolphins in the Mediterranean Sea exhibit sexual size dimorphism, with males reported as larger than females in cranial size (Nicolosi & Loy, 2021).

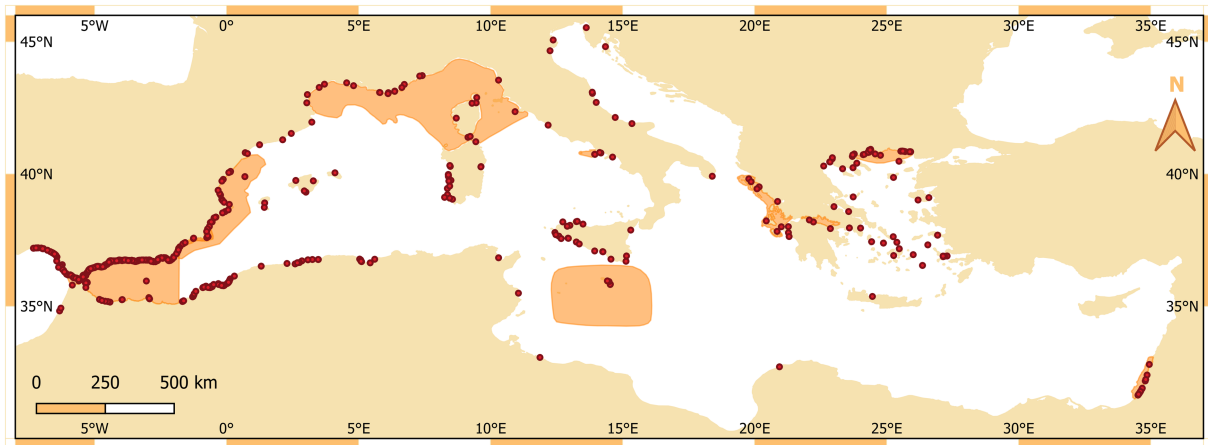


FIGURE 1 Map of the Mediterranean showing short-beaked common dolphin strandings (red dots) and long-term research efforts on this species and Important Marine Mammal Areas (IMMAs; shaded orange areas). **Stranding data sources:** (1) Mediterranean Database of Cetacean Strandings (MEDACES; <http://medaces.uv.es/>); (2) Italian Stranding Database (University degli Studi di Pavia, Museo di Storia Naturale di Milano, Ministero dell'Ambiente e della Tutela del Territorio e del Mare; <http://mammiferimarini.unipv.it/>); (3) Vella (2005) for Maltese Islands; (4) Milani et al. (2017) for North Aegean Sea; (5) Larbi Doukara (2021) for Algerian coast; (6) Benamer (2016) for Libyan coast additional to those by MEDACES; (7) Masski and De Stephanis (2015) for Moroccan coast; (8) Genov et al. (2021), Izola, Slovenia; (9) Lazar, Holcer, Mackelworth, Klincic, and Herceg Romanic (2012), Island of Cres, Croatia. **Long-term research areas and IMMAs, including *Delphinus delphis*, sources:** (1) Kerem et al. (2012) and Brand et al. (2021) for Levantine area (also IMMA); (2) Bearzi et al. (2003, 2005) for Eastern Ionian Archipelago (also IMMA); (3) Frantzis and Herzing (2002), Bearzi, Bonizzoni, Santostasi, Eddy, et al. (2016), and Bearzi, Bonizzoni, Santostasi, Furey, et al. (2016) for Gulf of Corinth (also IMMA); (4) Milani et al. (2017, 2019) for North Aegean waters; (5) Mussi & Miragliuolo (2003, 2005) and Mussi et al. (2021) for waters of Ischia Island (also IMMA); (6) Vella (2005), Vella (2015), and Vella and Vella (2016) for Central Mediterranean waters around the Maltese Islands; (7) Bearzi et al. (2003) and Pace et al. (2015) in southern part of the Pelagos Sanctuary; (8) Cañadas and Hammond (2008) and Giménez, Cañadas, et al. (2018) for the Alboran Sea (also IMMA); (9) Gómez de Segura et al. (2006, 2007) ALEGRO-Provençal basin

Data on lengths of common dolphins from more recent Algerian research reported that male, female, and unsexed individuals that stranded between 2008 and 2012, and collected for necropsy, ranged in body lengths from 110 to 220 cm (mean 181, $n = 8$), 170 to 195 cm (mean 177, $n = 4$), and 155 to 180 cm (mean 167, $n = 2$) respectively (Larbi Doukara, 2021). All four females were sexually mature, with one pregnant female (175 cm) carrying a male foetus measuring 81.5 cm in length. Lengths of some sexually mature females were notably smaller (170–175 cm, $n = 3$) than observed on average in the NE Atlantic (188 cm; Murphy et al., 2009). It was reported that six of the eight males were sexually mature. As the two smallest males in that study were both 110 cm in length (see Larbi Doukara, 2021, Table 2), this suggests that mature males ranged in body length from 194 to 220 cm.

Mean body size of individuals that stranded along the Spanish Andalusian coast between 1996 and 2009 was 163.3 ± 35.6 cm, with larger individuals stranding on the Atlantic coastline (Bellido et al., 2012). The youngest individuals (<150 cm) stranded more frequently during summer and autumn (Bellido et al., 2012), consistent with peak sightings of calves in groups in more coastal waters during the summer—particularly along the shelf edge in the western half of the Alboran Sea and off southern Almería (Cañadas & Hammond, 2008). Giménez, Marçalo, et al. (2018) analysed the stomach contents of common dolphins stranded in the south-west Mediterranean Sea between 2006 and 2014 (see Section 3.2), ranging in length

from 113 to 203 cm for males ($n = 13$) and from 107 to 222 cm for females ($n = 22$). Further dietary analysis using stable isotopes on common dolphin tissues sampled from the same region proposed that individuals are weaned at up to 150 cm in length (Giménez et al., 2017). In the NE Atlantic, studies have indicated that weaning may commence between 3 and 6 months after birth (Brophy, Murphy, & Rogan, 2009), though some individuals may not be fully weaned until around 10 months of age (Murphy, 2004), which is equivalent to approximately 140 cm in body length (Murphy & Rogan, 2006), and the length of lactation period may increase with maternal age (Murphy et al., 2013).

The Mediterranean Database of Cetacean Strandings (MEDACES; <http://medaces.uv.es/>), which was set up to coordinate all national and regional efforts under the Barcelona Convention, has collated common dolphin stranding records submitted by numerous stranding programmes operating throughout the basin, including Algeria, France, Greece, Israel, Italy, Spain, and Tunisia. Stranding records include information on stranding location, sex, body length, and decomposition state. Overall, 1,000 records have been submitted for common dolphins that stranded between 1971 and 2017. Three larger-sized records for common dolphins stranded in Algeria and reported as 270 cm to 295 cm in length were excluded from current analyses. Confirmation of body length data for a number of individuals that stranded in Greece could not be obtained, and thus body length data from MEDACES Greece ($n = 74$) were not included in subsequent

analyses. However, from the strandings in the North Aegean Sea recorded between 2000 and 2013 (Milani C, et al., 2000–2013, unpublished data; Milani et al., 2017), it was possible to obtain body length measurements for three females, nine males, and four unsexed common dolphin specimens, which ranged in size between 106 cm and 240 cm with an average body length of 203 cm ($n = 16$) and an *SD* of 31.4 cm. These strandings were recorded in spring ($n = 8$), autumn ($n = 5$), and winter ($n = 3$). Additionally, one other very small specimen of common dolphin of only 43 cm was also recorded in January 2005.

MEDACES stranding information on sex and length were available for 675 and 330 individuals respectively. Stranded common dolphins ranged in body length from 82 to 250 cm, though one 62 cm unsexed individual was reported in MEDACES as stranded in a decomposed state in the month of March along the Spanish Alboran Sea coast. Owing to the small size of the dolphin, this may have been an aborted or premature birth case. Most calves less than 100 cm in length were reported stranded in the Western Mediterranean Sea between the months of June and September ($n = 12$), with one additional individual reported stranded in November. All stranded common dolphins reported in MEDACES, apart from one individual, were 230 cm or less in body length. The larger-sized individual measured 250 cm in length, and stranded in March 2008 in Ceuta, the Spanish autonomous city on the North African coast. Excluding this individual, reported common dolphin body lengths by MEDACES for specimens stranded within the Mediterranean Sea basin range from 86 to 223 cm for females ($n = 125$), 82 to 222 cm for males ($n = 138$), and 62 to 230 cm for unsexed ($n = 66$) specimens. The largest sample

available was from Spain, where female, male, and unsexed individuals ranged in body length from 86 to 206 cm ($n = 98$), 82 to 220 cm ($n = 111$), and 62 to 224 cm ($n = 38$) respectively (excluding the larger-sized female reported from Ceuta of 250 cm).

In the stranding data from MEDACES Algeria, female, male, and unsexed individuals ranged in body length from 112 to 223 cm ($n = 17$), 90 to 220 cm ($n = 16$), and 100 to 230 cm ($n = 22$) respectively. Bimodality was noted in these data for length size classes 120–129 and 210–219 cm, and a median value of 172 cm was estimated. For MEDACES Tunisia, two dolphins were reported stranded, both unsexed, measuring 110 cm and 230 cm in length, whereas the body length of a stranded adult male common dolphin in Malta, Vella A (1999, unpublished data) was 225 cm (Vella, 2005). Eight common dolphins were reported as stranded between 2001 and 2008 in MEDACES for Italy; no length data are available for these individuals. However, data from 51 common dolphins that stranded along the Italian coastline between 1987 and 2018 that are contained within the Italian cetacean stranding database (Pavia University, Milan Natural History Museum, Italian Ministry of Environment (MATTM); <http://mammiferimarini.unipv.it/>) were included in the current analysis. From this database, females ranged in length from 84 to 217 cm ($n = 19$), males from 99 to 225 cm ($n = 14$; with one individual reported as 250 cm in length, stranded in the Central Adriatic region, at Marina Palmense in 1998, not included in Figure 2), and unsexed individuals from 95 to 203 cm ($n = 9$). Figure 2 presents the total body length frequency distributions of stranded common dolphins for the Mediterranean ($n = 403$, 82–240 cm) from the various sources mentioned. The body length modal class size is 190–199 cm, similar to

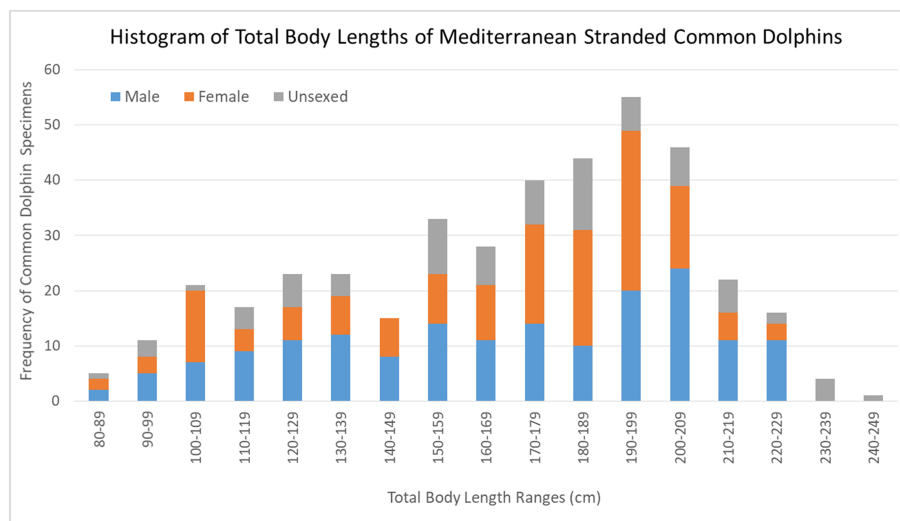


FIGURE 2 Total body length frequency distribution for common dolphins that have stranded in the Mediterranean. Data for Spain ($n = 248$), France ($n = 12$), Algeria ($n = 55$), (d) Israel ($n = 12$) between 1971 and 2017 were obtained, with permission, from the Mediterranean Database of Cetacean Strandings. Data for Italy ($n = 42$) between 1987 and 2018 were obtained, with permission, from the database on Italian cetacean stranding records (Pavia University, Milan Natural History Museum, Italian Ministry of Environment). Additional data for Algeria ($n = 8$) are from Larbi Doukara et al. (2016) and Larbi Doukara (2021); for the North Aegean ($n = 16$) between 2000 and 2013 from Milani et al. (2017) and Milani C, et al. (2000–2013, unpublished data); for the Maltese islands ($n = 1$) from Vella (2005) and Vella A (1998–2014, unpublished data); and for Cres Island, Croatia ($n = 1$) from Lazar et al. (2012). Additional to sizes included in the graph, there were five stranded specimens recorded as measuring 250 cm and two other specimens measuring less than 80 cm in length

that reported for common dolphins in Irish waters in the NE Atlantic population (Murphy & Rogan, 2006).

A long-term study on strandings between 1991 and 2008 in the Alboran Sea region revealed increasing numbers of common dolphin strandings from 1997 to 2008 along Spanish and Moroccan coasts, with a record 115 strandings in 2003 along Moroccan shores (Rojo-Nieto et al., 2011).

The relatively lower number of strandings of *D. delphis* reported in most of the Mediterranean, when compared with the higher stranding numbers of the Atlantic and Andalusian coasts (Bellido et al., 2012), contributes to limited availability of information on the biology of the species across the Mediterranean. Therefore, estimates of life history parameters are generally elucidated from other populations of common dolphins, and recent reviews have summarized available life history information on the contiguous NE Atlantic population (Murphy, Evans, Pinn, & Pierce, 2021; Murphy et al., 2013). The maximum age reported in the wild for the species is 30 years (Murphy, Perrott, McVee, Read, & Stockin, 2014), though for the NE Atlantic population most stranded and bycatch individuals were less than 20 years in age (Murphy, Collet, & Rogan, 2005; Murphy et al., 2009). Published information on mating/calving periods, annual pregnancy rates, calving intervals, and the average age attained at sexual maturity (ASM) and average length attained at sexual maturity (LSM) for female common dolphins are summarized in Murphy et al. (2018) and as follows: Estimates of the ASM and LSM for female *D. delphis* range from 7.8 to 8.4 years and 172.8 to 188.8 cm respectively (Ferrero & Walker, 1995; Institute of Zoology, 2015; Murphy et al., 2009; Read, 2016; Westgate & Read, 2007), and estimates in the ASM and LSM for male *D. delphis* range from 8.5 to 11.9 years and 197.5 to 204 cm respectively (Ferrero & Walker, 1995; Institute of Zoology, 2015; Murphy et al., 2005; Read, 2016; Westgate & Read, 2007). Common dolphins in temperate populations tend to have an extended unimodal mating and calving period; this extends from May to September in the NE Atlantic, with a more active period in July and August (Murphy et al., 2005, 2009). The presence of enlarged testes and the existence of moderate sexual dimorphism is suggestive of investment in post-mating traits among male common dolphins, which may result from a promiscuous mating system (Murphy et al., 2005, 2013; Murphy & Rogan, 2006).

Common dolphin gestation is reported as 10–12 months, with a calving interval of 1–3 years (Perrin, 2018). Gestation and calving interval studies from the Mediterranean for this species are lacking; thus, further estimates are being reported from the NE Atlantic. Gestation has been estimated to last approximately 1 year (Murphy et al., 2009). Estimates for the annual pregnancy rate for temperate populations of common dolphins (including *D. capensis*) range from 26% to 40%, with the lowest pregnancy rate observed in the NE Atlantic, and estimates for the calving interval range between 2.5 and 3.8 years (Ferrero & Walker, 1995; Institute of Zoology, 2015; Murphy et al., 2009; Westgate & Read, 2007). However, it should be noted that some females may reproduce more frequently than others (Murphy et al., 2010). The low annual pregnancy rate observed in the NE Atlantic population has been attributed to either the population

being at carrying capacity, or the prey base declining at approximately the same rate as the dolphin population (Murphy et al., 2009), or exposure to endocrine-disrupting pollutants causing reproductive failure and dysfunction (Murphy et al., 2010, 2018).

3.1.1 | Hybrids

Although rare in other geographic regions inhabited by this species, hybrids have been observed between the common dolphin and bottlenose dolphin *Tursiops truncatus* in the Bay of Algeciras (Espada, Olaya-Ponzzone, Haasova, Martín, & García-Gómez, 2019), and striped dolphin in Greek waters (Antoniou, Frantzis, Alexiadou, Paschou, & Poulakakis, 2018). In the latter case, the animals form mixed-species groups in the Gulf of Corinth (Frantzis & Herzing, 2002) where hybrids are common (Bearzi, Bonizzoni, Santostasi, Eddy, et al., 2016; Bearzi, Bonizzoni, Santostasi, Furey, et al., 2016) and reported to be fertile, reproducing with other hybrids and also the parental species (Antoniou et al., 2018). The existence of hybrids in the Gulf of Corinth has been attributed to a decline in local common dolphin abundance (Antoniou et al., 2018; Santostasi et al., 2021), with only 22 (95% CI: 16–32) common dolphins reported in the central and southern sea regions of the Gulf of Corinth, in contrast to more abundant 1,331 (95% CI: 1,122–1,578) striped dolphins (Santostasi et al., 2016). Fifty-five hybrids (95% CI: 36–84) with intermediate pigmentation patterns have been documented by visual observations (Bearzi, Bonizzoni, Santostasi, Eddy, et al., 2016; Bearzi, Bonizzoni, Santostasi, Furey, et al., 2016; Santostasi et al., 2016). Pigmentation patterns observed in some ‘intermediate’ striped dolphins included an absence or limitation in size of the pale grey flank and with a shape similar to the yellowish thoracic patch in the hourglass pattern of common dolphins, whereas ‘intermediate’ common dolphins often presented with a yellowish thoracic patch that was confined to a limited area, starting well behind the eyes and at the level of the flippers (Frantzis & Herzing, 2002). Where genetic analysis was undertaken, these individuals were identified as being of admixed ancestry through the use of nuclear DNA markers (Antoniou et al., 2018). Interestingly, most cases where the maternally inherited mtDNA was assessed in hybrids, it was reported to be that of *S. coeruleoalba*, suggesting that male common dolphins mated with the more abundant female striped dolphins (Antoniou et al., 2018). Survival has been reported to be constant for common, striped, and intermediate ‘hybrid’ dolphins within the Gulf of Corinth (pooled estimate for these three: 0.94; 95% CI: 0.92–0.96, 2011–2015; Santostasi et al., 2016).

3.2 | Foraging strategies and diet

The Delphinidae family displays a wide variety of feeding behaviours and preferences (e.g. Acevedo-Gutierrez, 2002; Ford & Ellis, 2006; Vaughn, Shelton, Timm, Watson, & Würsig, 2007; Weiss, 2006). Common dolphins have traditionally been considered as opportunistic feeders, mainly feeding on small pelagic fish and neritic cephalopods (Cooke & Klinowska, 1991; Gannier, 1995; Young & Cockcroft, 1994),

with their diet reflecting local prey availability and abundance (Collet, 1981; Evans, 1994; Santos et al., 2013). However, other studies have indicated that this species has a degree of selectivity with a strong preference for prey with high calorific content (Meynier et al., 2008; Spitz, Mouroucq, Leauté, Quéro, & Ridoux, 2010). As this species is not known to typically dive deeper than 150 m, it has been suggested that it restricts most of its feeding activities to surface waters (Evans, 1994). Seasonal and spatial foraging differences have been found throughout their distributional range (Reyes, 1991), and they have been reported to feed on large shoals of small pelagic or epipelagic fish by, for example, using a cooperative feeding strategy (Jefferson, Leatherwood, & Webber, 1993; Santos et al., 2013; Silva, 1999).

European anchovy (*Engraulis encrasicolus*), European sardine (*Sardina pilchardus*), round sardinella (*Sardinella aurita*), and garpique (*Belone belone*) have been identified as the common dolphin's main prey in Mediterranean areas, where their diet was initially studied (Bearzi et al., 2003; Boutiba & Abdelghani, 1995; Orsi Relini & Relini, 1993). In the Gulf of Naples, common dolphins were reported to feed mainly on the Atlantic saury (*Scomberesox saurus*) since the 1930s (Police, 1932); this prey preference has been maintained over the years, as documented in the waters off the island of Ischia (Mussi & Miragliuolo, 2003, 2005; Mussi et al., 2021).

The diet of common dolphins in neritic areas is relatively well known through the study of stomach contents of stranded animals (e.g. Aguiar dos Santos & Haimovici, 2001; Gonzales, Lopez, Guerra, & Barreiro, 1994; Meynier, 2004; Ross, 1984; Santos et al., 2013; Sekiguchi, Klages, & Best, 1992; Young & Cockcroft, 1994). For example, Silva (1999) studied the diet of common dolphins in Atlantic Portuguese waters, where she found that they were feeding on a great variety of fish, with sardines (*S. pilchardus*) being the most important species in the diet. Nevertheless, despite the decline in sardine stocks in recent years, sardines remained the most important prey of common dolphins in Portugal (Marçalo et al., 2018), suggesting that common dolphins in Portuguese waters specialize in feeding on this species. On the other hand, the diet of common dolphins in oceanic areas is not as well studied as in neritic areas, where they feed on species from the deep scattering layer, especially meso- and bathypelagic species (Brophy et al., 2009; Pusineri et al., 2007). In the oceanic French waters, common dolphins have a diet mostly composed of fish, with cephalopods being of secondary importance. Here, the myctophid *Notoscopelus kroeyeri* was the dominant species. Resulting from this, a nocturnal feeding strategy was suggested, as they could only capture this species when they perform their nictemeral vertical migrations to the surface during the evening and the night (Pusineri et al., 2007). The diet composition found in this latter study is taxonomically different to the results obtained from the neritic areas (e.g. Marçalo et al., 2018; Santos et al., 2013; Silva, 1999). Therefore, *D. delphis* seems able to follow two different foraging strategies: either selective predation (Meynier et al., 2008; Spitz, Mouroucq, Leante, Quero, & Ridoux, 2010) or opportunistic feeding. The latter occurs when preferred prey are missing or depending on age–sex class and seasonal prey availabilities (Collet, 1981; Murphy et al., 2013; Santos et al., 2013).

Recent research has shed more light on the diversity of the diet composition of common dolphins in different regions of the Mediterranean. From the Alboran Sea and the Strait of Gibraltar, stomach content analysis of 37 stranded dolphins indicated that the species is mainly piscivorous, feeding predominantly on mesopelagic prey. Although common dolphins inhabit mainly coastal waters in this region, the narrow continental shelf seems to facilitate the availability of Myctophids and other members of the mesopelagic assemblage when these migrate to the surface at night (Giménez, Marçalo, et al., 2018). The Myctophidae was the most important family, followed by the Sparidae family. The main Myctophidae species was the Madeira lantern fish (*Ceratoscopelus maderensis*), and among the Sparids it was the bogue (*Boops boops*). Cephalopods, in contrast, were only found in low quantities (Giménez, Marçalo, et al., 2018). It has been estimated that the common dolphin population in the Alboran Sea could consume ~7,646 t (95% CI: 3,804–12,842 t) of Madeira lanternfish, 2,991 t (1,136–5,557 t) of bogue, 2,841 t (901–5,511 t) of European sardine, and 1,942 t (183–4,380 t) of gobies (Gobiidae) annually (Giménez J, 2006–2014 unpublished results). Although the sardine is not the main prey species in the Alboran Sea (Giménez, Marçalo, et al., 2018) their consumption is considerable, and a decrease in sardine stock biomass could have undesirable consequences for the endangered common dolphin subpopulation.

The stomach content analyses of eight stranded specimens of *D. delphis* (out of 17 strandings recorded between 1998 and 2013) in the Greek North Aegean Sea (Milani et al., 2016, 2017, 2019) revealed that they primarily preyed on species from the Clupeidae, Myctophidae, Centracanthidae, and Sparidae families. Among these prey species, the round sardinella was found to have a very strong seasonal migration pattern in the study area, arriving in large shoals very close to the Thracian coasts during spring (Kallianiotis, Kosmidis, Ghitarakos, & Papadopoulos, 2005). Benthopelagic species, such as European barracuda (*Sphyraena sphyraena*), *Pagellus* spp. and *Spicara* spp., typical of the continental shelf, also featured in their diet. On the other hand, cephalopods featured poorly in the diet, representing less than 1% both in terms of number of prey items and in biomass (Milani et al., 2019). In general, the common dolphin shows a very wide prey diversity that includes several important commercial species; however, the presence of the latter was not found to be dominant in any of the specimens investigated by Milani et al. (2016) and Milani et al. (2019). This would corroborate observations by Bearzi et al. (2010) in other Greek coastal waters, where ecological interactions between common dolphins and fisheries were found to have minor effects on fisheries. Bearzi et al. (2010) reported that common dolphin association differed according to fishing gear, where the highest was found with purse seiners and a lower association with beach seiners, bottom trawlers, and trammel (static gear) boats, and no association with longliners.

In Israeli waters, information on the diet of five individuals revealed the consumption of 'uncommon' prey items. The most prevalent species found in the stomachs were the Balearic eel (*Ariosoma balearicum*), a sand burrower that is also the main dietary component

of bottlenose dolphins (*T. truncatus*) in the area. It was hypothesized that common dolphins in the area must be following bottom trawlers to feed on benthic species, similar to the activities of bottlenose dolphins (Brand et al., 2016, 2021).

4 | THREATS

4.1 | Prey depletion

Delphinus delphis are considered to have experienced declines in populations through the reduction in prey due to overfishing (Bearzi et al., 2008) and shifting prey distributions brought about by climate change (Cañadas & Vázquez, 2017). The energy required for long-distance movements by large common dolphin groups would need to be supported by plentiful seas that provide the rich abundance of high-calorific prey to satisfy such energetic demands (Giménez, Marçalo, et al., 2018; Meynier et al., 2008; Spitz et al., 2010). Owing to these energetic requirements, it is not surprising to note that group sizes of common dolphins, usually in their hundreds (especially in the Atlantic, Strait of Gibraltar, and the Alboran Sea), are fast declining in the Mediterranean, with an average of around 20–30 individuals or less being reported (Bearzi et al., 2003). The rise in the Mediterranean fishing industry's efficiency has impoverished most of the areas where this species hunts its prey, with clear declines in numbers and shifts in distributions of individuals studied.

4.2 | Fisheries bycatch

Fisheries impact marine mammals unintentionally or indirectly by affecting their critical habitat and their prey availability (Northridge, 1991), or directly by injuring them (e.g. in the case of net depredation). On the other hand, marine mammals can impact fisheries by removing bait or taking fish from hooks, nets, or traps, thus damaging fishing gear, or feeding on highly commercial species (Food and Agriculture Organization of the United Nations (FAO), 2019). Most fisheries, including towed net (e.g. pelagic and bottom trawl, purse seine) and static net (e.g. bottom-set gillnets, trammel nets, and longlines) fisheries may experience an interaction with marine mammals. Static nets, a mainstay gear used in small-scale or artisanal fisheries in the Mediterranean and the Black Sea, are prone to such interactions (FAO, 2018).

Dolphin association and mortality in fishing gear has been reported for various countries around the Mediterranean Sea, including Algeria, Croatia, France, Greece, Israel, Italy, Malta, Morocco, Spain, Tunisia, and Turkey (Abad et al., 2002; Aguilar & Silvani, 1995; Azzali & Virno Lambertì, 1993; Blasi & Pace, 2006; Brotons, Grau, & Rendell, 2008; Díaz López, 2006; Di Natale, 1995; Di Natale & Notarbartolo di Sciarra, 1994; Environmental Justice Foundation, 2007; Fernandez-Contreras, Cardona, Lockyer, & Aguilar, 2010; Frantzis, 2009; García-Tiscar, Cañadas, Sagarminaga, & Hammond, 2003; Milani et al., 2017; Miragiuolo, Mussi, &

Bearzi, 2002; Öztürk & Öztürk, 1998; Reeves et al., 2005; Scheinin, 2010; Silvani, Gazo, & Aguilar, 1999; Tudela, Kai Kai, Maynou, El Andalossi, & Guglielmi, 2005; Van Canneyt & Peltier, 2006; Vella, 2001). Data also exist for dolphin bycatch in the driftnet fishery for swordfish *Xiphias gladius* along the Aegean coast of Turkey (Öztürk, Öztürk, & Dede, 2001).

An estimated 1,682 cetaceans were reported to have been caught by the whole Italian driftnet fishery in 1991 (Di Natale, 1995). The fishing effort of this fleet was concentrated mainly in the Tyrrhenian and Sardinian seas during 1990–1991. Previous studies on the impact of the Italian driftnet fishery confirm these high figures for cetacean bycatches (Di Natale & Mangano, 1983).

Cetacean species caught by the large-scale Moroccan driftnet fleet in Mediterranean waters include various species, with common and striped dolphins being reported as those most commonly caught (Tudela et al., 2005). Annual bycatch estimates by this fleet amounted to 3,647 dolphins (50% of *D. delphis* and 50% of *S. coeruleoalba*) in the Alboran Sea and a further 13,358 in the Strait of Gibraltar and adjacent Atlantic waters (Tudela et al., 2005). These authors reported that only four boats captured a total of 237 dolphins (both common and striped) during an 8 month period. Estimated catch rates for this Moroccan fleet were of 0.64 individuals (both dolphin species combined) per fishing operation (equivalent to 0.06 dolphins per kilometre of net set). Bycatch rates for common and striped dolphins were estimated at 12.3% and 10.2% of the respective population sizes in the Alboran Sea, and shows the extreme threat to their populations that the fishery represents (catch rates above 1–2% are considered unsustainable for small-cetacean populations) (Tudela, 2004).

Silvani et al. (1999) in a study on the Spanish driftnet fleet operating until 1994 in the Alboran Sea revealed that the fleet of 27 boats caused the death of 366 common and striped dolphins in 1993 and 289 in 1994. Almost all were already dead when brought on board. The resulting bycatch rate of dolphins was 0.1 individuals per kilometre of net set per fishing operation. Most of the common dolphins caught were extremely young calves, and the majority of striped dolphins were juveniles; less-experienced younger animals are more likely to get entangled in driftnets than adults are.

The activity of the more widespread purse seine fleets targeting small pelagic fish in the Mediterranean did not seem to lead to the high dolphin mortalities caused by driftnets (Di Natale, 1990; Silvani, Raich, & Aguilar, 1992), although frequent accidental bycatches of common and striped dolphins by purse seiners are reported off the coasts of southern Spain, southern Italy, and northern Africa (Tudela, 2004). An EU-funded project on the Spanish purse seine fleet targeting small pelagic species (sardine and anchovy) in the Alboran Sea revealed mortalities of about 300 dolphins annually, the majority of which were common dolphins (University of Barcelona, 1995, in Tudela, 2004). This Spanish purse-seine fleet, however, was found to catch as many as 5,700 individuals annually, though the majority of them were reported to be released alive, nonetheless strongly contributing to the decline of common dolphin numbers along the Spanish Mediterranean coast (University of Barcelona, 1995, in Tudela, 2004).

Reports on incidental captures point to the entanglement of various cetacean species, including common dolphins, in artisanal fixed nets (gillnets and trammel nets) (Di Natale, 1983a, 1983b, 1983c; Di Natale & Mangano, 1983; Duguy, Besson, et al., 1983; Duguy, Casinos, et al., 1983). Duguy, Casinos, et al. (1983) and Duguy, Besson, et al. (1983) also referred to striped, common, and bottlenose dolphins and a few fin whales incidentally caught by trawlers off France and Italy (Tudela, 2004).

Though the Alboran Sea has been reported as one of the regions in the Mediterranean where common dolphins are most abundant, it has also been reported as an area of very high bycatch rates for the species through various fishing activities. The Moroccan driftnet fleet represents a high threat to the survival of the common dolphin population in the Western Mediterranean (Tudela, 2004).

Adequate monitoring of the fleets in the rapidly growing Mediterranean tuna purse seine fisheries were and still are necessary to ensure that their activity does not unduly affect dolphin populations (Tudela, 2004).

More recently, port inspection visits conducted in Italy, Albania, and Tunisia in 2013 (Baulch, van der Werf, & Perry, 2014) indicated that illegal driftnetting continued in Albania and Tunisia, with unconfirmed indications of illegal activity also documented in Italy.

Illegal, unreported, and unregulated fishing efforts and ghost fisheries in the Mediterranean continue to inflict cetacean deaths that remain unreported (FAO, 2018). Research that may help investigate fisheries causing mass dolphin deaths, such as that by Peltier et al. (2020), would need to be applied throughout the Mediterranean as well. Crosti, Arcangeli, Romeo, and Andaloro (2017) undertook a study assessing the correlation between fishing capacity and cetacean strandings around Sicily. Carcass drift modelling was used to find areas coinciding with fishing effort statistics of various fleets, generated from the vessel monitoring system. Using reverse drift modelling, two main mortality areas were identified. There was a positive correlation between the origin of stranded bycatch dolphins and the fishing effort distribution of French midwater pair trawlers, Spanish otter bottom trawlers, and French Danish seiners that requires further investigation.

Snape et al. (2018) highlighted the paucity of information regarding the nature and extent of interactions between bottlenose dolphins and Mediterranean small-scale fisheries. Such scarcity of information decreases the effectiveness of any ecosystem-based fisheries assessments and a full understanding as to whether and to what extent common dolphins fall victims to bycatch. A recent review on the technical mitigation to reduce marine mammal bycatch (Hamilton & Baker, 2019) should be considered for Mediterranean cetacean populations.

From the 50 stranded specimens of common dolphins listed in the Italian stranding database, only six had recorded causes of death along Italian coasts between 1992 and 2018. The majority of strandings being reported were from Sardinia (17/50) and Sicily (20/50). Four of the six reported causes of death of stranded common dolphins attributed to possible bycatch in fisheries activities were from Sardinia and Sicily.

Out of the 1,002 stranding reports of common dolphins in the Mediterranean included in the MEDACES database (1971–2018) only

16 report the cause of the stranding or death. Out of these 16 reports, 14 are related to fishing gear or bycatch, with the great majority of these reported in Spain (11), followed by Algeria (two) and Israel (one). The general, lack of information on cause of death in the stranding database is a limiting factor in assessing the extent to which bycatch or fishing gear may affect common dolphin survival in the Mediterranean, although the limited number of reports suggest that fisheries-related causes of death could play an important role in mortalities of common dolphins. Too often, bycatch or deaths of dolphins do not get reported by fishermen, and knowledge of the extent of this problem depends on extracting and reporting relevant information from every stranding case.

From studies in the Gulf of Kavala and Thassos Island (Milani et al., 2017, 2019), a stranded adult male common dolphin was reported entangled in fishing gear. It was also found that common dolphins in the region interacted with different fishing gear, mainly with pelagic purse seines, followed by bottom trawl nets, trammel nets, and gill nets. However, the Pianka's niche overlap index among common dolphin diet composition from stomach content and fisheries target species in the area showed that the values ranged from 0.12 with bottom trawling to 0.26 with purse seines and 0.28 static nets. These are rather low values considering that the max value is 1, indicating that common dolphins seem to feed mostly on species that are not targeted by the fisheries in the region. Nonetheless, the danger associated with fishing gear entanglement exists.

The use of acoustic deterrent devices (i.e. pingers) on nets has been shown to be effective in preventing lethal interactions with bottlenose dolphins (Vella, 2016). However, such pingers were found to be ineffective on common dolphins in the North Atlantic (Berrow et al., 2009; Murphy et al., 2013), and evidence of their effectiveness on common dolphins in the Mediterranean is still lacking.

Conservation policies focusing on the recovery of cetacean populations should urgently take into account potential fishing interactions. Illegal, large-scale driftnets continue to be used in the Mediterranean without any monitoring and enforcement. Educational programmes for fishermen, focusing on building awareness of cetacean conservation and providing them with basic guidelines on how to reduce both cetacean bycatches and mortality are essential (Tudela, 2004; Tudela et al., 2005).

In Andalucía, southern Spain, 25 common dolphins were necropsied between 2011 and 2014. Seventeen of them (68%) showed signs of bycatch as the main cause of death (Fernández-Maldonado, 2016), thus highlighting fishing as one of the most severe threats to common dolphins in the Alboran Sea. From these cases, 12 died along the coast of Málaga and four in the Bay of Algeciras, two important areas for the conservation of this species, as they are considered feeding and breeding grounds (Giménez et al., 2011). In the Bay of Algeciras, injuries inflicted by human interactions have been described, including fishing interactions and propeller strikes, due to the high intensity of recreational fishing and whale-watching activities in the area (Olaya-Ponzzone, Espada, Moreno, Cárdenas Marcial, & García-Gómez, 2020).

4.3 | Health status

Necropsies of common dolphins in the Mediterranean are not numerous, but their findings are of special relevance due to the conservation status of the species. Detailed necropsies of stranded common dolphins can provide information on the health status and causes of death of the endangered subpopulation, information that is critical for their conservation.

Other causes of death included one case of infanticide of a common dolphin neonate. The main injuries sustained were severe, multifocal, cutaneous teeth marks all over the animal's body, diffuse subcutaneous and muscular bruising, and bleeding, especially in the dorsal region of the skull (Fernández-Maldonado, 2016).

Testicular neoplasms have been only infrequently reported in marine mammals worldwide, but a testicular neoplasia in a common dolphin involving a Sertoli cell tumour, an interstitial (Leydig) cell tumour, and a seminoma was found in an individual that stranded on the Almerian coastline (Alboran Sea; Díaz-Delgado et al., 2012). Furthermore, a lymphatic spread of the Sertoli cell tumour to an adjacent retroperitoneal lymph node was observed. Although confirmation of further health implications is extremely challenging in dolphins, Díaz-Delgado et al. (2012) do not rule out the metastatic potential of the tumour.

In the North Adriatic Sea, a female common dolphin that was found stranded alive presented with a renal heterotopia involving the lung parenchyma and contributed to the first description of heterotopic kidney tissue occurrence in the lung of any domestic or wild animal species (Di Guardo, Marruchella, Affronte, Zappulli, & Benazzi, 2005).

For the first time, *Erysipelothrix rhusiopathiae* was reported in a common dolphin off the Spanish Mediterranean coast (Fernández-Maldonado, 2016). Serological studies for *Brucella* species infection in odontocetes have shown that common dolphins off the Spanish Mediterranean coast are seronegative for *Brucella* in contrast to 12.5% of striped dolphins tested (Van Bresseem, Van Waerebeek, Raga, et al., 2001). A *Toxoplasma* sp. was detected in one adult (out of 25) common dolphin by Fernández-Maldonado (2016). In an earlier study, antibodies of *Toxoplasma gondii* were detected in serum samples from two of four stranded common dolphins (Sobrino et al., 2007). The occurrence of this obligate intracellular parasite, which causes the infectious disease toxoplasmosis, seems to be common in this species, as it is for striped and bottlenose dolphins in the region (Sobrino et al., 2007). Six short-beaked common dolphins stranded along the Spanish Mediterranean coastline were analysed for intestinal helminth parasites. Three species of helminths were recorded; these included the digenean *Synthesium delamurei*, the cestode *Tetrabothrius forsteri*, and tetraphyllidean plerocercoids, similar to other cetacean species, although with a comparatively poorer helminth fauna than that of neritic species, such as bottlenose dolphins (Quiñones, Giovannini, Raga, & Fernández, 2013).

The extent of shared habitat and foraging resources between striped and common dolphins would also have an effect on potential exposure to diseases, such as the cetacean or dolphin morbillivirus

epizootics that have caused high mortality in odontocetes in Europe, the USA, and Australia (Van Bresseem, Van Waerebeek, Jepson, et al., 2001; Van Bresseem et al., 2014) and have affected striped dolphins in the Mediterranean (Aguilar & Raga, 1993; Raga et al., 2008) and common dolphins in the Black Sea since the 1990s (Birkun et al., 1999). Novel morbillivirus outbreaks are also being reported to affect striped dolphins in recent years (Mira et al., 2019; Pautasso et al., 2019). It has recently been reported that such cetacean morbillivirus has an increased tendency to cross 'interspecies barriers' (Jo, Osterhaus, & Ludlow, 2018), while having an immunosuppressive effect on dolphins becoming predisposed to other infections as well (Keck et al., 2010). Owing to the significant demographic and evolutionary effects of these infectious diseases on wild populations, further studies on the genetic basis of disease resistance or susceptibility are required.

4.4 | Pollution

Anthropogenic sources of contaminants and wastes have been fast accumulating and spreading throughout the Mediterranean Sea from both land- (Koutsodendris, Papatheodorou, Kougiourouki, & Georgiadis, 2008) and sea-based origins (Torneró & Hanke, 2016). A large-scale survey in the Mediterranean Sea found 78% of the observed marine debris larger than 2 cm to be of anthropogenic origin, with plastic constituting 96% of this (Suaria & Aliani, 2014). Ingestion and entanglement in debris and marine litter has been reported in over 60% of all cetacean species, providing evidence that multiple factors can also interact and create impacts far greater than any one factor alone (Fossi, Panti, Bains, & Lavers, 2018; Panti et al., 2019). Common dolphins have been found stranded with ingested meso- or macro-litter, or been entangled in it, which may also include pieces of gillnets or plastic bags (ACCOBAMS-MOP7, 2019).

Though marine litter may be measured visually, contaminants load analysis relies on the availability of tissue samples that are often limited in number and distribution. Organochlorine concentration's impact on *D. delphis* was considered low in the 1990s and not affecting their decline in the Western Mediterranean (Borrell, Cantos, Pastor, & Aguilar, 2001); however, the cumulative effect of these lipophilic compounds may still need to be monitored, in tandem with other contaminants that are increasingly finding their way into the sea. High concentrations of dichlorodiphenyltrichloroethane metabolites and polychlorinated biphenyl congeners (known as endocrine disrupting chemicals) have been found in various Mediterranean cetacean species, including common dolphins. Additionally, a statistical correlation has been found between benzo[a]pyrene mono-oxygenase activity and dichlorodiphenyltrichloroethane levels in skin biopsies of the Mediterranean common dolphins. These results suggest that benzo[a]pyrene mono-oxygenase induction could be considered as an effective indicator of exposure to organochlorine endocrine disrupting chemicals, which have an endocrine disruptive capacity on the dolphins (Fossi et al., 2003). Organochlorine

concentrations in south-west Mediterranean common dolphins were found to exceed levels considered to be safe in marine mammals (Borrell & Aguilar, 2005). Additionally, a common dolphin stranded in the Island of Cres, Croatia, North Adriatic Sea, in 2004 and analysed for various organochlorine contaminants had concerning concentrations in various tissues (Lazar et al., 2012). Such conditions would predispose affected dolphins to immunosuppression, facilitating disease contraction (Lauriano, Di Guardo, Marsili, Maltese, & Fossi, 2014).

Six trace elements (copper, iron, cadmium, lead, zinc, and nickel) were investigated in seven stranded common dolphins along the Algerian west coast. Concentrations of the different elements were analysed in the liver, muscle and blubber with concentrations varying according to age and sex (Larbi Doukara, Bouslah, Bouderbala, & Boutiba, 2014).

More recent studies by Barón, Hauler, et al. (2015) and Barón, Giménez, et al. (2015) considered the bioaccumulation and biomagnification of classical halogenated flame retardants and alternative flame retardants in *D. delphis* and other two delphinid species in the Alboran Sea. Though bioaccumulation was not found, levels of halogenated flame retardants increased with body size in these dolphins.

Alonso et al. (2014) reviewed brominated flame retardants, the polybrominated diphenyl ethers (PBDEs), and the naturally produced methoxylated PBDEs levels in cetacean blubber worldwide. Whereas the reported mean levels of PBDEs in common dolphins from the NE Atlantic ranged between 422 and 758 ng g⁻¹ lipid weight (lw), lower levels of PBDEs were found in common dolphins from the Strait of Gibraltar 199 ng g⁻¹ lw (74.3–323 ng g⁻¹ lw; Barón, Giménez, et al., 2015; Barón, Hauler, et al., 2015).

Underwater noise is considered another serious type of pollution in the Mediterranean. The Marine Strategy Framework Directive indicator 11 (Underwater Noise) focuses on achieving good environmental status by monitoring for noise and its effects on marine life (using indicator species such as cetaceans) across the Mediterranean in relation to regional or subregional established threshold values (Humar et al., 2020; Vella et al., 2018, 2019). Intense maritime traffic, sonar for military exercises and fishing, seismic exploration, offshore construction, drilling, and piling may disturb species, affecting normal activities necessary for their survival (Murphy et al., 2013; Richardson et al., 1995), and may even be implicated in *D. delphis* mass stranding events (Jepson et al., 2013). To date, no information is available about the impact of noise on the common dolphins in the Mediterranean Sea. Data collected in the eastern Atlantic showed that the species modifies its vocal emissions in response to increased noise by increasing the maximum frequency of the whistles when exposed to high anthropogenic noise levels masking the same frequencies (Papale, Gamba, Perez-Gil, Martin, & Giacoma, 2015). As whistles are social calls, noise-induced variations may alter the information content and change effective communication, parent-offspring proximity, and group cohesion (Fouda et al., 2018). In addition, physiological responses to noise, such as effect on hearing abilities (temporary or permanent reductions in hearing sensitivity, i.e. auditory threshold shifts), symptoms associated with decompression sickness, and stress reactions to chronic exposure, are of particular concern (Murphy

et al., 2013). Several studies have documented how boat traffic linked to dolphin watching negatively affects the resting and foraging activities of common dolphins (Neumann & Orams, 2006; Stockin, Lusseau, Binedell, Wiseman, & Orams, 2008). Likewise, the foraging behaviour of this species was found to be altered by vessel interactions related to tourist dolphin-watching activities (Meissner et al., 2015), with potential implications for individual health and reproduction (Young & Cockcroft, 1995). In the Mediterranean, disturbance by cetacean-watching vessels is increasing and occurs in Algeciras Bay (a recognized feeding and breeding ground for common dolphins; Giménez et al., 2011) mainly by companies in Gibraltar (UK), but also in the Pelagos Sanctuary with documented whale-vessel collisions (Di-Meglio, David, & Monestiez, 2018). More research effort on the impact of vessel collisions on common dolphins is required in the Mediterranean. Similar studies in New Zealand waters have observed blunt trauma in a common dolphin *Delphinus* sp. likely caused by a vessel collision (Martinez & Stockin, 2013). This species also features among the global review list of species that suffer from vessel strikes (Schoeman, Patterson-Abrolat, & Pion, 2020).

Though conservation management usually targets the removal or reduction of specific threats to biodiversity, it is important to note that, in the Mediterranean Sea, the cumulative effects of multiple threats need to be better understood to effectively conserve endangered species in general (Coll et al., 2011). Mediterranean common dolphins are known to be impacted by multiple threats, but the cumulative or synergistic effects, both in terms of individual health and at a population level, still need further research. Additionally, climate change leading to changes in temperature and current regimes, and increasing noise and other sources of pollution, all affect prey species abundance, thus affecting predators, such as *D. delphis* (Pace et al., 2016). Introduced and incoming species into the Mediterranean, including novel diseases, may add further threats. Sea-bed mining and blue economy industries leading to further exploitation of marine areas and resources that are within suitable *D. delphis* habitats would exacerbate pressures on the species.

5 | CONSERVATION MANAGEMENT

5.1 | Effective conservation areas

Large conservation areas for common dolphins are limited, as these would need to include both coastal territorial waters and offshore international waters with effective collaboration between countries. Natura 2000 marine sites, MPAs, and IMMAs may contribute to some pockets or oases for survival, but corridors and surrounding waters may still suffer from increasing underwater noise, changing marine environment, increasing pollution, epidemics, and decline in prey abundance.

In the meantime, the recognition of possible segregations within the *D. delphis* Mediterranean subpopulation, reflected in the anatomical features, feeding ecology, population genetic structure, and whistle characteristics, points towards caution against lumping species

abundance and population size estimates at the Mediterranean regional scale, as this may not be enough to plan for long-term conservation of the diversely adapted groups scattered throughout the region. The level of fragmentation within this subpopulation and the size of the home range of individuals and groups that may be area specific are still unknown. Small populations are exposed to the Allee effect, which sees a decline in population fitness as its size, density, and genetic diversity decrease, increasing the chances of inbreeding depression and vortex mechanisms, leading inevitably to population extinction (Luque et al., 2016). Therefore, monitoring the extent of genetic diversity among common dolphins found in different areas of the Mediterranean may provide an important early warning signal of these conditions.

To improve the effectiveness of conservation measures, monitoring the status of *D. delphis*, through non-destructive and non-invasive collection and investigation methods using skin biopsies and faecal and DNA samples from free-ranging animals, is increasingly possible. This provides optimal chances of following the susceptibility and effects of an increasing array of stressors, including genotoxicity and immuno-suppression caused by contaminants and debris in the marine environment (Fossi et al., 2000, 2003; Fossi & Marsili, 2011; Marsili et al., 2012).

5.2 | Effective monitoring and research recommendations

Methods used to monitor *D. delphis* are diverse and have been developing in the Mediterranean through marine surveys (including platforms of opportunity on cruise liners to dedicated aerial surveys), sea-user questionnaires, social media data and fisheries-associated research, photo-identification methods, and acoustic studies. Each method has its own strengths and weaknesses, which have been highlighted in two international workshops focusing on this species. In fact, the first international common dolphin workshop held in Kolmården (Sweden) linked to the 18th European Cetacean Society Conference in 2004 (Stockin, Vella, & Evans, 2005) highlighted knowledge gaps for this species over its entire distribution range and placed the spotlight on the first Mediterranean studies that revealed both the abundance (Vella, 2005) and the decline of this species due to anthropogenic activities Bearzi et al. (2003). Large-scale meta-population studies are clearly needed to determine common dolphin distribution, habitat- and resource-use within the Mediterranean, and the degree of connectivity between different areas (Triossi, Willis, & Pace, 2013). Equally relevant was the reporting of the interactions between *D. delphis* and the pelagic trawl fisheries in the NE Atlantic that led to mass strandings of this species with clear signs of bycatch (Ridoux, 2005). This highlighted the need to find ways of managing fisheries to avoid bycatch mortalities, which remains a pertinent problem today, especially with large fishing fleets using advanced technologies to aid their fishing efficiency. A better understanding of subpopulation size and structure, increased efforts towards collecting tissue samples at every stranding event for genetic analysis, and use

of aerial and marine surveys were highlighted, together with assessing anthropogenic activities, prey availability, maritime traffic, and pollution. All this research would need financial support, which was considered the principal limitation towards achieving these targets (Stockin & Vella, 2005).

The slow progress in the understanding of the status of this species throughout its Mediterranean distributional range, together with the reported decline in numbers in certain parts of this region, emphasized the importance of sharing information, as undertaken for other cetacean species, including the Mediterranean subpopulation of the sperm whale (Pace, Mussi, Wurtz, & Gordon, 2014). Thus, 12 years later, the first international common dolphin workshop on the Mediterranean common dolphin was held in Ischia (Italy), which highlighted the benefits of standardizing abundance estimates in local studies to allow for comparison across the whole region. Stranding investigations were also highlighted as essential to assess the causes of death and health status of individuals in different parts of the Mediterranean and allow for collection of tissue samples for various additional research, including genetic analysis and life history studies (Pace et al., 2016).

Recommendations coming out of the Ischia international workshop on Mediterranean *D. delphis* include the following:

1. The improvement of existing knowledge through comprehensive surveys.
2. Implementing mitigation procedures to reduce the impacts by human activities from noise, disturbance, and collisions (such as leisure boating, dolphin watching, commercial shipping) and mortalities in fishing gear.
3. Improving spatial planning and MPAs designation to prevent further species declines and habitat loss.
4. Identifying and implementing precautionary measures to reduce further impoverishment of prey abundance through fisheries activities management (e.g. no-take zones) and reduce further degradation of the marine environment through management against pollutants and wastes (Pace et al., 2016).

Implementation of these important recommendations would go a long way towards achieving a better understanding of the needs of the common dolphin and the specific anthropogenic impacts that need to be dealt with to avoid further declines of its numbers in the Mediterranean.

5.3 | Policies, conventions, agreements, and directives

Though the threats to *D. delphis* are increasing, so have national conservation policies and international conventions, agreements, and directives. These should instil greater determination from governments around the Mediterranean and the EU to ensure that these legal structures deliver benefits from greater scientific knowledge to improve the effectiveness of management and thus finance sustained monitoring and enforcement of laws to protect both the species and its habitat.

More specifically:

1. The Convention on Biological Diversity (CBD) calls on contracting parties to conserve species through maintenance of viable populations and recovery of threatened species amongst other obligations. The SPA/BD Protocol (Barcelona Convention) is the Mediterranean's main tool for implementing the CBD and the Protection of the Marine Environment and Coastal Region of the Mediterranean (Barcelona Convention), which list several cetacean species, including *D. delphis* (Annex II), through the creation of specially protected areas and specially protected areas of Mediterranean importance. The CBD has also recently called for the identification of ecologically or biologically significant areas in marine areas beyond national jurisdiction, based on scientific criteria outlined in Annex I to CBD Decision IX/20.
2. The Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), Appendix II—Mediterranean Cetaceans, addresses the conservation of European wild flora and fauna and their natural habitats, with a particular focus on the protection of endangered natural habitats and species, including migratory ones.
3. The Convention on Migratory Species (The Bonn Convention) calls for conservation measures in support of migratory species threatened with extinction throughout all or a significant proportion of their range, listed on Appendix I of the convention, which includes *D. delphis* as well. Migratory species with an unfavourable conservation status that need or would significantly benefit from international cooperation organized by tailored agreements are listed in Appendix II of this convention. Appendix II lists 44 cetacean species.
4. Marine mammals protection regulations are also present at national level in many countries around the Mediterranean (e.g. Legal Notice 203 of 2003 in Malta) which provide protection to the 19 species of cetaceans as listed in Annex I of ACCOBAMS.
5. *Delphinus delphis* is considered a species of community interest listed in the Habitat Directive 92/43 EEC under annex IV under Article 17 of the Habitat Directive.
6. The Convention on International Trade in Endangered Species of Wild of Flora and Fauna also includes *D. delphis* in Appendix II.
7. *Delphinus delphis* and other cetacean species are to be monitored as part of indicators 1 (marine biodiversity) and 11 (noise) of the Marine Strategy Framework Directive in order to achieve good environmental status through the implementation of national to regional monitoring protocols.

Though the legal structures and conservation objectives for endangered species or populations, including the Mediterranean common dolphin, are already in place, effective financial support to undertake the necessary monitoring, management, and enforcement still need to materialize, in this region. This limitation is slowing progress in achieving the much-needed transnational cooperation or collaboration towards conservation of offshore, pelagic, and epipelagic species in international waters. The *Cetacean Manual for MPA Managers*

(Franzosi, Genov, & Tempesta, 2013), created to guide MPA managers when dealing with cetacean strandings, is useful to inform on whom to contact in case of the latter, thus aiding the collection of the much-needed information from stranded specimens. However, financial support to monitor and manage established national MPAs and to implement action plans for cetaceans (such as national action plans or Mediterranean-wide conservation plans; Bearzi et al., 2004; UN Environment/Mediterranean Action Plan Barcelona Convention Secretariat, 2017) is often missing, thus diminishing the effective value of these conservation efforts to mere 'paper parks' and 'paper plans'.

As technological advancements in global monitoring systems improve the efficiency with which human activities at sea may be kept under close surveillance, so improved monitoring and research of pelagic species, such as *D. delphis*, should aid their conservation. At the same time, further innovations will facilitate field, laboratory, and analytical computing work to better understand this species, its resilience and its habitat's status, in a fast-changing Mediterranean Sea. Relevant spatial planning and MPA designation will very much continue to depend on expanding scientific knowledge.

6 | CONCLUSIONS

The common dolphin, *D. delphis*, has been the subject of two international workshops and has been assessed and listed as Endangered in the Mediterranean by the IUCN Red List (Bearzi et al. 2003). Herein, recommendations for conservation management, including improved research methodologies, have been formulated to improve this species' overall conservation status in the region and to avoid further local extinctions. We also emphasize the need to adopt the precautionary approach that any human-induced disturbance should be treated as detrimental until proven otherwise—even in heavily impacted environments (Bulleri, Underwood, & Benedetti-Cecchi, 2007). Science-policy-management integration is required to achieve effective implementation of legal structures already in place, and to safeguard the marine environment and this species in the long term, both within and outside protected areas. With new information becoming available, an update of the assessment of the Mediterranean subpopulation of the species under the IUCN Red List criteria is necessary. The role of conservation scientists in integrating scientific findings and translating this knowledge into applicable measures that conservation managers and policy enforcers may put in place effectively towards reducing the plight of this species is fundamental. This is more so when one considers this species' pelagic existence, where *out of sight* often leads it to be *out of mind*—a distraction that has been allowing various pressures on marine biodiversity and environment to increase for too long.

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