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MEDITERRANEAN FIN WHALE'S (*BALAENOPTERA PHYSALUS*) RESPONSE TO SMALL VESSELS AND BIOPSY SAMPLING ASSESSED THROUGH PASSIVE TRACKING AND TIMING OF RESPIRATION

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ABSTRACT

Twenty-five fin whales (*Balaenoptera physalus*) were individually studied in their Ligurian Sea feeding grounds to describe and measure short-term responses to the close approach of a fast-moving inflatable craft from which biopsy samples were collected. Passive tracking was performed with a new technique based on simultaneous determination of (1) position of the observation vessel, (2) laser-measured distance between the target animal and the observation vessel, and (3) azimuth of the target animal with respect to the observation vessel. Tracking was combined with timing of the surfacing intervals. Two different

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swimming-surfacing patterns supposed to be related to feeding and traveling, respectively, were observed. Supposed feeding whales reacted to disturbance by changing their behavior into traveling. Two different avoidance strategies were performed simultaneously by the whales: travel at increased velocity and reduction of the time spent at the surface. After the disturbance ceased, the surfacing activity never completely reverted to predisturbance conditions during one hour of postexposure control and supposed feeding behavior appeared to be suspended indefinitely. Our results suggest the need for whale watching regulations in the Ligurian Sea, particularly as far as presumed feeding whales are concerned.

Key words: *Balaenoptera physalus*, fin whale, human-caused disturbance, laser range-finder, passive tracking, behavior, whale watching, Mediterranean, timing of respiration.

Fin whales (*Balaenoptera physalus*) are the only mysticetes found regularly in the Mediterranean Sea. During summer an estimated 900 individuals concentrate in feeding grounds mostly located in the western part of the Corsican-Ligurian Basin (Forcada *et al.* 1995). There is strong genetic evidence that this population is reproductively isolated from Atlantic populations (Bérubé *et al.* 1998). Having a restricted geographical and feeding range, in an area of heavy boat traffic, Mediterranean fin whales appear particularly vulnerable to human impact (Forcada *et al.* 1996), despite the fact that the Ligurian, the Corsican, and part of the Tyrrhenian seas have been declared a "Mediterranean Sanctuary for Marine Mammals" with an Agreement signed in Rome on 25 November 1999 by France, Italy, and Monaco.

Besides existing threats, one more can be envisaged. The presence of fin whales off developed coasts provides the potential for whale watching as a commercial enterprise. At present this industry is rather small, but expansion is foreseeable. This may increase the risk of whale harassment that has been described for other species in areas where whale watching has rapidly expanded in the last two decades (Reeves 1977, Baker and Herman 1989, Stone *et al.* 1992, Corkeron 1995). For these reasons behavioral studies to assess the Mediterranean fin whales' tolerance to human-caused disturbance appeared necessary.

The degree of disturbance caused by whale watching has been the focus of debate (Reeves 1977, Reeves 1992). Effects of anthropogenic disturbance may range from momentary alteration of behavior (Gauthier and Sears 1999) to possible interference with reproduction or feeding (Richardson *et al.* 1990, Miller *et al.* 2000). Even though our study was conducted on fin whale feeding grounds, the foraging of fin whales cannot be easily detected from the surface because they apparently feed at considerable depth (Relini *et al.* 1992, Panigada *et al.* 1999). So a direct evaluation of possible interference with foraging was difficult.

As indicators of disturbance, the following parameters were most commonly used in previous studies: respiration rates, surfacing-dive sequences, velocity and orientation. In humpback whales (*Megaptera novaeangliae*), blow intervals and dive times were affected by the presence of boats (Baker and Herman 1989, Corkeron 1995). Similar, although "subtle," changes were shown in bowhead whales (*Balaena mysticetus*) feeding in the Canadian Beaufort Sea where drilling and dredging noise occurred (Richardson *et al.* 1990). Avoidance reactions in terms of different swimming speed and headings were described in southern right whales (*Eubalaena australis*) during the calving season in Patagonia (Rivarola *et al.* 2001). Regarding acoustical anthropogenic disturbance, humpbacks tend to perform longer songs during Low Frequency Active Sonar (LFAS) playbacks (Miller *et al.* 2000). Also, in fin whales, surfacing and respiration rates appeared influenced by the presence of boats in a study off the coast of Maine (Stone *et al.* 1992).

Movement parameters of whales are often sampled by shore-based theodolite; however, Mediterranean fin whales are sighted almost exclusively offshore. Other techniques, such as satellite or radio tracking suitable for offshore investigations, are somewhat invasive and have an insufficient temporal resolution for the characterization of specific activities (Joyce *et al.* 1990, Watkins *et al.* 1996).

To test behavioral reactions to disturbance through movement parameters, we developed a new technique of passive tracking using a laser range finder and a GPS (Global Positioning System), combined with the concurrent monitoring of respiration. This allowed tracking at sea, overcoming the limitation of theodolite tracking. The aim of this study was to measure the fin whales' short-term responses to close approach by a fast-moving inflatable boat through changes in ranging behavior and respiration intervals.

Methods

The research was conducted in the western portion of the Ligurian Sea (Fig. 1). Sightings occurred within an area bounded by 42°50′–43°40′N and 7°40–9°10′E. Data were collected from 1995 to 1997 between June and August of each year, aboard a 18-m ketch motorsailer. Whales were approached with a 4.5-m inflatable boat, powered by a 25-hp outboard engine. Target animals were spotted by visually scanning the sea under appropriate sighting conditions defined as: wind speed $\leq$5.4 m/sec and wave height $\leq$0.5 m (corresponding to a Beaufort scale value $\leq$3 and international scale value $\leq$2, respectively). Twenty-five individual fin whales were approached and studied. Concurrent photo-identification showed that the sampled whales were all different individuals.

Whale position as a function of time was determined trigonometrically by a technique based on simultaneous determination of vessel position by GPS (Magellan NAV 5000D, maximum error 15 m) and relative distance and azimuth of target animals computed by means of laser range-finder binoculars ("LRF", Leica Vector 1500 DAES 7 $\times$ 42, class 1). On average, whale positions were determined every 1.7 min, SD = 3.65.

The precision of the LRF system was assessed by tracking a small boat moving along a random course at velocities ranging from 0.8 to 7.1 m sec^{-1} ($\bar{x}$ = 2.8 m sec^{-1}, SD = 1.3) from shore. On the boat a GPS system independently recorded the position at 20-sec intervals. Over a test period of 25 min, the ratio between measurements obtained with LRF and with GPS was 0.960 for the total distance and 0.963 for the average velocity. Surface and tidal currents are minor in the study area, especially in summer, and their influence on the whales' recorded velocity was thus considered negligible (Hela 1963, Albérola *et al.* 1995).

The timing of the whales' respiration was recorded to the nearest second on a hand-held computer (Psion Organizer II). GPS and LRF data were acquired in real time by means of a portable computer running a custom-designed software ("HighWhale") which enabled us to calculate movement and respiration parameters and to display the whales' tracks. To avoid potential ambiguities due to the difficulty of readily distinguishing one surfacing whale from another, only lone

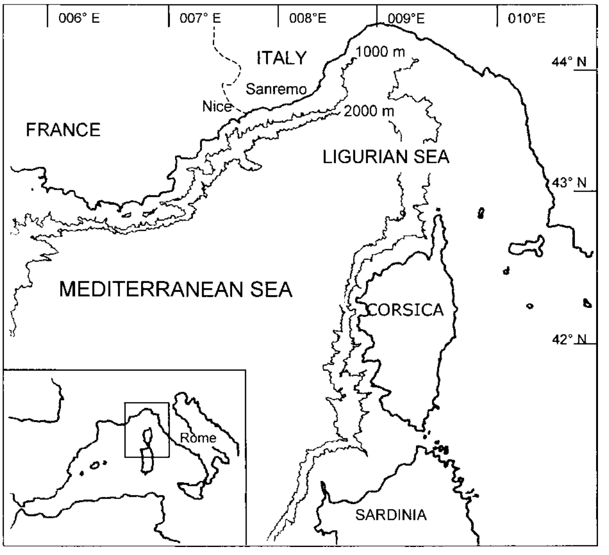

Figure 1. Map of study area.

whales or focal individuals that were easily recognizable (through scars, fin shape, or pigmentation patterns) were studied (group size: $\bar{x}$ = 1.28, SD = 0.54, range 1–3). Data were collected with a repeated-measures design: each target animal was continuously studied during three consecutive phases of the experimental protocol. Each phase lasted approximately one hour (n = 69, $\bar{x}$ = 65 min, SD = 4).

Pre-approach phase—The observation vessel maneuvered at a low, no-wake speed (5 km h^{-1}) and kept at a distance ≥200 m from the animal (unless the whale itself approached the boat).

Approach phase—The whale was approached to within 5–10 m by the inflatable boat, moving with sudden speed (range 0–26 km h^{-1}) and directional changes. Two researchers on board took pictures for photo-identification and a biopsy sample by means of a crossbow. The approaching boat was directed parallel to the whale's track with a slightly convergent route. Close distance could usually be maintained only shortly during surfacing periods, as the whales tended to surface at a certain distance after a dive and had to be approached again.

Post-approach phase—Procedures identical to the pre-approach phase were resumed.

As studies on humpback and fin whales have suggested that reactions to biopsy darting are minimal and short term (Weinrich *et al.* 1991, 1992; Clapham and Mattila 1993; Brown *et al.* 1994; Gauthier and Sears 1999), the effect of the biopsy was not analyzed separately from the prolonged and continuous disturbance caused by the inflatable boat.

Respiration intervals were distinguished from dives on the basis of a log-survivorship analysis (Fagen and Young 1978). Although the analysis was performed on the surfacing intervals of the three phases separately, a single cut-off point of 26 sec was apparent and thus was used for all phases. Twenty-six seconds was consistent with values (25 sec) calculated for this species by Stone *et al.* 1992.

Data were collected on movement, diving, and respiration.

Movement

Index of Linearity—This is the ratio of the net distance between initial and final tracking point over the total distance traveled during the tracking period (Fig. 2).

Velocity (as referred to the sea surface)—The ratio of the total horizontal distance traveled during the tracking period over the total duration of the tracking.

Ranging Index—The diagonal of the minimum area that includes the whale's course, weighted by the duration of the tracking period:

$$\text{Ranging Index} = \frac{\sqrt{(LAT_{\max} - LAT_{\min})^2 + (LONG_{\max} - LONG_{\min})^2}}{T_s}$$

where $LAT_{\max}$ and $LONG_{\max}$ are the highest values for latitude and longitude in the track, expressed in distances (m) from, respectively, the equator and the Greenwich meridian; $LAT_{\min}$ and $LONG_{\min}$ are the lowest values; T_s is the duration of the sample (sec).

Diving Pattern

Dive Time—The interval between two successive blows spaced by 26 sec or more.

Surface Time—Sum of all consecutive blow intervals lasting less than 26 sec.

Percentage of Surfacing—Proportion of sampled time spent at the surface (according to the definition of "Surface Time" given above).

Respiratory Activity

Blow Rate—The number of blows per tracking duration.

Number of Blows—Number of blows per Surface Time.

Blow Interval—Time between two successive blows spaced by less than 26 sec.

Only complete cycles (*i.e.*, complete dives followed by complete surface times) were considered for the analysis. For Dive Time, Surface Time, Number of Blows, and Blow Interval a mean value was calculated for each phase. For Blow Rate, Index of Linearity, Velocity, and Percentage of Surfacing a single value was calculated for each phase.

Results

The total duration of all sample periods was 73 h 55 min. Eighteen samples were obtained from focal individuals observed during the Pre-approach, Approach, and Post-approach phases. One more sample had only Index of Linearity and Velocity data. Observations for six further individuals included only the Pre-approach and Approach phases and were thus excluded from repeated-measure analysis.

One factor ANOVA for repeated measures was performed, followed by a Fisher's LSD (Least Significant Differences) *post hoc* test for comparisons between the three phases (the total duration of sample periods tested in this way was 58 h 3 min). Differences were considered significant at a level of $P < 0.05$. Most of the measured parameters differed significantly during the Approach phase as com-

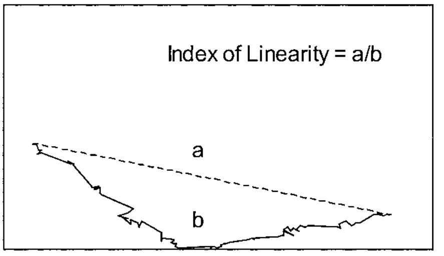

Figure 2. Illustration of how Index of Linearity was calculated for each fin whale's track.

pared with the Pre-approach phase. The disturbance had significant effects on swimming, diving, and respiratory behavior (Table 1).

Swimming-respiratory Parameters

Both Index of Linearity and Velocity increased significantly from Pre-approach to Approach. The Surface Time and the Percentage of Surfacing both decreased, but Blow Interval did not change. Blow Rate and Number of Blows per surfacing both decreased. Dive Time showed no significant changes.

During the Post-approach phase, the Pre-approach condition was regained for Surface Time, Blow Rate, Number of Blows per surfacing. However Index of Linearity and Velocity remained significantly higher, and Percentage of Surfacing remained lower (Table 1).

Movement

The degree of complexity of individual whale movements differed over the three phases as indicated by the frequency distribution of the Index of Linearity (Fig. 3). The Index of Linearity of undisturbed whales appeared to be distributed bimodally, indicating the presence of two distinct moving patterns. The Approach phase produced a shift of eight whales toward the group with higher values (*i.e.*, an increase in linearity), which did not substantially change in the Post-approach phase.

Whales with an Index of Linearity <0.5 used a relatively small mean area (Ranging Index: $\bar{x} = 27.21$ m min^{-1}, SD $= 11.6$), whereas the second group (Index of Linearity $\geqslant 0.5$) used a significantly larger mean area (Ranging Index: $\bar{x} = 59.82$ m min^{-1}, SD $= 29.06$), (Student's t-test, unpaired t-value $= 3.8$, $n_1 = 14$, $n_2 = 11$, $P < 0.01$). Examples of different swimming patterns and their change during the three phases are given in Figure 4.

The general shift from a convoluted to quasi-linear pattern was not the only effect associated with disturbance. Table 2 shows a comparison between the three phases of the study for the same parameters considered in Table 1, when taking into account only those whales which had a quasi-linear swimming pattern during the Pre-approach phase (and did not change thereafter). Having only few repeated measures ($n = 7$) the non-parametric equivalent of repeated measures ANOVA (Friedman's test) was used. No change in Index of Linearity was observed during the three phases. A significant overall effect of "treatments" was shown in Velocity and Percent of Surfacing. Thus, the increase in Velocity occurs also independently

Table 1. Comparison between mean values of the three experimental phases.

	Pre-approach phase (1) $\bar{x} \pm$ SD	Approach phase (2) $\bar{x} \pm$ SD	Post-approach phase (3) $\bar{x} \pm$ SD	*F*	*Post hoc* comparisons
Index of Linearity	0.5 (± 0.3)	0.65 (± 0.2)	0.70 (± 0.2)	8.6	(*) 1 *vs.* 2; 1 *vs.* 3
Velocity (m/sec)	1.3 (± 0.5)	1.6 (± 0.6)	1.6 (± 0.6)	3.5	(*) 1 *vs.* 2; 1 *vs.* 3
Dive Time (sec)	227.5 (± 133.3)	215.1 (± 89.4)	253.1 (± 127.8)	0.6	ns
Surface Time (sec)	90.0 (± 34.6)	56.4 (± 17.2)	75.2 (± 29.6)	7.8	(*) 1 *vs.* 2; 2 *vs.* 3
Percentage of Surfacing	24.0 (± 8.8)	17.6 (± 7.5)	20.1 (± 7.3)	6.7	(*) 1 *vs.* 2; 1 *vs.* 3
Blow Rate (blows/min)	1.1 (± 0.4)	0.9 (± 0.3)	1.0 (± 0.3)	6.9	(*) 1 *vs.* 2; 2 *vs.* 3
Number of Blows per surfacing (N)	5.2 (± 2.4)	3.7 (± 1.1)	5.5 (± 3.6)	3.5	(*) 1 *vs.* 2; 2 *vs.* 3
Blow Interval (sec)	17.1 (± 1.5)	16.4 (± 1.8)	17.0 (± 2.0)	0.7	ns

(*) $P < 0.05$ for one-factor ANOVA, repeated measures (df = 2, n = 19 for Index of Linearity and Velocity, n = 18 for other parameters).

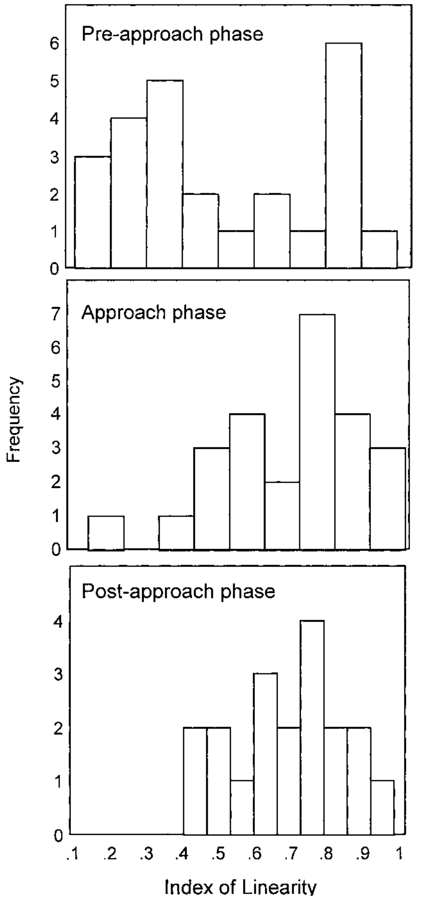

Figure 3. Frequency distribution of Index of Linearity in three experimental phases.

from the shift in swimming pattern. The same is valid for Percentage of Surfacing, which mean value decreases in Approach in respect to Pre-Approach.

Surface Time vs. Number of Blows

The relationships between Surface Time and the Number of Blow intervals per surfacing are shown in Figure 5. The different phases are represented by three positive significant linear relations (three phases respectively: $F = 388.1$, 165.4, and 2,687.8, all $P < 0.01$). Although a parallelism test indicated a slight difference between the slopes (which represent the interval between blows) (ANCOVA, $F = 3.89$, $P = 0.03$), the differences in slopes were small in absolute terms (16.1, 16.5, 15.1).

Discussion

The present study reveals that a close disturbance from a speed boat for approximately one hour caused a significant change in fin whale swimming and

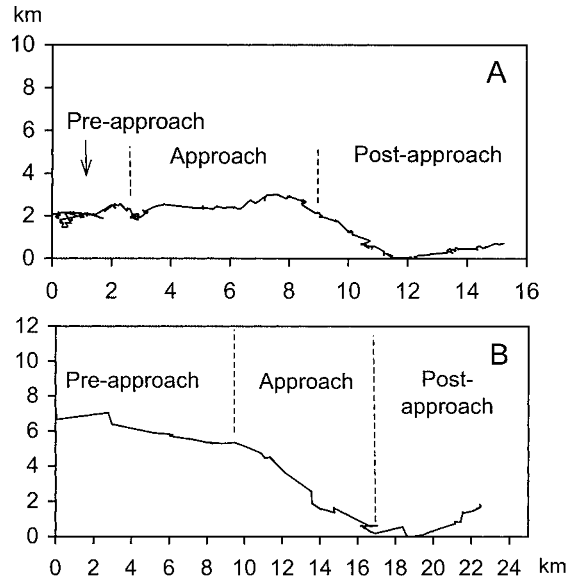

Figure 4. A. Example of convoluted swimming pattern (Pre-approach phase), shifting to quasi-linear pattern (Approach and Post-approach phases). Indexes of Linearity are 0.24 (Pre-approach), 0.70 (Approach), 0.64 (Post-approach). Sample was taken on 27 June 1996 from 0820 to 1140 (Approach phase from 0921 to 1040). B. Quasi-linear moving pattern. Indexes of Linearity are 0.84 (Pre-approach), 0.77 (Approach), 0.83 (Post-approach). This sample was taken on 6 August 1995 from 1727 to 2048 (Approach phase from 1844 to 1956).

respiratory patterns, as compared to a control period. The effect of the presence of the observation vessel probably cannot be dismissed entirely. So, strictly speaking, we have evaluated the additional impact that the approaching of a small speedboat has on a whale that was already followed at distance by a larger vessel. Nevertheless, the comparison between the Pre-approach and the Approach phase well support the assumption that the speed boat had a higher impact on whale behavior. Moreover, one hour after contact ended the animals had not resumed the initial pre-disturbance pattern.

Two distinct swimming-surfacing patterns were observed and seemed to be affected differentially by disturbance. We hypothesize that the two observed swimming-surfacing patterns (one "wide-ranging" and one "narrow-ranging") are related to distinct behavioral states: (1) a quasi-linear, high surface velocity, and low blow-rate behavior suggesting travel; and (2) a convoluted, low surface velocity, together with a higher blow rate, likely related to feeding (see also Lafortuna *et al.* 1998).

Fin whales in the Ligurian Sea are known to perform the deepest dives on record for this species, very likely related to feeding behavior (Panigada *et al.* 1999). Actually, the lower net horizontal velocity of narrow-ranging fin whales, as compared to wide-ranging whales, can be explained by hypothesizing a vertical displacement involved in deep diving, as also reported for bottom-feeding gray whales by Würsig *et al.* (1986) and Mallonée (1991). In comparing two in-

Table 2. Comparison between mean values for samples showing linear track in Pre-approach phase.

	Pre-approach phase $\bar{x}$ (± SD)	Approach phase $\bar{x}$ (± SD)	Post-approach phase $\bar{x}$ (± SD)	χ^2	P
Index of Linearity	0.77 (± 0.12)	0.77 (± 0.16)	0.76 (± 0.17)	1.9	ns
Velocity (m/sec)	1.3 (± 0.5)	1.7 (± 0.6)	1.8 (± 0.6)	6.1	(*)
Dive Time (sec)	253.9 (± 157.8)	247.1 (± 92.8)	290.6 (± 109.7)	2	ns
Surface Time (sec)	76.3 (± 26.1)	57.8 (± 11.1)	71.0 (± 11.1)	3.7	ns
Percentage of Surfacing	18.9 (± 8.4)	14.7 (± 6.7)	17.6 (± 4.4)	6	(*)
Blow Rate (blows/min)	0.9 (± 0.4)	0.7 (± 0.3)	0.8 (± 0.20)	2	ns
Number of Blows per surfacing (N)	4.2 (± 1.7)	3.3 (± 0.9)	4.4 (± 1.0)	2.6	ns
Blow Interval (sec)	17.5 (± 1.7)	16.9 (± 1.1)	16.3 (± 1.3)	4.8	ns

(*) $P < 0.05$ for test of Friedman (df = 2, n = 8 for Index of Linearity and Velocity, n = 7 for other parameters).

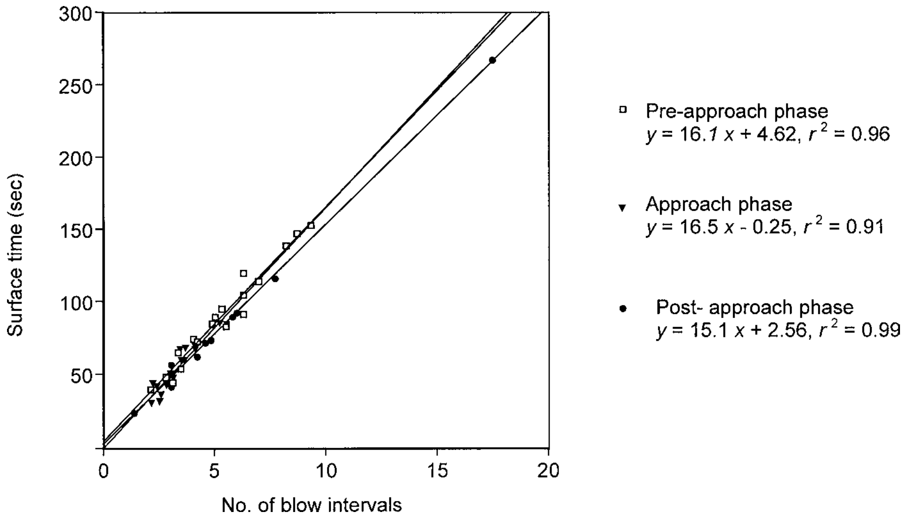

Figure 5. Linear regressions of number of blow intervals per surfacing (Number of Blow intervals) and duration of surfacing (Surface Time) for three experimental phases.

dividual fin whales, one supposedly feeding and one traveling, Lafortuna *et al.* (1998) found similar swimming velocities during surfacing periods, but markedly different lateral movement (still as referred to the surface) during dives. In 1998 we performed LRF tracking coupled with the measurement of diving by means of a time-depth recorder (TDR) on a single fin whale. The whale showed a quasi-linear route during shallow diving (maximum 20 m) and a convoluted route during deep diving (maximum 474 m). Furthermore, narrow-ranging fin whales also have a higher Blow Rate, which is consistent with the greater metabolic demand during the foraging activity, as observed also in minke whales (Blix and Folkow 1995). Surface time also increased in supposed feeding animals (as the interval between consecutive blows during the surfacing tends to be rather constant, fin whales seem to regulate their blow rate mainly by adjusting the fraction of time spent at surface).

In the present investigation we found that disturbed whales shifted from narrow-ranging activity (likely feeding) to wide-ranging activity (likely traveling). Concurrently, a significant increase in net whale velocity was apparent, likely indicating an avoidance reaction. In fact, a significant increase in net velocity during the Approach phase was observed also in whales already "wide-ranging" during the Pre-approach phase (see Table 2). An increase in speed as a reaction to disturbance was also reported by other studies in different cetacean species (Reeves 1977, Baker and Herman 1989, Richardson *et al.* 1990, Rivarola *et al.* 2001).

Blow Rate and Percentage of Surfacing significantly decreased in disturbed whales as compared with the Pre-approach period. Again this may be a result both of the interruption of "narrow-ranging" activity and of a purposeful reaction. Disturbed whales seemed to cease the feeding and begin to travel. In the subset of only-wide-ranging whales, the Percentage of Surfacing became significantly shorter during disturbance, as well. This may indicate that reduction of the surface time is also an avoidance response.

Thus, fin whales appear to react in two different but simultaneous ways: (1) a horizontal avoidance, consisting of ceasing the "narrow-ranging" activity and escaping with an increased swimming velocity; and (2) a vertical avoidance, consisting in the reduction of the time spent at the surface. Similar strategies of avoidance, although employed alternatively, were described in humpback whales by Baker and Herman (1989). However, it cannot be dismissed that both reactions may be, entirely or in part, an effect of biopsy sampling. Gauthier and Sears (1999) reported that fin whales most often responded to biopsies by submerging, and presumably this could account for a shorter surface time.

Disturbed whales did not dive longer, as might have been expected as part of the vertical avoidance behavior. Like velocity, dive time also has a positive relation to blow rate (Dolphin 1987, Shaffer *et al.* 1997); thus longer dives would be in contrast with shorter surface times, and the adoption of longer dives combined with an increase in velocity may be physiologically constrained.

Blow Rate and Percentage of Surfacing significantly changed between Pre-approach and Approach phase, but the interval between consecutive blows during the surfacing time only slightly changed across experimental phases and seemed relatively independent of behavioral responses (Fig. 5). Although Baker and Herman (1989) found changes in blow intervals in humpback whales to be a sensitive indicator of disturbance, we do not feel that in this study those differences are of practical use. Also Stone *et al.* (1992) report a constancy of blow intervals in fin whales independently of disturbance by boats.

After disturbance, while the respiratory activity became more similar to the pre-disturbance condition, the "narrow-ranging" activity appeared to be suspended, at least within the period of the Post-approach phase. Fin whale prey in this area consists exclusively of the euphausiid *Meganyctiphanes norvegica*, as determined from the animals' stomach contents and fecal analyses (Viale 1985, Orsi Relini and Cappello 1992, Relini *et al.* 1992). Although the information concerning abundance and distribution of krill in the Mediterranean Sea is rather scanty, *M. norvegica* is reported to have a considerable spatial variability in the Ligurian Basin (Forcada *et al.* 1996, Labat and Cuzin-Roudy 1996), as in other areas (Sameoto 1983, Nicol 1986). When a patch of food is abandoned to escape a disturbance, a new patch may not be readily available. At the end of the Approach phase the whales were on average 3.7 km (SD = 2.2) from the point where they suspended their presumed foraging activity.

In conclusion, the measured effect of disturbance is probably not negligible, as we had relatively low power to find differences given our relatively small sample (Underwood 1997) yet differences were clear. Under the perspective that one of the likely reactions is the interruption of feeding, possible long-term effects cannot be ruled out. Thus, it appears advisable that the exposure of whales in the Ligurian Sea to increasing commercial and private vessel traffic be carefully monitored and regulated. Regulations for whale watching activities should take into account: (1) the behavior of the target whales. Straight-heading individuals should be singled out by experienced operators and favored rather than presumably foraging whales, and (2) vessel approach characteristics (as also reported in humpback whale studies by Clapham and Mattila 1993); keeping the vessel at a distance >200 m and maneuvering at low speed is likely to elicit little or no visible reaction from fin whales.

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