

## Exposure and behavioural response of satellite-tracked Cuvier's beaked whales (*Ziphius cavirostris*) to naval traffic in the western Mediterranean Sea

### Abstract

Cuvier's beaked whale (*Ziphius cavirostris* G. Cuvier, 1823) is the only Ziphiidae species commonly found in the Mediterranean Sea. The Mediterranean population has been listed as 'Vulnerable' in the IUCN Red Data List as a result of the limited number of mature individuals (< 10,000) and the high genetic differentiation and isolation from the neighbouring Eastern North Atlantic. Moreover, recent genetic assessments found that Cuvier's beaked whales inhabiting the Mediterranean Sea are clustered in two different evolutionarily significant units (ESUs) belonging to each distinct basin, the western and the eastern basins. Such ESUs have low genetic diversity and historical demography indicative of population contraction. One of the Cuvier's beaked whale's high-density areas in the Mediterranean Sea is the Ligurian Sea, where the 'International Sanctuary for Protection of Mediterranean Marine Mammals', the Pelagos Sanctuary, is located. Facing the Sanctuary are densely inhabited coastlines, with economically important urban, industrial, touristic, and agricultural activities. As a consequence, the maritime traffic in its waters is particularly intense with noise levels that are sufficient to cause behavioural disturbance to cetaceans. The small population size, the high degree of site-fidelity, and the genetic structure of the Mediterranean Cuvier's beaked whales may render them particularly vulnerable to such intense shipping disturbance. In this study, we estimated the exposure of Cuvier's beaked whale in the Ligurian Sea to shipping disturbance and the potential changes in its diving behaviour and movement pattern. First, we started by analysing the horizontal and vertical movement separately, using the first location and diving profile data collected from satellite-linked depth-recording tags deployed on eight animals in this area. The locations nonuniformly collected over deployment time, were fit by a Continuous-Time Correlated Random Walk model (CTCRWs) to simulate 100 1-hour resolution tracks for each individual. Subsequently, we investigated the spatial use and movement pattern of the tagged animals by calculating the minimum convex polygons, the 95% and 50% Kernel density estimates and their respective topographic metrics (bathymetric depth, slope, distance to shelf break), and the net squared displacement from each individual 100 tracks. We found that Cuvier's beaked whales in the Ligurian Sea moved inside small areas (less than 5186 km<sup>2</sup>), mostly using waters above flat (median slope = 2.8°, ranging from 0.0° to 25.0°) and deep seafloor (median bathymetry = 2317 m, ranging from 807 to 2613 m), and did not displace more than 70 km from the deployment location exhibiting the typical 'home range' movement pattern strategy. Diving behaviour and its variation with time-of-day, lunar illumination and bathymetry was analysed after time series depth samples processing to define dives and surfacing events and classify the dives. *Ziphius* is known to perform two types of dives: long, deep foraging dives and shorter, shallower dives. However, unlike other Cuvier's beaked whale populations, the maximum depths of the dives in our study showed a highly trimodal distribution, with a third additional mode centred at 375-425 m. These dives, classified as deep dives (named type 1), are performed in waters above slightly deeper seafloor and they were found to replace the deeper deep dives (named type 2) during the day. Diel variations in diving behaviour were also found in shallow dives depth, duration, and rate, IDDI's duration and number of consecutive shallow dives, maximum surfacing duration and percentage of time spent at the surface and in shallow dive. Whereas lunar illumination did not affect Cuvier's beaked whale diving behaviour. The results obtained from the analysis of the horizontal and vertical movements were finally used in conjunction with ship locations data derived from Automatic Identification System (AIS) to quantify the marine traffic within a range of 10 km of tagged animals and analyse their behavioural change when exposed to vessels by predicting twelve disturbance metrics using Linear and Generalized Linear Mixed-Effects Models. Our results showed that Cuvier's beaked whales in the Ligurian Sea are chronically exposed to high levels of shipping disturbance. On average, *Ziphius* encountered ships for 31 % (S.D.: ± 9 %) of the deployment duration, with individual exposure ranging from 19 % to 47 %. The traffic to which tagged whales were exposed was predominantly composed of passenger (32 %), followed by pleasure (26 %) and cargo (25 %) vessels. During the encounters, ships travelled with a median average speed of 13 kt (ranging from 1 to 42 kt) and approached the tagged whales up to a median value of 4 km ranging from 4 m to 10 km. The median encounter duration was 40 minutes. The shortest exposure lasted less than 1 minute and the longest was 40 hours. Finally, our study showed that the presence of ships around the animals causes significant changes in their diving behaviour, with possible repercussions on the foraging

success. In a scenario of increasing maritime traffic, these behavioural changes are likely to become chronic, with effects on the health and the vital rates of the western Mediterranean Cuvier's beaked whale inhabiting this limited area characterized by intense shipping traffic. Therefore, it is crucial to learn about the long-term consequences of such an increasing disturbance on this population, to implement an effective conservation policy.