Aquatic Mammals 2010, *36*(1), 59-66, DOI 10.1578/AM.36.1.2010.59

Association Between Blue Whale (*Balaenoptera musculus*) Mortality and Ship Strikes Along the California Coast

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Abstract

Blue whales (*Balaenoptera musculus*) are distributed worldwide, and although severely depleted by commercial whaling, their abundance off the California coast now appears to be increasing. Little is known about natural causes of mortality of blue whales, but human-related mortality continues despite legal protection. Ship strikes are a significant mortality factor for other species of baleen whale, and changes in shipping traffic have been advocated to minimize further deaths. Between 1988 and 2007, 21 blue whale deaths were reported along the California coast, typically one or two cases annually. Three pulses in strandings were observed, with three carcasses observed in fall 1988, three in 2002, and four in fall 2007. Two of the four animals in 2007 were first observed dead in the Santa Barbara Channel and had wounds typical of a ship strike. Blue whale strandings were spatially associated with locations of shipping lanes, especially those associated with the Ports of Los Angeles and Long Beach, and were most common in the fall months.

Key Words: blue whale, *Balaenoptera musculus*, ship strike, trauma, shipping lane, *Sarcocystis*

Introduction

Blue whales (*Balaenoptera musculus*) are distributed worldwide, with four recognized subspecies and five potential subpopulations in the North Pacific, although these populations might not be totally discrete (Reeves et al., 1998; McDonald et al., 2006b). Blue whale stocks were severely depleted by commercial whaling, with the North Pacific post-whaling population of blue whales estimated at 1,400 animals (Gambell, 1976). Since then, their abundance off the California coast appears to be increasing, probably because of both changes in their distribution and an overall increase in population (Reilly & Thayer, 1990; Barlow, 1994; Calambokidis & Barlow, 2004). Recently, the abundance of blue whales in the eastern North Pacific was estimated using both line-transect and capture-recapture methods, giving estimates of 3,000 and 2,000 animals, respectively (Calambokidis & Barlow, 2004). Blue whales are only present seasonally off the coast of California and their movements are correlated with aggregations of the euphausiids *Euphasia pacifica* and *Thysanoessa spinfera* (Mate et al., 1999).

Little is known about natural causes of mortality of blue whales, although rake marks and observation of a killer whale (*Orcinus orca*) attack on one animal indicate predation occurs (Tarpy, 1979). Human-related mortality continues despite protection from commercial whaling as there have been several observations of blue whales on bows of ships (Norman et al., 2004). Ship strikes are an important cause of mortality for other species of baleen whale, especially northern right whales (*Eubalaena glacialis*), fin whales (*B. physalis*), and humpback whales (*Megaptera novaeangliae*), with up to one third of all fin and right whale strandings attributed to ship strikes in some areas (Knowlton & Kraus, 2001; Laist et al., 2001; Panigada et al., 2006). Along the California coast, gray whales (*Eschrichitus robustus*) are also commonly hit by ships (Heyning &

Dalheim, 1990). Ship strikes are such an important factor in the lack of recovery of the critically endangered northern right whale (Knowlton & Kraus, 2001) that changes in shipping traffic speed and location, and placement of dedicated spotters on ships have been advocated to minimize future deaths (Vanderlaan & Taggart, 2007; International Whaling Commission [IWC], 2008). To this end, a 10-kt limit on vessel speed and changes to ship routing have been implemented during seasons of peak right whale abundance in some areas of the North Atlantic (International Maritime Organization [IMO], 2008; National Marine Fisheries Service [NMFS], 2008). Despite reports of blue whales observed draped over the bows of ships (Reeves et al., 1998; Norman et al., 2004), data on the frequency of ship strikes and identification of high-risk sites for this species have not been compiled. This paper summarizes two decades of blue whale strandings along the California coast from 1988 to 2007 and identifies regions of ship-strike-associated strandings.

Materials and Methods

Observations of dead whales close to shore or on the beach were reported by members of the general public to the California Marine Mammal Stranding Network or the National Marine Fisheries Service (NMFS). Occasionally, mariners involved in a collision with a whale reported the incident to the NMFS, and these animals were recorded as a vessel strike. Animals were examined in as much detail as logistics allowed. One animal received a complete necropsy as described by Rowles et al. (2001), including collection of tissue samples for histopathology and toxicology, fluids for biotoxin analysis, and examination of skeletal regions; this animal stranded in 2007 and was towed to a beach suitable for an in-depth necropsy. Additionally in 2007, partial necropsies were conducted on two of the strandings, and one other whale was measured, examined externally, and a skin sample was collected for genetic analysis. Biotoxin analyses were conducted in NOAA-contracted laboratories employing standard protocols.

Results

Strandings

Over the two decades included in this paper, 21 blue whale strandings occurred along the California coast (Table 1). These strandings were temporally and spatially patchy (Figure 1). Three pulses in stranding frequency were observed: the first in fall 1988 (n = 3), another in summer and fall 2002 (n = 3), and a third in fall 2007 (n = 4), the latter two pulses consisted of ship-struck whales. In both 1988 and 2002, the three reported strandings were spatially distributed throughout the state of California, ranging from the San Francisco Bay area in the north to San Diego in the south (a distance of over 700 km). In contrast, in 2007, the four strandings were clustered in the Southern California Bight, with most occurring in the Santa Barbara Channel; the maximum separation between these four confirmed reports was 180 km. In nine of the years, there was no blue whale mortality, while in others there were only one (n = 4) or two (n = 3) deaths. Of the 21 blue whale deaths along the California coast between 1988 and 2007, eight of these carcasses were confirmed to have died as a result of ship strikes via direct examination of the carcass or by the fact that that they appeared in port associated with a ship (n = 3). Five of the ship-struck whales were females, four of which were adults, and three were subadult males (Table 1). The ship-struck whales were found in the vicinity of the shipping lanes entering the San Francisco Bay, the Port of Los Angeles, the Port of Long Beach, and in the Santa Barbara Channel (Figure 1).

Two ship-strike-related mortality clusters occurred within the 20 y examined here. Two whales were mortally struck in 2002 and four in 2007. In 2002, a blue whale (CMMC-C158) had a series of six parallel vertical slashes along its right side and another had a broken left flipper and lacerations on the head, both suspected to be caused by a ship strike. In 2007 (8 to 19 September), five sightings of dead blue whales (representing at least four individual animals) were reported in southern California. This cluster of mortalities was sufficiently anomalous to be designated an "Unusual Mortality Event" (UME) by the NMFS (Wilkinson, 1996). On 8 September 2007, a 22-m-long male blue whale (DSJ2231) was discovered dead floating in Long Beach Harbor, Los Angeles County. It was towed out to sea for disposal after it was measured and sampled for genetics but before a necropsy could be performed. On 11 September 2007, a dead blue whale was observed floating in the Santa Barbara Channel north of Santa Rosa Island at 34° 20' N and 119° 25' W (Figure 1). This female whale (SBMNH-2007-19) stranded 2 d later on Hobson County Beach, Ventura County, on 13 September 2007. On 12 September 2007, another dead blue whale was seen floating off of San Clemente Island which did not strand. No additional information was collected from this animal, and it is assumed that this animal was the previously documented animal towed from the Long Beach Harbor. The following week (19 September 2007), a dead blue whale (SBMNH-2007-20) was observed in the Santa Barbara Channel at 34° 09.5' N, 119° 29.6' W

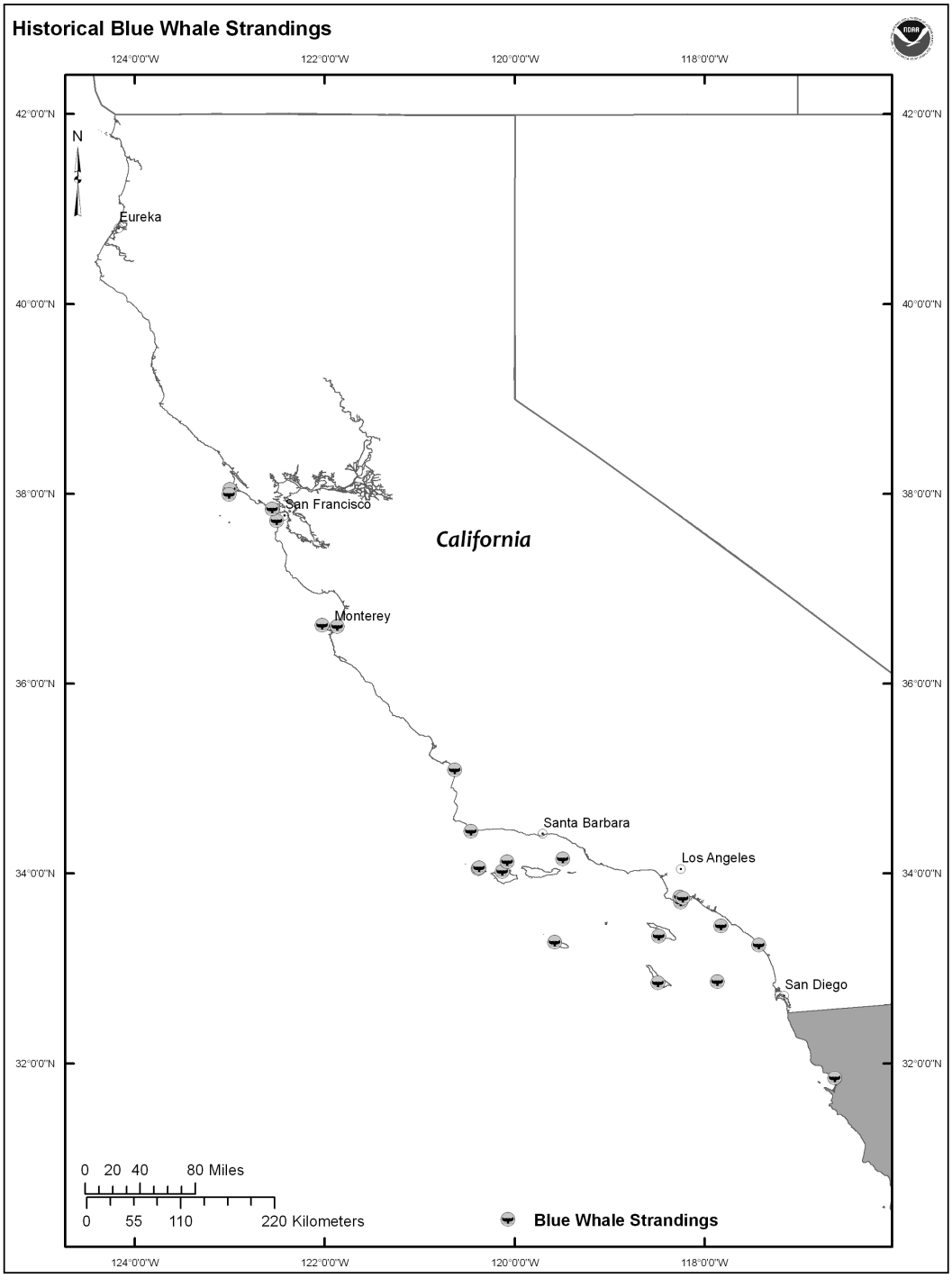

Figure 1. Initial locations of reported blue whale strandings with evidence of ship strike from 1988 through 2007

Table 1. Reported blue whale ship strikes in California between 1988 and 2007

Date	ID	Location	Carcass Condition Code*	Sex	Length (m)	Probable cause of death	Remarks
19 July 1988	LACMNH-JEH-384	San Clemente Island, Box Canyon	4	M	13.0		
15 Aug 1988	SBMNH-1988-31	San Luis Obispo, Oceano Dunes	4	F	26.0		
3 Sept 1988	CAS-RLD-300	San Francisco, Fort Funston	4	M	22.1	Unknown	Large abscess in right chest wall, penetrating chest cavity; gastro-intestinal tract empty; heart and lungs eaten away by sharks.
2 Sept 1989	CAS-RLD-337	Marin, Point Reyes National Seashore (PRNS), Great Beach	3	M	23.0		Length measurement taken from a distance of 5 to 6 m from carcass; fresh shark bites; 3-m great white shark observed in vicinity of carcass.
17 Aug 1992		Santa Barbara, Government Point	4	M	9.6		Carcass inaccessible.
12 Sept 1992		Marin, PRNS, Sea Lion Cove	4	U	16.8		
2 Aug 1993	LACMNH-TDL-169	San Nicolas Island, West End	3	F	24.4	Ship strike	Lesion consistent with hematoma in lower right jaw and gular regions; 3 to 5 propeller-like slashes through ventral pleats in gular region.
4 Oct 1993		Monterey, offshore	4	U		Unknown	Carcass floating offshore.
12 Jan 1994		Santa Rosa Island, Green Canyon	4	U	18.0		
11 Aug 1996	SBMNH-1996-078	San Miguel Island, Simonton Cove	4	M	22.4	Unknown	
14 June 1997	SCIC-97-001	Santa Catalina Island, between Ben Weston Point & China Point	4	M	23.2	Unknown	
22 July 2002	CMMC-C-158	Marin, Tennessee Valley Beach	4	F	23.5	Ship strike	Carcass first sighted floating offshore on 16 July 2002, 19.3 km west of Golden Gate Bridge.
4 Oct 2002		Port of Los Angeles, South of Angel's Gate	4	M	21.3	Ship strike	Suspected ship strike; broken left flipper; deep cuts on left side of head.
10 Oct 2002	NMFS-KXD-0033	San Diego, Camp Pendleton, White Beach	4	M	23.0	Unknown	

Date	ID	Location	Carcass Condition Code*	Sex	Length (m)	Probable cause of death	Remarks
22 July 2003		San Diego, offshore	1	U	13.7	Ship strike; NOT MORTALITY	Vessel collided (glancing blow) with animal that surfaced in front of vessel; vessel hit tail section of 12.2- to 13.7-m whale; whale appeared upset but not injured; no damage to vessel from collision; no blood observed in water according to reporting party.
21 Aug 2004	LACMNH-DSJ-2164	Port of Los Angeles, Berth 91	3	F	15.9	Ship strike	
1 Oct 2004	MLML-MM-1137 / TMMC-C-194	Monterey, del Monte Beach	3	M	18.1	Unknown	
8 Sept 2007	LACMNH-DSJ-2231	Los Angeles, Port of Long Beach, West Basin	3	M	22.0	Assumed ship strike	Animal discovered floating inside the Long Beach Harbor.
11 Sept 2007	SBMNH-2007-19	Santa Barbara Channel	4	F	24.0	Ship strike	First observed on 11 September 2007; washed in at Hobson County Park, Ventura County on 14 September 2007 and was necropsied.
12 Sept 2007		25 miles NE San Clemente Island	3	M			Dead floating whale reported, could be a re-sight of LACMNH-DSJ-2231.
19 Sept 2007		Playa Hermosa, Ensenada, Baja California, Mexico	3	U	22.0		Reported as a 22-m, moderately decomposed blue whale. The animal was buried by the local municipality and no samples were collected. **Note:** This animal could be a resight of LACMNH-DSJ-2331; however, the decomposition state, as shown by the photos, is not consistent with an animal that was Code 3 on 8 September 2007.
19 Sept 2007	SBMNH-2007-20	Santa Barbara Channel, South of Platform Grace	3	M	21.2	Ship strike	First observed in the Santa Barbara Channel on 19 September 2007; this animal was towed to shore and necropsied on 22 September 2007.
29 Nov 2007	SBMNH-2007-25	San Miguel Island, Simonton Cove	4	F	22.0	Ship strike	Right pectoral flipper severed; ~3.7-m male fetus found nearby.

*Carcass Condition Code: 1: Alive, 2: Fresh Dead, 3: Moderate Decomposition, 4: Severe Decomposition, 5: Mummified/Skeletal

and was towed to the mainland for full necropsy examination. On this same date, a fresh dead blue whale was observed on the beach near Ensenada, Mexico, but was disposed of before a necropsy could be conducted (L. Rojas, pers. comm., 19 September 2007). This whale was not included in the overall UME total due to a lack of necessary data to confirm the species identification and the inability to determine if it represented a unique individual or a re-sight of one of the carcasses observed previously.

Postmortem Examinations

Whale SBMNH-2007-19 was a 24-m-long female in good nutritional condition (ventral blubber thickness on the axillary girth 9 cm). There was a sharply demarcated linear mark on the skin surface running circumferentially from the dorsum around the left lateral flank approximately that was 1 m in length and 15 cm wide at the level of the posterior end of the throat grooves. Extensive staining consistent with hemorrhage was present in the blubber and underlying muscle along the left side of the animal, with a sharp demarcation between stained blubber and normal blubber approximately two-thirds around the animal, and petecchial hemorrhages in the blubber cranial to the lesion. Skeletal muscle below the discolored blubber was macerated, and transverse processes were severed from lumbar vertebrae in this region.

Whale SBMNH-2007-20 was a 21-m-long male in good nutritional condition with a mid-body lateral blubber thickness of 17 cm and a mid-body ventral blubber thickness of 9 cm. A detailed necropsy on this animal revealed comminuted fractures of five cranial ribs on the right side, the cranial thoracic vertebrae, and caudal skull, all with extensive associated skeletal muscle damage and staining consistent with hemorrhaging on broken margins implying an antemortem injury. Urine and gastric fluid tested by liquid chromatographic separation (LC-MS/MS) had no detectable levels of domoic acid or saxitoxin. The intestines contained moderate burdens of acanthocephalans morphologically consistent with *Bolbosoma turbinella* previously recorded in blue whales by Measures (1992). Histopathology revealed verminous pneumonia, glomerulonephritis, and myocardial fibrosis with intramyosial protozoal cysts. The glomerular changes chiefly involved the Bowman's capsule, which was thickened for most glomeruli; however, the parietal epithelial cells were typically flat and uniform. In those glomeruli where the capsules exhibit variable thickening, there was a mild increase in the thickness of glomerular basement membranes and occasional formation of adhesions between glomeruli and Bowman's capsule. Myocardial fibrosis was mild and unlikely to have resulted in cardiac dysfunction. Protozoal cysts that were morphologically most suggestive of *Sarcocystis* sp. were observed in myofibers without an associated inflammatory reaction. Interestingly, this is the first report of protozoa in blue whale myocardium, although such parasites have been observed incidentally in other marine mammals (Akao, 1970), and their pathogenicity is unclear.

The last reported 2007 blue whale stranding (SBMNH 2007-25) was a 22 m female found on 29 November at San Miguel Island. It had a severed right pectoral flipper, and an expelled male fetus measuring 365 cm in length was found a few hundred meters away.

Discussion

These data indicate that ship strike is an important cause of blue whale mortality along the California coast, and a spatial and temporal cluster in 2007 raised concerns about factors predisposing blue whales to this event. Photographic identification of blue whales using primarily small boat surveys and photographs of distinct markings has been conducted along the California coast since the mid-1980s (Calambokidis et al., 1990; Calambokidis & Barlow, 2004). During 2007, eight dedicated small boat surveys were conducted for photographic identification by Cascadia Research, and opportunistic photographs from whale watch boats by the Channel Islands Naturalists Corps were also examined. Additionally, suction cup tags were deployed on 12 animals that were part of 10 single or pairs of blue whales from 6 to 8 September 2007. These instruments recorded a wide variety of data, including depth, acoustics, pitch, and roll, and they allowed determination of whether feeding was occurring (see Goldbogen et al., 2006; Calambokidis et al., 2008).

Blue whales were more abundant in the Santa Barbara Channel during 2007 than in previous years and appeared to be most abundant in early September. Blue whales were photo-identified 796 times in 2007, representing 286 different individuals based on photographic identification (Calambokidis et al., 2009a). This is the highest annual number of individuals identified in the Santa Barbara Channel since this type of research began in 1992, despite fewer dedicated small boat surveys in 2007 (eight) compared to the average per year (ten), and eclipsing the previous maximum of 174 individuals in 2002. Most of these identifications were made in August (138 individuals) and September (199 individuals) of 2007 (266 unique IDs for the 2 mo) immediately preceding and during the time period of the

UME. High numbers of blue whales in the Santa Barbara Channel immediately prior to the ship-strike events were also revealed by the analysis of the data over the 8 d preceding the discovery of the first ship-struck blue whale (1 to 8 September) with 141 individual whales identified. The single highest number of blue whale identifications in any single day was made on 8 September 2007 (69 individuals). This was the same day the first ship-struck blue whale was documented and just 3 d before SBMNH-2007-19 was observed floating in the Santa Barbara Channel. In addition to more whales being in the vicinity of the Santa Barbara Channel in fall 2007, there were also some indications that blue whales were distributed within the shipping lanes more than in previous years. One concentration of feeding blue whales identified from 6 to 8 September 2007 was located in the shipping lanes, and another concentration area was within 1 nmi of the shipping lanes. Suction-cup tagging conducted 6 to 8 September 2007 showed that, of ten whales tagged outside of the shipping lanes, three whales traveled across or into the shipping lanes and that two others spent time within 1 nmi of the shipping lanes during the period between tag deployment and recovery. The tags also confirmed that the whales in this region were primarily milling and feeding at depths of 150 to 300 m during this period.

These data indicate that blue whales are susceptible to mortality from ship strikes off the coast of California during their seasonal association with the area, particularly when krill occur in the shipping lanes. Although blue whales are generally present in the region every year, fine-scale distribution of prey species into the shipping lanes, as happened in fall 2007, could significantly increase the risk of ship strikes on foraging blue whales by large vessels. Shipping traffic is increasing annually along the California coast (McDonald et al., 2006a). Increasing whale populations and oceanic changes may require animals to exploit new or return to historical waters in search of adequate resources (Calambokidis et al., 2009b). Thus, it is likely that the risk of blue whale mortality as a consequence of their seasonal presence in shipping lanes will continue. Ship strikes on whales are a cosmopolitan problem and well-documented in fin and right whales (Laist et al., 2001; Kraus et al., 2005; Panigada et al., 2006). Here results from stranding observations of blue whale mortalities resulting from injuries believed to be a result of vessel collisions demonstrate that blue whales are also at risk, and mitigation measures developed for other species of whales should be considered for blue whales off the California coast if further mortality is to be reduced.

Acknowledgments

We thank all the California Marine Mammal Stranding Network participants for assistance in generating the data reported here, the National Marine Fisheries Service Marine Mammal Unusual Mortality Event Response Fund for financial assistance, and the numerous volunteers who made full necropsy examinations in 2007 possible. We also thank Spencer Fire, National Ocean Service, for his rapid bio-toxin analysis, as well as volunteer pilot Stephen Parker and National Geographic photographer Flip Nicklin for reporting specimen SBMNH 2007-19 during their spotting and aerial photography in support of Oregon State University satellite's tagging of blue whales.

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