BLUE WHALE (*Baleanoptera musculus*) SHIP STRIKE THREAT ASSESSMENT IN THE SANTA BARBARA CHANNEL, CALIFORNIA

by

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Abstract

Blue Whale (*Baleanoptera musculus*) Ship strike Threat Assessment in the Santa Barbara Channel, California

The blue whale is the largest baleen whale and also the most massive animal to inhabit global waters (1979; Perrin, Wuersig, & Thewissen, 2002; Jefferson, Webber, & Pitman, 2008). From the early 20th century until 1966 some 330,000 blue whales were harvested in northern and southern waters, but most were taken from the Antarctic region (Reeves R.R., 1998; Bortolotti, 2008; Gambell, World Whale Stocks, 1976; Gambell, The Blue Whale, 1979; Ellis, 1991). This population decline caused the International Whaling Commission (IWC) to ban the hunt of blue whales in 1966 (Ellis, 1991). Modern research tools have provided insights into the abundance and distribution of blue whales (Calambokidis J., 2003; Calambokidis, Douglas, Falcone, & Schlender, 2007). The northeast Pacific blue whale population is one of the largest populations globally with an estimated 1,400 animals (Calambokidis, Douglas, Falcone, & Schlender, 2007). This population has shown little growth since the end of whaling when compared to other whale species such as the sperm or humpback (Bortolotti, 2008). Studies indicate ship strikes may be a threat to the recovery of northeast Pacific blue whale populations (Jensen & Silber, 2004). The Santa Barbara Channel in central California is a region hosting both shipping lanes and the feeding habitat of blue whales. In September of 2007, six blue whales were fatally struck, all of which occurred in the Santa Barbara channel region (Cascadia Research unpublished data). Upon assessment, ship strikes have been determined to be a threat on the population scale, potentially causing slowed growth or even decline. Several conservation strategies could be employed including vessel speed reduction, shipping lane shift, and posting observers on commercial vessels. Further studies are critical to advance the knowledge and technology that could mend this issue.

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Introduction

Ship strikes occur regularly where feeding habitat of whales and shipping lanes overlap (Bortolotti, 2008; Douglas 2008). A detailed assessment is needed to determine that this has the potential to slow or halt population growth of blue whales in close association with large vessel traffic. The research presented in this document will shed light on the threat of ship strikes slowing population growth on the northeast Pacific blue whale population, situated in the Santa Barbara Channel, which also hosts shipping lanes. The objective is to bring to light a conservation issue that has not been perceived as a danger to a fragile wildlife population.

Oceanic upwelling events transport cold, nutrient rich water close to the surface bringing with them plankton and krill; the staple diet of blue whales (Chandler, 1999). Such upwelling is newly (20-30 years) occurring within the Santa Barbara Channel, which is attracting a dense population (see chapter 3) of blue whales (Larkman & R.R., 1998; Calambokidis, Douglas, Falcone, & Schlender, 2007). Chapter one shows that this population is fragile due to an abnormally slow recovery from six decades of whaling (Bortolotti, 2008). In chapter two, study methodologies are presented that show how researchers understand blue whale population dynamics and diving/feeding behavior (Calambokidis J., 2003; Calambokidis, et al., 2007/08). Another important consideration for a ship strike assessment, shown in chapter 3, are the current abundance and distribution estimates of northeast Pacific blue whales. In chapter four, a threat assessment of ship strikes on northeast Pacific blue whales is made, given current literature and research. Finally, chapter five provides insights into the future of blue whale conservation, and presents strategies to prevent further ship strike events.

Chapter 1

BLUE WHALE BIOLOGY AND THE HISTORY OF POPULATION DECLINE

Taxonomy

The blue whale, (Linnaeus 1758), is a species of baleen whale (Perrin, 1979; Wuersig, & Thewissen, 2002; Jefferson, Webber, & Pitman, 2008). It belongs to the largest group of baleen whales, commonly known as *rorquals* (Jefferson, Webber, & Pitman, 2008). By mass, the blue whale is the largest animal known to have ever lived on Earth (Gambell, 1979; Reeves R.R., 1998). Adults in the Antarctic have reached a maximum body length of about 30 m and can weigh more than 150,000 kg (Reeves R.R., 1998). Blue whales in the Northern Hemisphere are generally smaller than those in the Southern Ocean. As is true of other baleen whale species, female blue whales are slightly larger than males (Ralls, 1976).

Blue whales are long-bodied and slender (figure 1) with a dorsal fin that is proportionately smaller and set further back than those of other baleen whales (Jefferson, Webber, & Pitman, 2008). Their rostrum is broad and flat. When a blue whale is feeding, its pleated throat and chest area expands to engulf an enormous amount of seawater and food. The water is then expelled and the filtered zooplankton is swallowed, after which the body outline returns to its characteristically slender shape (Reeves R.R., 1998).

Figure 1.*The slender shape of the blue whale allows it to travel efficiently over long distances (image provided by Cascadia Research Collective)*

The animals' color pattern is a mottled gray, which appears light blue when seen through the water. The characteristic pattern is unique to each animal and acts like a fingerprint in matching individuals for long-term photographic identification studies.

Studies of intra-specific variability have led to the designation of three subspecies (Jefferson, Webber, & Pitman, 2008): (a) *B. m.* in the Northern Hemisphere, (b) the slightly larger *B. m. intermedia* from the Antarctic and (c) the so-called "pygmy" blue whale, *B. m. brevicauda*, a smaller and morphologically distinct species found in the sub-Antarctic zone of the southern Indian Ocean and southwestern Pacific Ocean (Perrin, Wuersig, & Thewissen, 2002; Jefferson, Webber, & Pitman, 2008). There is also a "resident" population of blue whales (of unknown taxonomic status) in the northern Indian Ocean from the Gulf of Aden, going east at least to the Bay of Bengal (Reeves R.R., 1998). This population was named *Balaenoptera indica* by Anderson (1879). *B. m. musculus*, making up the northeast Pacific population, reside in an area (from British Columbia to Costa Rica) where ship strike threats are the highest. The densest part of this population (see chapter 3) (Calambokidis, Douglas, Falcone, & Schlender, 2007) occurs seasonally in central California, where ship traffic and feeding habitat overlap. This makes the northeast Pacific population particularly vulnerable to ship strikes.

Reproductive Biology

Little literature exists on this facet of blue whale research. Blue whale reproduction is still part of the mysterious behavior of these elusive animals. Neither copulation nor birthing of blue whales has ever been recorded. Though little is known about the specifics of reproductive and courting behaviors, enough is known for a basic understanding of population dynamics.

Gestation period for blue whales is approximately 10-12 months, and calves are nursed for about 6-7 months (National Marine Fisheries Service, 1998). Reproductive activity, including mating and births, takes place in the winter season (National Marine Fisheries Service, 1998). Weaning most likely occurs either at or during the migration to the summer feeding areas. Average calving interval is probably two to three years. The age at attainment of sexual maturity is uncertain but is thought to be 5-15 years (Yochem and Leatherwood 1985). Due to the problems of determining the lifespan of blue whales, the estimated lifetime reproductive output of an average female is still uncertain. Experts estimate animals to have an average life span of 30-80 years (Jefferson, Webber, & Pitman, 2008). Since sexual maturity is not reached until approximately 5-15 years of age (Perrin, Wuersig, & Thewissen, 2002) and calving interval is approximately every 2-3 years (Perrin, Wuersig, & Thewissen, 2002) one can qualitatively estimate that an average mother has the potential to produce approximately anywhere from 2-20 offspring in her lifetime (Cascadia Research Collective unpubl. data). Unfortunately, at this time no recorded and published lifelong reproductive output exists.

The distribution of these animals is global, yet their worldwide abundance today could be as low as 10,000-15,000 animals (Gambell, 1976; Bortolotti, 2008). It has been estimated that well over 300,000 blue whales (estimations of up to 350,000 animals (Gambell, 1976)) inhabited the oceans before the early 1920's (Jackson, 1978). During some six decades of whaling more than 330,000 blue whales were harvested and their population was drawn to near extinction (Bortolotti, 2008). This dramatic decline has made the blue whale vulnerable to extinction. Furthermore, because of their slow reproductive output and low population numbers ship strikes may be threatening blue whale population growth.

History of Blue Whale Decline

Blue whales were not hunted before the early 1900's because the technology could not compete with the animal's large bodies and fast speed (Calambokidis & Steiger, 1997: Bortolotti, 2008). This changed when Norwegian whaling Captain Svend Foyn, invented a new technology that formed the foundation of modern commercial whaling (Calambokidis & Steiger, 1997). Foyn used funds from his success in sealing operations and launched a steam-powered boat specifically designed to catch whales (Calambokidis & Steiger, 1997). Though blue whales were the target, other species such as sei, humpback and fin were also hunted. The technology began to prove successful while only few laws existed on whaling restrictions. Thus rapid development of modern whaling set the stage for global expansion of the industry (Calambokidis & Steiger, 1997).

Technological Advancement of Rorqual Whaling (1873 – 1923)

It took a combination of increased vessel speeds and weaponry to kill an animal as large and fast as the blue whale. The concept of a harpoon cannon had been around since the 1730's, but no one had built one that whalers could use (Bortolotti, 2008). The early designs were awkward to use, dangerous, and fired only small harpoon heads that were inadequate for blue whales (Bortolotti, 2008).

In the 1820's English rocket scientist William Congreve tested a harpoon propelled with black powder and fitted it with a shell that exploded on impact with the whale (Ellis, 1991). This proved a successful method of killing a blue whale, but the animal sank once it died. Over several decades of trial and error, the harpoon changed from exploding on impact, to exploding a few seconds after it was embedded in the animal (Jackson, 1978). To solve the problem of the sinking animals, whalers pulled alongside the dead animal and inserted an inflatable tube into the body cavity, which kept it afloat. The technology for hunting blue whales and other rorquals was in place by 1873, but Svend Foyn claimed a patent for it and had a monopoly on hunting blue whales (Ellis, 1991). Once Foyn's monopoly expired in 1883, other companies began taking blues and the annual take increased dramatically (Ellis, 1991). By the turn of the century, Norwegian whalers were rapidly declining large rorqual populations in the northeastern Atlantic (Bortolotti, 2008).

Floating Factories

Whalers began experimenting with a new way of processing whales on "floating factories" (Jackson, 1978). Up until this point boilers and separators had been used on shore. A prototype vessel of approximately 1,500 gross tons required a crew of 60 and was now capable of moving operations into the open sea (Jackson, 1978). In 1923 Norwegian captain Carl Anton Larsen (b. 1870) sailed the first pelagic factory ship (*The Sir James Clark Ross)* south into the Ross Sea off of Tasmania (Jackson, 1978). As whale stocks near land bases began to decline, floating factories could be taken out to sea for weeks at a time. As they evolved, the vessels eventually were able to displace more than 13,000 tons and carried a 500-man crew (Jackson, 1978). Still several problems existed with these ships until the introduction of (1) the "stern slipway," which allowed a whale to be hauled onto the stern and (2) the "whale claw," a device that fastened around the tail fluke and tightened automatically when tugged (Bortolotti, 2008; Jackson, 1978; Ellis, 1991). These represented the final technological advancements in the efficiency of whaling.

Whaling Antarctica (1906-1962)

With declining populations of large whales in northern waters, sights shifted from the north Atlantic to the southern waters of a small island off the coast of Antarctica called South Georgia.

> "If the blue whale is eventually to disappear from the earth, it would be safe to say that the seeds of its extinction were sown on a lonely Antarctic island called South Georgia." (Bortolotti, 2008).

In the hopes of finding a “ripe stock” of unexploited populations of right whales, Captain Larsen made the first whaling-specific journey to Antarctica in September of 1895 (Jackson, 1978). Still ill-equipped to hunt large rorquals, he watched humpback, fin and blue whales swarm his ship without a way to tap into this natural resource. It wasn’t until the early 20th the century that Larsen returned to the South Georgia region for whaling (Jackson, 1978). He used the sheltered bays of the island to build a whaling station, which made an ideal setup to begin hunting the populations of large whales. Humpback whales were the first species to be hunted in this region (Bortolotti, 2008). Within six years British and Norwegian fleets working in the untapped waters, took 6,197 humpback whales (Jackson, 1978). As this species became increasingly rare, blue whales were the next target for whaling in those waters. The season of 1914-15 saw more the 2,300 blues hunted, with another 1,800 killed in the nearby South Shetlands (Jackson, 1978). During these early years of modern whaling, the bounty was so plentiful that not all of the whale’s blubber was taken. Only the thickest blubber on the animal was cut off and the rest was discarded. This practice eventually led to regulations stating that whalers must make use of the entire carcass. With the Antarctic whaling practice in full boom, a steady population of 150 men resided in South Georgia, which then became the southernmost inhabited point of land on the planet (Bortolotti, 2008).

The arrival of World War I slowed the whaling industry as both ships and men were needed for the military (Ellis, 1991). Nonetheless whaling continued, and during each of the four wartime seasons, almost 3,900 blue whales were killed (Ellis, 1991). After the war, most of the harvested whale blubber got processed into margarine (Bortolotti, 2008).

By the 1920's chemists had removed the fishy aftertaste and refined hydrogenation techniques after which whale oil was almost exclusively converted into margarine products (Bortolotti, 2008). The whaling seasons of 1929-30 and 1930-31 produced the highest catch numbers the world had yet seen, with approximately 48,000 blue whales harvested (Bortolotti, 2008).

Antarctic whaling continued steadily for two decades until World War II slowed the industry (Ellis, 1991). The season of 1940-41 produced 5,000 animals, taken mostly by the Japanese, who had not yet entered the conflict (Ellis, 1991). The catch drastically dropped to about 200 whales for the combination of the next 2 seasons. From 1943-45, Norwegian expeditions killed around 1,400 blue whales, but collectively, the five war years produced about the same amount of blue whale kills as the first decade of the century (Bortolotti, 2008; Ellis, 1991). Many in the industry hoped that this would allow blue whale stocks to recover from the decline of some 48,000 harvested animals that had occurred from 1929-31 (Bortolotti, 2008). That was not to be. Once the war ended, Norwegian, British, Soviet and Japanese whalers continued to hunt blue whale populations in southern waters. This was not an adequate amount of time for any substantial population recovery.

The Global Shift of Whaling (1950-1966)

By the 1950's only about 1,200 blue whales were killed per season and whaling's focus shifted to the fin whale (Bortolotti, 2008). At this point in whaling, during the 1950's, a ban of blue whale takes would have hardly affected whaling profits. With looming threats such as the declining price in whale oil increasing labor costs, and lower productivity due to decreasing whale populations, companies did not put a ban on hunting blue whales (Ellis, 1991; Bortolotti, 2008). Compared to smaller whales, blues yielded high amounts of blubber, requiring fewer animals and less work to reach quotas (Bortolotti, 2008). Despite blue whale population declines, companies continued to pursue them into the 1960's (Bortolotti, 2008).

In other oceans, approximately 30,000 blues were taken out of southern waters, 8,200 from the north Pacific and 7,000 from the north Atlantic (Branch, Matsuoka, & Miyashita, 2004). When a committee was put in place to assess the remaining Antarctic population in 1963, they found no more than 600 individuals (Bortolotti, 2008). Once the ocean's largest population, Antarctic blues had been reduced to a startling 0.15% of their original size (Branch, Matsuoka, & Miyashita, 2004).

In figure 2, the effect of whaling on global populations can be seen. The noticeable difference between the decline (from pre-whaling to the 1930's) and the slow population increase (from 1965 on) shows the impact that the whaling industry has had on blue whale stocks.

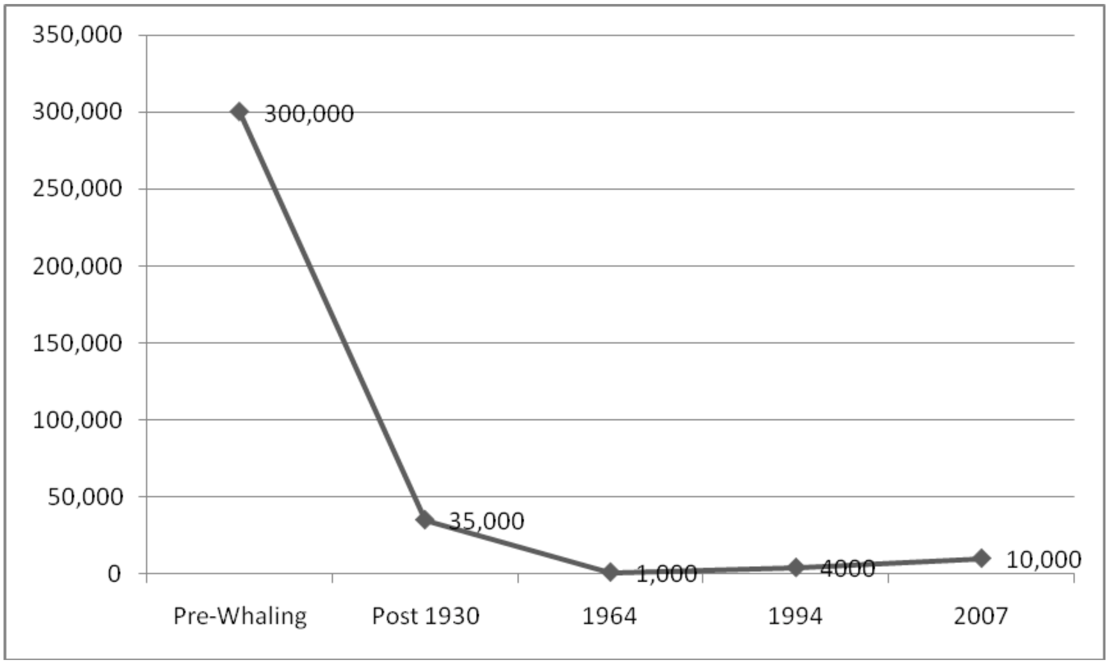

Figure 2. *Though global populations are increasing, it will be a long recovery before original numbers are once again reached (population values are approximate).*

The Implementation of Whaling Regulations (1961-1972)

With the decline of Antarctic populations, the last shore station in South Georgia closed after the 1961-62 season (Bortolotti, 2008). The British and Dutch left the Antarctic and began selling their vessels and equipment because it was not worth the expense to hunt the scarce population (Jackson, 1978; Mowat, 1972). During an International Whaling Commission (IWC) conference in 1964, whaling countries reported lower numbers of blue whales than in the past (Bortolotti, 2008). Norwegian whalers reported that they had only seen eight blue whales, four of which they had killed (Bortolotti, 2008; Mowat, 1972). The following year only the Soviets saw blue whales and reported killing 20 of them, though far more were taken unreported (Bortolotti, 2008).

In 1965 the nations of the IWC agreed, to ban killing the blue whale (Bortolotti, 2008; Ellis, 1991; Jackson, 1978; Mowat, 1972).

Despite the IWC's ban on blue whale catches, thousands of animals continued to be taken illegally. Between 1947 and 1972 soviet whalers took 43,000 humpbacks, 21,600 sperm whales and 9,200 blue whales (Mowat, 1972; Bortolotti, 2008). Many of these were taken after the IWC's ban, with 500 killed as late as 1971-72 (Bortolotti, 2008). After 1961 the soviets illegally killed almost 700 blue whales in the North Pacific (Bortolotti, 2008). These statistics came to light in 1993 and helped explain why blue whale populations had not recovered after nearly 30 years of protection (Bortolotti, 2008). In 1971-72, with the instatement of required observers on every whaling vessel, violations stopped almost immediately (Bortolotti, 2008).

It wasn't until the mid 1980's that attention towards blue whales was reawakened. This time it was not for hunting; it was for research. Populations were slowly beginning to recover and organizations such Cascadia Research Collective began taking photographs of blue whale sightings (1986) to begin monitoring their population distribution and abundance. The time had finally arrived to focus research attention on this fragile species and begin to understand their behavior for conservation purposes.

Chapter 2

BLUE WHALE STUDY METHODOLOGIES

By the time the IWC's ban on hunting blue whales went into effect in 1966 (Gambell, 1979) their numbers had been depleted from about 350,000 world-wide to some 15,000 animals. Blues were therefore officially declared endangered (Barlow, et al. 1995; Gambell, 1976; Calambokidis, Schorr, et al. 2007/08; Gambell, 1979). Despite the IWC's protective measures blue whale populations have remained low in numbers, with little to no recovery (Calambokidis, et al., 2007/08). In the four decades of blue whale protection, populations have shown approximately only 3% recovery (Barlow, et al. 1995; Gambell, 1976; Calambokidis, Douglas, Falcone, & Schlender, 2007). Little is known about why blue whale recovery is slow. Reasons may include illegal whaling, lack of food sources, and ship strikes (Calambokidis, et al., 2007/08). It is difficult to study animals that travel great distances in a short amount of time and spend most of their lives out of the visual range of humans. The methods to gather the necessary data are important in analyzing the threat of ship strikes. Researchers must first have an understanding of the animal's distribution, dive patterns, feeding behaviors and movement patterns.

Over the past two decades the methodologies of studying blue whales have developed into: (1) photographic identification used to determine long-term migration and distribution patterns (J. G. Calambokidis 1990; Calambokidis, et al. 2007; Calambokidis and Barlow, 2004), (2) ship surveys to examine distribution and abundance (Calambokidis, Douglas, Falcone, & Schlender, 2007; Dohl, 1983), (3) satellite tagging (Mate B. B., 1999) and most recently (4) acoustic studies using underwater hydrophones, acoustic arrays and suction cup tags to determine whale distribution and underwater feeding behavior (Calambokidis, et al., 2007/08).

Blue whale research is beginning to reveal insights into previously unknown facets of their lives. The techniques used and their results portray vital data for a thorough threat assessment of ship strikes. Vital pieces of data for this analysis include: the distribution of blue whales in relation to shipping lanes (studied via ship surveys, mark recapture modeling and photographic identification, Cascadia Research Collective 2006), as well as their dive patterns and feeding behavior (studied via bioacoustic tagging, Cascadia Research 1999). The latter is important in understanding when animals are within potential strike zones as well as surfacing intervals.

Photographic Identification/Line Transect Surveys

The methods for tracking and identifying individuals, as well as recognizing their abundance and distribution is typically conducted during systematic line transect surveys (see example in figure 3) on large vessels such as SCRIPPS Oceanography's and NOAA's (National Oceanic and Atmospheric Administration), as well as from small rigid hulled inflatable boats (appox. 5m in length) operating daily from shore (Calambokidis & Barlow, 2004).

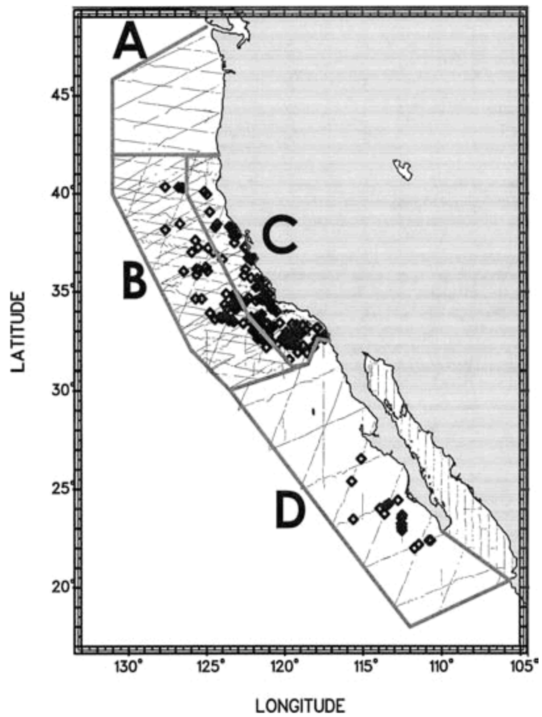

Figure 3. *Line-transect survey lines and sightings of blue whales, 1991–1996. Data reveal that the densest populations are near-shore central and southern California (Calambokidis & Barlow, 2004).*

Photographic identification images are taken with high quality camera and lens systems. The best ones are chosen and compared to a comprehensive catalogue of previously identified individuals (example of a photographic identification in figure 4). The catalogue consists of over 1,000 blue whales that have been identified since 1986 (Cascadia Research

Collective).

Figure 4. *Photo identification picture used to track individuals over a period of time. The mottled pattern near the dorsal fin is used to identify individuals (image provided by Cascadia Research Collective).*

These surveys (Barlow, et al., 1995; Calambokidis & Barlow, 2004) in combination with long-term photographic identification studies have revealed that the densest blue whale populations are near the shore in central and southern California (see detailed information in chapter 3). Though this information is important in understanding the threat of ship strikes, it still does not reveal insights into the animals' behavior underwater. To adequately assess strike potential as a danger, experts are gathering data revealing how deep animals dive, how long they dive for and what they are doing underwater (Calambokidis, et al., 2007/08). These pieces of information will help by showing time spent in or near ship strike zones (Calambokidis, et al., 2007/08).

Bioacoustic Tags

Since 1999 Cascadia Research Collective has been deploying Burgess bioacoustic probes (bprobes) and video imaging tags (CRITTERCAM) that attach via suction cups (Figure 5) (Calambokidis, et al., 2007/08).

These tags have revealed insights into previously unknown underwater behaviors and movement patterns (J. Calambokidis, 2003; Calambokidis, Schorr, et al. 2007/08), that help in understanding ship strike threat potential. Tag data has indicated that (1) blue whales spend more time at the surface during night hours than during the day; (2) they surface several times, generally every 5-15 minutes; and (3) they perform lunging feeding dives at depths of up to 300m (Calambokidis, et al., 2007/08). The latter discovery may indicate large energetic expenses causing fatigue and disorientation at the initial surfacing (Calambokidis, et al., 2007/08). Abrupt maneuvering away from a large vessel may not be an option for a recently surfaced whale.

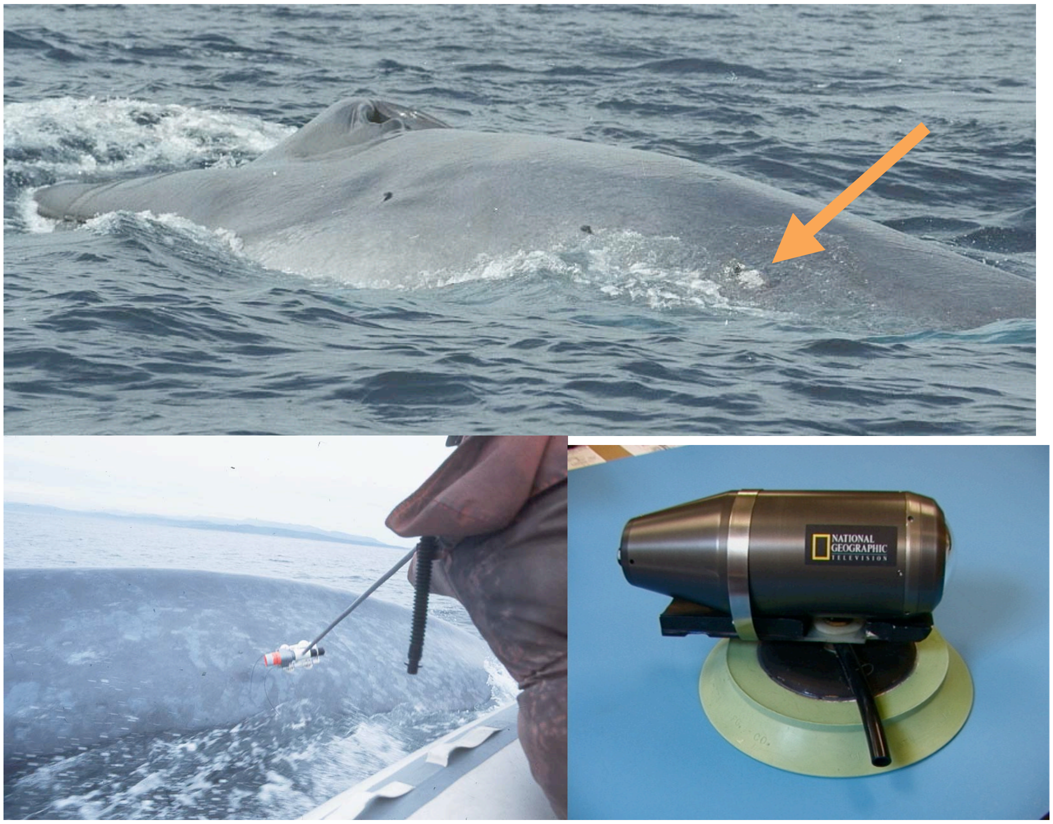

Figure 5. Clockwise from top*: Burgess Bioacoustic probe deployed on the back of a blue whale off the San Diego coast in 2002; suction-cup-attached imaging tag (CRITTERCAM); probe attachment method from a rigid hulled inflatable; (Calambokidis J. , 2003).*

Tag Observations of Feeding and Dive Behavior

The output data and results of tags deployed on blue whales in the past decade have revealed valuable insights into their feeding behavior, group dynamics and vocalizations (Oleson, Calambokidis, Burgess, McDonald, C., & Hildebrand, 2007; Calambokidis, et al., 2007/08). Tag deployments were conducted and collected in collaboration with Cascadia Research Collective, SCRIPPS Institute of Oceanography, Woodshole Oceanography Institute and Bill Burgess of the Greeneridge Institute. These data have revealed some information necessary to assess the threat of ship strike potential.

Lunge dives

Data was gathered during deployments such as those conducted in the Sea of Cortez in March, 2001 (longest complete record to date) and off of Costa Rica in January, 2008 (Calambokidis, et al., 2007/08). The combined use of sonar depth finders and tag deployments allowed researchers to find krill layers at specific depths and overlay these with dive charts from tag-data outputs (Cascadia Research Collective). The output revealed vertical lunges into krill layers from underneath (figure 6) (Calambokidis J., 2003). This is important in showing that blue whales feed almost exclusively on krill and will therefore be attracted to areas hosting dense aggregations of krill such as exist in the Santa Barbara channel. Furthermore, the density of blue whale populations is higher in areas hosting this vital food source.

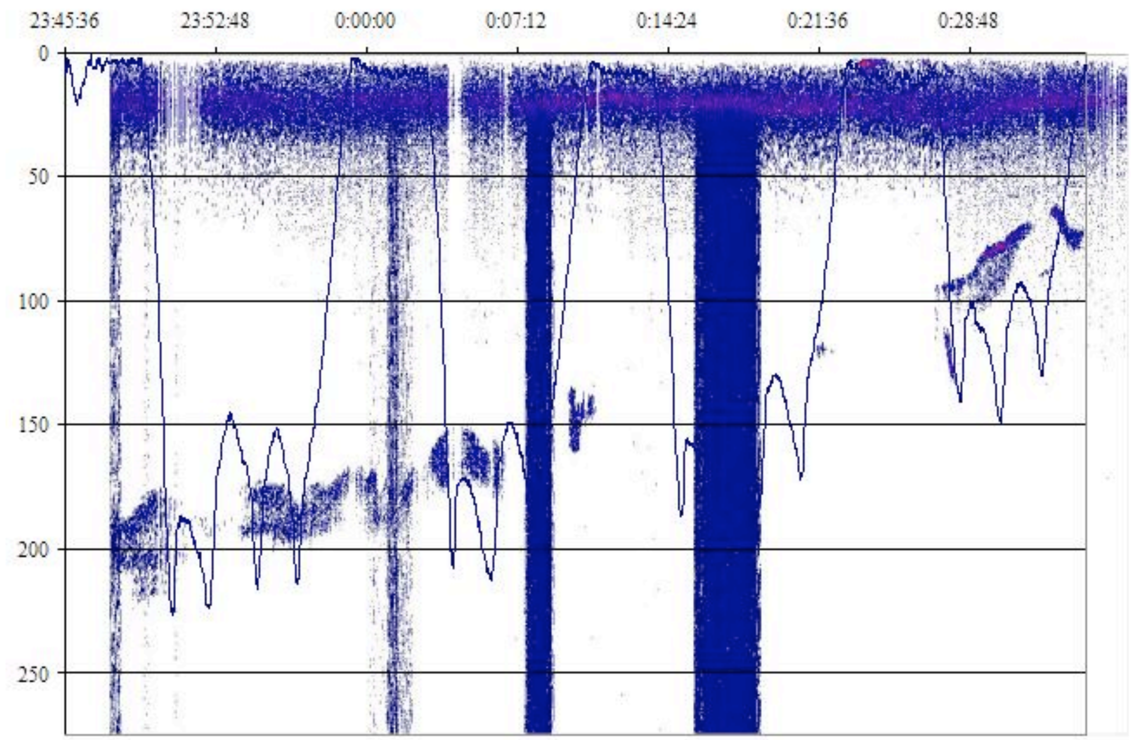

Figure 6. *Depth on the y-axis and time on the x-axis. Blue whale lunge dives (line graph) into krill layers (cloudy layering from sonar viewer) from underneath gathered in January 2008 off Costa Rica (Data collected, calibrated and provided by Cascadia research Collective).*

Diurnal Dive Pattern

Several tag deployments (Sea of Cortez 2007, Costa Rica Dome 2008, Southern California 2002) have revealed a diurnal dive pattern in blue whales (figure 7). This reaction is most likely due to the vertical migration of krill toward the surface at night (Calambokidis, et al., 2007/08), though little is known as to why krill migrate vertically from 250-300m to 0-20m. The whales tend not to feed during the night hours, but travel at slow speeds, conducting very shallow dives (figure 7: "milling" behavior occurring from 20:00 – 06:00) (Calambokidis, et al., 2007/08). Regarding ship-whale interactions, this may be an important discovery, as the potential for ship strikes may occur during the night hours when whales mill near the surface, well within strike depth (Cascadia Research Collective unpublished data). This potential may be amplified by the lack of visibility by observers who are unable to detect the animals from traveling vessels combined with the sleep behavior of the blue whales.

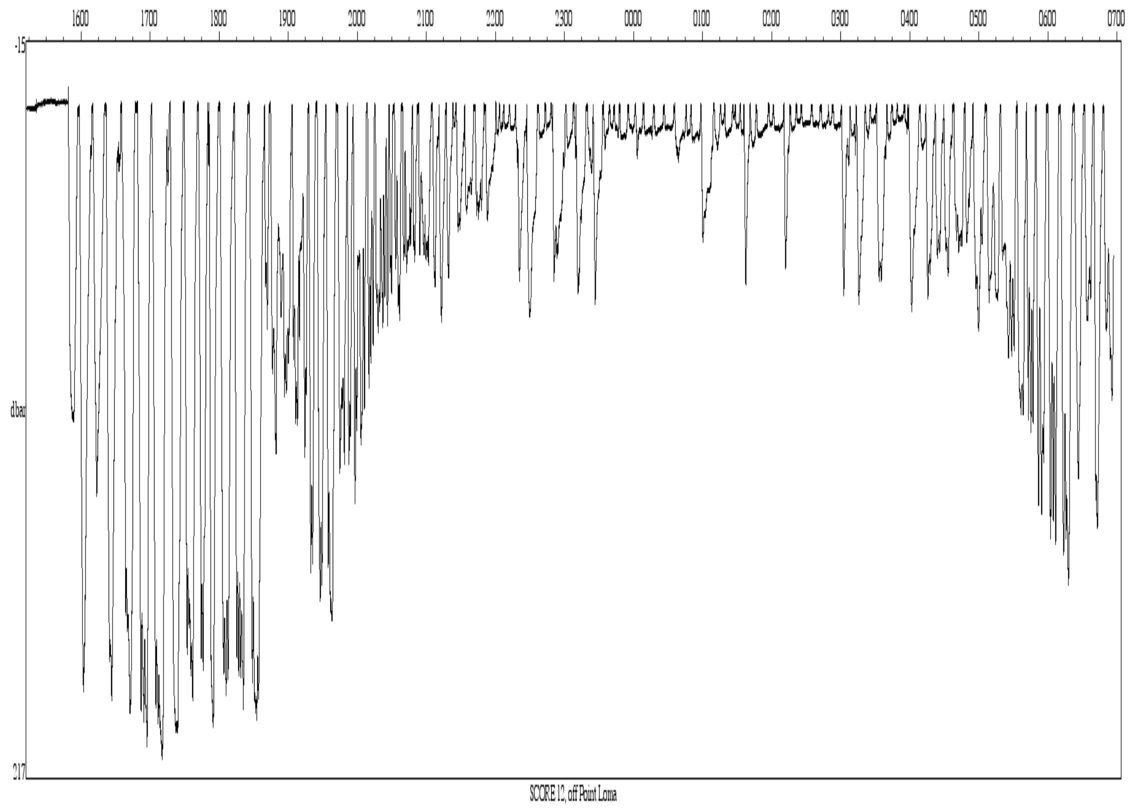

***Figure** 7. Blue whale dive chart from bioacoustic tag deployment starting at 16:00 and ending at 07:00. Deployed June 2002 off of Southern California. This chart indicates a dramatic diurnal shift in dive pattern, where the animal is staying closer to the surface after 20:00 (adapted from data provided by Cascadia Research Collective).*

Advancement in technology and extensive research efforts have made for a better understanding of blue whale behavior. With these new discoveries in place, blue whale conservation efforts such as ship-whale interaction threat assessments can be funded and researched. The key findings of bio-acoustic probes include:

- Blue whales often approach prey (krill layers) from underneath in vertical lunges, diving to depths of up to 300m (Figure 6) (Calambokidis, et al., 2007/08).
- Blue whales have a diurnal dive pattern, where the animals stay close to the surface during night hours (Figure 7) (Calambokidis, et al., 2007/08).
- Pairs of blue whales travel together (male-female), but do not engage in cooperative feeding (Oleson, Calambokidis, Barlow, & Hildebrand, 2007).
- Only males have been reported (identified via DNA samples from collected tags) to produce long vocal calls (Oleson, Calambokidis, Burgess, McDonald, C., & Hildebrand, 2007)

Though helpful in other facets of blue whale research, the latter two points are not relevant in assessing ship strike threats. The first two points however are important pieces of the puzzle in attempting to understand the behavior of blue whales that are in close geographic association with shipping lanes and ship strike zones. The northeast Pacific stock, most densely aggregated off the Central California coast, has the highest potential for ship strikes as habitat and vessel traffic overlap. The above mentioned research methods provided important insights into underwater behavior, but further research and knowledge is necessary to understand this population's abundance and specific distribution.

Chapter 3

CURRENT ABUNDANCE ESTIMATES OF NORTHEAST PACIFIC BLUE WHALES

A Brief on Global Estimates

Blue whales are considered endangered and have been depleted in their range due to many decades of whaling (Calambokidis, Douglas, Falcone, & Schlender, 2007). Although the populations of blue whales were severely depleted by whaling, no evidence is available to suggest that this over-exploitation resulted in a major change in their distribution. It is assumed that blue whale distribution is governed largely by food requirements and that populations are seasonally migratory (National Marine Fisheries Service, 1998). Movements towards the poles in spring allow the whales to take advantage of high krill production in summer. Movement toward the subtropics in the fall allow blue whales to reduce their energy expenditure while fasting, avoid ice entrapment in some areas, and engage in reproductive activities in the warmer waters of lower latitudes (National Marine Fisheries Service, 1998).

Despite international protection since 1966, the current global population is roughly estimated at 10,000- 15,000 animals (Barlow, et al., 1995; Gambell, 1976). The global population is organized into separate “stocks:” (numbers are rough approximations) 7,000-10,000 in the southern hemisphere (this includes the subspecies Pygmy blue whale *B.m.brevicauda),* 2,000-3,500 in the Northeast Pacific and 800-1,400 in the north Atlantic (Mate, Lagerquist, & Calambokidis, 1999, Barlow, et al., 1995). This is only a fraction of the original, pre-whaling global population, which has been estimated at near 350,000 (Gambell, 1976).

Northeast Pacific Population

This population is considered to be one of the largest globally and also one of the ones most studied (Calambokidis & Barlow, 2004). Due to the proximity of research facilities as well as their relative proximity to land masses, the northeast Pacific population has become one of the most documented global stocks. The research presented in this work will focus its attention to this specific blue whale stock, due to the availability of information and literature, as well as documented ship strike threats occurring most frequently within this population.

Photographic identification has revealed that the entire northeast Pacific population ranges from the Gulf of Alaska to Costa Rica (Calambokidis et al. 2004; Chandler et al. 1999). The population, which feeds off the coast of California from May through November (Dohl et al. 1983), is considered an independent stock (Barlow, et al., 1995). They migrate to Mexico and Central America in spring (Calambokidis *et al.* 1990, Stafford *et al.* 1999, Mate *et al.* 1999, Chandler *et al.* 1999) and have a size of roughly 1,500-2,000 individuals (Barlow, et al., 1995). Little is understood about the migration and general North/South movement patterns of this population (Barlow, et al., 1995). John Calambokidis at Cascadia Research Collective has been conducting extensive photographic identification of this stock since 1986 and has the best understanding of their movement and distribution (Bortolotti, 2008). Ship strikes have been reported most commonly in this population due to their proximity to land, their dense population and close association to ship traffic (Cascadia Research Collective unpubl. data; Jensen & Silber, 2004). Calambokidis et al (2007) reported the abundance and distribution of the northeast Pacific stock, revealing insights into their geographic association with the shipping lanes. They present an accurate estimate by (1) obtaining large representative samples from in- and off-shore waters, (2) comparing 2005 and 2006 survey efforts with past photographic identification, (3) generating a mark-recapture model from 2004-06 survey efforts and (4) comparing the acquired estimates from three similar abundance estimates generated over the last 15 years (Calambokidis, Douglas, Falcone, & Schlender, 2007; Calambokidis & Barlow, 2004). During distribution and data sampling it is often difficult to avoid bias due to "heterogeneity of 'capture' and probability of geographic sampling partiality" (Calambokidis, Douglas, Falcone, & Schlender, 2007). This may be introduced by surveying the same or similar regions year after year and therefore 'capturing' the same individuals. For an accurate abundance estimates, a representative sample of both photographic identification and mark-recapture modeling is required, as well as covering new areas during surveys (Calambokidis & Barlow, 2004).

Abundance

An abundance report to Southwest Fisheries Science Center (SWFSC) in 2007 utilized the above described methods and remains the most recent and the most up-to-date report, covering the years 2004-2006. The methods were similar to those used in past abundance surveys and the report included all results beginning in 1991 (Calambokidis, Douglas, Falcone, & Schlender, 2007).

The combined identifications from both coastal efforts and large vessel surveys represent the results of this effort (Calambokidis, Douglas, Falcone, & Schlender, 2007). These estimates show a steady increase from 816 in 1991-93 to 1,428 in 2004-06 (table 1.). Further, estimates based on all pairs of years regardless of the use of systematic surveys, generally showed an increase in abundance with the highest years being 2003-06 (Calambokidis, Douglas, Falcone, & Schlender, 2007).

n1 Systematic year			**n2 Adjacent years**				
Period	**Year**	**n1**	**Years**	**n2**	**m**	**Est.**	**CV**
1991-93	1992	281	1991 & 1993	193	66	**816**	0.09
1995-97	1996	183	1995 & 1997	368	56	**1,190**	0.10
2000-02	2001	286	2000 & 2002	449	99	**1,291**	0.07
2004-06	2005	179	2004 & 2006	388	48	**1,428**	0.11

Table 1. *Summary of mark-recapture estimates for blue whales off California and W. Baja Mexico. Sample n1 consists of all the identified whales from the year of the SWFSC systematic ship surveys and n2 is from coastal small-boat work in the adjacent years. The numbers of matches or recaptures are indicated as (m). Coefficients of variation (CV) are based on analytical formulae. Transcribed from information provided by Cascadia Research Collective* (*Calambokidis, Douglas, Falcone, & Schlender, 2007).*

Distribution

The Northeast Pacific blue whale distribution data is an outcome of assessing the abundance of this stock. A visual depiction of this population can be seen in figure 8. Most of the animals are grouped in the central California to Baja region with some isolated groups in nutrient rich waters off of Costa Rica. It is likely that the waters near Costa Rica host a small group of blue whale residents year-round. It must be noted in the image below that no time reference for these observations is given, which may indicate seasonal shifting.

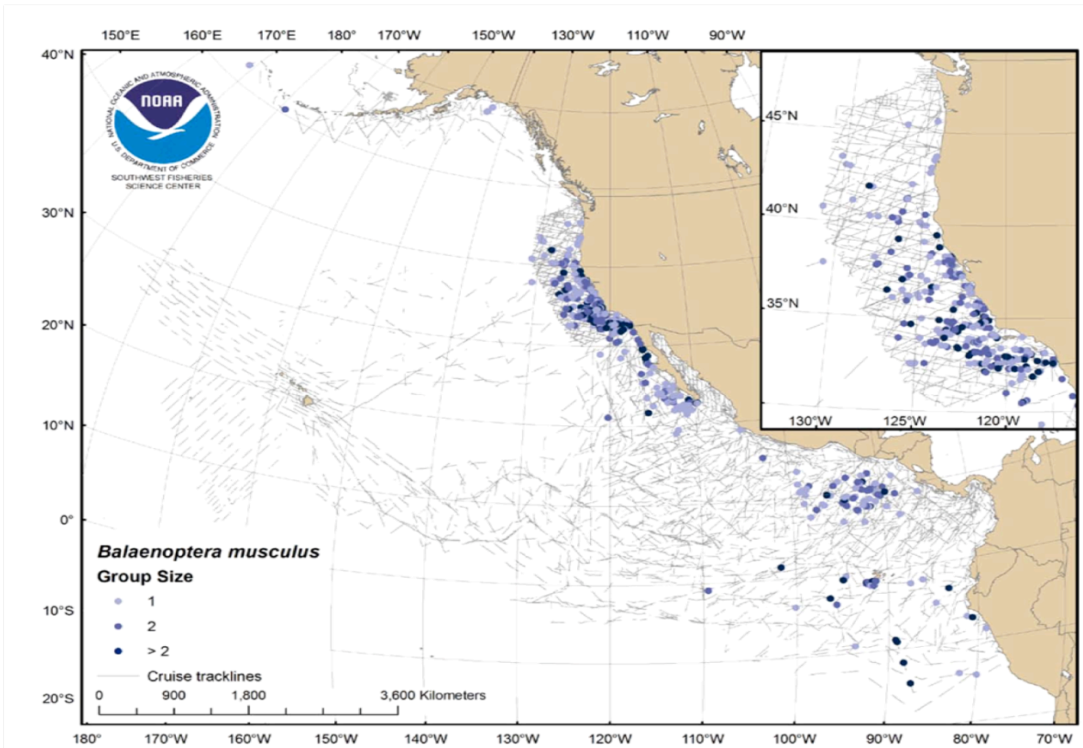

Figure 8. *Southwest Fisheries Science Center publication (2007) on the distribution of Northeast Pacific blue whales via transect surveys. Image provided by Cascadia Research Collective.*

Discussion

All abundance estimates that utilized identification in a year or combination of years showed fairly strong agreement, both in terms of average values and in patterns of annual variation (Calambokidis, Douglas, Falcone, & Schlender, 2007). Since samples were not obtained consistently in the same locations over the years, it may explain some variation in the pattern of abundance. In the 1990's there may have been some bias introduced into the abundance results, as most efforts were focused around the Central California region, which would have resulted in a downward trending abundance estimate (Calambokidis, Douglas, Falcone, & Schlender, 2007). To reduce the bias rate of heterogeneity of capture probability Cascadia Research Collective utilized a geographically broad survey methodology, as well as geographic variation, which may have lowered this bias (Calambokidis, Douglas, Falcone, & Schlender, 2007).

There is little literature and some controversy surrounding the specific abundance and distribution of blue whales on the west coast. The difficulties of surveying as well as the elusive travel patterns of these animals have created a field of limited funding and few specialists. On the other hand, surveys have consistently revealed (Calambokidis & Barlow, 2004; Calambokidis, Douglas, Falcone, & Schlender, 2007) that the densest part of this population of blue whales feed and forage in close proximity to or directly within areas that host shipping lanes. The Santa Barbara Channel is seen as the “poster child” of ship strike potential, since it hosts a high volume of ship traffic as well as a dense population of blue whales.

Chapter 4

SHIP-WHALE INTERACTION ASSESSMENT: The Santa Barbara Channel

The focus of this paper is limited to assessing ship-whale interactions in the Santa Barbara Channel and its surrounding region. It has been shown (Cascadia Research Collective, 2007) that incidence of ship strikes on blue whales have occurred on several occasions in the Santa Barbara Channel. Shipping lane traffic and blue whale feeding habitat overlap in this region, creating a rich opportunity for investigating a potential threat to the northeast Pacific stock. A thorough threat assessment in this specific region can be performed and analyzed by understanding blue whale biology, the history of their decline, study methodologies used and northeast Pacific population distribution and abundance.

Blue whales are commonly found during the summer and fall season within the Santa Barbara Channel (Calambokidis, Douglas, Falcone, & Schlender, 2007), as this is a productive region that supports large concentrations of their primary food source -- krill (Barlow, et al., 1995). This also happens to be a region hosting shipping lanes for commercial vessels (see figure 9). The close geographic association between blue whales and shipping traffic increases the likelihood of whale-ship interactions within this region. Often, the outcome of a ship strike is fatal, but non-fatal interactions due to close ship approaches may also be occurring. The potential outcomes of these interactions include cessation of feeding, interruption of social communication and changes in energetic expense (Cascadia Research Collective, unpublished data). Though little is known about blue whale reactions to underwater noise, interactions may be occurring at great distances due to the input of increased noise into the ocean from ship propellers and machinery (Calambokidis, et al., 2007/08). Understanding these interactions can inform us as to how to prevent or reduce the impact of shipping on whale populations.

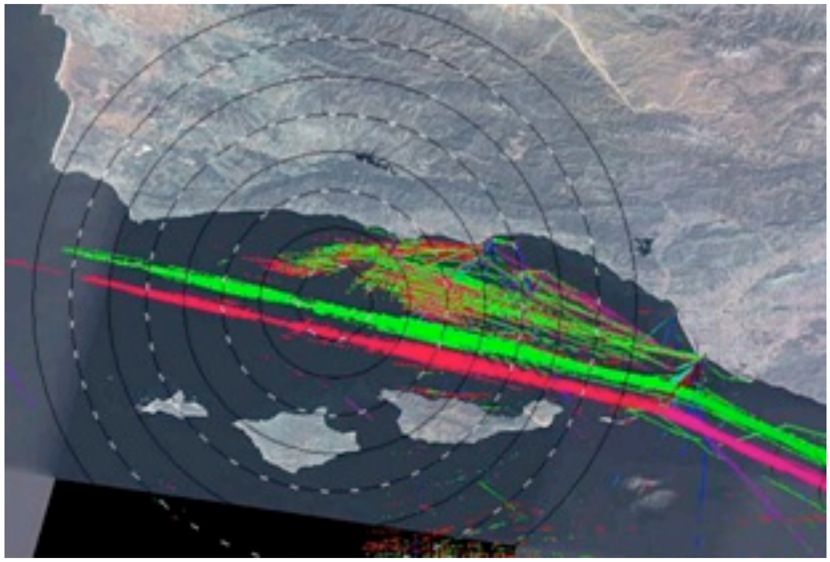

Figure 9. *Automatic Identification System (AIS) was used to identify ship tracks in commercial shipping lanes in the Santa Barbara Channel monitored for a 3 month period in 2007. Color indicates direction of travel (image acquired through Cascadia Research Collective).*

Due to increased numbers of blue whale fatalities within this geographic region (6 fatal blue whale ship strikes in fall 2007), Cascadia Research Collective has recently been researching this field extensively., The methods combine (1) suction cup acoustic tags, (2) seafloor acoustic recorders, (3) small boat surveys conducted daily from the coast and (4) commercial ship traffic details provided by the transmission of Automatic Identification System (AIS) (information provided by Cascadia Research Collective). The acoustic data collected by the tag can be used by researchers to determine the presence of sounds produced by the whales, the noise level prior to ship approach, and the sound level of the passing ship (Cascadia Research Collective unpublished data). Further, the sound of the flow noise that the passing water creates, which is generated by the swimming whale, can be used to provide estimates of swim speed (Calambokidis, et al., 2007/08). Acoustic recorders placed systematically within the Santa Barbara Channel may provide measurement of the noise produced by individual ships and overall ambient noise levels (conducted in collaboration with SCRIPPS Oceanography Institute). AIS transmissions provide the vessel's GPS coordinates, ship length, ship speed and direction and are recorded at a land-based receiving station in Santa Barbara.

It is crucial to acquire vessel details such as the (1) vessel type, (2) vessel length, (3) vessel's speed of travel and (4) vessel's direction of travel. This information allows for an adequate assessment of potential ship strike threats. It is important to note though, that only commercial vessels (e.g.: container/cargo ships, freighters and cruise ships) within the shipping lanes report via AIS. Other smaller vessels that still have potential for ship strike threat may be traveling within the feeding and foraging habitat of blue whales without AIS transmission.

Ship Detail

Vessel Types

Vessels types that travel near and within the shipping lanes and foraging habitat of blue whales vary greatly. The Large Whale Ship Strike Database (2003) describes the vessels (134 of 292 incidents with known vessel types) involved in reported strike cases as the following:

- 17.1% navy vessels
- 14.9% container/cargo ships/freighters
- 14.2% whale watching vessels
- 12.7% cruise ships/liners
- 11.9% ferries
- 6.7% coast guard ships
- 6.0% tankers
- 5.2% recreational vessels and steamships
- 3.0% fishing vessels

Care must be taken in interpreting these numbers as many ship strikes may be occurring unnoticed or unreported (Jensen & Silber, 2004). Furthermore, the high incidences of Navy and Coast Guard vessel strikes may merely be a representation of government and military standardized reporting practices (Jensen & Silber, 2004).

Vessel Speeds

Only 58 (19.8%) of the 292 reported cases of ship strikes reported their speed (Jensen & Silber, 2004). The range was from 2-51 knots with a mean speed of 18.1 knots (figure 10) (Jensen & Silber, 2004).

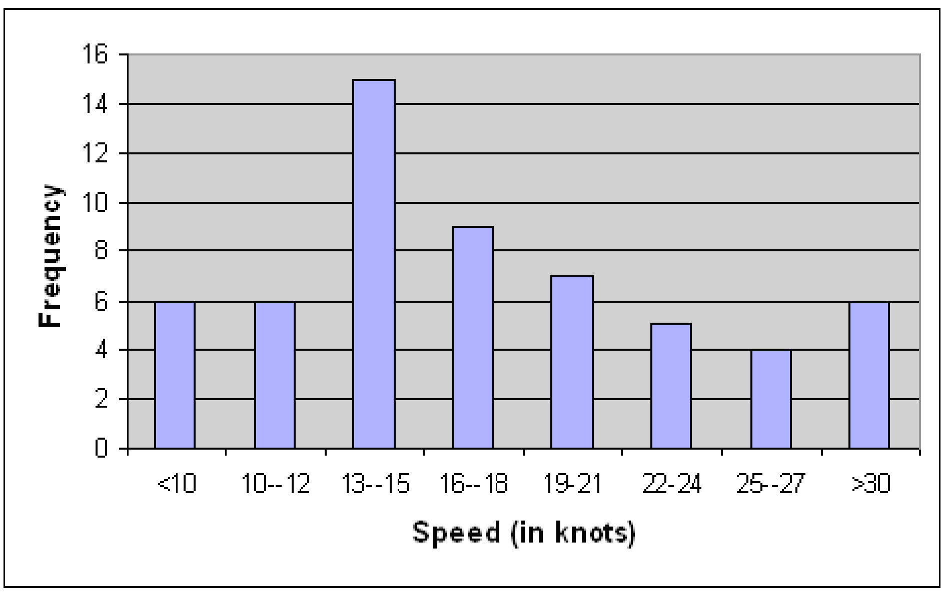

Figure 10. *Frequency of ship strikes in relation to ship speeds of reported cases (Jensen & Silber, 2004)*

It has been reported (Jensen & Silber, 2004) that the speed at which a strike causes serious injury or death is approximately 18.6 knots. Many (67.2%) of the reported vessel speeds were in the 13-15 knot range, followed closely by 16-18 knot and 22-24 knot ranges (figure 10) (Jensen & Silber, 2004).

Ship-Whale Interaction

The total record of past blue whale ship strikes occurring globally is not extensive (table 2). This collection of ship strike data (with the fist one occurring in 1980), were reported from commercial cargo, military and cruise vessels. It must be considered that these are merely the ones that were reported. Undoubtedly, more strike events have been occurring without notice or report, as well as struck whales sinking or floating out to sea. It can safely be assumed that many more strikes have occurred or are occurring unreported and unnoticed (Jensen & Silber, 2004).

Date	Location (incl. County)	Sex
08/07/1980	Vandenberg Air Force base, Santa Barbara	Male
08/17/1988	Oceana, San Louis Obispo	Female
08/17/1992	Lompoc, Santa Barbara	No Data
08/02/1993	San Nicolas Island, Ventura	No Data
01/12/1994	Santa Rosa Island, Santa Barbara	Male
08/11/1996	San Miguel Island, Santa Barbara	Female/ Fetus

Table 2. *Record of total past ship strikes of blue whales occurring globally, with most documented in the Central California region* (Jensen & Silber, 2004).

Ship Strikes in the Santa Barbara Channel

The Santa Barbara Channel is a productive feeding location for blue whales in the fall and summer months. As this is also the travel area of commercial ship vessels along the shipping lanes, ship-whale interactions may be common and threatening for blue whales feeding and foraging in the area (Calambokidis, et al., 2007/08). Small boat surveys conducted daily show a dense abundance of animals in close association with shipping lanes (figure 11).

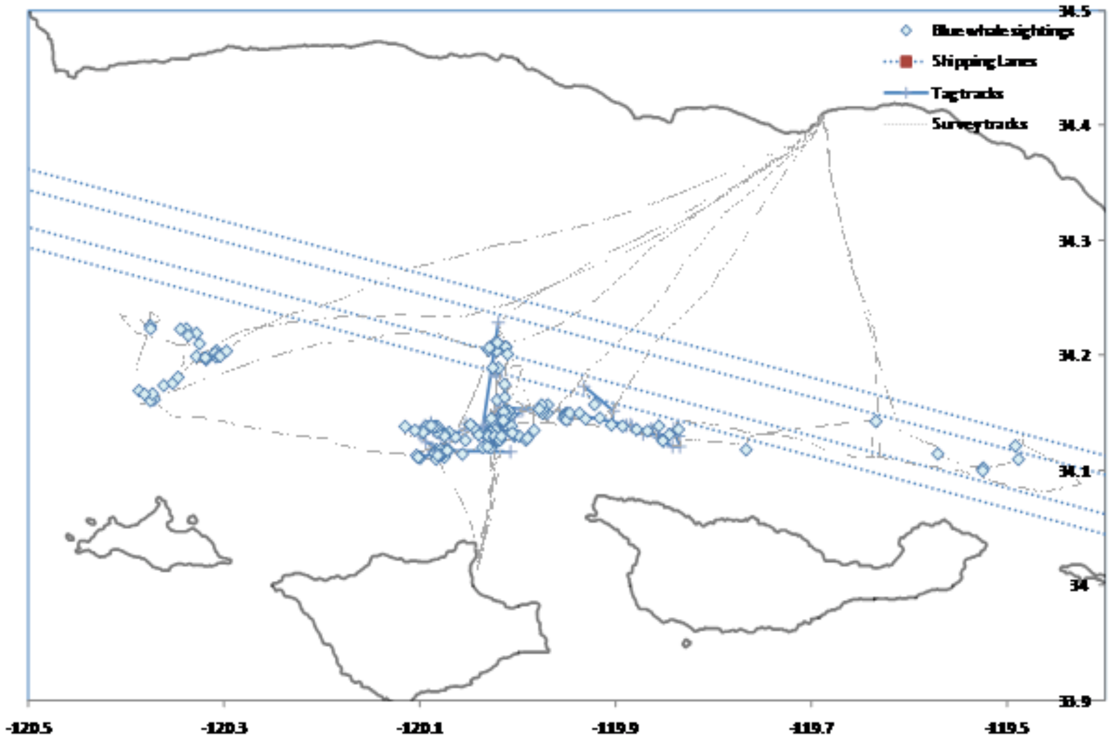

Figure 11. *Sightings and movements of blue whales in the Santa Barbara Channel, gathered by Cascadia Research Collective in September 2007 (Provided by Cascadia Research Collective).*

In the fall of 2007 six blue whales were reported fatally struck by ships. This was the largest ship strike event for blue whales on record (Jensen & Silber, 2004). All of the animals found were in or near Santa Barbara County (figure 12). Table 3 indicates the detailed summary of the 6 fatalities that occurred in a series of the most dramatic ship strike events to date (Jensen & Silber, 2004).

	Date	Location	Gender	Length (feet)
Whale 1	09/09	Long Beach Harbor	Male	72
Whale 2	09/11	Hobson Beach	Female	79
Whale 3	09/12	San Clemente Is.	No Data	No Data
Whale 4	09/19	N Baja, Mexico	No Data	No Data
Whale 5	09/20	Pt. Mugu	Male	70
Whale 6	11/29	San Miguel Is.	Female/ Fetus	72/13

Table 3. *Summary of deceased blue whales in fall 2007*

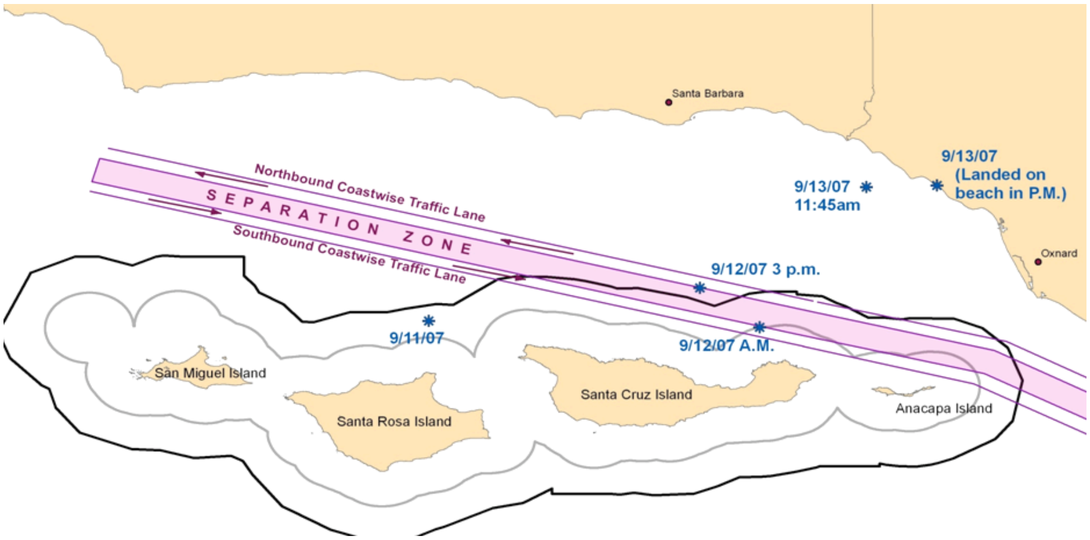

Figure 12. *Locations of deceased blue whales in the fall of 2007 (details included in table), adapted from data provided by Cascadia Research Collective. Map Credit: Channel Islands National Marine Sanctuary (CINMS)*

Causes of Injury or Death

Jensen and Silber (2004) reported 292 ship strike occurrences on large cetaceans. Of these, 48 resulted in injury and 198 resulted in fatality (Jensen & Silber, 2004). Though in many cases the fate of a struck whale is unknown (39 of the 292 cases), these data indicate that of the 292 reported ship strikes, 246 incidents showed evidence of a ship-whale interaction where animals were injured or killed (Jensen & Silber, 2004).

It is sometimes difficult to tell if an animal found dead was killed via ship strike ante- or post-mortem. Jensen and Silber (2004) included those cases that showed strong likelihood of ship strike evidence, which included propeller marks, bruising, hemorrhaging and severed flukes. Further, if a whale was found floating (blue whales float ventral side up, post-mortem) with no ship-strike marks showing ventrally, it can be assumed that if marks on the dorsal side indicated ship strike, the animal was killed ante-mortem (Jensen & Silber, 2004).

Necropsies and visual evidence indicate that the cause of death or injury is due either to blunt force trauma or propeller wounds (Cascadia research unpublished data). The blunt trauma is caused by the bulbous bow (figure 13) that freighters and other large ships have.

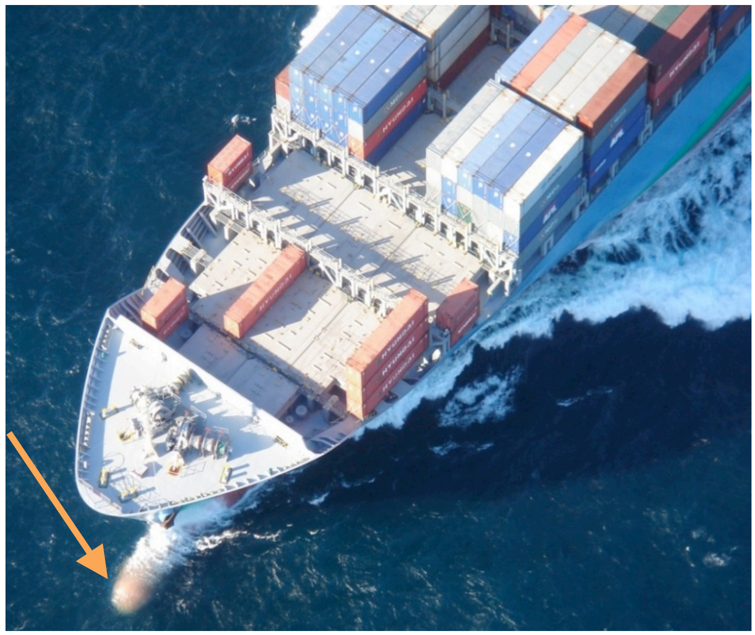

Figure 13. *The combination of a bulbous bow and the fast speed of a large vessel increase the potential for ship strike fatalities.*

Population Threat

No published literature has reported that ship strikes are causing harm or decline to blue whale populations. Cascadia Research Collective and other experts in the field are continuing to gather the data necessary to publish the details of this risk to blue whales. The data that has been collected so far (Cascadia Research Collective; June, July, August, September of 2007 and 2008), in combination with past published studies (Douglas, Calambokidis, Raverty, Jefferies, Lambourn, & Norman, 2008; Jensen & Silber, 2004; Calambokidis, Douglas, Falcone, & Schlender, 2007, Calambokidis, et al., 2007/08) is adequate enough to make an assessment of potential threat to blue whale populations.

Though blue whales travel most of the world's oceans, there is not enough data reporting ship strikes to make an assessment of the global context. It can only be assumed that ship strikes may occur where blue whale feeding habitat and commercial shipping lanes overlap. As this is a new field, focus must be turned to those areas that have been documented and studied more heavily than others (e.g.: Central California region).

It has been documented that a dense population of blue whales (1,428 animals for 2004-06 from central California to Baja Mexico) feed and forage in the Santa Barbara Channel region during the summer and fall months (chapter 2) (Calambokidis, Douglas, Falcone, & Schlender, 2007). This is also where commercial ships (e.g.: cargo, oil tankers, cruise liners: see chapter 4) travel. Past blue whale ship strike records have shown that most have occurred in the Central California region (Jensen & Silber, 2004 Cascadia Research unpublished data, 2007). In the fall of 2007 the biggest recorded fatal strike event of six animals occurred in the Central California region (Santa Barbara Channel) (Cascadia Research unpublished data, 2007). Blue whales, though long lived (30-80 years), have a relatively low reproductive output (approximately 2-20 offspring per lifetime). Furthermore, this is in relation to a population decline of approximately 90% from six decades of whaling (original numbers estimated at 9,000 animals in the northeast Pacific) (chapter 1) (Bortolotti, 2008; Ellis, 1991; Jackson, 1978; Gambell, 1979), which has made the species endangered and vulnerable.

The combination of these factors shows conclusive evidence that ship strikes are a considerable threat to blue whales. Though no long-term data (>5 years) exists of ship strikes causing blue whale populations to slow in growth or decline, the potential exists. For a species as threatened and as slow growing as blue whales, all conservation efforts are critical. Blue whales are being struck seasonally on a regular basis (Cascadia Research Collective unpublished data, 2007; Jensen & Silber, 2004) in areas of feeding habitat overlapping ship traffic. To continue to assess the threat of ship strikes and take necessary measures and precautions to reduce long term impacts is an important tactic in the future of blue whale conservation.

Chapter 5:
FUTURE BLUE WHALE STUDIES AND POSSIBLE CONSERVATION STRATEGIES

Blue whales have suffered many decades of decline and the global population is now only at a fraction of what it was before the whaling era. Though practically no blue whales have been intentionally killed by humans since the 1970's, populations are not showing signs of recovery. Other whale species that were heavily hunted have bounced back since they were declared endangered. Sperm whales for example, were hunted for nearly two centuries until 1986 when the IWC put a ban on their catch (Ellis, 1991). They are now off the endangered species list and populations are estimated as high as 400,000 animals worldwide. Fin whales, the closest relative to the blues, were whaled in large numbers: more than 700,000 in the Antarctic alone (Ellis, 1991). Though still only a fraction of these numbers exist in southern waters, they are abundant in the northern hemisphere and today are no longer considered endangered (Bortolotti, 2008). Whale populations typically increase once hunting has stopped, but the rate of recovery varies with the animal's biology and interaction with human activity. What is it about blue whales that will not allow their populations to bounce back to their abundance of the past?

Blue whale reproductive strategy aside, there are unknown reasons as to why populations are not recovering like experts had hoped. Because of these unknown factors, conservation efforts are an important tool in the long-term recovery of blue whale populations. It has been shown that the blue whale only faces one natural predator: the killer whale (Jefferson, Webber, & Pitman, 2008). Though attacks have been documented, these are rare and do not cause enough deaths to account for declining blue whale populations. Ship strikes have been documented as the main anthropogenic factor potentially causing harm to blue whale populations. A high priority for research organizations is investigating ship-whale interactions as a conservation threat to the northeast Pacific stock (Cascadia Research Collective unpubl. Data). For the prevention of fatal ship strikes, much more analysis, planning and research is necessary.

Unknowns

There is much difficulty in determining long term human impacts on blue whale populations. Though the threat assessment of ship strike potential on blue whales is a high priority, many unknown variables still exist (Cascadia Research Collective unpubl. data). Understanding these is the first step in realizing the specific aspects of research that need to be undertaken. Presently it is not possible to determine (1) the true number of ship strikes occurring on blue whales. Many struck animals go unnoticed by large vessels or do not get reported for fear of negative consequences. Furthermore, struck animals may simply sink or float out to sea. The lack of understanding of strike events is a symptom of (2) not knowing exactly when, where and in what situations ship strikes are occurring. Because many events go unnoticed it is difficult to find a trend to determine which locations yield high strike potential. Presumably risk is highest where foraging and feeding habitat overlap with dense ship traffic. In areas where shipping lanes and feeding habitat of whales overlap, close encounters occur frequently as well. It is therefore important to understand (3) how blue whales react or do not react to an approaching ship. This aspect of research will allow researchers to understand the factors that cause large ships to strike such fast swimming whales. Ship-whale interactions may be causing selective pressures that influence distribution and behavior. It is important to determine (4) how the resulting behavioral and distributional shift can be predicted. These as yet unknown factors are reasons why strike events are currently a threat to blue whales. Continued research efforts can play a vital role in preventing further ship strikes.

Continued Research

The best method for understanding the long-term population impacts of ship strikes on blue whales is continued research efforts. As noted in Chapter 3, research efforts are underway to further understanding of blue whale behaviors, their feeding ecology and their reproductive strategies. In regards of ship-whale interactions, an underlying research effort that can help provide useful large-scale data is (1) the continued monitoring of the overall distribution and abundance of blue whales (as seen in chapter 2). Another aspect that can shed light on this complicated field is focusing attention on areas of known close encounters of ships and whales (e.g.: Santa Barbara Channel, California; discussed in chapter 3). It is particularly in this arena that (2) the studies of blue whale underwater behavior in shipping lanes and their reaction to closely traveling ships offer a rich and valuable area for research. Research organizations have undertaken this by going in small (<5m), rigid hulled inflatable boats into the Santa Barbara channel and surveying and monitoring blue whales, while logging all ships in the area, and noting all close encounters (Cascadia Research Collective unpubl. Data). Along these lines, it is important to (3) monitor ship traffic. In particular, focus should be placed on those areas where blue whales feed and forage. This, as seen in chapter 3, will show vessel movement trends in particular areas, and allow for an assessment of higher and lower risk locations. To get a clearer idea of what the causes of ship-whale interactions are, (4) acoustic studies of whales and ships are also essential elements. Researchers have little understanding of the hearing physiology and mechanisms of blue whales, as well as what type of frequencies may cause reactions. Studying both the acoustic behavior of blue whales and the sound emissions of traveling vessels will help shed light on the factors causing ship strikes. As seen through past events (chapter 4), ship strikes cannot be foreseen. However, once a ship strike event has occurred and a blue whale carcass is inspected, much data can be extrapolated. It is therefore important to (5) plan and prepare for strandings in advance before the animal decays, sinks, or drifts off to sea. To accommodate important future studies it will be necessary to (6) develop an integrated monitoring plan specifically for blue whale ship strike events.

Possible Strategies to Avoid Ship Strikes

The North Atlantic Right Whale is a highly endangered baleen whale species that has faced detrimental population effects due to ship collisions. Recently (2008) a law was passed to slow ship speeds, which allows the animal time to maneuver out of potential strike zones. A strategy for lowering the threat of ship strikes on blue whales in the Santa Barbara Channel could be (1) adjusting ship speeds (to10 knots) considering temporal, geographic and seasonal conditions. Further, since blue whales have relatively short dive times (5-15 minutes), large blow plumes, and enormous body sizes, they may be easily detectable from great distances. Another strategy may therefore be (2) to place observers on ships where blue whales frequently occur within close proximity to shipping lanes. As seen in September 2007 (chapter 4), the high density of blue whales in the Santa Barbara Channel along with the close proximity of shipping lanes can have detrimental effects. To prevent a strike event like the one in fall 2007 from reoccurring, (3) adjusting shipping lanes may be a useful option. These adjustments don't necessarily need to be permanent. Important aspects to consider are temporal and seasonal variability, areas of feeding and foraging habitats, and regions where blue whales are consistently abundant, such as the Santa Barbara Channel. During seasonal variations, shipping lanes can be shifted within the channel or moved outside the channel. Since blue whale research in these areas is constantly being undertaken by researchers a helpful tactic would be to (4) provide abundance and distribution data of whale sightings to the shipping industry in a timely fashion. This can help the industry take necessary precautions and has potential to prevent further ship strikes.

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