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DIVE CHARACTERISTICS OF SATELLITE-MONITORED BLUE WHALES (*BALAENOPTERA MUSCULUS*) OFF THE CENTRAL CALIFORNIA COAST

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Abstract

Dive habits of four Northeast Pacific blue whales (*Balaenoptera musculus*) were studied using satellite-monitored radio tags. Tags summarized dive-duration data into eight 3-h periods daily. One tag additionally summarized dive depth and time-at-depth information for these same periods. Tracking periods ranged from 0.6 to 12.7 d and provided data for 17 three-hour summary periods, representing 2,007 dives (788 of which provided depth information). Total number of dives during a 3-h summary period ranged from 83 to 128. Seventy-two percent of dives were ≤1 min long. All whales spent >94% of their time submerged. Average duration of true dives (dives >1 min) ranged from 4.2 to 7.2 min. Seventy-five percent of depth-monitored dives were to ≤16 m, accounting for 78% of that animal's time. Average depth of dives to >16 m was 105 ± 13 m.

Key words: blue whale, *Balaenoptera musculus*, satellite telemetry, radio-tracking, dive behavior.

Respiration rates and diving patterns are important indices of whale behavior and are critical in transforming shipboard and aerial survey counts into accurate abundance estimates (Doi 1974, CETAP 1982, Hiby and Hammond 1989). Diel variations in activity, which might render whales more visible at certain times of day, are also significant factors to be taken into account in assessment techniques (Klinowska 1986). Diving and surfacing behavior has been examined for bowhead whales (*Balaena mysticetus*; Würsig *et al.* 1984, Dorsey *et al.* 1989), gray whales (*Eschrichtius robustus*; Würsig *et al.* 1986), humpback whales (*Megaptera novaeangliae*; Dolphin 1987), minke whales (*Balaenoptera acutorostrata*; Joyce *et al.* 1990, Stern 1992), and fin whales (*Balaenoptera physalus*; Stone *et al.* 1992, Kopelman and Sadove 1995), but respiration and diving patterns of blue whales are poorly documented (Leatherwood *et al.* 1982); diel variation in such behavior has not been studied.

In this study we monitored the movements and dive habits of blue whales in the eastern North Pacific with satellite telemetry. The goals were to remotely monitor dive behavior in a large, free-ranging cetacean and examine possible diel rhythms.

Methods

Four blue whales were tagged with satellite-monitored radio transmitters off the coast of central California from 20 August to 30 September 1993. Tags were deployed 1–4 m behind the blowhole with a 68-kg Barnett compound crossbow, from a 5.3-m rigid-hulled inflatable boat.

Argos-certified UHF transmitters emitted 400-mW signals to receivers on two NOAA TIROS-N weather satellites in sun-synchronous polar orbits. To conserve battery power, transmissions were scheduled to coincide with some of the times during which satellites were overhead (10–12 times/d for approximately 6–17 min each). During each transmission cycle, the tags transmitted every 40 sec when at the surface. A saltwater conductivity switch was used to insure the tag was at the surface before initiating a transmission. The tags were powered by lithium batteries.

Two types of sensor tags were used: a "duration" type, which collected dive duration information only, and a "depth" type, which collected information concerning dive depth as well as duration. We defined a dive as any submergence of the tag for longer than 6 sec. Tag locations were calculated by Service Argos from Doppler-shift data when two or more messages reached the satellite during one pass (Fancy *et al.* 1988). Argos provides an estimate of location accuracy by assigning each of their locations to one of six classes (LC-1, LC-2, LC-3, LC-0, LC-A, and LC-B). Location classes 0, A, and B have no predicted accuracy. Distances and speeds were calculated from Argos locations and then subjected to editing criteria to eliminate unacceptable locations. We allowed a radius of uncertainty of 11.5 km around each location (representing a radial error equal to two standard deviations from our testing of locations <LC-1; Mate *et al.* 1997) and eliminated all locations which resulted in speeds

Table 1. Duration categories for all four tags, and depth and time at depth categories for depth tag only, for blue whales tagged off central California, 1993.

Duration (min)	Depth (m)	Time at depth (%)
0–1	0–16	0–16
1–4	16–32	16–32
4–7	32–48	32–48
7–10	48–96	48–96
10–13	96–152	96–152
13–16	152–200	152–200
16–19	200–248	200–296
19–255	248–296	296–400
	296–400	400–2,040
	400–2,040	

>15 km/h for >1 h, or which were located on land >11.5 km from the nearest shoreline.

Depth Tag

One depth tag (DEP-1) was deployed, consisting of a Telonics (Mesa, AZ) ST-6 Argos transmitter, a Wildlife Computers (Woodinville, WA) controller board, and a pressure transducer. Transmissions were scheduled for four 2-h periods daily. Each 960-msec transmission consisted of a discrete identification code and 256 bits of sensor data, which included a cyclic redundancy check (CRC) code for error detection. Data on every dive were collected and summarized over eight 3-h summary periods daily. The summary information included the number of dives in ten different depth categories, ranging from 0 to 2,040 m; the number of dives in each of eight duration categories, ranging from 6 sec to 255 min; the percentage of time spent in each of nine depth categories, ranging from 0 to 2,040 m (Table 1); duration of the longest dive (2-min resolution), duration of the first dive to the deepest depth (2-min resolution), depth of the deepest dive (16-m resolution), longest surface duration uninterrupted by a submergence of greater than 6 sec (30-sec resolution), and total surface duration (1-min resolution).

The tag housing was a stainless steel cylinder 5 cm in diameter by 19 cm in length and weighing 0.80 kg, with two subdermal attachments. Attachments consisted of stainless steel rods (12.7 cm long, 0.6 cm in diameter) with double-edged blades at the distal end. One pair of folding toggles was mounted behind the blades to prevent outward migration of the tag. The tag was filled with plastic epoxy to reduce air spaces and add structural strength. A flexible 17-cm whip antenna was mounted in one end-cap perpendicular to the tag housing.

Duration Tag

Three duration tags (DUR-1, -2, -3) were deployed. Each consisted of an Oregon State University-designed sampling program loaded in a Telonics ST-6 Argos transmitter. The housings and attachments of these tags were identical to the depth tags with the exception that they lacked a pressure transducer. Duration tags were not filled with plastic epoxy and weighed 0.52 kg.

Duration tags collected data on every dive and summarized the information over eight 3-h summary periods daily. The data collected during each period consisted of the number of dives occurring in each of eight duration categories (Table 1), ranging from 6 sec to 255 min; maximum surface duration (1-min resolution); maximum dive duration greater than 10 min (2-min resolution); and percentage of time submerged (1% resolution).

Transmissions were scheduled for two 100-min periods each day. Each 320-msec transmission consisted of an identification code and 64 bits of data, including a CRC code.

Tag Data

For comparison with other respiration studies in which differentiation was made between blow intervals and dives, we computed average dive duration only for dives >1 min (hereafter referred to as "true dives"). Most blow intervals for blue whales are likely <1 min long, but tag software (1-min resolution in the first duration bin) prevented calculations based on dives of shorter duration.

The average duration of true dives was calculated using the following

$$\bar{x}\mathrm{dur}_i = \sum_{j=2}^{8} \text{mid-value}_{ij} \cdot \mathrm{dives}_{ij} / \mathrm{tdives}_i$$

where $\bar{x}\mathrm{dur}_i$ = average duration of dives greater than 1 min for period i; mid-value$_{ij}$ = middle value (min) of duration category j in period i; dives$_{ij}$ = number of dives in duration category j for period i. Dives <60 sec were excluded from calculations (duration category 1).

As dives in the upper 16 m of the water column (first depth range) likely represent surface activity associated with breathing, only dives >16 m deep were considered in average depth calculations. The average depth of dives to >16 m during a summary period was calculated using the following

$$\bar{x}\mathrm{dep}_i = \sum_{j=2}^{10} \text{mid-depth}_{ij} \cdot \mathrm{dives}_{ij} / \mathrm{tdives}_i$$

where $\bar{x}\mathrm{dep}_i$ = average dive depth for period i; mid-depth$_{ij}$ = middle value (m) of depth category j in period i; dives$_{ij}$ = number of dives in depth category j for period i.

Because dives were defined as submergences longer than 6 sec, the depth tag did not begin counting dive duration until 6 sec had elapsed. The first 6 sec of every dive were not included in the duration. For periods with an exact count of dives, the number of dives was multiplied by 6 sec and the product added to the time spent in the first depth category. For those periods for which there was no exact dive-number information (transmissions in which only time spent at depth information was error-free), the average number of dives from periods with exact dive counts was multiplied by 6 sec to provide a correction factor for the time at depth.

Data were divided into four periods of the day for diel comparisons. For depth tags, summary periods 2, 3, and 4, (2000–0459 PDT) were combined for night, summary periods 6, 7, and 8 (0800–1659 PDT) for day, and summary periods 1 (1700–1959 PDT) and 5 (0500–0759) for dusk and dawn, respectively. For duration tags, summary periods 6, 7, and 8 (2100–0559 PDT) were combined for night, summary periods 2, 3, and 4 (0900–1759 PDT) for day, and summary periods 1 (0600–0859 PDT) and 5 (1800–2059 PDT) for dawn and dusk, respectively. The time periods differed between the two tag types due to their different initialization times.

Visual Observations

Respiration patterns of untagged whales were observed from a 16.6-m vessel (R/V *'Cille*) using the focal animal sampling technique (Altmann 1974). Before beginning an observation, we took general behavioral observations and identification photographs of the whales. If more than one whale was present, the most easily distinguishable animal was chosen for respiration sampling. When it was possible to distinguish both animals in a pair by distinctive coloration or dorsal fin shape, respiration data were collected for both. Observation distances varied from 10 to 150 m.

The desired sampling period was 30 min. Sampling periods were terminated prior to 30 min when the focal animal could no longer be identified. The primary observer called out sightings to a second person who recorded exact times (h:min:sec) of exhalations and behaviors. Four variables similar to those measured in other respiration studies (Würsig *et al.* 1984, 1986; Dolphin 1987; Dorsey *et al.* 1989) were evaluated: true dive time (of dives greater than 1 min, for comparison with our tag data), duration of time at the surface (including time between blows) between successive true dives (surface time), number of blows during the surfacing, and the time between blows (blow interval). As in Dolphin's (1987) humpback study, duration of time at the surface was given the value of 0.1 min when the surface time included only 1 blow. Mean blow interval for each sampling period was calculated by dividing the sum of all blow intervals in a surfacing by the number of blow intervals and then taking the average of that value for all surfacings in the sampling period. Mean blow rate was calculated as described by Dorsey *et al.* (1989), by dividing mean number of blows per surfacing by mean surfacing-dive cycle (mean duration of surfacing plus mean duration of the following true dive). Surface-time proportion (expressed as a percentage) was calculated by dividing mean surface time by mean surfacing-dive cycle.

Results

Tracking periods ranged from 0.6 to 12.7 d and provided error-free information for 2,007 dives (Table 2). Sixty, fifty, and nineteen percent of transmissions contained CRC errors for whales DUR-2, DUR-3, and DEP-1, respectively. Data from these transmissions were not included in analyses. One error-free transmission was received for DUR-1. No statistical comparisons were made due to the small sample sizes.

The total number of dives for a 3-h summary period (all whales) ranged from 83 to 128 ($\bar{x}$ = 35 ± 8/h; n = 4; Table 3). Seventy-two percent of these dives were <1 min in duration (range 66.9%–76.0%; n = 4; Fig. 1). Dives <4 min in duration accounted for 89.2% of all dives for whale DUR-3. Whales DUR-1 and DUR-2 had their second highest percentage of dives in the 4–7 min range ($\bar{x}$ = 13.2% ± 0% and 12.1% ± 10.1%, respectively). Only whales DEP-1, DUR-2, and DUR-3 reported dives ≥10 min long. There were not enough data to determine whether the dive distributions followed any diel pattern; however, the dives of whale DUR-3 suggested the possibility of diel variation.

The percentage of time that the animals were submerged during each 3-h summary period ranged from 94.7% to 96.5% (n = 4; Table 3).

Dive Duration

Average duration of true dives (per period) for each whale ranged from 4.2 to 7.2 min ($\bar{x}$ = 5.8 ± 1.5 min; n = 4; Table 3).

The duration of the longest dive per period for whale DEP-1 ranged from 10 to 18 min ($\bar{x}$ = 13 ± 3 min; n = 6). Whale DUR-1 reported 0 for duration of longest dive, meaning no dives >10 min were recorded. Whale DUR-2 also reported 0's for 3 of 4 summary periods. The fourth period reported a maximum dive duration of 15 min. Whale DUR-3 reported 0's for 3 of 6 periods, with an average maximum dive duration of 14 ± 1 min for the remaining 3 periods.

For whale DEP-1, maximum surface duration during a summary period ranged from 7 to 90 sec ($\bar{x}$ = 48 ± 28 sec, n = 7). The duration-only tags had a 1-min resolution for this variable, and all reported 0's for maximum surface duration. Thus, there were no surfacings lasting >60 sec in the 11 summary periods reported.

Depth

Whale DEP-1 was the only animal for which depth information was available. Most dives were in the 0–16 m depth range ($\bar{x}$ = 74.8% ± 4.5%; n = 9; Fig. 2). The second highest percentage of dives ($\bar{x}$ = 15.4% ± 7.4%; n = 9) were made to 97–152 m. The average depth of dives >16 m was 105 ± 13 m (median = 103 m; range 84–121 m, n = 9).

Depth of the deepest dive during a summary period ranged from 112 to

Table 2. Deployment dates, number of days between deployment and date of last message, and number of messages received for four blue whales tagged off central California, 1993. 13 discrete summary periods received for whale DEP-1 contained information for 6 duration histograms, 9 depth histograms, and 7 time-at-depth histograms.

Whale #	Deploy date/time (UTC)	Date/time (UTC) of last message	# Days	# Messages	# Error-free summary periods	# Error-free dives
DUR-1	8/29/93 0001	8/29/93 1332	0.6	1	1	121
DUR-2	8/29/93 0146	9/6/93 0152	8.0	10	4	332
DUR-3	9/17/93 2340	9/30/93 1342	12.7	12	6	768
DEP-1	8/31/93 2105	9/12/93 1516	11.7	16	13	786
TOTAL			32.9	39	24	2,007

Table 3. Means (±SD) and medians of dive data collected during 3-h summary periods for all blue whales tagged off central California in 1993. Means for all whales combined calculated as average of each whale's individual average.

Whale #	% Time submerged	Total number of dives	Duration of true dives (>1 min) (min)	Depth of dives >16 m
All	95.8 ± 0.8 95.9 $n = 4$	105 ± 23 104 $n = 4$	5.8 ± 1.5 5.9 $n = 4$	—
DEP-1	95.9 ± 1.6 96.0 $n = 7$	88 ± 16 86 $n = 6$	6.9 ± 1.4 7.2 $n = 6$	105 ± 13 103 $n = 9$
DUR-1	96.0 $n = 1$	121 $n = 1$	5.0 $n = 1$	—
DUR-2	96.5 ± 0.6 96.5 $n = 4$	83 ± 16 79 $n = 4$	7.2 ± 1.5 7.1 $n = 4$	—
DUR-3	94.7 ± 2.1 95.0 $n = 6$	128 ± 42 128 $n = 6$	4.2 ± 1.8 3.7 $n = 6$	—

192 m ($\bar{x}$ = 151 ± 28 m; n = 9). Duration of the deepest dive during a summary period ranged from 4 to 18 min ($\bar{x}$ = 9 ± 5 min; n = 6).

Whale DEP-1 spent most of its time (78.2%) in the 0–16-m depth range, followed by 9.3% of its time at 17–32-m (Fig. 2). Although 15.4% of all dives went to the 97–152-m depth range, whale DEP-1 spent only 1.2% of its time there.

Visual Observation Data

We observed respirations of nine blue whales for a total of 3.3 h (Table 4). Average surface time for all whales was 64.8 ± 15.6 sec (n = 9). Average number of blows during these surfacing sequences was 4.0 ± 0.6 (n = 9), with mean blow intervals of 21 ± 4.2 sec (n = 9). True dive times averaged 3.3 ± 1.4 min (n = 9). Submergences <1 min in length accounted for 78.1% ± 1.7% of all dives. Maximum dive durations for the nine whales ranged from 3.2 to 6.5 min, with an average of 4.7 ± 1.1 min. Mean blow rate was 1.0 ± 0.2 blows per min (n = 9). Percentage of time near the surface averaged 25.4% ± 5.4% (n = 9).

Movements

We obtained five locations for whale DEP-1 and two for whale DUR-2. All locations were of location class 0 (LC-0) but fit our editing criteria. The minimum distance travelled from tagging to the last location was 274 km for whale DEP-1 and 124 km for DUR-2 (Fig. 3). These are straight-line distances and represent minimum distances travelled. As such, estimates of speeds are also minimums.

After tagging, whale DEP-1 travelled 57 km west in 4 h (14.2 km/h), 48 km southeast in 35.9 h (1.3 km/h), east 56 km in 23.7 h (2.4 km/h), south 32 km in 13.0 h (2.5 km/h), and 82 km west in 12.3 h (6.7 km/h). Although the whale was tagged in 280 m of water, all five subsequent locations were in water deeper than 1,000 m.

Following tagging in 90 m of water, whale DUR-2 traveled north-northwest 72 km in 59.6 h (1.2 km/h), then south 52 km in 12.9 h (4.0 km/h). Water depths at the first and second post-tagging locations were 55 m and 370 m, respectively.

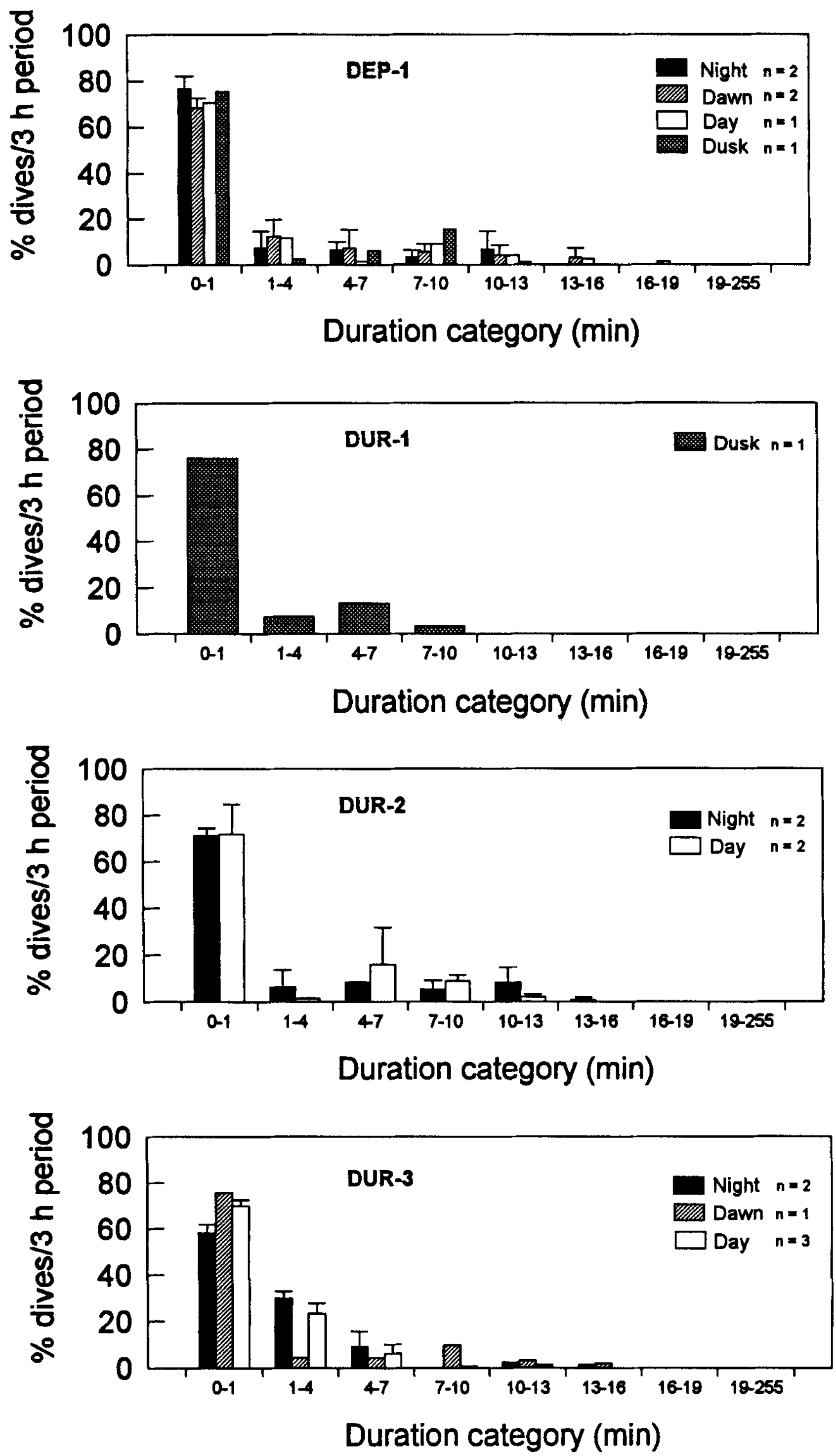
Discussion

Dive Duration

Dive-habit studies conducted during whaling operations reported dive durations for blue whales ranging from 10 to 50 min (Laurie 1933, Zenkovich 1936, Tomlin 1967). The longer dives could be due to whales exhibiting avoidance when chased by whaling ships. Doi (1974), Yablokov *et al.* (1974), and Lockyer (1976) also used whaling data but reported much shorter dive durations (5–7, 2–5, and 2–7 min, respectively). These values are much closer to the 5.9-min average true-dive duration from our tagged whales and the 3.3-min average durations from our visual observations. The average duration of dives >1 min for visually observed pygmy blue whales (*B. m. brevicauda*) off Peru was 9.9 min (range = 1.1–26.9 min; Donovan 1984). More recently, Croll *et al.* (1998) reported an average dive duration of 4.3 min for TDR-instrumented blue whales in the Santa Barbara Channel, California. It is unclear, however, what their definition of a dive was.

True-dive durations from this study are in close agreement with recent visual and telemetry studies of other baleen whale species: 2.88 min for summering North Atlantic fin whales (*Balaenoptera physalus*) with boats in the area, and 3.35 min without boats (Stone *et al.* 1992); 2.66 min for surface-feeding and 3.10 min for non-surface-feeding fin whales off eastern Long Island (Kopelman and Sadove 1995); 4.85 min for a fin whale in Iceland (Watkins *et al.* 1984); 3.18 min for summering gray whales (Würsig *et al.* 1986); 3.0 min for humpbacks (*Megaptera novaeangliae*) (Dolphin 1987); 4.42 min for summering bowhead whales (*Balaena mysticetus*) in 1980–1984 (Dorsey *et al.* 1989); 3.43–12.08 min for bowheads (Würsig *et al.* 1984); and 2.12 min for right whales off Cape Cod (Winn *et al.* 1995).

The proportion of the surface-dive cycle spent at the surface (25.4%) for our visually observed blue whales was very similar to reports for other species, with the exception of fin whales (Table 2). This latter difference is likely related to the way in which the data were collected rather than representing a biological difference. Our study defined a true dive to be any submergence


DEP-1
Night n = 2
Dawn n = 2
Day n = 1
Dusk n = 1
% dives/3 h period
Duration category (min)
0-1
1-4
4-7
7-10
10-13
13-16
16-19
19-255
DUR-1
Dusk n = 1
DUR-2
Night n = 2
Day n = 2
DUR-3
Night n = 2
Dawn n = 1
Day n = 3

>1 min, while Stone *et al.* (1992) used 25 sec. The latter cutoff would result in shorter surface durations, hence smaller proportions of time spent at the surface, as well as shorter dive durations. This bias is further emphasized when considering proportions of time spent at the surface obtained from our tagged whales. The tags were programmed to record any submergence >6 sec as a dive. Consequently, the average proportion of time submerged for these whales was 95.8%.

Tag Data vs. *Visual Data*

Overall durations of true dives were shorter for the visual observations than those from tagged whales (3.3 *vs.* 5.9 min). The proportion of dives <1 min in length was only slightly higher for whales observed visually than for tagged whales (78% *vs.* 72%). The maximum dive durations reported for the nine visually observed whales were much shorter than those reported for tagged whales. All of these "differences" are likely due to either small sample sizes (total visual observation time being only slightly longer than a single 3-h summary period from tagged whales) or the limitations of observers to reacquire whales which swim out of visual range during long dives (Dorsey *et al.* 1989). Harvey and Mate (1984) discovered similar bias in their analyses of visual *vs.* VHF radio tag data for gray whales (*Esrichtius robustus*).

Dive Depth

The overall distribution of dive depths for whale DEP-1 revealed a bimodal distribution, with most dives between 0–16 m and 97–152 m. Dives in the first 16 m may represent primarily blow intervals during surface time between longer dives. More than 72% of all dives were <1 min in duration and <16 m deep. Surface-feeding may also have contributed to numbers of dives and time in the first 16-m depth range.

Dives to the 97–152-m depth range were the second most frequent (15.2% of all dives) and took place in water >1,000 m deep. Only 1.2% of the whale's total time underwater was spent at that depth range, however. Whale DEP-1 also dove to depths of 200 m, but again, spent very little time there (<1%). Such behavior indicates a pattern of "spike dives" (Martin and Smith 1992) where the whale spends more of its time descending or ascending than swimming along at depth. This may reflect searching the water column for prey or a preference for feeding during descent and/or ascent rather than at the bottom of the dive. A similar pattern was seen in pygmy blue whale dive traces from a depth sounder in the Indian Ocean

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Figure 1. Average percentage of dives in each of eight duration categories, divided into four times of day, for four blue whales tagged off central California in 1993. Error bars represent one standard deviation.

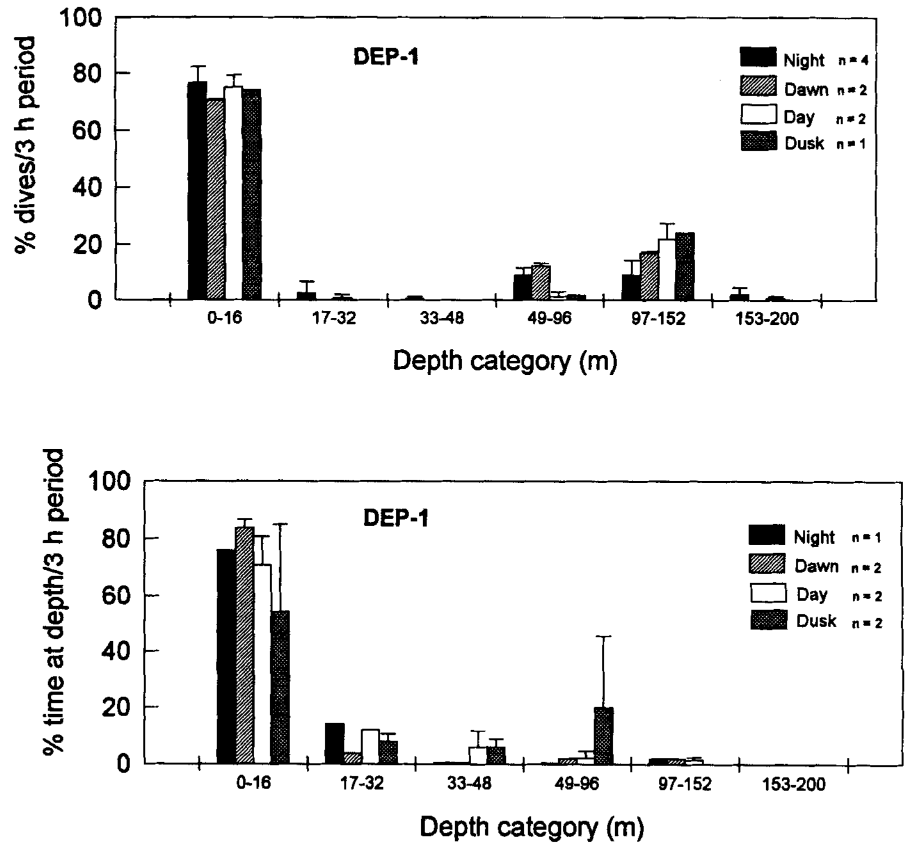

Figure 2. Average percentage of dives reaching their maximum depth in one of six depth categories (n = 9) and average percentage of time spent in each of six depth categories (n = 7) during 3-h summary periods for blue whale DEP-1, tagged off central California in 1993. Histograms divided into four times of day. Error bars represent one standard deviation. Depth categories beyond 200 m not included, as no dives made beyond that depth.

(Alling *et al.* 1991). In several instances the whales appeared to descend below the deep scattering layer and then ascend through it. Right whales east of Cape Cod have been reported occasionally diving deeper than the main prey patch, possibly as a means of detecting changes in depth distribution of prey patches (Winn *et al.* 1995).

Average depth of dives for TDR-instrumented blue whales in the Santa Barbara Channel, California was 68.1 m (Croll *et al.* 1998). This value is almost exactly midway between the average depths reported in this study (average depth of all dives/period = 33 m; average depth of dives >16 m = 105 m). As with duration, it is unclear from Croll *et al.*'s (1998) study what the definition of a dive was.

Table 4. Comparison of visually observed surface/respiration activities for several species of mysticete whales.

Species	Blow rate (blows/min)	Blow interval (sec)	Blows per surfacing	Surface time (sec)	% Time near surface	Source
Balaenoptera musculus	1.00	21	4.01	64.8	25.4	This study
Balaenoptera physalus	1.06	13.0	—	—	—	Kopelman and Sadove 1995
						Stone *et al.* 1992
	0.84	15	2.8	49.8	13.12	(boat present)
	0.81		3.12	54.6	13.6	(no boat)
Megaptera novaeangliae	1.15	15	3.2	66	25.2	Dolphin 1987
Esrichtius robustus	1.05	13.8	4.2	53.4	22	Würsig *et al.* 1986
Balaena mysticetus	0.77	13.8	4.3	71.4	21	Dorsey *et al.* 1989
						Würsig *et al.* 1984
	1.28	13.2	4.3	67.2		(1980–81 data)
	0.70	15	7.4	123		(1982 data)
Eubalaena glacialis	—	11.8	—	—	—	Watkins *et al.* 1996

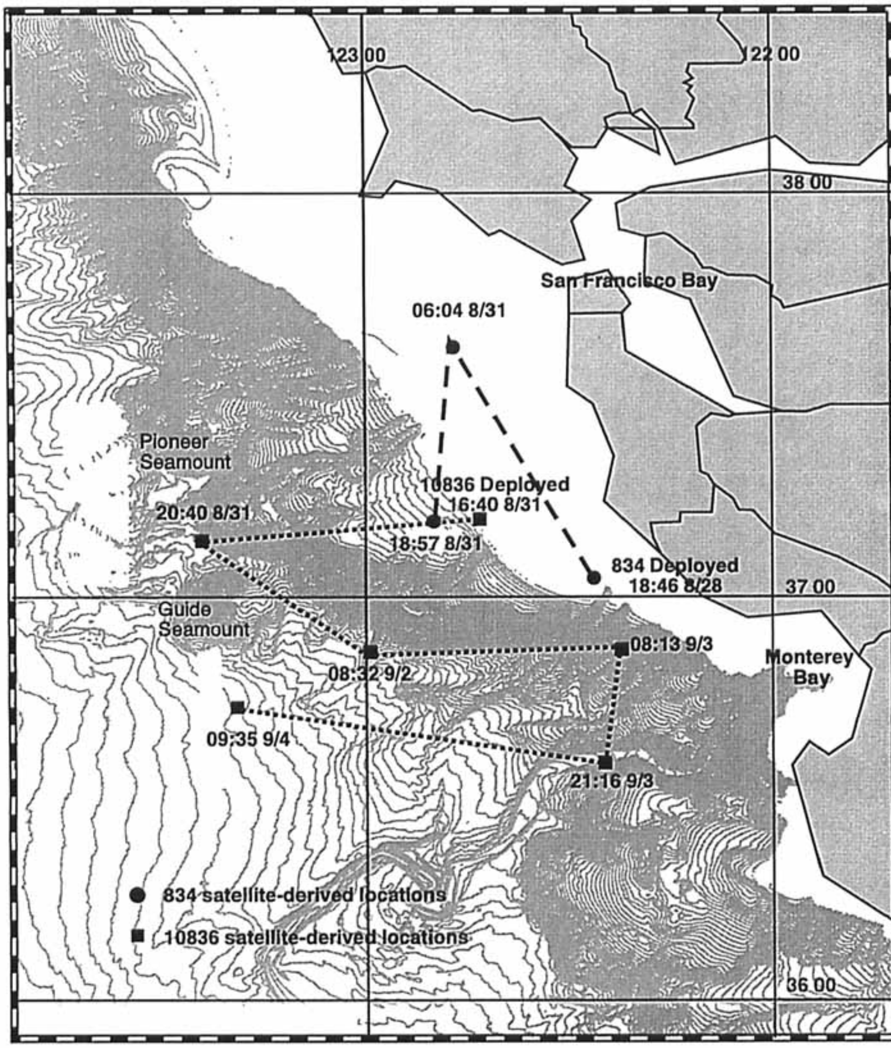

Figure 3. Tagging and satellite-derived locations for whales DEP-1 and DUR-2. Offshore contours begin at depths of 150 m with subsequent contours at 50-m intervals.

Movements

Although only a few locations were received for two whales, they do convey a sense of the range, speed, and variation of movements and depth of water traversed. Neither animal stayed in the area in which it was tagged but ranged widely off the coast of central California. Similar wide-ranging movements were typical of blue whales tagged off Southern California with Argos tags (Mate *et al.* 1999).

The post-tagging locations for whale DUR-2 were both within 40 km of land over the continental shelf or near the shelf edge (55 m and 370 m water depth, respectively).

After tagging, whale DEP-1 moved to a location 90 km offshore, returned nearshore within 24 km of the coast, and then moved 100 km offshore again in three days. These wide-scale movements may reflect the animal's search for food. The first offshore location was approximately 25 km southeast of Pioneer Seamount (770 m below sea level) and 15 km northwest of Guide Seamount (1,642 m below sea level). Subsequent locations show the animal at the edge of Monterey Canyon and directly over the Canyon itself. Later, the whale was approximately 33 km southeast of Guide Seamount (118 km west of Monterey Bay). As cetacean food is probably most concentrated in regions of high general productivity (Hui 1985), whale locations in these regions may not be coincidental. Regions of irregular bottom topography, such as seamounts and canyons, are often areas of greater upwelling and mixing of nutrients, providing for high densities of plankton (Hui 1979). Pioneer Seamount typically has increased biological productivity (Smith *et al.* 1986). Additionally, great concentrations of zooplankton biomass, particularly *E. pacifica* have been found 185 km west of Monterey Bay (Huntley *et al.* 1995).

For future studies we recommend increasing the transmission repetition rate to 10 or 20 sec to provide more sensor data, as well as more and better-quality locations. We also recommend collecting information on individual dives in addition to summary information, so that direct comparison can be made between the depths and durations of dives and a biologically meaningful differentiation between blow intervals and dives determined. Individual dive information could also allow for examination of the shape of the dives. However, dive-shape information would come at the cost of reporting fewer dives, due to Argos constraints on message length (256 bits/transmission).

This study provides the first telemetered information on the dive habits of free-ranging blue whales. The sample size is small, however. We believe this was due to short-term tag attachment, possibly caused by hydrodynamic drag from the high swimming speeds we observed for blue whales. Additionally, the 40-sec transmission repetition rate combined with blue whales' habit of spending more than 90% of their time underwater limited the number of possible transmissions.

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