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Cuvier's beaked whale *(Ziphius cavirostris)* diving behavior as obtained by visual observation methods and consequences in terms of visual detection during surveys

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Abstract. We studied Cuvier's beaked whale (*Ziphius cavirostris*) behavior in the northern Mediterranean Sea, using conventional boat-based survey methods, including a towed hydrophone array. Between 2007 and 2012, 18 ziphius groups were sighted with suitable weather and sea conditions and data were collected during 80 minutes in average for each group. The observed surface/dive sequences followed the beaked whales specific diving pattern, with feeding dives (61 minutes long in average) separated by series of breathing phases (178 secondes long in average) and non-feeding dives (12.2 minutes long average). Our results are consistent with those obtained worldwide with tagging techniques.

Keywords: *Ziphius cavirostris*, Mediterranean Sea, behavior, boat survey, dive cycle.

Résumé. **Le comportement de plongée du Ziphius de Cuvier (*Ziphius cavirostris*) étudié par observation visuelle - Conséquences pour la détection visuelle durant les prospections**. Nous avons étudié le comportement de groupes de Ziphius de Cuvier (*Ziphius cavirostris*) en Méditerranée nord-occidentale, à l'aide de techniques classiques d'observation, avec un bateau de 12 m équipé d'un hydrophone remorqué. Entre 2007 et 2012, 18 groupes de ziphius ont été étudiés avec des conditions d'observation adaptées et les données ont été collectées pendant 80 minutes en moyenne pour chaque groupe. Nous avons trouvé des cycles de sonde/surface classiques pour les ziphiidés: des sondes de prédation de 61 minutes en moyenne, entrecoupées de séquences de respirations (178 secondes en moyenne) et de sondes de récupération de 12.2 minutes en moyenne. Nos résultats sont comparables à ce qui a été déterminé dans plusieurs régions du monde grâce à des techniques de taggage.

Mots-clés : *Ziphius cavirostris*, Méditerranée, comportement, prospection en mer, cycle de sonde.

Introduction

Ziphiids can easily be missed during visual and acoustic surveys because they spend the majority of their time underwater and are often unconspicuous while at the surface, and they only vocalize for some 20 % of their time (Aguilar de Soto *et al*., 2012). This causes problems

to estimate their abundance from visual and acoustic surveys, because the availability bias (derived from the proportion of time a whale is visible at the surface, or vocalizing) is high and difficult to determine (Barlow *et al*., 2006; 2013). This is also a conservation problem during military sonar operations since most mitigation techniques rely on the visual detection of whales (Dolman *et al*., 2009). Tagging experiments have been intensively used to evaluate the beaked whale surface availability and dive cycle (Tyack *et al*., 2006; Johnson *et al*., 2009). It was determined that beaked whales perform complex dive cycles, comprising one deep and long feeding dive (60 minutes or more), followed by a series of shorter and shallower non-feeding dives (typically less than 20 minutes). However, the tagging technique is not widely available and requires contact with cetaceans, which may alter cetacean behavior during one full dive, or more. To study Cuvier's beaked whale (*Ziphius cavirostris*) surface/dive cycles, conventional boat-based visual observation is also useful, as long as weather conditions enable continuous data collection. We studied the surface-dive cycles of Cuvier's beaked whales (CBW) in the northwestern Mediterranean from 2007 to 2012, using conventional sailboat observation techniques aided with a 32 kHz or 48 kHz bandwidth hydrophone system.

Material and methods

Our survey platform was a 12 meter sailboat, powered by a 75 hp auxiliary engine: while on search, an average speed of 2.5 $m.s^{-1}$ (5 knots) could be obtained under all weather conditions. This boat has been used for Groupe de Recherche sur les Cétacés since 1995, with towed hydrophones.

Ziphius schools were located by sampling an area previously identified as favorable, mostly in the northern/central Tyrrhenian Sea (Gannier, 2011), using combined visual (four active observers) and acoustic techniques (100 m stereo towed hydrophone in 2007-2008, or 200 m in 2010-2012). Sampling was carried out only with wind equal to or less than Beaufort 2. The hydrophone and pre-amplifier bandwidth was 0.2-32 kHz or 0.2-48 kHz (respectively for 2007-2008 and 2010-2012) in order to be compatible with CBW feeding clicks frequency range: Johnson *et al*. (2004) determined the spectral energy to be maximal at 40 kHz, but click power started below 20 kHz for CBW.

Once the whales were visually detected they were approached to a distance of about 300 m, and their surface/dive activity was observed and measured with binoculars and stopwatch. This focal follow lasted as long as possible in order to document successive surface and dive episodes. The hydrophone was used to determine

when the whales engaged in a deep feeding dive, as Tyack *et al*. (2006) showed that CBW usually only click when engaged in such a feeding dive. This technique proved efficient whenever the boat was static (no water flow noise) and the diving whale at less than 500 m horizontal distance. This field work was extremely demanding in terms of (fine) weather conditions.

The whales were typically observed from a minimal distance of 200 m, hence minimizing the risk of natural behavior disruption. However, on some occasions, ziphius schools closed our sailboat during several minutes. Most surface/dive observations were carried out in the Tyrrhenian Sea between 2007 and 2012.

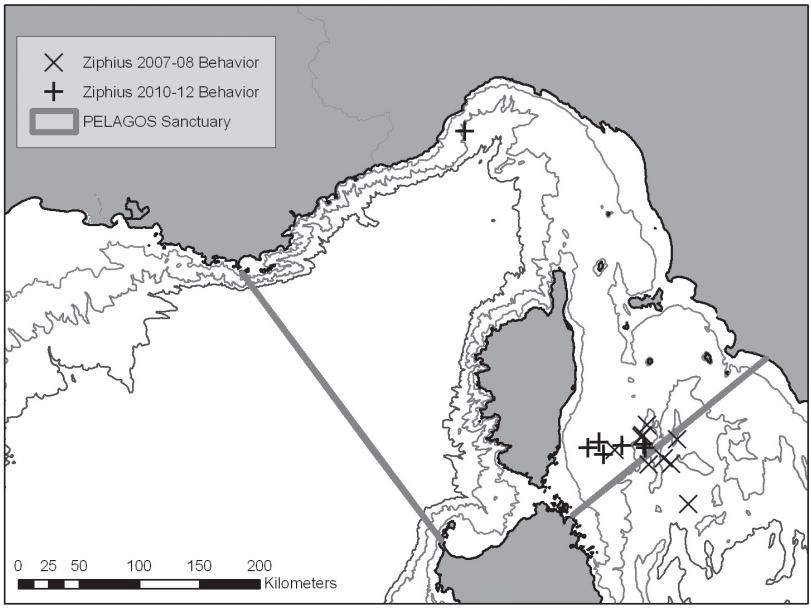

Figure 1. Locations of Cuvier's beaked whale groups, between 2007 and 2012.These locations relate to CBW groups on which focal-follow observation was carried out.

Results

Because very good sea conditions were required to carry out this research, only 18 ziphius groups could be studied from 2007 to 2012 (Fig. 1), among which seven were monitored over a prolonged period (global average observation duration = 80.1 minutes). A total of 24 hours and 16 minutes were spent in monitoring from 2007 to 2012, including 12 hours and 19 minutes from 2010 to 2012. Among the ziphius groups observed during our behavior study, school size

averaged 2.4 (range 1-8). In large groups, the behavior timing was based on focal individuals, the most conspicuous. A total of 61 dives and 63 surface sequences were timed (Table I).

Table I. Data set used for the surface/dive study (2007-2012). For feeding dives, numbers in brackets indicate dives for which no duration could be determined, because whale surfacing could not be observed.

Date	Hour	School size	Number of feeding dives	Number of other dives	Number of surface sequences
14/07/07	13:17	2	1	5	6
15/07/07	7:59	3	(1)	3	3
15/07/07	14:16	3	(1)	4	4
16/07/07	6:25	1	(1)	1	1
16/07/08	15:58	1	(1)	3	4
24/07/08	13:05	1	1	2	2
24/07/08	14:44	2	1 (1)	4	5
31/07/08	10:52	3	(1)	4	5
19/08/08	12:27	2	0	2	2
19/08/08	17:00	3	0	1	1
19/08/08	18:19	2	(1)	2	2
09/08/10	17:47	8	1	0	1
11/07/11	10:41	3	(1)	2	3
11/07/11	13:45	5	1 (1)	8	9
12/07/11	14:30	2	0	3	3
12/07/11	19:56	1	0	2	2
18/08/11	14:42	4	1 (1)	7	8
07/08/12	13:14	2	1	1	2
	-	-	**7 (10)**	54	63

The observed surface/dive sequences followed the beaked whales specific pattern, with long feeding dives separated by series of breathing phases and non-feeding dives (Fig. 2). An average of 5.7 non-feeding dives were performed between two successive feeding dives, as determined on three occasions.

Feeding dives were 61 minutes long on average (SD = 11.2). Non-feeding dives were 12.2 minutes long average (SD = 2.7) and were followed by breathing sequences lasting 178 s on average (SD = 89 s), with one breathing event every 10 s on average.

Depending on group size and synchrony, whales were not always visible during breathing phases: based on two detailed timing follow-ups, ziphius groups were visible at the surface for 2 min during every 3 min breathing phase (about 2/3 of the duration of a breathing sequence).

In summary, we observed surface/dive cycles consisting in one 61 minute feeding dive, followed by 5 or 6 non-feeding dive/breathing phase sequences, each lasting 15.2 min, making a total cycle of 160 minutes in average (Fig. 2).

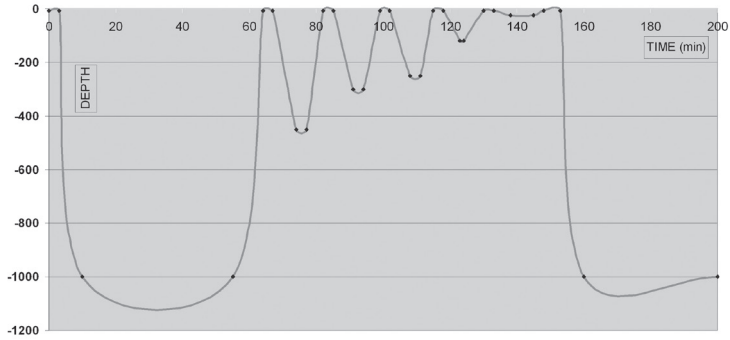

Figure 2. An average Cuvier's beaked whale dive/surface cycle. Depth values are empirical, since they were not collected during our study.

Assuming that ziphius were visible 2/3 of the time during their breathing phases, and taking average dive durations as determined in our study, CBW were available at the surface about 8.4 % of the time during a typical dive-surface cycle in the Mediterranean Sea.

Discussion

Our results are consistent with those obtained by Tyack *et al.* (2006) in the Ligurian Sea, with data from DTag experiments carried out on seven whales in 2003 and 2004 (Table II).

Table II. Dive cycles of Ziphius in the Ligurian Sea as obtained from tagging experiments (Tyack *et al.*, 2006). The code of the tagged whales is composed by the year and the Julian day of the tagging followed by a letter indicating the tagging sequence of the day. Numbers in brackets indicate standard deviations.

Tagged whale code	Average feeding dive duration (min)	Average depth during feeding dives (m)	Number of "shallow" dives between successive deep dives	Mean interval between two deep dives (min)
2003 260a	50.3	824	-	-
2003 263a	55.3 (12.8)	1145	0	61.3 (47.3)
2004 160a	84.5	1322	3	72.9
2004 161a	55.0 (6.4)	937	4	65.8 (19)
2004 161b	54.8 (4.9)	1065	3	56.9 (22)
2004 175a	67.9 (0.8)	1195	1	66.4 (32)
2004 179a	50.8	737	1	98.8
average	**58.0** (11.4)	1070	2.2	**63.4** (31)

For these authors, the average duration of a complete dive cycle is 121 minutes with an average of 2.2 “shallow” dives of 15.2 min mean duration. The difference with our results for average number of “shallow” dives may reflect the methodology: in our case, a whale was considered in “shallow” dive when it was no longer visible at the surface for several minutes, when for Tyack *et al*. (2006) a “shallow” dive was recorded whenever a whale reached an immersion higher than 20 meters. Then, very shallow dives may explain the difference between studies. This possibility is confirmed by Baird *et al*. (2006), from tagging experiments in Hawaii: the authors observed very shallow dive series for CBW: from limited samples, they found an inter-deep-dive interval of about 2 hours, with 3 to 4 intermediate dives between two successive deep feeding dives. Southall *et al*. (2014) found higher number of intermediate dives during tagging experiments off southern California.

From our results and the available literature, it is clear that CBW diving cycle can be variable, depending on location and other non-geographical factors. However, there are always intermediate dives between deep and long excursions, and their determination is necessary for estimating the surface availability of ziphiids.

The probability of detecting ziphius on the track line, based on this availability, was found to be 0.08, close to the value of 0.07 expressed by Barlow *et al*. (2006) from other surface/dive data. This value is applicable in cases of non-limiting detectability conditions, i.e. calm sea and good light, and should be considered as a maximum value in near perfect visual detection conditions. Any degradation in sea state or light conditions would result in a further decrease of the above detection probability. Therefore, it is obvious that a true absence of CBW from a given location can hardly be verified from visual survey only.

Conventional boat-based behavior studies of beaked whales require very fine wind and sea conditions, which were difficult to obtain during our research in the northwestern Mediterranean Sea. From 2010 to 2012, a total of nine weeks of survey time was allocated to the study, and seven focal follows were performed during 13 survey days with Beaufort 0-2 sea conditions. In terms of sighting rates, 21 whales were counted within nine days in the Tyrrhenian Sea (effort of 787 km), giving an average of 2.7 whale/100 km, and four ziphius were sighted in four days in the gulf of Genova (419 km of effort), resulting in 1.1 whale/100 km (Gannier, 2012). Higher sighting rates (4.7 ind./100 km) were previously obtained in the central Tyrrhenian Sea (Gannier, 2011).

Conclusion

Boat-based visual observation provides an useful method to study beaked whales surface-dive sequences. However, it requires very favourable sea conditions and consequently a long survey duration, and an adequate survey platform. Based on our study, the availability bias of Cuvier's beaked whales during visual surveys is very strong, and such surveys deliver heavily down-biased estimates when this effect is not properly accounted for. The very low surface availability of Cuvier's beaked whales also implies that visual mitigation techniques are not sufficiently efficient to mitigate potential hazardous effects during intense sound source emissions, such as military sonars.

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