

MOVEMENTS OF NORTH PACIFIC BLUE WHALES DURING THE FEEDING SEASON OFF SOUTHERN CALIFORNIA AND THEIR SOUTHERN FALL MIGRATION¹

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ABSTRACT

The satellite-acquired locations of 10 blue whales (*Balaenoptera musculus*) tagged off southern California with Argos radio tags were used to identify (1) their movements during the late summer feeding season; (2) the routes and rate of travel for individuals on their southern fall migration; and (3) a possible winter calving/breeding area. Whales were tracked from 5.1 to 78.1 d and from 393 to 8,668 km. While in the Southern California Bight, most of the locations for individual whales were either clumped or zigzagged in pattern, suggesting feeding or foraging (searching for prey).

Average speeds ranged from 2.4 to 7.2 km/h. One whale moved north to Cape Mendocino, and four migrated south along the Baja California, Mexico coast, two passing south of Cabo San Lucas on the same day. One of the latter whales traveled an additional 2,959 km south in 30.5 d to within 450 km of the Costa Rican Dome (CRD), an upwelling feature. The timing of this migration suggests the CRD may be a calving/breeding area for North Pacific

¹ Ken Norris always maintained an active interest in seasonal abundance and distribution of large whales, which included his own radio-tagging experiments with gray whales. He was an enormous source of encouragement to me (BRM) from my earliest VHF tagging experiences in late '70s to satellite-monitored tagging of blue whales reported here. He was always excited to hear new information and eager to offer his interpretations. Ken was a life-long student with an inquiring mind. His energy, humor, enthusiasm, creativity, and giving nature will be missed by all who received these "gifts" from him.

blue whales. Although blue whales have previously been sighted in the Eastern Tropical Pacific (ETP), this is the first evidence that whales from the feeding aggregation off California range that far south. The productivity of the CRD may allow blue whales to feed during their winter calving/breeding season, unlike gray whales (*Eschrichtius robustus*) and humpbacks (*Megaptera novaeangliae*) which fast during that period.

Key words: blue whale, *Balaenoptera musculus*, satellite telemetry, radio-tracking, feeding, migration.

Blue whales (*Balaenoptera musculus*) were heavily exploited by commercial whaling. Despite international protection since 1966, a rough estimate of the world-wide population is 15,000 whales: 10,000 (including 5,000 pygmy blue whales, *B. m. breviceauda*) in the southern hemisphere (Gambel 1976); 3,500 for the North Pacific (NMFS 1998); and 800–1,400 in the North Atlantic (NMFS 1998). This is only 8% of the 186,000 blue whales estimated by Gambell (1976) as the pre-exploitation population. The species is considered endangered throughout its range (Klinowska 1991). The blue whales feeding off California in the summer have been estimated at 2,134 (Barlow *et al.* 1995) and may be the largest remnant population in the world. This feeding aggregation is considered a separate stock within the North Pacific (Barlow *et al.* 1995).

With the exception of the resight data of Calambokidis *et al.* (1990), little is known about the detailed movements of these animals on their summer feeding grounds or about their migratory speeds, routes, and winter destinations. Seasonal north-south movements between summer feeding and winter calving/breeding areas are typical for most baleen whale species. However, for almost all blue whale populations, movement patterns and wintering areas are poorly understood (Mizroch *et al.* 1984).

Over 1,000 blue whales have been photographically identified off California with some matches to whales off both coasts of Baja California Sur, Mexico (Calambokidis *et al.* 1990). Tershy *et al.* (1990) reported that blue whale numbers in the Gulf of California peak between mid-March and mid-April, although the numbers seen are <5% of the estimated number feeding off California. Rice (1974) reported peak abundance of blue whales off Baja California from February to early June when most animals were moving north, and again in October when most were moving south. Rice (1974) noted an absence of blue whales during November through January, as did Reilly and Thayer (1990), and speculated that they had either moved south into tropical waters or west.

Observers have encountered blue whales during all months of the year off Central America, primarily near an area of upwelling and increased productivity known as the Costa Rican Dome (CRD, approximately 9°N, 89°W; Wade and Friedrichsen 1979; Reilly and Thayer 1990; Wade and Gerrodette 1993). Reilly and Thayer (1990) speculated that this aggregation consisted of (1) northern hemisphere whales during the northern winter and southern hemisphere animals during the southern winter, (2) non-migratory juveniles,

or (3) a distinct resident population. Subsequently, Wade and Gerrodette (1993) estimated a population of 1,415 blue whales in the eastern tropical Pacific (ETP) from surveys between late July and mid-November, 1986–1990, reinforcing the notion that these are either resident whales or southern hemisphere whales during the austral winter.

The purpose of our study was to examine the movements of blue whales feeding along the California coast and to obtain information about the route and rate of their southbound migration to winter calving/breeding areas.

METHODS

We used the Argos Data Location and Collection System to track radio-tagged blue whales in southern California. Tags transmit ultra-high frequency (UHF) radio signals to Argos receivers on two National Oceanic and Atmospheric Administration (NOAA) TIROS-N weather satellites. The satellites are in sun-synchronous polar orbits, with each passing over our study area three to seven times daily. To conserve power, we limited transmissions to times when satellites were most frequently overhead. Locations were determined by Service Argos from Doppler shift of tag transmissions created by the speed of the satellite passing overhead (Harris *et al.* 1990).

Tags were applied with a 68-kg Barnett compound crossbow from a 5.5-m rigid-hulled-inflatable boat. Two types of tags were used, both consisting of Telonics transmitters (ST-6 or ST-10), housed in stainless steel cylinders. Tags were attached to the whale's back with two subdermal anchors, each consisting of a stainless steel rod with a cutting tip and either backward-facing wires (Mate *et al.* 1998) or barbs (Mate *et al.* 1997) to hold them in the blubber layer. The larger "depth-sensing" tags (19 cm long by 5 cm in diameter) transmitted data summarizing the whale's dive habits (not presented in this manuscript). The smaller "location-only" tags (17 cm long by 2.5 cm in diameter) were identical to those used on humpback whales, *Megaptera novaeangliae* (Mate *et al.* 1998). As UHF radio signals rapidly attenuate in seawater, transmissions to the satellites could only be successful when the whale was at the surface. Thus, a conductivity switch on the tag determined when the whale was at the surface before initiating transmissions. While at the surface, tags were capable of transmitting at different intervals from once every 10 sec to once every 40 sec, depending upon the model and year of application. Each tag had its own discrete identity code.

This report details only the movements derived from Argos-acquired locations. The accuracy of those locations depended upon the number and time between messages received during the time the satellite passed overhead from horizon to horizon (up to 16 min, \bar{x} = 10 min). Argos provides an estimate of location accuracy by assigning each of their locations to one of six classes. Sixty-eight percent of location classes 1, 2, and 3 (abbreviated LC-1, LC-2, and LC-3) are predicted to be within 1.0, 0.35, and 0.15 km, respectively. Location classes 0, A, and B have no predicted accuracy, usually because fewer than three messages were received or because there was not enough time be-

tween the messages. We conducted tests prior to tag deployment to determine location accuracy when Argos reported locations <LC-1.

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) and eliminated all locations which resulted in speeds >15 km/h for >1 h, or which were located on land >11.5 km from the nearest shoreline.

The tracks of tagged whales should be interpreted with caution. The lines between locations provide only the chronology of their occurrence and do not represent the actual route traveled between them. Because the time intervals between locations are not equal, speeds cannot be inferred from the distances alone.

RESULTS

We tagged ten blue whales off southern California, primarily near Santa Rosa, San Miguel, and San Nicholas Islands (Table 1), from August through October in 1994 and 1995. Many of the whales we tagged were feeding (lunging to the surface, mouths widely agape, through dense surface swarms of krill (*Thysanoessa spinifera*)). Blue whales and visually identifiable concentrations of krill tended to be more common at the western end of the Santa Barbara Channel (Fiedler *et al.* 1998).

The number of locations we received daily for each whale varied according to the tag type, transmission repetition rate, transmission duty cycle, and the whale's surfacing behavior. The larger depth-sensing tags lasted an average of 10.3 ± 5.20 d ($n = 3$), while the smaller location-only tags lasted 28.6 ± 24.11 d ($n = 7$). These values were not significantly different ($P = 0.09$).

The overall average speed of individual whales ranged from 58 to 172 km/d ($\bar{x} = 108 \pm 33.3$ km/d; Table 1). Regression analysis showed a significant relationship between the speeds of individual whales and the number of locations received per day ($r^2 = 0.53$; $P = 0.008$).

None of the tagged whales showed an appreciable difference in speed immediately after tagging as compared with subsequent days.

Movements within California

Clusters of locations were typical for most of the tagged whales (Fig. 1–4). Eight whales tagged in the western Santa Barbara Channel remained there 1.0–10.6 d ($\bar{x} = 4.2 \pm 2.90$ d) before moving out of the area. We do not know how long the whales were in the area prior to tagging.

Two whales (#2 and #3) tagged northwest of San Nicholas Island on the same day moved in the vicinity of the island for two weeks before traveling to remarkably different destinations; one went farther offshore west and south of San Nicholas Island (Fig. 2a) and the other moved 680 km north from Point Conception in 5.5 d (124 km/d; 5 km/h) to Cape Mendocino (Fig. 2b).

Table 1. Tag types, tagging dates, received locations, retained locations, calculated distances traveled, durations of operation, and speeds for 10 blue whales tagged in California, 1994–1995.

Tag #	Tag type	Tagging date	# Locations received	# Locations retained	Distance (km)	# Days to last location	Speed (km/d)
1	location	10/01/94	96	76	2,382	13.9	172
2	location	08/23/95	34	22	1,756	18.8	93
3	location	08/23/95	36	22	2,154	18.6	116
4	location	09/10/95	56	52	1,314	10.6	124
5	depth	09/10/95	44	42	896	15.5	58
6	location	09/18/95	66	46	2,503	17.8	141
7	location	09/18/95	154	127	8,668	78.1	111
8	depth	09/19/95	38	34	1,064	10.2	104
9	depth	10/02/95	10	9	393	5.1	77
10	location	10/02/95	54	50	3,362	42.2	80
Mean			59	48	2,449	23.1	108
(SD)			(40.4)	(33.6)	(2,355.4)	(21.7)	(33.3)

Four whales visited an area 150 km south-southwest of San Miguel Island within 22 d of one another: whale #2 on 10 September; whale #4 on 21 September; whale #5 on 26 September; and whale #9 on 7 October.

Migratory Routes and Speeds

Four whales (#1, #6, #7, and #10) were tracked south of the U. S./Mexico border for a portion of their southbound fall migration (Fig. 3, 4). All four whales passed San Clemente Island, the most southerly of the Channel Islands, between 29 September and 10 October. All four whales arrived at Vizcaino Bay, 650 km southeast of San Clemente Island, between 5 and 21 October (Table 2).

Whales #1 and #6 took an offshore route west of all the Channel Islands along the 900-m depth contour, on a trackline from Point Conception to the north end of Vizcaino Bay.

Whales #10 and #7 favored a more inshore route, with both whales passing Cabo San Lucas on the same day (5 November). Whale #7 traveled the farthest, on a route roughly parallel to the Mexican coastline at 200–500 km offshore along the 2,500–3,200-m depth contour, until 13°N. Its last location was approximately 450 km west-northwest of the CRD (Fig. 4b).

Migratory (linear trend) movement, as opposed to clustered movement, accounted for 73%, 64%, 50%, and 49% of the distance between locations for whales #6, #10, #7, and #1 respectively. The highest sustained speeds for each whale were achieved consistently along the northern Baja California coast, ranging from 103 to 195 km/d (Table 2).

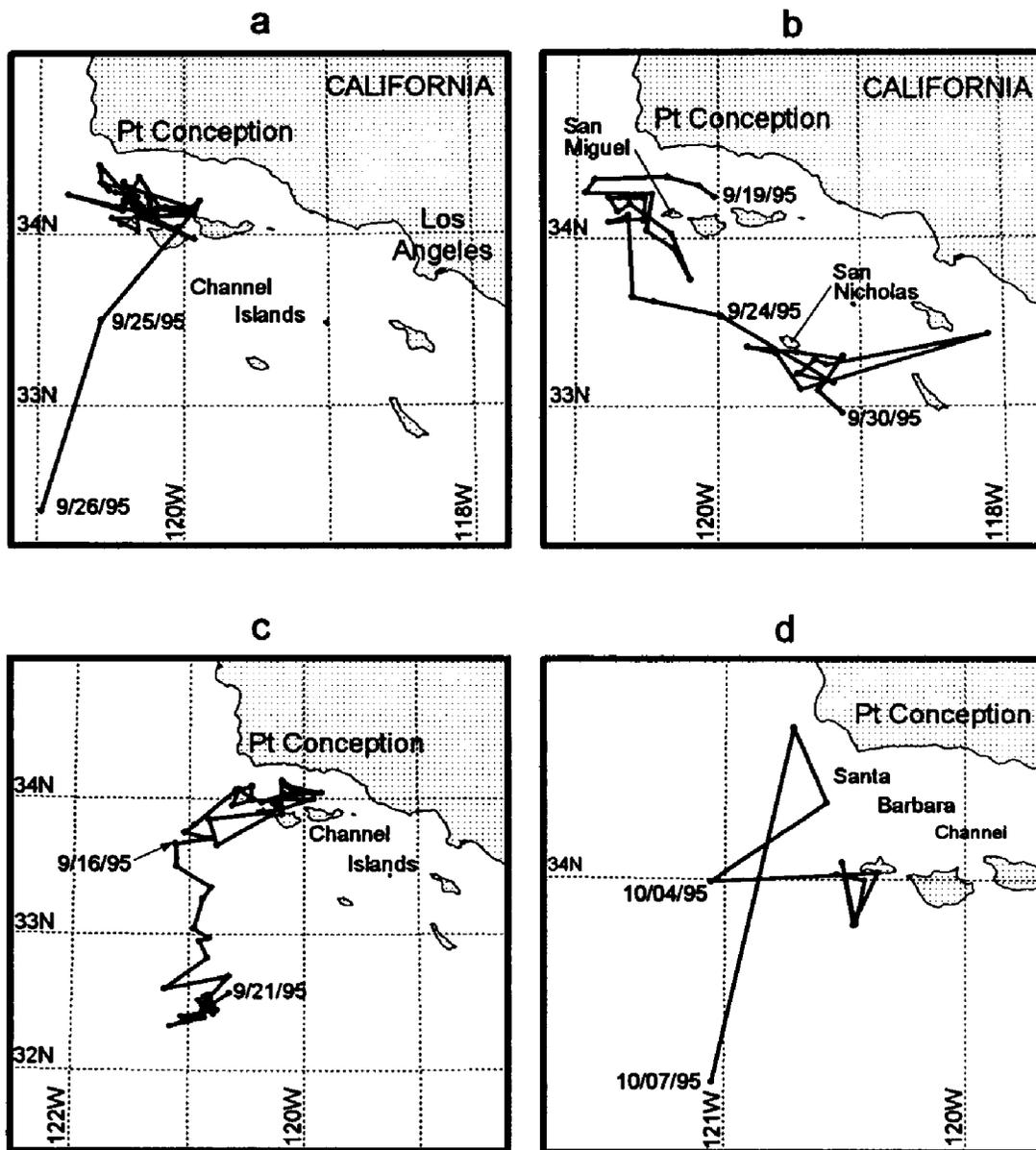


Figure 1. Satellite-acquired locations of blue whales: (a) Whale #5 tagged in Santa Barbara Channel and tracked at least 896 km during period 10–26 September 1995; (b) Whale #8 tagged in Santa Barbara Channel and tracked at least 1,064 km during period 19–30 September 1995; (c) Whale #4 tagged in Santa Barbara Channel and tracked at least 1,314 km during period 10–21 September 1995; (d) Whale #9 tagged in Santa Barbara Channel and tracked at least 393 km during period 2–7 October 1995.

DISCUSSION

This study provides the first detailed description of the movements of individually-tracked blue whales, both while on their summer feeding grounds and during their migration to wintering areas. As all but one whale remained in the area in which they were tagged for several days after tagging, and speeds of all whales immediately after tagging were similar to speeds during

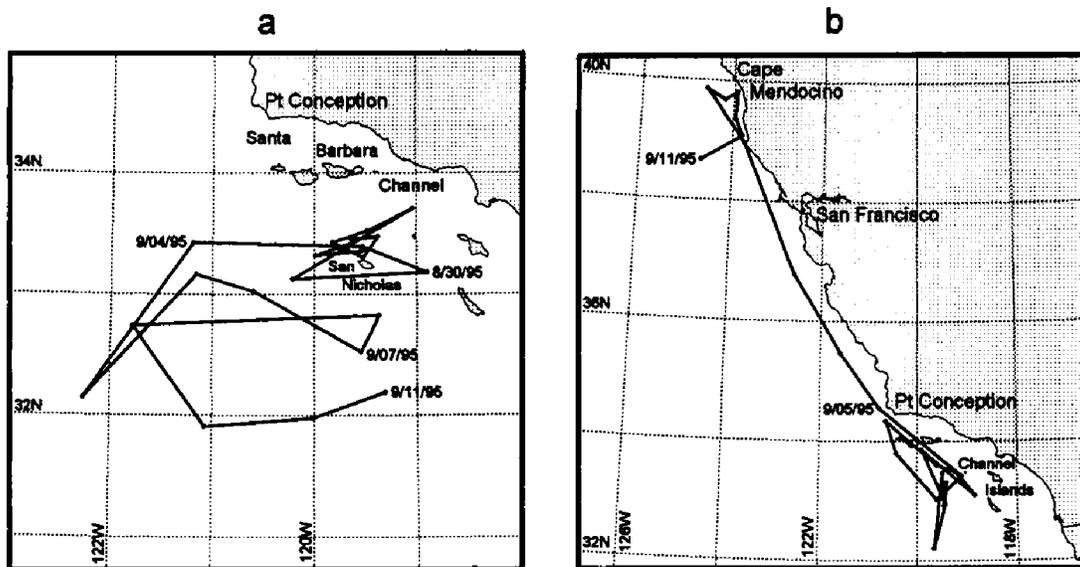


Figure 2. Satellite-acquired locations of blue whales: (a) Whale #2 tagged off San Nicholas Island and tracked at least 1,756 km during period 23 August–11 September 1995; (b) Whale #3 tagged off San Nicholas Island and tracked at least 2,154 km during period 23 August–11 September 1995.

other periods of clustered locations, we believe short-term tag effects (if any) were negligible.

Feeding

Feidler *et al.* (1998) established a strong relationship between the distribution of blue whales in the west end of the Santa Barbara Channel and the

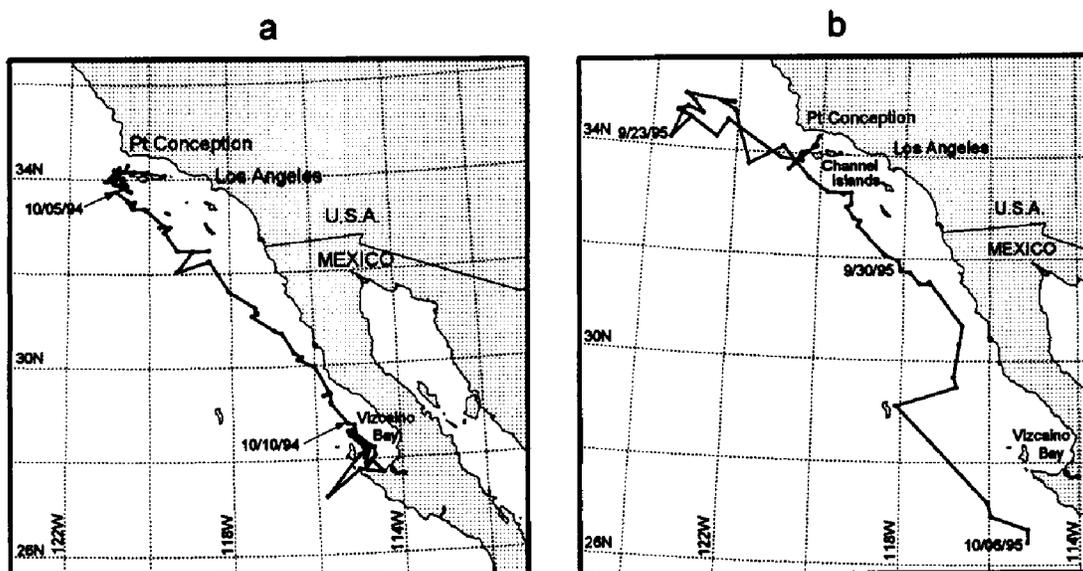


Figure 3. Satellite-acquired locations of blue whales: (a) Whale #1 tagged in Santa Barbara Channel and tracked at least 2,382 km during period 4–15 October 1994; (b) Whale #6 tagged in Santa Barbara Channel and tracked at least 2,503 km during period 18 September–6 October 1995.

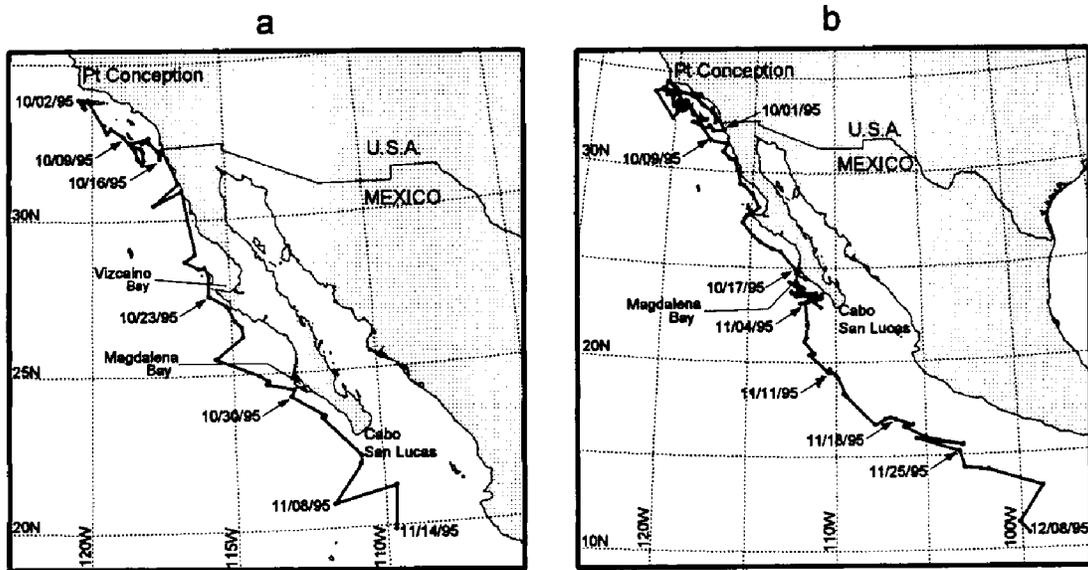


Figure 4. Satellite-acquired locations of blue whales: (a) Whale #10 tagged in Santa Barbara Channel and tracked at least 3,362 km during period 2 October–14 November 1995; (b) Whale #7 tagged in Santa Barbara Channel and tracked at least 8,668 km during period 18 September–6 December 1995.

high density of krill found there. They found that wind-driven upwelling is focused just north of Point Conception and is advected south into the Channel Islands. Further, they found that circulation in the Santa Barbara Channel may retain the krill aggregations along the north side of San Miguel Island and Santa Rosa Islands. Croll *et al.* (1998) provided compelling evidence that blue whales equipped with short-term time-depth recorders in this region were diving to depths where krill concentrations were most dense ($\bar{x} = 68.1 \pm 57.5$ m). Thus, the clusters of locations for individual tagged blue whales in this area likely represent feeding. We suspect that clusters of whale locations in other areas, including along the migration route, also represent feeding.

Upwellings may have played a role in the distribution of other tagged whales. Of the four tagged whales passing through an area approximately 150 km southwest of San Miguel Island, most were within 15 km of San Juan Seamount, which rises to within 600 m of the ocean's surface. Irregular bottom topography and islands contribute to locally intense, highly variable mixing and upwelling within the Southern California Bight (Smith *et al.* 1986), enhancing productivity and prey availability. This phenomenon is intensified in fall months through the interaction of the California Current and the Davidson Counter Current (Smith *et al.* 1986). Whale #4 went north to Cape Mendocino, a major center of upwelling in the California Current (Smith *et al.* 1986). Whale #7 spent 19 d between Magdalena Bay and Cabo San Lucas. An upwelling in this area has produced large quantities of euphausiids (*Euphausia pacifica*, *Thysanoessa gregaria*, and *Nematoscelis difficilis*) and red crabs (*Pleuroncodes planipes*) (Brinton 1979). Blue and gray whales (*Eschrichtius robustus*) have been observed near Magdalena Bay feeding on pelagic red crabs (*Pleuroncodes planipes*) (Rice 1974, 1978). Blue whales may have been attracted to these

Table 2. Dates of arrival, distances traveled, and speeds for four southbound migrant blue whales between four enroute locations.

Whale #	San Clemente Island (32°40'N)	Dates of arrival, distances traveled, time enroute, and apparent speed				Last location
		Vizcaino Bay (28°30'N)	Magdalena Bay (24°50'N)	Cabo San Lucas (22°50'N)		
1	10/6/94	10/10/94 860 km, 4.4 d, 195 km/d				Vizcaino Bay
6	9/29/95	10/5/95 977 km, 6.4 d, 153 km/d				Vizcaino Bay
10	10/10/95	10/21/95 1,187 km, 11.5 d, 103 km/d	10/28/95 640 km, 6.5 d, 98 km/d	11/5/95 506 km, 7.7 d, 66 km/d	11/14/95 610 km, 9.0 d, 68 km/d	
7	9/29/95	10/12/95 2,122 km, 13.5 d, 157 km/d	10/17/95 676 km, 5.0 d, 135 km/d	11/5/95 1,670 km, 19.0 d, 88 km/d	12/6/95 2,959 km, 30.5 d, 97 km/d	
Mean ± SD		1,286 ± 573.2 dm 8.9 ± 4.25 d 152 ± 37.7 km/d	658 ± 25.4 km 5.7 ± 1.06 d 116 ± 26.2 km/d	1,088 ± 823.1 km 13.3 ± 7.99 d 77 ± 15.5 km/d		

potential feeding areas by the vocalizations of other whales, by environmental cues or, perhaps, merely by remembering previous feeding success there.

Speeds and Timing

The distances and speeds reported in this study are calculated from straight-line distances between locations. Our editing criteria permit acceptance of locations with moderate errors, which may result in overestimates of these distances and speeds. In reality, however, our distances and speeds are more likely underestimated by not accounting for indirect movement between locations. This bias is borne out in the positive relationship between number of locations received per day and speed. The underestimation of distance and speed is more likely when whales are feeding (meandering) than when they are moving in a single direction (such as during migration). Our visual observations suggest feeding whales rarely keep a particular heading for very long. Therefore, calculated distances and speeds of tagged whales may be particularly misleading during periods of clustered locations. Blue whales moving in a directed manner averaged 5–7 km/h over periods of 3–7 d, but these speeds may also be underestimated.

Despite differences in departure dates from the Channel Islands, migration routes, speeds, and delays while en route, whales #7 and #10 passed west of Cabo San Lucas (22°50'N) simultaneously. Our tagged-whale departures, whaling records (Tonnessen and Johnsen 1982), and observations by other investigators (Calambokidis *et al.* 1990, Rice 1974) indicate that whales are not present off southwest Baja California from November through January, reinforcing the notion that their calving/breeding habitat is somewhere beyond the Baja California peninsula.

The data from whale #7 are the first confirmation that whales feeding off the California coast use the CRD region. This supports one of Reilly and Thayer's (1990) hypotheses that whales near the CRD represent northern hemisphere whales during the northern winter. However, this does not preclude their other hypotheses proposed for whale aggregations in the ETP.

The CRD is a nearly-permanent 200-km-diameter upwelling feature of the ETP where the thermocline comes to within 10 m of the surface. The surface layer in this area is enriched with nutrients from the cold water immediately below it, contributing to high primary and secondary productivity. Reilly and Thayer (1990) suggested that blue whale occurrence in the CRD region may be due to the great zooplankton abundance found there (Brinton 1979) and speculated that foraging may be an important secondary factor in their migration to low latitudes. The authors suggest that blue whales may select winter habitat that is most favorable for feeding. Our track of whale #7 to the west of the CRD is well within the distribution of blue whale sightings reported by Reilly and Thayer (1990) in that area. As productivity has been shown to be higher to the west of the CRD than in the CRD itself (Fielder *et al.* 1991), the locations for whale #7 lend further support to the idea of foraging. Because of their large size, blue whales have higher absolute energy

requirements than do smaller whales. Fasting during the winter reproductive season like gray whales and humpback whales may not be feasible. We do not know if this potential winter feeding activity is dependent on sex, age, or reproductive condition.

Despite the large size of whales, tag size appears to be important. We believe the reduced hydrodynamic drag of the smaller tags resulted in longer-lasting attachment. Even so, the average tracking period in this study was only 27 d. Thus tag longevity (attachment) is still a major problem. Deployment of even smaller (and perhaps implanted) tags will likely increase attachment longevity to reveal more about the critical habitats of blue whales and their migrations.

ACKNOWLEDGMENTS

This project began through generous gifts from Faye Stewart, Lucille Stewart, and Loren L. Stewart. It was further funded by the Office of Naval Research, National Marine Fisheries Service (WHAPS study), Minerals Management Service, and donors to the Oregon State University Endowed Marine Mammal Program. We thank the National Marine Fisheries Service for research permit #841; Rod Mesecar for tag design and assembly; Martha Winsor for location editing and figure preparation; Thomas Follett for figure editing; Veryl Barry for office management and manuscript preparation; Sara Heimlich for earlier draft editing; Greg Krutzikowsky for piloting our research vessel and field assistance; Sallie Beavers, Taku Fuji, Terri Herbert, Vicki Hoover, Susan Lynds, Trey MacDonald, Mary Lou Mate, Michelle Mate, Barbara Pijanowski, Rob Schick, and Kate Stafford for assistance in the field; collaborators Chris Clark and Brian Corzilius at Cornell University for development of an acoustic sensor for the ST-6 transmitters; and Phil Clapham, Steve Reilly, and two anonymous reviewers for reviewing drafts of this manuscript. This paper is dedicated to the memory of Lucille Stewart and Dr. Ken Norris.

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Received: 6 April 1999

Accepted: 19 May 1999