Day and Night-Time Diving Behavior of Fin Whales in the Western Ligurian Sea

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Abstract-Mediterranean fin whales concentrate in the Ligurian Sea during the summer to feed on large swarms of the euphausiid *Meganyctiphanes norvegica*, known as one of their principal prey in the Northern Hemisphere. The diving behavior of 15 whales was studied, within a long-term study on the habitat use of this species, between 1998-2002 by using suction-cup attached tags, equipped with velocity-time-depth-recorders. Here we report the results of three successful taggings, during which the tag remained on the whales for a minimum of 6 hours (mean time = 8h 9min), and during which the whales reached depths of at least 468 m (estimated maximum depth 565 m). The diving behavior performed by the 3 tagged individuals differed considerably. Two whales started to perform deep dives (>400 m) after 5 PM, in coincidence with the presumed upward migration of the deep scattering layer, while until 5 PM they remained close to the surface performing 45 dives shallower than 100 m (mean depth = 27.8 m, SD = 19.0). The third whale was tagged at 11:50 AM and till 6 PM performed a series of 19 deep dives (mean depth = 449.0 m, SD = 22.5). One of the deployed tags remained on the whale till 10 PM, and showed a steady decrease in diving depth, dropping from 400 m at 7:40 PM to less than 50 m at 9:50 PM. The data presented here suggest that Mediterranean fin whales are unlikely to dive deeper than 600 m. The different depths reached by the tagged whales at the same time of day in different days indicate that prey distribution throughout the water column changes from time to time. Moreover, the diving behavior performed by the second whale suggests that fin whales in the Ligurian Sea follow the deep scattering layer's diel upward migration.

I. INTRODUCTION

This paper presents insights on the diving behavior of Mediterranean fin whales (*Balaenoptera physalus*) in the western Ligurian Sea. The data were collected during the summer months between 1998 and 2002, within a long-term study on the ecology of the species in the area. The aim of this research was to describe the diving behavior of fin whales while in their major feeding ground in the Mediterranean Sea, relating it to the diel vertical upward migration of the deep scattering layer.

The fin whale is the only regular mysticete species present in the Mediterranean Sea, where it concentrates in the northwestern part of the basin during the summer months [1].

Biopsy samples, collected for genetic analyses in the Ligurian Sea, revealed that Mediterranean fin whales constitute an isolated population, with scarce interaction with the North Atlantic conspecifics [2].

A line transect survey conducted in the western Mediterranean Sea has estimated the fin whales population at 3500 individuals during the summer [3], with approximately 900 of these whales that concentrate in the Corso-Ligurian-Provençal Basin, known as their major Mediterranean feeding area [4, 5].

The study area throughout the research project included the continental shelf and offshore waters of the western Ligurian Sea (Fig. 1).

This area of approximately 24 000 Km^2 has a mean depth of 2300 m and is characterized by a well-defined cyclonic circulation active all year round, which enhances strong up-welling currents and maintains a low surface temperature [6, 7].

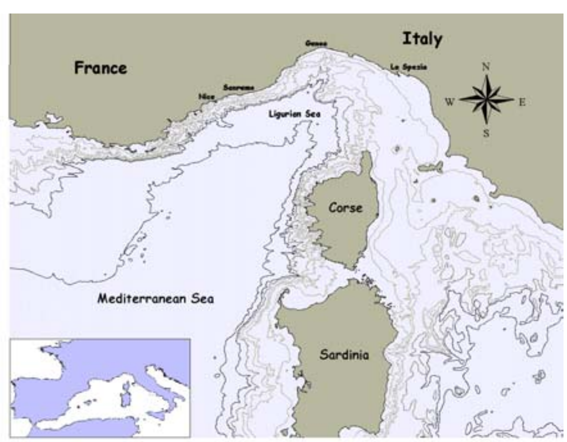

Fig. 1 – The Corso-Ligurian-Provençal Basin and the study area.

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Thanks to these particular oceanographic features, the Corso-Ligurian-Provençal Basin represents an area of high productivity, with a large biomass of euphausiids dominated by *Meganyctiphanes norvegica* [8], counting for the 65% of the euphausiid population [9], and being considered one of the principal prey species of fin whales [10].

The species remains at depths deeper than 800-1000 m during the day and migrates towards the upper layers (35-150 m) during the night, with diel vertical migrations of variable amplitude, ranging from 100 m in February to 600 m in August [11].

Consequently, the Corso-Ligurian-Provençal Basin hosts a richer cetacean fauna compared to bordering regions, characterized by lower primary productivity [12]. Such cetaceans abundance brought - in November 1999 - Italy, France and the Monaco Principality to sign a joint declaration for the establishment of an International Sanctuary for the protection of marine mammals.

II. MATERIALS AND METHODS

During the study period research cruises were conducted in the summer months on board of a 20 m long motor-sailer (Fig. 2), equipped with a 4.50 m long inflatable craft.

The whales were tagged with two different instruments: a VHF radio transmitter (2-5902, Advanced Telemetry Systems, Isanti, Minnesota, USA) and a velocity-time-depth-recorder (Mk6, Wildlife Computers, Redmond, Washington, USA).

Fig. 2 – The research vessel.

The radio had a frequency of 150 MHz and was used to track the movements of the animals while at the surface and to retrieve the instruments after spontaneous detachment from the back of the whales. The signal emitted by the transmitters was received by a VHF receiver (R2000, Advanced Telemetry Systems) positioned onboard the research vessel, while the beam of the animal was given by an automatic-direction-finder (ADF-system, Advanced Telemetry Systems) equipped with four directional Yagi antennas.

The v-TDR was programmed to measure relative speed of the animal, depth of dives, temperature of the water and light level at 2 seconds intervals; the v-TDR had a depth range of 0-500 m, with a depth sensor accuracy of 1% of the reading $\pm$ 2 m. These instruments were encased in an epoxy resin support (Fig. 3), mixed with glass micro-bubbles to provide buoyancy; the tag, measuring 20 cm in length and weighting 375 g in air, was remotely attached to the animals by means of a suction cup.

The whales were approached with the inflatable craft or with the research vessel and tags were deployed using a 6 m long aluminum pole or a modified spear gun (Fig. 4). In order to increase the time of permanence on the whales and collect sloughed skin for genetic analyses, the interior of the suction cup was covered with a thin layer of silicon grease.

Fig. 3 – The tag with the v-TDR and VHF radio.

Fig. 4 – The tagging procedure.

III. RESULTS

Fifteen fin whales have been tagged between 1998 and 2002, totaling over 35 h of dive data. The sensors remained on the body of the whales (Fig. 5) for different periods of time, varying from few minutes to more than 8 hours.

In this paper we report the diving behavior of three whales, one tagged in 1998 and the other two in 2002 (Tab. 1); these data were selected since the time of attachment of the tag lasted at least 6 hours and depths of dives reached more than 450 m, thus allowing comparison of the recorded data.

Fig. 5 – A whale with an attached tag.

Tab. 1 – The selected data.

Whale code	Date	Time	Duration
Bp 483	19 July 98	09:45 to 17:50	8h 5min
Bp 626	19 July 02	14:45 to 22:00	7h 15min
Bp 627	20 July 02	11:48 to 17:59	6h 11min

The first whale (Bp 483) was sighted on the 19th of July 1998, it was tagged at 9:45 AM and followed since 6:08 PM, when the tag, spontaneously detached from the animal, was recovered and the data were downloaded in a laptop.

Fig. 6 shows the dive profile of Bp 483; the collected data indicates that before 5:00 PM the whale remained close to the surface performing 35 shallow dives of less than 100 m (mean depth = 26.2 m, SD = 15.9). At 5:00 PM the whale started to perform deeper dives, reaching in two consecutive occasions depths of at least 470 m; during the third dive the tag detached at 420 m and came afloat to the surface [13].

The second whale, Bp 626, was sighted and tagged on the 19th of July 2002 at 2:45 PM; the tag detached from the animal at 10:00 PM and was recovered the next day at 7:45 AM. Fig. 7 presents the dive profile of this whale. The data show that before 5:00 PM the whale remained in proximity of the surface performing 10 dives shallower than 100 m (mean depth = 33.6 m, SD = 27.7). At 5:00 PM the whale started to perform deeper dives, reaching depths of at least 466 m. At 7:40 PM the whale started to decrease its diving depths, dropping steadily from 400 m to less than 50 m at 9:50 PM.

The third whale, Bp 627, was tagged on the 20th of July 2002 at 11:50 AM and the sensors remained on the animal till 6:00 PM. During that time the whale performed a series of 19 deep dives (mean depth = 449.0 m, SD = 22.5); while performing the last dive the whale lost the tag at 364 m, which was then recovered once at the surface (Fig. 8).

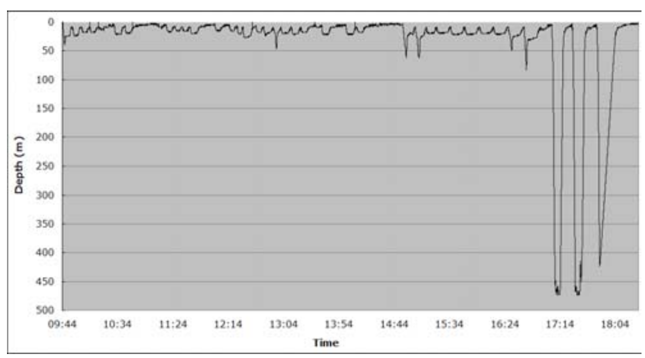

Fig. 6 – The dive profile of Bp 483.

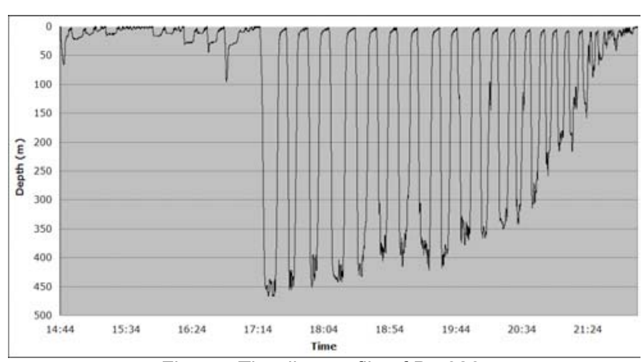

Fig. 7 – The dive profile of Bp 626.

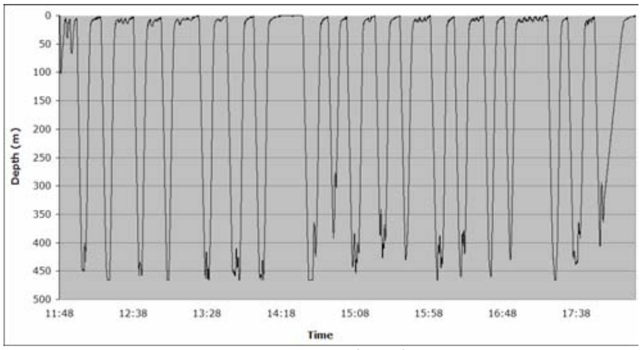

Fig. 8 – The dive profile of Bp 627.

The v-TDRs also recorded the temperature of the water, expressed in degrees Celsius, and the light level, which was *a-posteriori* converted to illuminance (lux) as described in [14] using the following equation: ln (lux) = 0.13 x TDR output – 12. Temperature and illuminance were plotted versus depth (Figs. 9 and 10, respectively) to highlight possible fluctuations in these values between the three different days, to explain the different diving behavior displayed by the tagged fin whales.

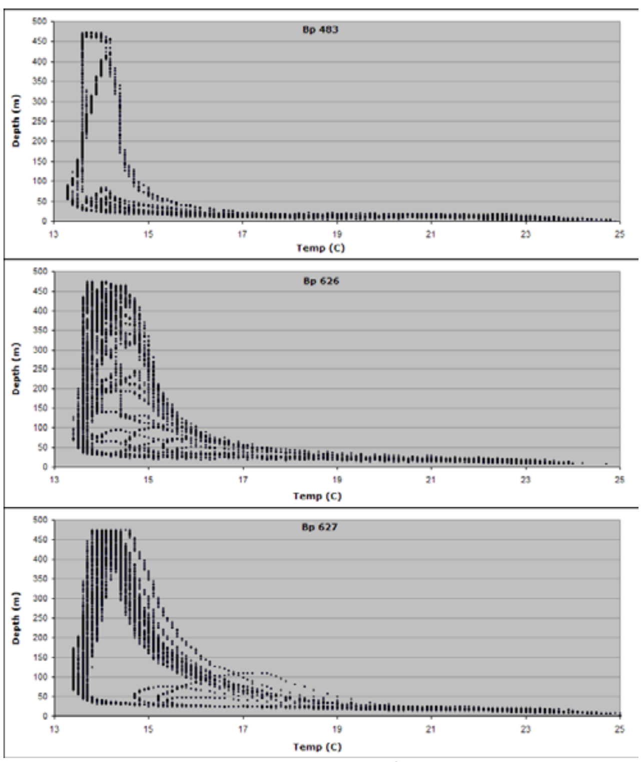

Fig. 9 – Temperature vs. depth for the 3 whales.

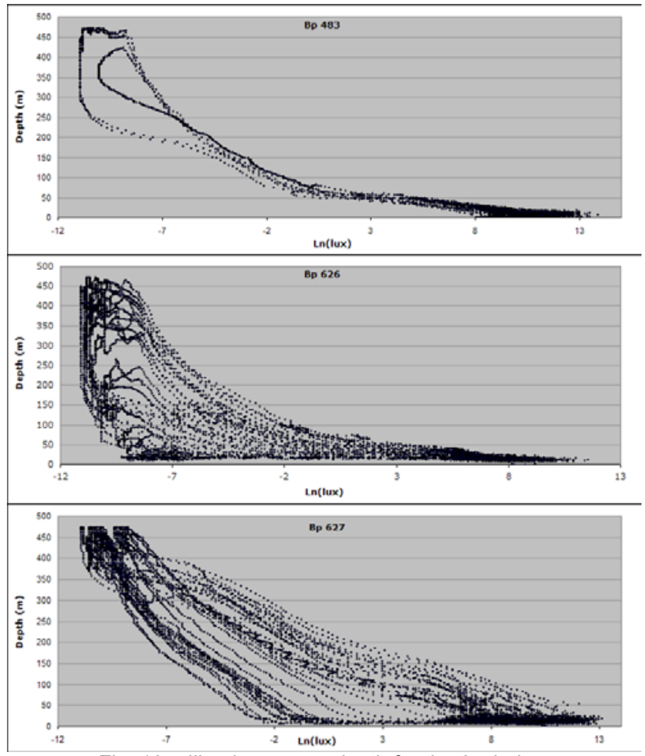

Fig. 10 – Illuminance vs. depth for the 3 whales.

Cloud coverage was also analyzed for the three different days in order to monitor possible factors that could affect the diving behavior of the studied whales. The data, obtained from the Osservatorio di Imperia, located on the coast in proximity of the operation area, are presented in Tab. 2.

Tab. 2 – Cloud coverage values (1-10).

Time	19 July 98	19 July 02	20 July 02
08:00	4 (haze)	0 (clear sky)	8 (haze)
14:00	5 (haze)	1 (clear sky)	3 (clear sky)
19:00	0 (clear sky)	2 (clear sky)	3 (clear sky)

IV. CONCLUSIONS

The deep diving behavior presented here appears most likely related to feeding. Fin whales have been reported to concentrate in the study area for feeding purposes, in addition this area has been indicated as the principal feeding ground for the species in the Mediterranean Sea [1]. Most of the deep dives performed by the three whales presented a series of ascending and descending vertical excursions in proximity of the bottom of each dive, with amplitudes up to 50 m. These spikes have been described for fin and blue whales in the Pacific Ocean and in the Sea of Cortez, and have been interpreted as feeding lunges [15].

According to the distribution of *M. norvegica* throughout the water column [8, 16], fin whales Bp 483 and Bp 626 showed a "predictable" diving/feeding behavior [13], by remaining close to the surface during most of the day and starting to perform deep dives in the late afternoon, in coincidence with the diel vertical migration of their prey. This premise is further supported by the behavior of Bp 626, which shows association to the deep scattering layer (DSL), following its migration towards the surface and presumably feeding on it (Fig. 7). This behavior has been described for another cetacean species in the Ligurian Sea [17], where the diving habits of pilot whales were studied. Those data provided evidence of deep dives (max 648 m) performed in the late afternoon towards the deep scattering layer to feed on squids associated to it, while during the night deep diving behavior was not recorded, with the pilot whales remaining close to the surface.

Unlike the first two whales, Bp 627 behaved in a completely unpredictable way, performing a series of deep dives in the late morning and early afternoon. This behavior may be attributed to feeding or to scouting dives in search of food; however, the depths reached by these dives and in particular their repetitiveness support the hypothesis of feeding dives. This hypothesis is further corroborated by the time vs. depth profile (Fig. 8), which presents one or more spikes at the bottom of some dives [15], thus leading to consider these dives as foraging ones.

The presumed foraging behavior observed in the first two whales is in agreement with the description of the nyctemeral migration of the Mediterranean krill [8, 9], while the third case seems in contrast with it. We propose that prey distribution throughout the water column may be highly variable, and may change in depth and patchiness from day to day, rendering fin whales' prey available also during daylight hours. However, at present the available data to support this hypothesis are still fragmented, relying only on one case, and do not allow any speculation on the behavior displayed by the third whale.

Different factors may induce changes in the vertical distribution and amplitude of movements of the DSL; our attention focused on temperature and light level, which were recorded by the applied instruments, and cloud coverage, derived by inland measurements. The graphs (Figs. 9 and 10) describing these parameters in respect to depth of dives did not evidence any visible difference in the observed values and no correlation between the different diving behavior of the whales was found. The monitoring of the cloud coverage did not allow any interpretation too, indicating similar weather conditions in the three days of data collection.

The depth sensor mounted on the TDRs had a range of 0-500 m and it stopped recording data when exceeding depths of approximately 470 m, that represents the instrumental limit of the sensor. This resulted in a flat horizontal line at the bottom of some dives, lasting up to 156 s (Bp 627); therefore, given a mean ascent and descent speed of 1.7 m s^{-1} – calculated for the 100 m before and after the flat horizontal line – we can estimate a maximum diving depth of 598 m, if the whale had gone straight up and down, as also described in [13]. Our hypothesis is that fin whales diving range lies within this value of approximately 600 m.

More effort should be dedicated to studying the diving behavior of this species in the Ligurian Sea, where particular oceanographic conditions render the area quite "unique" in terms of krill distribution and fin whales foraging behavior. In particular we suggest collecting more parameters regarding the whales, like diving angle, stroke and glide frequency [18], and orientation (pitch, roll, heading of the animal), to describe in more detail the underwater behavior of these animals. The concurrent deployment of XBTs or XCTDs would allow direct sampling of the water column, shedding light on the possible factors influencing fin whales diving behavior.

We propose the collection of diving data covering the 24 hours period; this would allow a more complete description of the foraging behavior and in particular will confirm the association of fin whales with the deep scattering layer. Moreover, this will investigate whether fin whales follow also the downward vertical migration, performed by the krill early in the morning.

We also recommend investigating the winter diving behavior, to assess whether the Mediterranean fin whales have extended their feeding activities in the winter, as proposed by [1]. This would most likely produce different results from the summer ones, since prey abundance peaks in February at shallower depths (200 m), with diel vertical migrations of approximately 100 m [9].

In conclusion, the provided data indicate that feeding fin whales in the western Ligurian Sea may be good indicators of the vertical distribution of the DSL, and TDR data can also be used to track the diel vertical migration of the Mediterranean krill.

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