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Sperm whales ability to avoid approaching vessels is affected by sound reception in stratified waters

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ABSTRACT

Collision with vessels is a major cause of whale mortality in the Mediterranean Sea. The effect of non-spherical sound propagation effects on received levels (RL) was investigated for the sperm whale (*Physeter macrocephalus*). Relevant dive patterns were considered in each case and the RL were compared for two periods using a ray tracing software, the winter conditions and the summer stratified situation. RL were plotted as a function of time in a simulated collision case for two vessel speeds representative of a conventional merchant ship (15 knots) and a fast-ferry (37 knots). In almost all simulated cases, RL featured a brutal 23–31 dB re 1 μPa rise from below 100 dB while the vessel approached the whale at close range. Summer situations were worse because this transition occurred at closer ranges, resulting in acoustic warning times of less than 30 s in the fast ferry case. These results suggested that sperm whales could not be able to achieve an escape manoeuvre in a critical situation such as a fast vessel approaching under stratified waters conditions.

1. Introduction

Shipstrikes represent a threat for the recovery and conservation of endangered or isolated whale populations (Laist et al., 2001). This is the largest contributor to anthropogenic mortality for the critically endangered North Atlantic right whale *Eubalaena glacialis* (Kraus et al., 2005). It has also been recognized as a major threat for the future conservation of fin whales *Balaenoptera physalus* in the Mediterranean (Panigada et al., 2006), a sea totalling approximately 28% of the world merchant shipping traffic (SCOT, 2004). Although, there is less emphasis on the other large whale species common in the Mediterranean Sea, the sperm whale *Physeter macrocephalus*, there is recent evidence that Mediterranean sperm whales are also victim of ship collisions (Weinrich et al., 2006). Although the authors suggested that there was no evidence of a populational risk, data were unsufficient to provide any trend on sperm whale ship-strike mortality. However, an examen of photo-identification data suggested that a significant proportion of the western Mediterranean population is victim of collision with ships, or injured by vessel propellers (Fig. 1): from a total of 189 photo-identified individuals, 11 showed obvious signs of a physical contact with a ship (photo-identification database, Groupe de Recherche sur les Cétacés). This indication did not account for dead animals, either stranded or not recorded at all.

Compared to fin whale, the sperm whale is well known for its stereotyped deep dive cycle: during foraging activity in the NW Mediterranean, whales spend approximately 17% of their time at the surface, with an average of 43 blows (Gannier et al., 2012). During daytime, sperm whales are most often observed foraging, and only occasionally resting (pers. obs.). Therefore, sperm whales are regularly exposed to ship collision during their routine feeding activity in spite of a short stay at the surface. Ridgway and Carder (2001) showed that sperm whale auditory sensitivity extended at least from 2.5 kHz to 60 kHz, results consistent with spectral energy content of their clicks (Madsen et al., 2002). Recent Controlled Exposure Experiments (CEE) carried out off Norway indicated that sperm whales reacted to 1–2 kHz sounds (Miller et al., 2011), and CEE in the Gulf of Mexico also indicated reactions to low frequency pulse sounds (Miller et al., 2009) suggesting that sperm whales have a good hearing sensitivity including in moderately low frequencies, below 1000 Hz. Consequently, we assumed that sperm whales are not hit by vessels because they are not able to hear their noise.

High collision risks arise from high abundance of both whales and boats: sperm whales are common in the NW Mediterranean Sea from spring to late autumn (Gannier et al., 2002; Laran and Drouot, 2007). In the NW Mediterranean Sea, vessel traffic reaches

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Fig. 1. Photograph of a sperm whale flukes with obvious signs of ship propeller collision.

its maximum during summer with a continuous increase over the years and includes different types of fast ships (Di-Méglio et al., 2010). Hence, there is a large overlap of traffic high density areas and sperm whale favourable habitats (David and Di-Méglio, 2010). Collision avoidance relies on the ability of whales or ship crew to detect each other. Whenever conditions are such that ship crew are not able to perform either detection or manoeuvre, avoidance only depends on the whale ability to detect a vessel, eventually identify it as a threat (depending on course and speed), and then to achieve an escape manoeuvre.

Speed has been identified as a key factor in the ship-strike issue, because it contributes to a higher collision mortality (Vanderlaan and Taggart, 2007). Speed also plays a major role in perception of a closing boat and to whale escape success (Laist et al., 2001). The auditory perception of approaching vessels was suspected to be a contributing factor in ship-strikes affecting northern right whales (Terhune and Verboom, 1999). Sound propagation in stratified waters is known to be strongly anisotropic (Ürick, 1975): near surface sound velocity profiles (SVP) are characterized by one or more inflexion points. Ray-tracing modelling showed that, under Mediterranean summer stratified conditions, a drop of more than 20 dB exists in the sound transmitted by an approaching vessel to a surfacing whale, as compared to transmission losses predicted by a spherical spreading law (Gannier and Marty, 2005). Such a stratified density situation occurs in offshore waters of the northern Mediterranean Sea from mid-spring to late autumn. Conversely, the water column is more homogeneous in terms of density during winter and early spring.

This study intended to show that summer stratified water conditions are more likely to favour collisions than winter situation. We modelled the sound levels received by a sperm whale during the approach of vessels on a collision course. We compared two sound propagation cases, winter and summer, to provide evidence that summer was inherently more critical. We focused on sperm whales, because they are difficult to detect visually, a consequence of their foraging dive cycle, and they seem to be frequent victims of ship-strikes in Mediterranean and other temperate seas.

2. Material and methods

The aim of our study was to show that ship-strike risks were strongly influenced by vessel noise propagation, and much higher during summer. Our study dealt with transmission loss modelling for two vessel types approaching a whale on a collision course: the receiver was a sperm whale which was considered during two critical parts of its foraging cycle, the ascending phase and the surface breathing phase.

2.1. Area of study, species distribution and dive cycle

Sperm whales are common in the NW Mediterranean Sea (Gannier et al., 2002), and more frequent in the Ligurian Sea in summer and autumn (Laran and Drouot-Dulau, 2007). Sperm whales are more abundant along the continental slope of Provence and western Riviera (Gannier et al., 2002). A recent report on vessel traffic evolution (Di-Méglio et al., 2010) outlined that the liguro-provençal continental slope is highly frequented by merchant ships year-round. The central Ligurian Sea is affected by passenger and ferry traffic between the continental coast of France and Italy, and the islands of Corsica and Sardinia, including a seasonal component. Although it is not accounted for in reports, we observed a substantial increase of large and fast motor-yacht traffic during the last ten years, those vessels frequently transiting along continental slope. Both distribution pattern and ship traffic justified our choice of a location off the Ligurian continental slope for acoustic reception simulation, with 1500 m depth (around 43°45′N/008°15′E).

The collision risk is totally dependent on the whale presence close to the surface. Sperm whale feeding activity cycles in the Mediterranean include dives about 45 min in average duration and whales stay about 9 min at the surface for breathing purposes (Watwood et al., 2006; Gannier et al., 2012). Precise dive cycles have been obtained from tagged animals: in the central Ligurian Sea, a whale was observed to forage at 800–900 m depth for about 29 min and then to ascend to the surface with a mean vertical rate of about 1.5 m/s (Watwood et al., 2006). Sperm whales were observed to follow similar diving patterns continuously during the day, with few resting phase at the surface (Teloni, 2005). During their breathing phases, they usually stay at the surface without performing dives.

2.2. Collision scenarios

Our simulation was based on "virtual collision" scenarios for which a vessel was supposed to approach a whale on a direct collision path. For the surface phase, sperm whales were assumed to be breathing 10 min, receiving acoustic levels at a depth of 2 m (approximately equivalent to the immersion of their lower jaw). The dive ascending phase was studied according to results mentioned above (Watwood et al., 2006): the sperm whale was considered to ascend from 800 m at a vertical speed of 1.5 m/s. Received levels (RL) were expressed as a function of time remaining before "virtual collision", taking the critical case of a whale lying or surfacing right on the vessel pathway. We assumed that whale surface speed was equal to 0 in order to reach simpler results. We did not attempt to take account of whale hearing sensitivity and directionality.

As we focused on the seasonal aspect of collisions, scenarios were simulated for the winter and the summer. March was chosen as the most illustrative month of the winter period in the Ligurian Sea: sperm whales are regularly observed in the area from late winter (Laran and Drouot-Dulau, 2007). August was chosen as a typical summer situation: the strongest stratification in subsuperficial waters is encountered during mid-summer. Sea temperatures, densities and sound velocities corresponding to these periods were extracted from Levitus database (Fig. 2).

2.3. Vessels as a sound source

The two vessel types considered in this study were (1) a conventional container ship with a cruising speed of 15 knots, and (2), a fast ferry with a cruising speed of 37 knots. For both vessels, the sound source was supposed to be located 5 m below surface. The vessel noise was considered as omnidirectional, although