CHAPTER THREE

Fin Whales, *Balaenoptera physalus*: At Home in a Changing Mediterranean Sea?

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Abstract

1. The relationship of Mediterranean fin whales (*Balaenoptera physalus*) to their Atlantic conspecifics has puzzled zoologists for centuries. Recent data indicate the occurrence of two distinct populations, one resident in the Mediterranean Sea and the other a seasonal visitor to the western Mediterranean from the northeastern North Atlantic Ocean.
2. Resident Mediterranean fin whales are nomadic opportunists that have adapted to exploit localised mesoscale hotspots of productivity that are highly variable in space and time. These appear to be fairly widespread across the region during winter, whereas in summer favourable feeding habitat is dramatically reduced, concentrating mostly in the western Ligurian Sea and Gulf of Lion. This prompts a reinterpretation of the movement pattern of resident fin whales, based on a contraction/dispersion hypothesis caused by seasonal variability in available feeding habitat, as opposed to a pattern of migrations occurring along defined directions as is common in other Mysticetes.
3. Calving peaks in autumn but has been observed year-round throughout the Mediterranean, suggesting that resident fin whales engage in breeding activities whenever favourable physiological conditions occur. It can be assumed that the Mediterranean environment, which is relatively forgiving in comparison to oceanic

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habitats, combined with negligible predation pressure and high potential for sound-mediated socialisation due to the region's relatively small size, might have provided year-round resident fin whales an extended and more flexible calendar of breeding and feeding opportunities.

4. Considering the Mediterranean fin whales' small and possibly decreasing population size, low survival rate and the high pressure from many threats deriving from human activities such as vessel traffic, noise, chemical pollution and likely climate change, their status raises considerable concern and conservation measures should be urgently implemented.

1. INTRODUCTION

Fin whales (Fig. 1) are circumglobal cetaceans, found in all the world's major oceans. They occur mainly, although not exclusively, in offshore temperate and polar waters, and rarely in the tropics (Edwards et al., 2015). Most of the world's fin whales are thought to be migratory; however, their movements do not seem to follow a simple pattern (Jefferson et al., 2015). Fin whale seasonal migration has been traditionally considered, mostly on the basis of research from whaling vessels, to be regularly occurring between supposed temperate winter breeding grounds and higher-latitude summer feeding grounds (Gambell, 1985). However, it is now recognised that unlike other mysticetes such as humpbacks and grey whales, fin whale movements cannot be shoehorned into such simple schemes, and that they are subject to

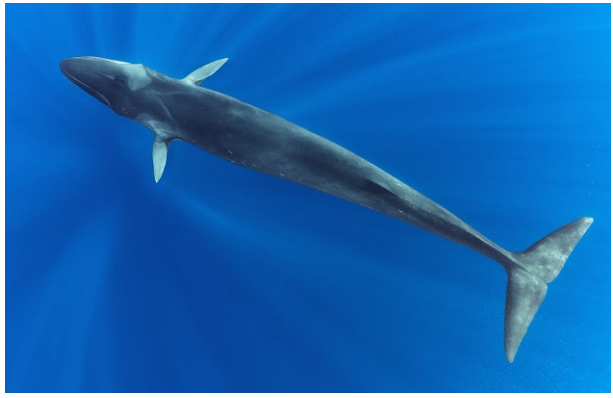

Fig. 1 A fin whale (*Balaenoptera physalus*) displays the asymmetrical colouration of its head region as it dives into the clear waters of the Pelagos Sanctuary for Mediterranean Marine Mammals. *Photograph courtesy of Danny Kessler © and Tethys Research Institute.*

a much more complex set of factors affecting habitat use. This was already understood long ago, when Kellogg (1929) stated that: 'The migration routes of finbacks are not so well known as those of humpbacks, and the observed facts of gestation indicate that their journeys do not have any especial connection with their breeding habits […] Climate seemingly has little influence in curtailing their wanderings, for finbacks appear to be indifferent alike to Tropic and Arctic temperatures, and travel where they will'.

While fin whale presence during summer in high-latitude feeding grounds is commonplace in both hemispheres, their winter migrations towards lower latitudes show a much less clear pattern. There have been an increasing number of observations of fin whales overwintering in their polar and subpolar feeding grounds, and no certain existence of specific winter breeding grounds anywhere (for a summary of these observations, see Geijer et al., 2016). An increasing body of knowledge, partly deriving from still-unpublished satellite and acoustic tracking efforts of oceanic fin whales, points to a continuum of migratory strategies, ranging between a more 'traditional' latitudinal round-trip displacement model and more opportunistic nomadism (defined by Jonzen et al., 2011, as: 'irregular movements' at seasonal timescales 'in response to environmental fluctuations, and typically also characterised by between-year variability in the geographic location of reproductive events'). Such nomadic habits cause the whales to move between locations characterised by the presence, often temporary, of favourable feeding conditions (Geijer et al., 2016). Furthermore, fin whales can also be nonmigrating, permanent residents in specific low- or mid-latitude locations containing persistently favourable habitat, e.g. in the East China Sea and northern Sea of Japan (Mizroch et al., 2009), in the Gulf of California (Tershy et al., 1993) where genetic evidence attests to their isolation (Bérubé et al., 2002), and in the Mediterranean Sea, as explained in this chapter.

Fin whales are a common mysticete in the North Atlantic Ocean, where a total of roughly 53,000 individuals was estimated to exist around the year 2000 (Reilly et al., 2013). These were classified by the International Whaling Commission (IWC) into seven management units, based largely on catch and marking data: Nova Scotia, Newfoundland-Labrador, West Greenland, East Greenland-Iceland, North Norway, West Norway-Faroe Islands and British Isles-Spain-Portugal (Donovan, 1991). Unsurprisingly, evidence exists that some movement occurs across the boundaries of these management units, indicating that the units are not discrete. The current IWC model proposes seven hypotheses for stock structure within these

management units. The model assumes a central group of stocks that feed in the area between East Greenland and the Faroe Islands; a Spanish stock; and, under most hypotheses, an eastern and western group of stocks (IWC, 2010). Mediterranean fin whales are currently defined as a distinct population from those in the North Atlantic, with a range that perhaps extends out to southern Portugal (IWC, 2009).

2. POPULATIONS OF FIN WHALES IN THE MEDITERRANEAN SEA

The question of whether or not fin whales in the Mediterranean are isolated from fin whales in the Atlantic Ocean, has been debated for a long time. The first to suggest that fin whales in the Mediterranean may have been an isolated, nonmigrating population, was the Norwegian marine zoologist G.O. Sars in 1881, noting simultaneous fin whale sightings off Norway and in the Mediterranean (Jonsgård, 1966). Two contrasting theories—one involving resident isolation and the other seasonal immigration from the North Atlantic Ocean—have occupied zoologists for the better part of two centuries, and are described in detail in Notarbartolo di Sciara et al. (2003). Discussions, however, were always based upon speculation and indirect inference until significant levels of divergence and heterogeneity in both mitochondrial and nuclear DNA were found between Mediterranean and Eastern North Atlantic fin whales; this was based on genetic analyses performed on skin tissue remotely collected from free-ranging individuals in the Ligurian Sea (Bérubé et al., 1998).

The notion of a Mediterranean genetically distinct breeding and feeding population, isolated from the Atlantic Ocean, was also supported by contaminant analyses (Aguilar et al., 2002) and satellite tracking studies (Bentaleb et al., 2011; Cotté et al., 2011; Panigada et al., 2015). However, this was inconsistent with the concept of fin whales moving in and out of the Mediterranean from the Atlantic Ocean through the Strait of Gibraltar. This concept is corroborated by: (a) the historical presence of the species near the Gibraltar Strait in North Atlantic waters, where thousands of fin whales were caught by short-lived whaling activities that occurred there between 1921 and 1954 (Clapham et al., 2008; Sanpera and Aguilar, 1992), and (b) recent observations of fin whales in the Gibraltar area, which were seen crossing the Strait primarily westward in summer and eastward in winter (Gauffier et al., 2009, 2012).

An explanation of this apparent contradiction was provided by acoustic monitoring performed through the deployment of archival bottom-mounted audio recorders in nine different locations of the Western Mediterranean and northeastern North Atlantic Ocean between 2006 and 2009 (Castellote et al., 2012a). The use of song characteristics to describe population affiliation over a broad geographical range had been already successfully applied to mysticete species including fin whales (Hatch and Clark, 2004). Recordings by Castellote et al. (2012a) revealed long sequences of typical fin whale songs—i.e. reproductive displays (Croll et al., 2002) occurring during most of the year (Clark and Gagnon, 2002)—which fell into two patterns that were consistently and significantly distinct on the basis of inter-note interval and note bandwidth. One pattern was recorded in the northeastern North Atlantic Ocean from the Azores to the Gibraltar Strait, and across the Strait into the Mediterranean Sea all the way to the Balearic Basin. The other, identical to songs previously recorded in the Ligurian Sea (Clark et al., 2002), was recorded east of the Balearic Basin into the Provençal Basin. These recordings are indicative of the simultaneous presence in the Mediterranean Sea, of two different fin whale populations: a genetically and culturally distinct population of resident Mediterranean fin whales (hereafter the "MED whales") found between the Provençal Basin and the Balearic Basin, and members of a northeastern North Atlantic population ("NENA whales") travelling into the westernmost portion of the Mediterranean. The latter animals very likely cross the Strait of Gibraltar in winter and remain in the Mediterranean Sea until summer (Fig. 2).

Many questions still remain about the use and partitioning of the Mediterranean region by members of these two populations. These include the extent of the interactions between MED and NENA whales, the importance of the Mediterranean habitat for the NENA whales, and the extent of the dispersal of the MED whales westward, possibly all the way to the Atlantic Ocean. Acoustic studies conducted in March 2011 (Castellote et al., 2012a) confirmed the coexistence of song types from both NENA and MED whales in the Balearic Basin, but not in the Provençal Basin, thus indicating (a) the existence of seasonal sympatry between males of the two populations, (b) that the Balearic Basin seemed to mark the easternmost range limit of the NENA males, and (c) the presence of NENA singers in the Mediterranean during both winter and summer (Castellote et al., 2011, 2012a). The presence of NENA male singers in the Western Mediterranean is indicative of breeding-related behaviour in the area, however no information is yet available about the migratory behaviour of NENA females.

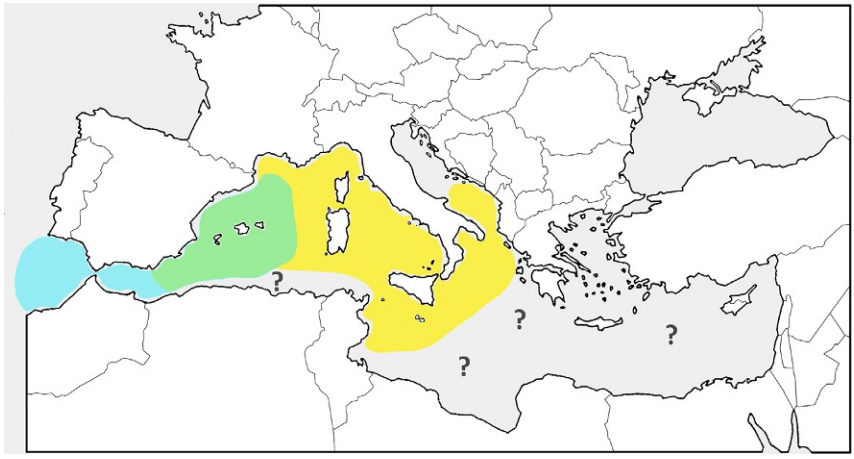

Fig. 2 Presumed distribution of fin whale (*Balaenoptera physalus*) populations in the Mediterranean Sea. *Blue*: north-east North Atlantic population (NENA whales). *Yellow*: Mediterranean population (MED whales). In *green* the presumed overlap between the two populations. NENA whales' distribution in the wider Atlantic Ocean is not shown.

Analyses of stable isotopes conducted on Mediterranean fin whale baleen plates add further elements to the picture. Bentaleb et al. (2011) compared fin whale baleen plate stable isotopes from a sample of nine stranded individuals in the Western Mediterranean with isotopes found in the whales' main prey, the euphausiid *Meganyctiphanes norvegica*, collected both in the Atlantic Ocean and in the Mediterranean Sea. In their analysis, most of the fin whale isotopes in their sample were consistent with the Mediterranean *M. norvegica* isotopic signature, indicating that feeding by the sampled whales had occurred only in the Mediterranean Sea. Those authors, however, also discovered two outliers from plates collected near Malaga, Spain, in the Alborán Sea, with $\delta^{13}C$ values intermediate between those of Atlantic and Mediterranean *M. norvegica*, further confirmed by Ryan et al. (2013) as occurring within the isotopic niches of both Biscayan and Irish/United Kingdom fin whales. These two outliers were interpreted by Castellote et al. (2013) as being NENA whales stranded during their Mediterranean visit, whereas Gimenez et al. (2013) suggested that they might have been MED whales that had previously foraged in the North Atlantic Ocean. A similar question refers to a single fin whale (#10842) tagged in the Provençal Basin in summer 2003. This animal travelled into the North Atlantic, unlike seven other whales tagged in the same experiment and

who remained in the tagging area throughout the subsequent winter (Bentaleb et al., 2011). Was whale #10842 a NENA visitor returning to the North Atlantic, as suggested by Castellote et al. (2012a, 2013), or was it a MED whale venturing into the North Atlantic, as suggested by Gimenez et al. (2013)? Considering that passive acoustic data indicate regular movements by the NENA whales between the North Atlantic and Mediterranean basins, and considering the absence of the MED song type in the Alborán Sea, the Strait of Gibraltar and the Azores, the first hypothesis seems more likely. Genetic studies supporting a limited but recurrent, male-mediated gene flow in MED whales between the Ligurian Sea and the North Atlantic Ocean (Palsbøll et al., 2004) do not preclude the second hypothesis. However, such gene flow could also be consistent with just male NENA whales occasionally mating with female MED whales inside the Mediterranean.

In conclusion, and in spite of the remaining uncertainties, the current scientific knowledge indicates that two fin whale populations coexist within the Mediterranean Basin, with low but recurrent gene flow between them: a visiting NENA population and a permanent MED population. The remainder of this chapter will examine in greater detail the ecology of this latter population.

3. THE MEDITERRANEAN SEA AS FIN WHALE HABITAT

As mentioned earlier, satellite telemetry experiments point to the prolonged permanence of fin whales in the Mediterranean. Of eight fin whales tracked by satellite in the northwestern Mediterranean during summer 2003, all except one remained in the tagging area through autumn and winter (Bentaleb et al., 2011; Cotté et al., 2011). Further tagging studies performed in September 2012 in the Ligurian Sea (Fig. 3) resulted in the tagging of another eight fin whales, some of which retained tags for extended periods (up to 142 days). This clearly indicates the propensity of the tagged whales to remain in Mediterranean waters (Panigada et al., 2015).

The MED whales occur throughout the Mediterranean, from the Balearic Islands to the Levantine Sea, although they are in large part found in a subregion between the Gulf of Lion in France and southern Italy, as well as farther to the south into the Strait of Sicily and the wide Tunisian shelf (Notarbartolo di Sciara et al., 2003). An area of particular importance for fin whales, comprising the Ligurian, Corsican, Sardinian and Tyrrhenian seas, was designated as a protected area named the 'Pelagos Sanctuary for Mediterranean Marine Mammals'; this was established in 1999 by a treaty

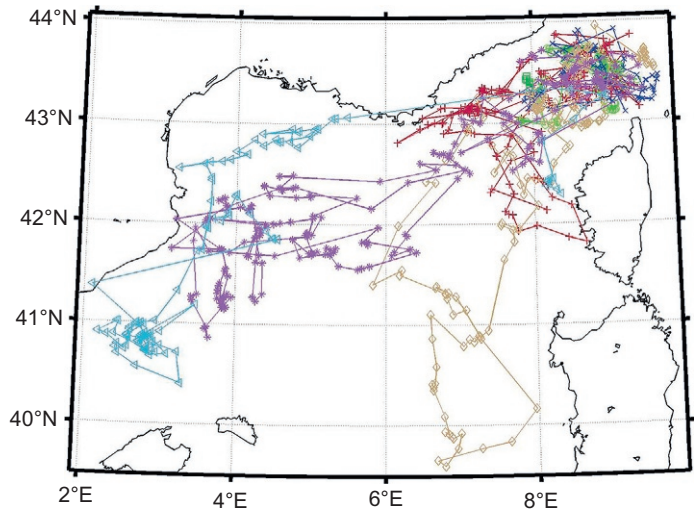

Fig. 3 Tracks of eight fin whales (*Balaenoptera physalus*) which were fitted with satellite tags in the Ligurian Sea in September 2012.

among France, Italy and the Monaco Principality (Notarbartolo di Sciara et al., 2008). East of Italy, in the Ionian Sea and southern Adriatic Sea, fin whales are also found with some regularity, although apparently in smaller numbers than in the Western Mediterranean. By contrast, records of the species' occurrence in the Eastern Mediterranean and along its southern shores (e.g. in the Aegean and Levantine seas) are much rarer, likely resulting in part from low density, and in part from lack of systematic observations (Notarbartolo di Sciara et al., 2003).

Year-round residency by fin whales in the Mediterranean Sea has required ecological and behavioural adaptations to regional specificities, notably regarding the whales' feeding and breeding needs. Fin whales have been observed engaging in feeding in the Mediterranean throughout the year. Most of the observations concern summer, e.g. in the Ligurian Sea (Notarbartolo di Sciara et al., 2003; Orsi Relini and Giordano, 1992), off eastern Sicily (Puzzolo and Tringali, 2001) and in the southern Tyrrhenian Sea off the island of Ischia (Mussi et al., 1999). In the latter area, feeding was inferred from swimming behaviour and frequently observed defecation episodes. Feeding was also seen in spring off eastern Sicily (Catalano et al., 2001) and in winter in the central Tyrrhenian Sea off northeastern Sardinia (Magnone et al., 2011), as well as in the Strait of Sicily near Lampedusa Island (Canese et al., 2006) where whales were frequently observed foraging at the surface by swimming in formation.

The observations of fin whales moving across a marine region such as the Mediterranean Sea, known to be largely oligotrophic (e.g. Huertas et al., 2012), to feed in specific and predictable locations and times of the year, imply that the following two conditions are met: (a) the existence of a mosaic of mesoscale productive features, highly variable in space and time, favouring zooplankton growth, and (b) the whales' ability to locate and exploit such features in a timely fashion. Based on these assumptions and on experience gathered from the Atlantic bluefin tuna, *Thunnus thynnus* (another predator of *M. norvegica*, Druon et al., 2011), by relating the proximity of over 10 years of fin whale sighting locations ($n = 1451$) to concurrent remotely sensed oceanic fronts of chlorophyll a (Chl a), Druon et al. (2012) developed a model to detect and map on a daily timescale fin whale potential feeding habitat. Although not accounting for a portion of primary productivity which occurs at depth, which is undetected by satellite remote sensing (Macias et al., 2014), Druon et al.'s (2012) model proved to be very accurate when ground truthed with actual fin whale movements monitored by satellite tracking. Subsurface primary productivity is indeed substantially lower than the surface productivity hot spots linked to mesoscale features (chlorophyll fronts), notably due to the exponential decrease of light with depth and the decrease of the chlorophyll/carbon ratio.

Proof of the accuracy of the Druon et al. (2012) model is provided by the tracks of two whales which were satellite tagged in March 2015 off Lampedusa Island in the Strait of Sicily, and tracked for the subsequent 29 (whale n. 87776) and 44 (whale n. 87780) days (Panigada et al., 2015). During the first 15 days of tracking the whales remained in the waters of the Strait of Sicily, which were at that time highly productive; the whales clearly engaged in feeding behaviour as was evident from direct observation and defecation episodes as well as from inference of the tracked swim pattern (Fig. 4A). During the two subsequent fortnights both whales had moved to the north, abandoning the Sicily Strait where productivity was waning; the whales took advantage along the way of short spells of productivity in the Tyrrhenian Sea (whale n. 87776: Fig. 4B), and ultimately ended in the Ligurian Seas, where by that time the productivity conditions had sharply improved (whale n. 87780: Fig. 4C).

Based on the Druon et al.'s (2012) model, potential fin whale feeding habitat in the Western Mediterranean Sea undergoes considerable seasonal variation, ranging from a highly diffused condition in winter and spring to extreme summer concentration in the Ligurian Sea and Gulf of Lion area and, to a minor extent, along the southeastern shores of Italy (Fig. 5).

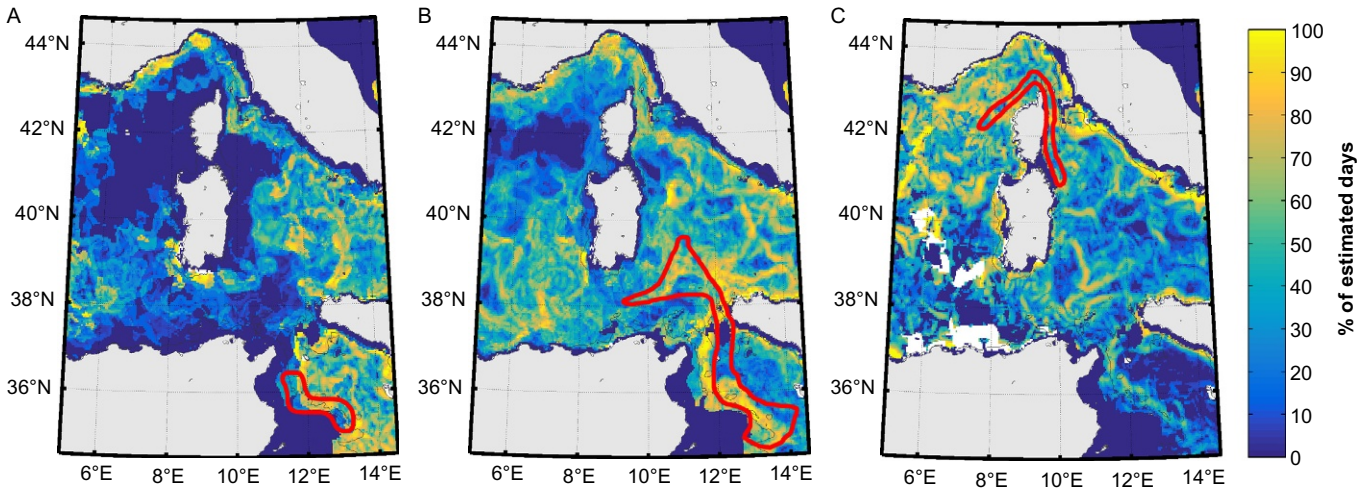

Fig. 4 Dynamic representation of fin whale (*Balaenoptera physalus*) feeding habitat (% of occurrence) from 16 March to 30 April 2015. The *encircled areas* indicate the positions of satellite-tagged fin whales during the three successive periods. (A) 16–31 March (e-tags #87776 and 87780); (B) 1–15 April (e-tags #87776 and 87780) and (C) 16–30 April (e-tag #87780). Depth contour is 200 m; blank is habitat coverage $<$5% or CHL coverage $<$1%.

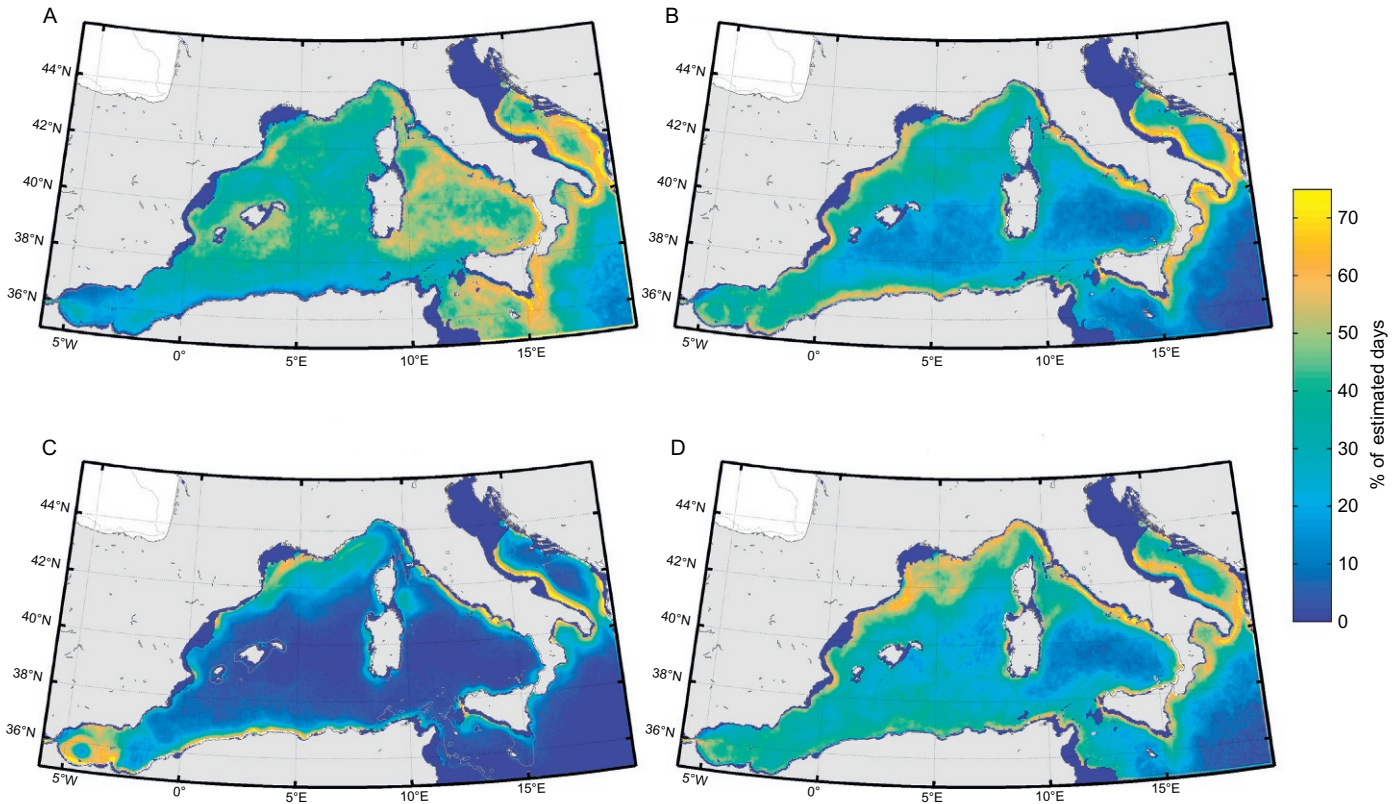

Fig. 5 Occurrence of potential fin whale (*Balaenoptera physalus*) feeding habitat (in % of occurrence) in the western Mediterranean, averaged over 13 years (2003–15) subdivided between winter (A: January–March); spring (B, April–June); summer (C, July–September) and autumn (D, October–December) (200 m depth contour).

These observations require a reinterpretation of the movement patterns of MED whales in the Western Mediterranean. These are often depicted as fixed migratory movement patterns from unknown winter breeding grounds to the Ligurian-Provençal Basin summer feeding grounds along well-defined corridors (e.g. Marini et al., 1996). We suggest that: (a) the whales' gathering in the northwestern Mediterranean Sea in summer is caused by the contraction of feeding opportunities elsewhere (although such gathering may appear to be occurring by recurrent travelling along a defined route where a passage is confined by coastlines, e.g. between Corsica and the Italian mainland, or between the Balearic Islands and the Iberian Peninsula), and (b) that the whales' dispersal from the Ligurian Sea after summer is a consequence of the diffused reappearance of favourable feeding conditions over a much wider Mediterranean surface. Such reinterpretation of fin whale movements in the Western Mediterranean Sea is based upon a contraction/dispersal hypothesis caused by the seasonal variability of available feeding habitat, as opposed to a migration hypothesis occurring along defined routes. The former is corroborated by the wide movements irradiating in many directions out of the Ligurian Sea at the end of summer, demonstrated in eight fin whales tagged in the Ligurian Sea at the end of summer 2012 (Fig. 3). It also explains the observed continued presence of whales in the Ligurian-Provençal Basin during winter, albeit at much lower densities, as evidenced by surface observations (Gannier and Gannier, 1993), winter aerial surveys (Panigada et al., 2011a) and passive acoustic monitoring (C.W. Clark, Cornell University, personal communication, 2016).

Druon et al.'s (2012) niche model further reveals substantial interannual differences in the distribution of potential fin whale feeding habitat, e.g. between 2003 and 2005 (Fig. 6). This was strikingly reflected by corresponding differences in fin whale encounter rates during extensive summer vessel-based surveys in the Pelagos Sanctuary, which increased by a factor of four from 2003 to 2005 (A. Azzellino, Politecnico di Milano, personal communication, 2016). Considerable interannual changes in patterns of fin whale occurrence in the adjacent central Tyrrhenian Sea over a 20-year period were also reported by Arcangeli et al. (2012, 2014).

Much uncertainty still remains concerning the presence, movements and habitat use of fin whales in the Eastern Mediterranean Basin and along the entire length of the African coast, due to the dearth of direct observations in those areas. Seasonal changes in the mean yearly distribution of potential fin whale feeding habitat in the Eastern Mediterranean Sea derived from the Druon et al. (2012) model shows that feeding habitat in the Eastern Basin

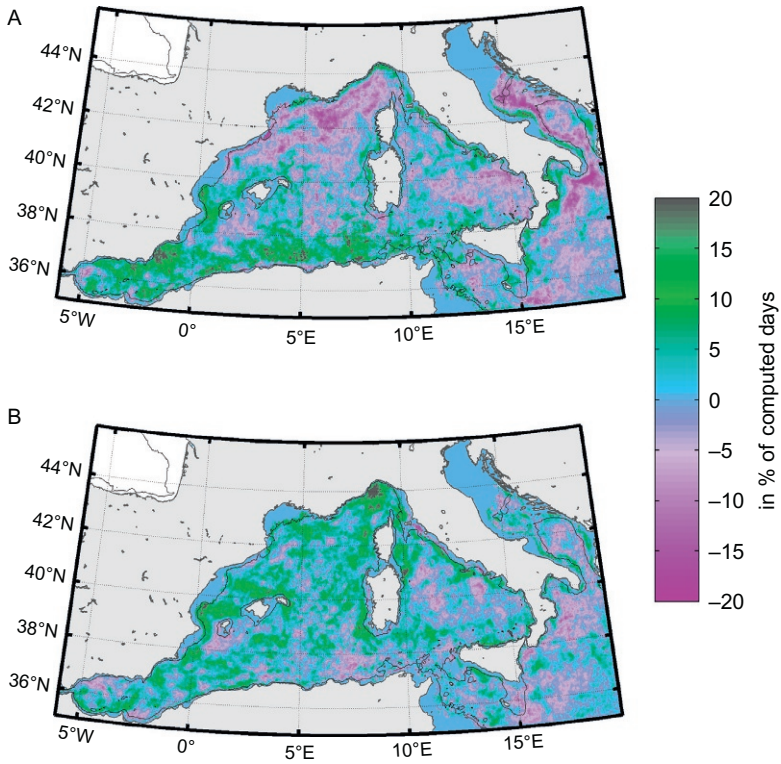

Fig. 6 Occurrence of potential fin whale (*Balaenoptera physalus*) feeding habitat (in % of occurrence) in the Western Mediterranean. (A) 2003 average and (B) 2005 average (200 m depth contour).

during summer almost completely disappears (Fig. 7C). By contrast, several locations seem to be apt to host temporary aggregations of feeding fin whales in the other seasons, most notably in winter; these include the western Ionian Sea from the east coast of Sicily to the south towards Libya, the southern Adriatic Sea (see also Fig. 4), parts of the Aegean Sea, the waters comprised between the eastern tip of Crete and Cyprus including the conspicuous Rhodes Gyre, and the coastal waters of Syria, Lebanon and Israel. Confirmation of the actual presence of fin whales in these locations unfortunately only comes from a handful of direct observations, limited to the central and southern Adriatic (Lipej et al., 2004; Pierantonio and Bearzi, 2012), the Sicilian Ionian coastal waters (Aissi et al., 2008; Puzzolo and Tringali, 2001; Sciacca et al., 2015; Tringali et al., 1999, 2006) and Israel (Kerem et al., 2012). Building on the contraction/dispersal

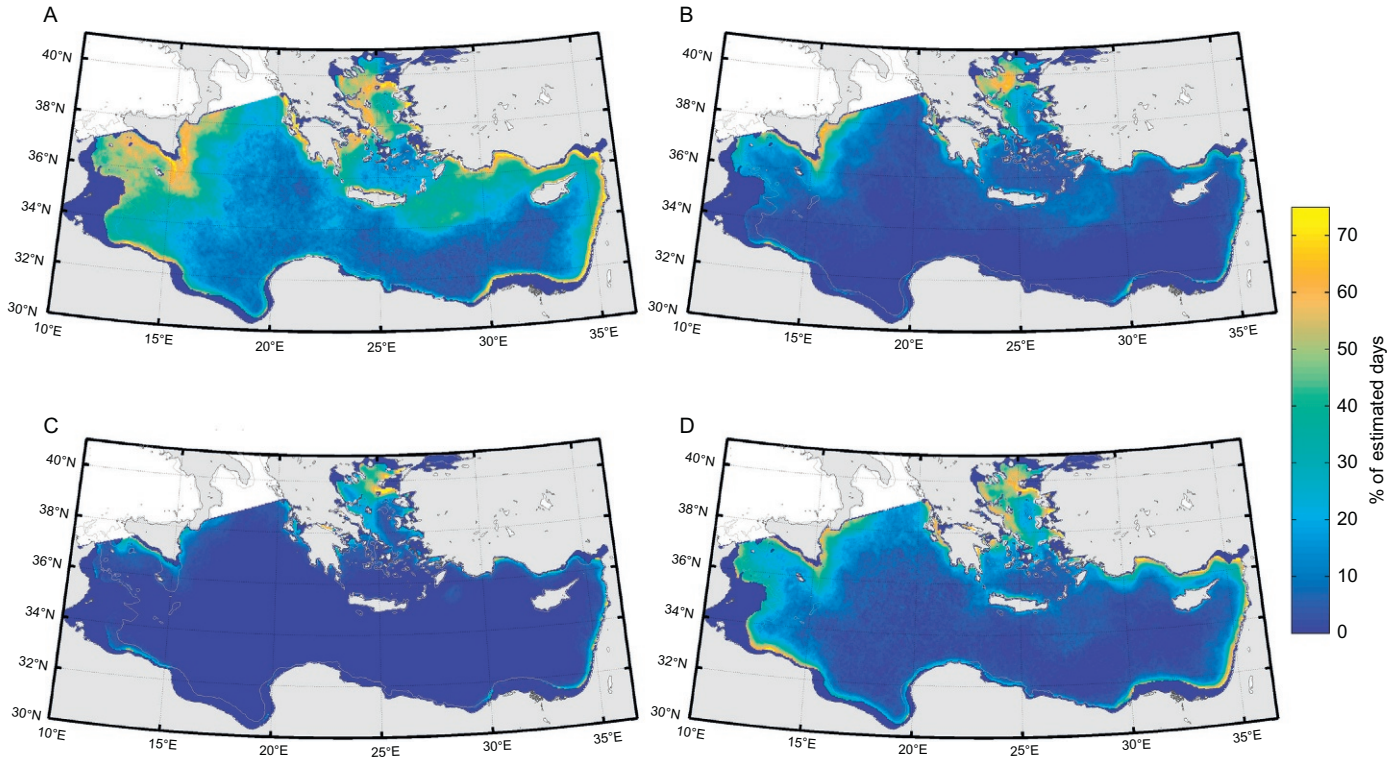

Fig. 7 Occurrence of potential fin whale (*Balaenoptera physalus*) feeding habitat (in % of occurrence) in the Eastern Mediterranean, averaged over 13 years (2003–15) subdivided between winter (A, January–March); spring (B, April–June); summer (C, July–September) and autumn (D, October–December) (200 m depth contour).

hypothesis, it would be sensible to presume that fin whales occur in feeding gatherings between autumn and spring in many of the Eastern Mediterranean locations, where substantive potential feeding habitat is predicted (i.e. above ca. 40% of occurrence), like that observed around Lampedusa Island in winter.

Similar to the absence of a specific feeding season for MED whales, breeding in this population occurs all year long; however, a peak of births during autumn is evident on the basis of a record of 56 newborn fin whales reported from the Mediterranean in Notarbartolo di Sciara et al. (2003). As expected, records of newborn whales originated mostly from the western portion of the region where whale density is higher. However, newborns also occurred in the Eastern Mediterranean, supporting the hypothesis that MED whales, rather than gathering in specific breeding grounds, engage in breeding activities wherever favourable physiological conditions occur. Unlike for other mysticetes such as humpback and grey whales, major uncertainties concerning the locations of specific fin whale breeding grounds still exist also with regard to oceanic populations (Kellogg, 1929; Mizroch et al., 2009).

Piecing together the past knowledge with recent information from telemetry and habitat modelling, the available evidence supports the suggestion by Geijer et al. (2016) that MED whales, instead of regular migrants, are nomadic opportunists moving between specific sites where oceanographic conditions cause the recurring appearance of localised prey abundance. As proposed in Notarbartolo di Sciara et al. (2003), it can be assumed that the Mediterranean environment (which is meteorologically and climatically relatively forgiving in comparison to oceanic habitats), combined with negligible predation pressure and high potential for sound-mediated socialisation due to the region's small size, might have provided year-round resident fin whales an extended calendar of breeding and feeding opportunities. At the same time, unlike their oceanic conspecifics needing to migrate to calve out of cold water for energetic reasons, this condition would release MED whales from the need to migrate to distant locations for calving purposes.

4. STATUS AND THREATS

The Mediterranean population of fin whales was assessed as Vulnerable on the International Union for the Conservation of Nature's (IUCN) Red List (Panigada and Notarbartolo di Sciara, 2012). The listing was justified on the basis of the following statements:

1. The Mediterranean subpopulation, which is genetically distinct from fin whales in the Atlantic, contains fewer than 10,000 mature individuals.
2. The subpopulation experiences an inferred continuing decline in number of mature individuals.
3. All mature individuals are in one subpopulation.

Some of the above statements now need to be reexamined, based upon more recent information on Mediterranean fin whale ecology (Castellote et al., 2012a), which has been gathered since the population was assessed in the IUCN Red List. Statement (1) is still valid in terms of the Mediterranean population being distinct from North Atlantic fin whales, however the population estimate of >3500 individuals by Forcada et al. (1996), generated by line transect surveys performed between the Strait of Gibraltar and the Ligurian Sea, likely sampled NENA whales as well as MED whales, thereby contradicting statement (3). By consequence, a population estimate limited to MED whales could be significantly smaller, and perhaps consistent with a higher threat classification.

Conversely, statement (2) likely remains valid. Threats to fin whale survival in the Mediterranean Sea include direct mortality caused by collisions with vessels and, to a lesser extent, bycatch and disease. Vessel disturbance, chronic negative effects and habitat exclusion caused by anthropogenic noise, pollution and climate change are also of concern.

Ship strikes are likely the main source of nonnatural, human-induced mortality in MED whales (Panigada et al., 2006), particularly in areas of heavy vessel traffic. A study of potential risk of ship strike using habitat estimates and density of maritime traffic showed that the collision risk is concentrated along the main maritime routes and substantially grows in the Pelagos Sanctuary area during summer—the whales' core habitat in that season—due to both the seasonal increase of maritime traffic (passenger transport) and the shrinking of favourable fin whale feeding habitat (Vaes and Druon, 2013). Ship traffic in the area already grew fourfold between 1992 and 2012, and is expected to further grow by 23% over the next decade (Panigada et al., 2008). In a scenario involving future steep increase of maritime traffic in the Mediterranean Sea, fin whale mortality caused by vessel collisions is a mounting concern. A further concern is that an increase in shipping entails an increase in noise in the fin whale communication band. This might, through habituation to the chronic noise production by distant shipping, impair the whales' ability to respond with effective avoidance to approaching vessels, as hypothesised in the case of the endangered North Atlantic right whale, *Eubalaena glacialis* (Terhune and Verboom, 1999).

Even in the absence of direct mortality caused by ship strikes, the disturbance caused by intense traffic through whale habitat is a reason for concern. Vaes and Druon (2013) noted the near absence of whale sightings along the shipping route connecting the Strait of Gibraltar to the Strait of Sicily, one of the world's busiest, in spite of the presence of favourable feeding habitat predicted along that route by Druon et al.'s (2012) model. Vessel disturbance can also be of concern if caused by unregulated whale watching, particularly in the crammed Ligurian Sea feeding grounds, where disturbed whales have been shown to interrupt their feeding activities for unknown durations (Jahoda et al., 2003).

Anthropogenic underwater noise is now recognised as a worldwide cetacean conservation problem, and recent studies have shown a broad range of negative effects in a variety of taxa (Williams et al., 2015). Background noise levels in the Mediterranean Sea are higher than in any other ocean basin (Ross, 2005), with ship traffic and seismic surveys being among the primary sources of noise (Maglio et al., 2015). Low-frequency specialists, in particular mysticetes, may well be particularly susceptible to the effects of anthropogenic noise on their communication (Hildebrand, 2005). Therefore, it can be assumed that Mediterranean fin whales are disproportionately affected by chronically exposed high levels of noise. Acoustic and behavioural changes by both MED and NENA whales have been documented in response to two different types of anthropogenic noise typically occurring in the Mediterranean Sea: shipping and seismic airgun noise. Fin whales modified their song characteristics under increased background noise conditions and under seismic airgun activity conditions; and they abandoned the area for a time period well beyond the 10-day duration of seismic airgun activity (Castellote et al., 2012b). Acoustic changes in fin whale songs might compensate the masking effects of increased background noise, but the metabolic costs to the animals could be higher. Furthermore, song modifications might affect song effectiveness, in particular changes in note interval and bandwidth, since these seem to be related to population identity (Castellote et al., 2012a) and might play an important role in reproduction (Croll et al., 2002).

Interactions with fishery activities are considered to have a minor effect on Mediterranean fin whales (Notarbartolo di Sciara et al., 2003). Even during the 1980s and 1990s, a period in which driftnet fishing for large pelagic fish was at its peak in the northwestern Mediterranean Sea and caused elevated incidental mortality in many cetacean species, documented bycatch of fin whales was rare (Notarbartolo di Sciara, 1990; Podestà and Magnaghi, 1989). Fin whale prey depletion by fishing is not a concern, given the

predominance in the whales' diet of euphausiids, which are not targeted by fisheries in the region.

Like all marine top predators in the Mediterranean Sea, and in spite of their position at a lower trophic level than odontocetes such as striped and bottlenose dolphins, fin whales are exposed to significant levels of chemical pollution. This includes organochlorines, trace elements, dichlorodiphenyltrichloroethane (DDT) metabolites, and endocrine-disrupting chemicals. Recent attention is being focused on emergent contaminants, such as bisphenol A, brominated flame retardants and phthalates, which have been found to occur in high concentrations in the blubber of fin whales; the latter are related to the presence in the Mediterranean environment of large amounts of marine litter, and in particular plastic debris and microplastics (Cózar et al., 2015; Fossi et al., 2012, 2014, 2016). Contaminant load can might negatively affect fin whale reproductive functions due to their reported estrogenic and antiandrogenic effects (Fossi et al., 2003, 2007), and a potential weakening of the whales' immune response. Such consideration raises particular concern in view of the recent evidence, deriving from direct (immunohistochemical and biomolecular) and indirect (serologic) investigations, of dolphin morbillivirus (DMV) infection or exposure in five out of nine fin whales stranded in Italy between 2011 and 2013. This suggests the potential of an epidemic cluster of fatal DMV in MED whales, and stresses that DMV should be regarded as one of the major biological threats to fin whales in the Mediterranean Sea (Mazzariol et al., 2016).

Finally, the effects of climate change and ocean acidification on the Mediterranean marine environment have been flagged as a potentially increasing threat to MED whales; in particular such changes might affect the viability, abundance and distribution of *M. norvegica*, the whales' main food supply in the region (Gambaiani et al., 2009). Climate change-induced alteration of water mass circulation in the Mediterranean, possibly detected already decades ago (Bethoux and Gentili, 1996), is likely to affect the spatiotemporal pattern of the region's marine productivity; however, the complexity of the involved ecological phenomena still presents a challenge to unambiguous cause–effect interpretation (Wyatt, 2010). Alterations in Mediterranean marine productivity patterns may present a serious impediment to the ability of fin whales to locate transient food sources, although the whales' nomadic opportunist attitudes might help them to overcome such challenge.

Considering all of the threats to MED whales, actual and potential, listed earlier, the observed population decrease raises considerable concern. A comparison between line transect population estimates conducted within the boundaries of the Pelagos Sanctuary 18 years apart indicates a >60%

decline since the 1992 estimate of 901 whales (CV = 0.217; 95% CI: 591–1374) (Forcada et al., 1995; Panigada et al., 2011b). The 1992 estimate was corroborated by comparable results obtained during independent survey efforts by Gannier (1997). Furthermore, photo-identification data collected over 18 consecutive summers (1990–2007) and analysed by Zanardelli et al. (2011) with a Jolly–Seber open population model yielded a population size in 1990 of 980 whales (CV: 0.20; 95% CI: 670–1437), a rate of population change of 0.99 (95% CI: 0.92–1.07), and an unexpectedly low apparent survival rate (0.88, 95% CI: 0.76–0.94). The observed decrease of fin whales can be explained in several different ways, and likely reflect the high observed interannual variability of feeding habitat (Fig. 6); for instance, a higher contraction of summer feeding habitat in the early 1990s might have resulted in higher whale concentrations in the Pelagos Sanctuary in those years, with density levels there that may have no longer occurred in subsequent years. Thus, successive relocation of MED whales to different areas within the boundaries of their known range is not unlikely.

However, the alternative explanation of population decline caused by a decrease in survival rate and/or reproductive success, reinforced by the low measured level of apparent survival, cannot be discounted until synoptic surveys encompassing the entire population range (as advocated by Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area, ACCOBAMS, for more than a decade) have been conducted.

5. RECOMMENDATIONS

Considering the conditions of the MED whale population described earlier, the uncertainties that still surround them, and the cumulative effects in a resident population of the many impacting pressures in a semienclosed region heavily affected by human activities, the highest precaution is recommended. The MED whales should be treated as a high regional conservation priority, and their IUCN Red List status should be reassessed.

Well-identified threats such as vessel collisions and anthropogenic noise should be addressed through the enactment of timely and effective measures. Priority should be given to define appropriate ways to minimise vessel collisions and reduce acoustic factors that could contribute to exclusion from or loss of fin whale habitat.

Concerning ship strikes, emphasis should be placed on the implementation of routing schemes and speed reduction zones in areas and periods where distribution modelling exercises identify potential for high fin whale

densities at appropriate temporal and geographical scales. As is well known, the most effective and until now the only demonstrated method to address lethal strikes consists in reducing vessel speed. This has been shown in a number of studies, in large part concerning North Atlantic right whales (Conn and Silber, 2013; Laist et al., 2014); these results are valid also for fin whales (Laist et al., 2001; Panigada et al., 2006). Furthermore, reducing speed also reduces ship noise, therefore this should be considered a double mitigation action.

Other sources of anthropogenic noise are also a concern, particularly considering the diffused proliferation of commercial and scientific seismic surveys in the Mediterranean Sea (Maglio et al., 2015). Control, regulation and permit application procedures for these activities in the Mediterranean Sea should be addressed in accordance to the European Union Marine Strategy Framework Directive (European Union, 2008), as well as the Habitat Directive (European Union, 1992) requirements, and environmental impact assessments should consider the mitigation of fin whale noise impact a priority. To effectively address noise pressure on this highly sensitive Mediterranean species, mitigation should consider both direct close-range physiological effects (e.g. through the identification of exclusion zones, the involvement of independent observers and the adoption of manoeuvres such as power downs, shut downs, ramp ups), and long-range behavioural effects (e.g. through spatial and temporal limitations to avoid ensonifying known or predicted high-density areas or times, or by establishing buffer zones around sensitive areas).

Mindful that the threat of shipping noise to marine life has been recognised, among others, by the IMO (International Maritime Organization, 2014) and by the European Union (2008), noise fields within fin whale important habitat should be regularly monitored and mapped, thereby providing guidance and insight on the need for and ways of mitigating negative effects. Commercial whale watching operations targeting fin whales in the species' important habitat should be regulated and carefully monitored.

Enhancing place-based protection of MED whale habitat is another important consideration. In the light of the seasonal dynamics of MED whales' feeding habitat and their consequences on the whales' distribution and movements, a reassessment of the Pelagos Sanctuary boundaries and seasonal importance is strongly urged. For example, seasonally and/or dynamically managed protected zones could be implemented to address the danger of ship strikes, as occurs in North Atlantic right whale habitat in US waters (Asaro, 2012). An extension to the west of the boundaries of the Pelagos Sanctuary should also be considered in order to encompass

the entirety of fin whale summer feeding habitat, notably given the dramatic reduction of such habitat during summer at the Mediterranean scale. Conversely, habitat protection in recurrent seasonal movement areas, as well as during the colder seasons in other Mediterranean areas known to host important fin whale concentration should be given appropriate consideration through the designation of a network of seasonally managed marine protected areas, thereby increasing the percentage of fin whale important habitat falling under conservative management regimes (Notarbartolo di Sciara et al., in press).

Finally, existing gaps in fin whale ecological knowledge should be addressed through directed research studies to properly inform and strengthen conservation and management actions. These studies should include aerial- and ship-based targeted surveys, population structure studies including behavioural and reproductive interactions between the NENA and MED populations, as well as satellite tracking experiments and passive acoustic monitoring to gain a detailed understanding of the species' presence in the southern and eastern portions of the Mediterranean Sea.

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