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# COLLISIONS BETWEEN SHIPS AND WHALES

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## Abstract

Although collisions with motorized ships are a recognized source of whale mortality, little has been done to compile information on the frequency of their occurrence or contributing factors. We searched historical records and computerized stranding databases for evidence of ship strikes involving great whales (*i.e.*, baleen whales and the sperm whale). Historical records suggest that ship strikes fatal to whales first occurred late in the 1800s as ships began to reach speeds of 13–15 kn, remained infrequent until about 1950, and then increased during the 1950s–1970s as the number and speed of ships increased. Of 11 species known to be hit by ships, fin whales (*Balaenoptera physalus*) are struck most frequently; right whales (*Eubalaena glacialis* and *E. australis*), humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter catodon*), and gray whales (*Eschrichtius robustus*) are hit commonly. In some areas, one-third of all fin whale and right whale strandings appear to involve ship strikes. To assess contributing factors, we compiled descriptions of 58 collisions. They indicate that all sizes and types of vessels can hit whales;

most lethal or severe injuries are caused by ships 80 m or longer; whales usually are not seen beforehand or are seen too late to be avoided; and most lethal or severe injuries involve ships travelling 14 kn or faster. Ship strikes can significantly affect small populations of whales, such as northern right whales in the western North Atlantic. In areas where special caution is needed to avoid such events, measures to reduce the vessel speed below 14 kn may be beneficial.

Key words: mortality, strandings, ship collisions, species conservation, right whales.

As steam-powered ship technology evolved in the 1800s, reports of ships striking whales began to appear (Allen 1916; Schmitt 1976, 1979). These collisions appeared to occur rarely; however, recent information suggests that ship strikes of whales may be more common than previously suspected and, in some cases, may constitute significant conservation issues.

Kraus (1990) reported that at least 20% (5 of 25) of endangered northern right whales (*Eubalaena glacialis*) found dead between 1970 and 1989 off the eastern United States and Canada had large propeller slashes or massive injuries indicating they were killed by ships. Of the living right whales for which good-quality photographs are available, 7% (12 of 168) had scars caused by ship strikes. An updated analysis (Knowlton and Kraus, in press) links ship strikes to 35% (15 of 43) of right whale deaths between 1970 and 1998, and to at least 47% (8 of 17) of their deaths from 1991 to 1998, a period when carcass recovery and necropsy efforts improved. Because there are only about 300 animals in the population (Knowlton *et al.* 1994, Caswell *et al.* 1999), ship strikes pose a serious threat to recovery and intensive management efforts have been undertaken in both the United States and Canada to reduce the number of vessel-related deaths (Marine Mammal Commission 1999).

Humpback whales (*Megaptera novaeangliae*) also may be struck by ships more frequently than previously thought in some areas. Wiley *et al.* (1994) found that 30% (6 of 20) of carefully examined humpback whale strandings along the U.S. Atlantic coast between 1985 and 1992, most of which were near the Chesapeake Bay, had injuries caused by ships.

In some areas recurring ship strikes involving hydrofoils and high-speed vessels (*e.g.*, those that operate at speeds of 28 kn and higher) also suggest ship collisions may be relatively common in some areas. After several collisions between ferries and sperm whales in the Canary Islands, one of which caused the death of a passenger, André *et al.* (1997) tried unsuccessfully to deter sperm whales from ferry routes by broadcasting low-frequency sounds. Five collisions in the Sea of Japan between high-speed jetfoil ferries and what were thought to be whales also were reported, two of which resulted in injuries to several passengers and three of which involved vessel damage (Honma *et al.* 1997).

Although this information suggests that collisions between ships and whales are more common than previously thought, no attempt has been made to compile information on the frequency of such collisions, the types of vessels

involved, the speed of ships when whales were hit, collision locations, the behavior of whales immediately before being struck, or other potentially relevant factors. The lack of such information has hampered efforts to evaluate the significance of ship strikes for whale populations and to develop appropriate mitigation measures. Therefore, we compiled and analyzed information on the nature and extent of collisions between motorized ships and large whales from four sources: (1) historical collision records, (2) recent whale stranding records, (3) anecdotal accounts from vessels involved in collisions, and (4) data on the number and speed of ships.

## Methods

We focused on collisions between motorized vessels and great whales (*i.e.*, baleen whales and the sperm whale, *Physeter catodon*). Collisions with vessels under sail were excluded from the analysis because of data limitations and a lack of evidence that such collisions cause significant injuries to whales.

*Historical collision records*—To assess collisions with whales before 1951, we reviewed newspaper clippings, early stranding records, and scientific publications. It was not possible to verify independently the accuracy of these reports, except in rare cases where photographs of struck animals accompanied the reports. To minimize error, we considered only accounts citing vessel crew members whose descriptions indicated that the struck whale was seen clearly (*e.g.*, it was caught on a ship's bow or seen thrashing off the stern). Historical whale stranding records from the early 1600s to 1915 along northeastern North America (Allen 1916), and from 1913 to 1966 for the British Isles (Harmer 1927; Fraser 1934, 1946, 1953, 1974) were also reviewed for reports of ship strikes or stranded whales with massive injuries, such as fractured skulls and severed tails. We found no other long-term data sets for large-whale strandings before the 1970s.

*Recent stranding records*—We searched computerized stranding databases for all records of whales killed or possibly killed by ships. These included records for the U.S. Atlantic and Gulf of Mexico coasts (maintained by the Division of Mammals, National Museum of Natural History, Smithsonian Institution, Washington, DC), Italy (maintained by the Centro Studi Cetacei, Museo di Storia Naturale di Milano), and France (the Institut de la Mer et du Littoral, La Rochelle). Stranding records for southern right whales (*E. australis*) in South Africa (Best *et al.,* in press) also were examined.

From each database, we generated a list of the species, date, location, and nature or source of injury for each identified or possible ship strike. Records were attributed to ship strikes when they reported either (1) massive blunt impact trauma (*e.g.*, fractures of heavy bones including skulls, jaws, or vertebrae) or apparent propeller wounds (*i.e.*, deep slashes or cuts into blubber on the dorsal aspect, or (2) a dead whale on the bow of a ship. Given the force needed to break large whale bones, it was considered unlikely that fractured jaws, skulls, or vertebrae were caused by anything other than ship collisions. Similarly, it was assumed that long, deep, parallel slashes were caused by ship

propellers. Dead whale stranding records ascribed to ship strikes were summed and the total was compared to the total number of dead whale strandings for that species from all causes. Time frames for searches varied by database depending on the year in which well-organized stranding response efforts began and the last year for which data entry was relatively complete.

*Anecdotal accounts*—To examine factors contributing to ship strikes, we compiled accounts describing observed collisions between ships and whales from published literature, a request for collision descriptions posted on the Internet (marmam@uvvm.uvic.ca), and inquiries to whale biologists, government officials, and mariners likely to have documented such events. We also reviewed newspaper clippings, articles, and unpublished first-hand accounts of vessel collisions with various species of marine life gathered by William C. Cummings (5948 Eton Ct., San Diego, CA 92122), who published a request for descriptions of such events in *Yachting* (March 1974) and *Sea Frontiers* (July–August 1974).

The following information was recorded from each event whenever available: date; time; location; species of whale struck; whether the struck whale was seen before the collision; a description of the impact; fate of the whale or signs of injuries; type, name, and size of the vessel; vessel speed and weather conditions at the time of the collision; and vessel damage. When a vessel's name was provided, Lloyds Registry of Shipping was used to determine and/or verify vessel length. It was not possible to verify other information. To ensure account accuracy, we included only descriptions based on the crew of vessels involved in collisions, witnesses to the collisions aboard a nearby vessel, or individuals who, as part of their official duty, investigated cases of whales brought into port on bows of ships or other reported ship strikes. In many cases, event summaries were provided to individuals reporting the event to verify their accuracy.

Struck whales were assigned to one of five fate categories: killed, severe injury, minor injury, no apparent effect, or unknown fate. Whales were listed as killed if they were seen dead on a vessel's bow or described as having been cut into pieces and sank. Whales struck with reports of blood in the water or bleeding wounds were considered severely injured. Whales seen alive after a collision with fresh wounds exposing blubber or thrashing off the stern but with no mention of blood in the water or bleeding wounds, were categorized as receiving a minor injury. Whales seen swimming away after being hit with no visible marks and with behavior similar to that observed before the whale was hit (*e.g.*, resuming feeding) were considered to have sustained no apparent injury. The fate of whales not seen after a collision and lacking any report of blood in the water was considered to be unknown.

*Historical data on the number and speed of ships*—We determined the number of motorized vessels 100 gross tons or larger registered by Lloyds Resister of Shipping in the last year of each decade from 1880 through the 1990s (The Committee of Lloyds Register 1890, 1950; Lloyds Register of Shipping 1992). We also examined the maximum sustained speed of more than 1,400 passenger vessels built for trans-Atlantic service in decades from the 1830s to the 1970s

(Smith 1978). These speeds were based on the average speed of each vessel's fastest trans-Atlantic crossing. For each decade, we determined the number of passenger ships built for trans-Atlantic crossing, their average maximum sustained speed, and the percentage that were able to maintain speeds above 15 kn and 20 kn.

## Results

Evidence of ship collisions was found for 11 species of great whales. Overall, fin whales (*Balaenoptera physalus*) were hit most frequently. Collisions with northern and southern right whales, humpback whales, gray whales (*Eschrichtius robustus*), and sperm whales were relatively common in some areas. There were comparatively few collision records for minke whales (*B. acutorostrata*), blue whales (*B. musculus*), and sei whales (*B. borealis*). Records for Bryde's whales (*B. edeni*) and bowhead whales (*Balaena mysticetus*) were rare.

### *Historical Evidence of Collisions*

There were few accounts of motorized ships hitting whales before 1951. The earliest account we found involved the steamship *Munroe* moored in Narragansett Bay, Rhode Island, in 1877. According to Allen (1916), the captain reported that, "by some curious accident," a small whale, possibly a minke whale or small fin whale, became caught between the ship's propeller and stern while the ship lay at dock. To dislodge the animal, whose vigorous struggles to free itself raised the ship's stern, the captain started the engine. The propeller then "inflicted such injuries upon the whale's head that it rushed upon a shoal . . . and became stranded." Between 1885 and 1950, we found only 14 accounts of collisions between moving ships and whales (Table 1). Several cases involved whales caught on the ship's bow.

Allen (1916) described five ship collisions from 1885 to 1915. One involved a sailing vessel, the schooner *Adelia T. Carleton,* in June 1904; four others involved motorized vessels (Table 1). One collision, involving the *Admiral Sampson,* "just grazed (a whale, which) came up almost immediately astern and followed along for some distance as though bent on revenge." The other collisions were more serious. The *Lawrence* struck a whale that was seen off the stern "rolling about as if in distress" after being hit at a speed of about 13 kn; the *Graecian* struck a whale "with such force as to cut the animal into two parts"; and the *Waldimir Reitz* hit a whale head-on "knocking a four-foot hole in the (ship's) bow."

Allen (1916) also reported two finback whales were found floating in Massachusetts Bay in July 1842. After being towed to shore and stripped of blubber, both were found to have broken lower jaws. He reported that "it was supposed that the two had been fighting, and so had fatally injured each other, but the usual peaceable nature of this species is rather against such a supposition." He noted no other injuries typical of recent ship strikes among ap-

*Table 1.* Records of collisions between motorized ships and whales prior to 1951.

| Year | Species struck | Fate of whale | Vessel (name/type) | Location | Source |
|---|---|---|---|---|---|
| 1885 | unidentified | unknown | *Alexander M. Lawrence, No. 4*/pilot boat | 20 mi east of Nantucket, MA, USA | Allen 1916 |
| 1896 | sperm whale? | killed | *Seminole*/liner | Off Sandy Hook, NJ, USA | Schmitt 1979 |
| 1903 | unidentified | unknown | *Puma*/steamship | Placenta Bay, Newfoundland | Allen 1916 |
| 1904 | unidentified | killed | *Swazi*/steamship | Atlantic Ocean | Anonymous 1904 |
| 1906 | unidentified | injured? | *Admiral Sampson*/steamship | Off Chatham MA, USA | Allen 1916 |
| 1908 | unidentified | killed? | *St. Louis*/liner | Off Newfoundland, Canada | Schmitt 1979 |
| 1908 | sperm whale | killed | *Kensington*/liner | Off Newfoundland, Canada | Anonymous 1908 |
| 1910 | unidentified | killed | *Pallenza*/steamship | North Atlantic | Anonymous 1910 |
| 1913 | unidentified | unknown | *Waldmir Reitz*/cargo ship | Off Newfoundland, Canada | Allen 1916 |
| 1912–1915 | unidentified | killed | *Graecian*/steamship | Off U.S. East Coast | Allen 1916 |
| 1926 | unidentified | killed | *Berengaria*/liner | North Atlantic | Schmitt 1979 |
| Mid-1930s | unidentified | killed | *Maunganui*/steamship | Near Raratonga, South Pacific | W. Cummings[a] |
| 1940 | baleen whale | killed | *New Orleans*/tanker | Off Cape Hatteras, NC, USA | Burgess 1940 |
| 1940–1945 | sperm whale | killed | U.S. destroyer | North Atlantic | Slijper 1962 |
| 1950 | Bryde's whale | killed | tanker | Red Sea, Egypt | Anonymous 1950 |

[a] William C. Cummings, unpublished data held by the Marine Mammal Commission, 4340 East-West Highway, Rm. 905, Bethesda, Maryland, 20814, U.S.A. 28 April 1999.

proximately 200 records compiled for five whale species (finback, right, sei, blue, and little piked or minke).

Records of 164 large whale strandings in the British Isles from 1913 to 1966 (Harmer 1927; Fraser 1934, 1946, 1953, 1974) included no evidence of ship strikes even though some strandings were attributed to other human causes (*e.g.*, commercial whaling, shootings, and possibly anti-submarine warfare) and one record mentions broken rib and flipper bones. Because rib and flipper bones are thinner than skulls and jaws and subject to breaking as dead animals roll in the surf, we did not consider such injuries as evidence of a ship strike.

Other than Allen (1916), the first references we found in the scientific literature to whales being killed or injured by ships involved events in the 1950s. Gilmore (1959) cited reports of flukeless humpback whales and gray whales off California in the 1950s and speculated on ship collisions as the cause. Slijper (1979) noted four cases of ships colliding with what were thought to be sleeping sperm whales in the 1950s.

### *Stranding Records*

Since the mid-1970s, marine mammal stranding programs have provided a basis for documenting collisions between ships and whales. Indeed, the value of stranding records to document such human-related mortality was among the fundamental reasons cited for the need to improve stranding programs (Geraci and St. Aubin 1979).

*United States*—Along the U.S. Atlantic coast (Maine to Dade County, Florida), 407 strandings of seven whale species were recorded between 1975 and 1996. Overall, 14% (58 of 407) of the records indicate vessel collisions as the known or possible cause of death (Table 2). Evidence of ship collisions, however, was limited to five species: fin whales (33%, 31 of 92 stranding deaths), northern right whales (33%, 10 of 30 stranding deaths), humpback whales (8%, 10 of 123 stranding deaths), minke whales (5%, 5 of 105 stranding deaths), and sei whales (67%, 2 of 3 stranding deaths). None of the six Bryde's whales or 48 sperm whales revealed signs of a ship collision. Although there were no blue whale strandings during the search period, a dead blue whale was brought into Narragansett Bay, Rhode Island, on the bow of a tanker on 3 March 1998, bringing to six the number of species with vessel-related injuries recorded along the U.S. Atlantic coast. Ship strike locations were distributed broadly for most species; however, for humpback whales, all but one occurred between the Delaware River and Okracoke Island, North Carolina. Between those points, 25% (9 of 36) of the humpback whale strandings involved vessel injuries.

A high proportion of struck right whales and humpback whales were calves and juveniles: 75% of the eight struck right whales whose ages could be estimated were calves or juveniles; 80% of the 10 struck humpback whales were $\leq$11 m, lengths considered to be three years of age or less (Stevick 1999).

*Table 2.* Whales killed or possibly killed by vessel collisions from stranding records of dead whales along the U.S. East Coast (Maine to Dade County Florida): 1975–1996. Data from the Cetacean Distributional Database, Smithsonian Institution, Washington, DC.

| Date | Location | Comments |
|---|---|---|
| Northern right whale (*Eubalena glacialis*); 33.3% of records (10 of 30): | | |
| 4/15/76 | Cape Cod, MA | Calf, large bruise |
| 11/5/76 | Portland, ME | Floating unrecovered, propeller cuts on back |
| 3/5/79 | Long Island, NY | Juvenile, severed tail |
| 2/21/83 | Island Beach, NJ | Juvenile, severed tail |
| 8/7/86 | Cape Cod, MA | Juvenile, five large propeller cuts from left ventral side around to middorsal area |
| 3/12/91 | Fernandina Beach, FL | Juvenile, fractured skull and gillnet around tail |
| 1/5/93 | St. Augustine, FL | Calf, reported when hit, series of propeller slashes from dorsal peduncle to head, and lower left flank to throat |
| 12/6/93 | Virginia Beach, VA | Floating unrecovered, propeller gash on right side |
| 1/30/96 | Sapelo, GA | Adult recovered floating offshore, shattered skull |
| 3/10/96 | Cape Cod, MA | Adult, 3-m gash on back |
| Humpback whale (*Megaptera novaeangliae*); 8.1% of records (10 of 123): | | |
| 2/5/90 | Nags Head, NC | 11.1-m female, broken mandible and head damage |
| 11/8/91 | Island Beach, NJ | 9.0-m male, three propeller cuts on head, fractured occipital condyle |
| 2/14/92 | Virginia Beach, VA | 8.6-m male, propeller wounds, fractured mandible and eye socket |
| 4/16/92 | Assateague Is., MD | 8.9-m female, disarticulated skull, blunt trauma |
| 4/22/92 | Hatteras, NC | 8.9-m female, extensive skeletal damage |
| 10/9/92 | Metompkin Is., VA | 8.7-m female, bruising around axilla, dislocated mandible |
| 4/10/94 | Ocracoke, NC | No length, axillary hemorrhage ventral to left pectoral, hemorrhage to posterior third of mandible |
| 4/2/96 | Virginia Beach, VA | 7.2-m female, fractured mandible, appeared emaciated |
| 5/9/96 | Cape Henlopen, DE | 6.7-m female, deep propeller cuts behind blowhole |
| 11/3/96 | Corolla, NC | 8.4-m male, acute trauma to skull, blunt trauma to left lateral peduncle, fractured left squamosal |
| Fin whale (*Balaenoptera physalus*); 33.7% of records (31 of 92): | | |
| 4/13/75 | Newark Bay, NJ | Floating near harbor |
| 5/27/75 | Brigantine, NJ | Stranded on beach |
| 1/28/76 | Groton, CT | Stranded on beach |
| 10/18/79 | Baltimore, MD | Brought into port on bow of Russian cruise ship |
| 1/7/80 | Portsmouth, VA | Floating near harbor |
| 2/17/80 | Philadelphia, PA | Floating in harbor |
| 3/31/81 | Norfolk, Va | Brought into port on bow of ship, later determined to have been hit off Atlantic City, NJ |
| 4/23/82 | Portsmouth, VA | Stranded on beach |
| 6/7/82 | Hog Island, VA | Stranded on beach |

*Table 2.* Continued.

| Date | Location | Comments |
|---|---|---|
| Fin whale (*Balaenoptera physalus*); 33.7% of records (31 of 92): | | |
| 8/2/82 | Elizabeth City, NJ | Brought into port on bow of ship, hit off Boston, MA |
| 1/24/83 | Norfolk, VA | Brought into port on bow of ship, bruising evident, reportedly hit off New York |
| 1/25/83 | Norfolk, VA | Floating near harbor, bruising evident |
| 7/31/83 | Manhattan, NY | Possible ship strike brought into port on bow of ship |
| 10/14/83 | Fire Island, NY | Slashes on left ventral side, possible ship-strike |
| 3/7/84 | Baltimore, MD | Brought into port on bow of ship, bruising evident |
| 8/27/85 | Montauk, NY | Floating with propeller slashes, possible ship strike |
| 5/6/86 | Hoboken, NJ | Brought into port on bow of cruise ship |
| 7/2/86 | Delaware River, NJ | Reportedly struck by container ship |
| 8/18/87 | Boston, MA | Folded in half forward of dorsal fin on right side, likely brought into port on bow of ship |
| 1/15/88 | Marshfield, MA | Identified as possible ship collision |
| 1/24/88 | Cape Hatteras, NC | Stranded on beach |
| 5/4/88 | Deal, NJ | Boat hit found floating |
| 7/14/89 | North Kingstown, RI | Fractured lower jaw, line entangled on right flipper |
| 11/25/90 | Curtis Bay, MD | Stranded, ship strike mark mid-lateral on left side |
| 6/2/92 | Long Beach Is., NJ | Stranded on beach, several fractured vertebrae |
| 7/31/92 | Port Newark, NJ | Floating near harbor, fractured vertebrae in midsection |
| 3/12/94 | Virginia Beach, VA | Stranded on beach |
| 8/1/95 | 30 mi SE of Cape Cod, MA | Carried to St. George, Bermuda on the bow of a cruise ship after being hit, bruising and spinal injuries |
| 11/14/95 | Charleston, SC | Brought into port on bow of ship, fractured skull |
| 4/18/96 | Penns Grove, NJ | Floating in Delaware River, broken vertebrae, blunt trauma to right pectoral fin and surrounding area |
| 7/14/96 | Elizabeth, NJ | Floating near harbor, bow impact to left flank |
| Sei whale (*Balaenoptera borealis*); 66.7% of records (2 of 3): | | |
| 5/13/88 | Baltimore, MD | Brought into port on bow of ship, damaged skull |
| 11/17/94 | Boston, MA | Brought into port on bow of container ship |
| Minke whale (*Balaenoptera acutorostrata*); 4.8% of records (5 of 105): | | |
| 7/8/75 | Boothbay, ME | Stranded, body heavily bruised |
| 10/2/75 | New Harbor, ME | Floating and towed to shore |
| 5/13/88 | Duxbury Beach, MA | Stranded, one large gash and three smaller gashes |
| 3/15/92 | St. Johns River, FL | Propeller strike from a large vessel |
| 10/1/93 | Sandbridge, VA | Left mandible broken |
| Bryde's whale (*Balaenoptera edeni*); 0% of records (0 of 6) | | |
| Sperm whale (*Physeter catodon*); 0% of records (0 of 48) | | |

*Table 3.* Whales killed or possibly killed by vessel collisions from stranding records of dead whales in Italy: 1986–1997. Data from the Centro Studi Cetacei, Museo di Storia Naturale di Milano, Italy.

| Date | Location | Comments |
|---|---|---|
| Fin whale (*Balaenoptera physalus*); 20% of records (8 of 39): | | |
| 6/23/86 | Livorno, Tuscany | Floating 5 mi offshore with propeller cuts on back |
| 6/28/86 | Livorno, Tuscany | Floating offshore between Corsica and Italian mainland with propeller wounds on back |
| 5/22/87 | Olbia, Sardinia | Brought into port of Olbia on bow of ship |
| 5/20/89 | Olbia, Sardinia | Struck by ferry near entrance to Olbia harbor |
| 4/28/90 | Porto Torres, Sardinia | Struck by ship 1.5 mi from port, seen alive with a deep wound on back and found dead a day later |
| 4/30/91 | Genova, Liguria | Brought into port on bow of ferry |
| 5/20/94 | Cagliari, Sardinia | Stranded with propeller wounds on right side, fractured right flipper |
| 5/25/95 | Livorno, Tuscany | Brought into port on bow of ship, fractured jaw and other wounds |
| Minke whale (*Balaenoptera acutorostrata*); 33% of records (1 of 3): | | |
| 7/31/97 | Genova, Liguria | Stranded with fractured skull |
| Sperm whale (*Physeter catodon*); 6% of records (4 of 71): | | |
| 4/27/87 | Savona, Liguria | Stranded with propeller wounds |
| 1/16/88 | Cagliari, Sardinia | Stranded with propeller wounds |
| 1/24/97 | Messina, Sicily | Stranded with propeller wounds, fractured skull |
| 8/9/97 | Ischia, Campania | Stranded, three deep wounds |

The blue whale found on a ship's bow in 1998 also was a juvenile. Data to assess ages of most other struck whales were not available.

Along the U.S. Gulf of Mexico coast (Texas to Monroe County, Florida), there were 31 dead whale strandings involving four species from 1975 through 1996: 2 sei whales, 4 minke whales, 8 Bryde's whales, and 17 sperm whales. Only one stranding was identified as a possible ship strike—a sperm whale with propeller wounds found in Louisiana on 9 March 1990. The database included evidence of at least two other species struck by ships in the Gulf of Mexico: a northern right whale calf found dead in Texas on 30 January 1972 before our search period, and a live humpback whale seen swimming off Naples, Florida, on 19 February 1994 with fresh propeller wounds.

*Italy*—Stranding records for Italy from 1986 through 1997 listed 113 dead whales involving three species (Table 3). Overall, 12% (13 of 113) cited ship collisions as the known or possible cause of death, including 20% (8 of 39) of the fin whales, 6% (4 of 71) of the sperm whales, and 33% (1 of 3) of the minke whales. Ferries serving Corsica and Sardinia off Italy's west coast were implicated in several vessel-related deaths. There also was a record of a sperm whale hit by a hydrofoil on 2 September 1992 off Sicily and last seen alive with "superficial wounds."

*Table 4.* Whales killed or possibly killed by vessel collisions from stranding records of dead whales in France: 1972–1998. Data from the Institut de la Mer et du Littoral, La Rochelle, France.

| Date | Location | Comments |
|---|---|---|
| Fin whale (*Balaenoptera physalus*); 22% of records (16 of 72) | | |
| 7/5/72 | Med. Sea, off Calvi (N. Corsica) | 18-m male hit by a ferry, seen dead floating at sea |
| 9/3/72 | Med. Sea, Nice | 12.6-m male hit by ferry *La Corse*, brought into port on bow of ship |
| 8/30/73 | Med. Sea, between France and Corsica | 15-m animal hit by ferry *La Corse*, brought into port on bow of ship |
| 9/10/74 | Med. Sea, between Menton and Antibes | 15-m animal cut through middle, seen floating offshore for 3 d |
| 4/3/76 | Med. Sea, Toulon | 14.3-m male hit by merchant ship, brought into port on bow of ship, several ribs and cervical vertebra broken |
| 10/19/76 | Atl. O., Bay of Biscay, Lorient | 12.5-m female stranded alive, large propeller cuts on back, probable ship strike |
| 9/19/82 | Med. Sea, Villeneuve les Maguelonnes | 13.5-m animal stranded dead, cut through middle of the back, probable ship strike |
| 1/21/85 | Med. Sea, Port La Nouvelle La Franqui | 18-m male stranded alive, large propeller cuts on its back, probable ship strike |
| 11/10/86 | Med. Sea, Fos sur Mer | 16-m animal hit by tanker, brought into port on bow of ship |
| 5/13/91 | Atl. O., Bay of Biscay, Donges | 18.8-m male hit by tanker *Edouardo LD*, brought into port on bow of ship, broken jaw |
| 9/9/93 | Med. Sea, St. Tropez | Hit by ship, seen dead floating at sea |
| 9/9/93 | Med. Sea, Toulon | 16-m female hit by ferry *Ile de Beaute*, brought into port on bow of ship |
| 7/19/94 | Atl. O., English Channel, Le Havre | 14.5-m male hit by merchant ship *Fidelio*, brought into port on bow of ship |
| 9/26/95 | Med. Sea, Fos sur Mer | 18-m female hit by merchant ship *Japan Senator*, brought into port on bow of ship |
| 7/26/96 | Med. Sea, between France and Corsica | 14-m male hit by a ferry *Danielle Casanova*, brought into port on bow of ship |
| 2/24/97 | Med. Sea, Marseille | 5.2-m male stranded alive, large hematosis on right side of thorax, possible ship strike |
| Sei whale (*Balaenoptera borealis*); 0% of records (0 of 2) | | |
| Minke whale (*Balaenoptera acutorostrata*); 0% of records (0 of 17) | | |
| Humpback whale (*Megaptera novaeangliae*); 0% of records (0 of 6) | | |
| Sperm whale (*Physeter catodon*); 0% of records (0 of 30) | | |

*France*—French stranding records for the period 1972 through 1998 included 127 dead whales of five species (Table 4). Overall, 13% (16 of 127) of the records listed ship strikes as a known or possible cause of death. For fin whales, vessel-related injuries were noted in 22% (16 of 72) of the strandings,

*Table 5.* Southern right whales killed or possibly killed by vessel collisions from stranding records of dead whales in South Africa: 1963–1998. Data from Best *et al.*, in press.

| Date | Location | Comments |
|---|---|---|
| Southern right whale (*Eubalaena australis*); 20% of records (11 of 55): | | |
| 7/27/83 | Beachview, Port Elizabeth | 14.3-m adult, five apparent propeller gashes |
| 2/8/84 | Jakkalsfontein | Adult, seen from air, major damage around midlength |
| 10/16/84 | East London Harbor | 7.2-m calf struck by dredge, propeller wounds |
| 9/10/88 | 25 km E of Sundays River | 14.1-m male thought to be animal struck by ferry two days earlier, propeller gashes and damaged rostrum |
| 9/10/88 | 25 km E of Sundays River | 14.0-m male no external injuries but possibly struck by same ferry |
| 8/16/93 | Between Long Beach and Koppie Alleen | Calf found with tail cut off |
| 10/10/93 | Lekkerwater, De Hoop | Female calf found with tail cut off |
| 9/22/94 | Kabeljoubank, Breede River | 11.23-m juvenile, cuts across back |
| 11/10/94 | Shell Bay, St. Helena Bay | 10.7-m juvenile, diagonal slashes near genital aperture |
| 7/28/96 | Scarborough, Cape Peninsula | 14.6-m adult, broken rostrum and missing skull bones |
| 7/10/98 | Die Dam, Quoin Point | Female calf found with tail cut off |

most of which (13 of 16) occurred along the Mediterranean coast. Five collisions involved ferries along the Mediterranean coast, five others were attributed to merchant ships or tankers. A specific vessel type was not ascribed in the remaining six cases.

*South Africa*—A review of southern right whale stranding records from 1963 through 1998 in South Africa (Best *et al.,* in press) identified ship collisions as a known or possible cause for 20% (11 of 55) of recorded deaths (Table 5). Fifty-five percent (6 of 11) of the ship strikes involved calves or juveniles. In five cases ship strikes were cited as a definite cause of death and in six cases they were considered a possible cause. Two of the five definite ship strikes involved known vessels, a hopper dredge and a ferry. Best *et al.* (in press) also listed five non-fatal collisions with right whales. These involved two motor launches, a 6-m inflatable boat, a catamaran whale-watching boat, and a fisheries patrol boat.

*Types of injuries*—Ship strike injuries to whales take two forms: (1) propeller wounds characterized by external gashes or severed tail stocks; and (2) blunt trauma injuries indicated by fractured skulls, jaws, and vertebrae, and massive bruises that sometimes lack external expression. The frequency of the two injury types varied among species. Propeller injuries comprised a high proportion of ship collision injuries among right whales stranded along the U.S. Atlantic coast (70%; 7 of 10 whales) and South African coast (73%; 8 of 11 whales), while blunt trauma alone was indicated in 93% (29 of 31) of the fin

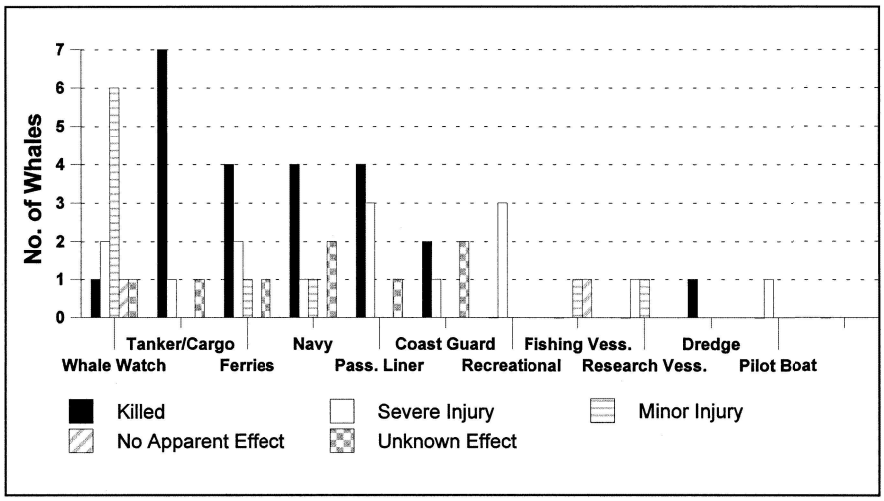


*Figure 1.* Number and fate of whales struck by different vessel types from collision accounts found in this study. Killed = observed carcass; Severe Injury = report of bleeding wounds or observation of blood in the water; Minor Injuries = visible non-bleeding wound or sign of distress with no report of blood; No Apparent Effect = resighted with no apparent wound or sign of distress and resumed pre-collision activity; Unknown = whale not resighted and no report of blood in the water.

whales struck on the U.S. Atlantic coast and at least 69% (11 of 16) struck fin whales in France. Blunt trauma injuries also were responsible for both sei whales and the blue whale struck by ships along the U.S. Atlantic coast.

Differences in frequency of injury types among species appears to be related to morphology. Long, sleek rorquals tend to be caught on the bows of ships and carried into port where they are likely to be found and recorded in stranding databases. For example, most fin whales with blunt trauma injuries (20 of 31 on the U.S. Atlantic coast and 9 of 16 in France) were carried into port on ship bows or found floating in or very near major harbors. Both sei whales and the blue whale found along the U.S. Atlantic coast also were found on the bows of ships entering port. In contrast to these rorquals, there were no records in any of the examined databases of stockier species, such as right whales, humpback whales, or sperm whales, being caught on vessel bows or found in ports.

### *Anecdotal Records*

We found descriptions of 58 collisions between motorized vessels and whales (Appendix 1). As shown in Figure 1, they include a wide range of vessel types: whale-watching vessels (including a high-speed vessel), cargo ships (including four with bulbous bows), ferries (including three high-speed ferries), Navy ships (a submarine traveling at the surface, a frigate, a heavy cruiser, an aircraft carrier, two destroyers, and two hydrofoils), passenger vessels (including two

with bulbous bows), Coast Guard patrol boats, private recreational craft, commercial fishing vessels, research vessels, a pilot boat, and a hopper dredge. The smallest vessel was a 4-m outboard; the largest was a 232-m passenger liner. High speed vessels were involved in 15% of the 40 accounts found since 1975. Vessel damage was reported in 14 cases; in 18 other cases there were affirmative reports of no damage, and for 26 accounts information on vessel damage was not available.

The collision accounts involved at least 10 whale species: 8 humpback whales, 6 fin whales, 5 sperm whales, 3 blue whales, 3 gray whales, 2 minke whales, 2 southern right whales, 2 Bryde's whale, 1 northern right whale, 1 killer whale, and 25 whales not identified as to species. Twenty-three accounts (40%) report the whale was killed; 23 others (40%) cite evidence of injuries, including 15 classified as severe injuries (some of which may have been fatal), and 8 scored as minor injuries. One minor injury involved a whale hit by the bow of a whale watching vessel in 1991. Resightings of the whale, a photo-identified individual, revealed rapid healing over the next six years. Two accounts (3%) reported no apparent effect on struck whales and in 10 cases (17%), the fate of the whale was listed as unknown.

Most severe and lethal whale injuries involved large ships. Of the 15 whales considered severely injured, three were hit by vessels less than 20 m long, three by vessels between 20 and 80 m long, and nine by ships longer than 80 m. Of 23 collisions in which whales were killed, at least 20 (87%) involved ships more than 80 m long. The smallest vessels involved in collisions fatal to whales were a 20-m high-speed ferry moving at 45 kn, a 24-m whale-watching boat moving at about 25 kn, and a 25-m Coast Guard patrol boat moving at about 15 kn; two of these three involved collisions with calves. All but one account classified as a minor injury ($n = 8$) or no apparent effect ($n = 2$) involved vessels less than 45 m long. The exception was a pilot boat whose length is unknown and may have been less than 45 m.

Fourteen accounts involved whales caught on ship bows, and in at least eight of these incidents, vessels had to use reverse thrust to remove the whale. The smallest ship reporting a bow-pinned whale was a 121-m container ship. Similar to stranding records, almost all records of whales caught on ship bows involved rorquals (*i.e.*, three blue whales, two fin whales, and two Bryde's whales) or unidentified species ($n = 5$); there also was one record of a sperm whale caught on a ship's bow. Stockier whale species (*e.g.,* right whales, gray whales, and humpback whales) were rare or absent among reports of bow-caught animals; they included only one humpback whale and one whale questionably identified as a right whale.

In most cases, whales struck by vessels either were not seen or were seen too late be avoided. Excluding 13 accounts with information insufficient to determine whether whales were seen before the collision, 93% (40 of 43) of the accounts reported that the whale either was not seen before it was hit ($n = 17$) or it surfaced immediately in front of the vessel too late to be avoided ($n = 23$). In one case (a commercial fishing vessel), the whale was observed feeding near the vessel for some time before it turned in front of the bow and

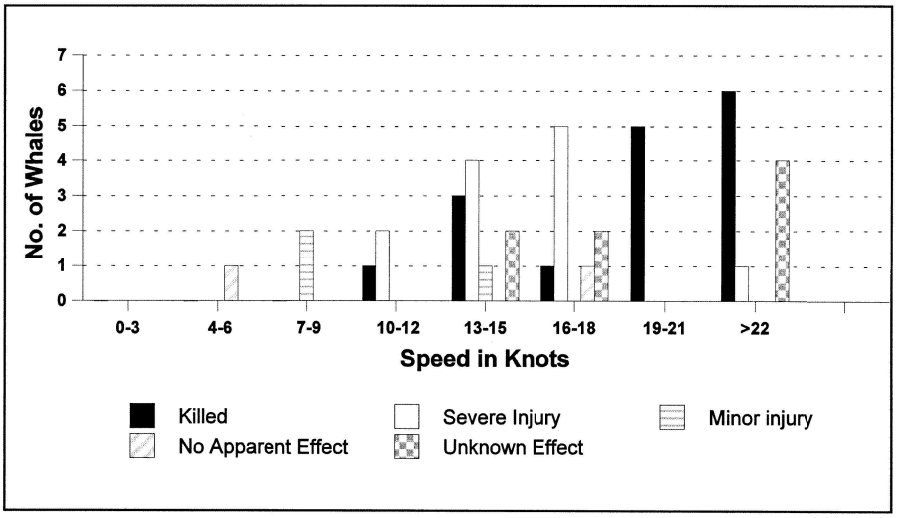


*Figure 2.* Severity of injuries to whales struck by vessels traveling at known speeds. Killed = observed carcass; Severe Injury = report of bleeding wounds or observation of blood in the water; Minor Injuries = visible non-bleeding wound or sign of distress with no report of blood; No Apparent Effect = resighted with no apparent wound or sign of distress and resumed pre-collision activity; Unknown = whale not resighted and no report of blood in the water.

was hit. Two other cases reported that the whale was seen before the collision, but it was not clear how long before.

Most accounts reporting that whales were seen immediately before impact provide little or no information on whale behavior at that time. A few, however, suggest a last-second flight response may occur in some cases; one whale apparently breached directly in front of a submarine leaving port and landed on its bow, and another reportedly lunged quickly just before being hit by a whale-watching vessel. Perhaps the best evidence of a last-second flight response was an event reportedly video-taped on 5 March 1988 in which a small pod of migrating gray whales dived suddenly when a large commercial ship approached to within about 27 m (Heyning and Dahlheim, in press).

Vessel speed at the time of impact was reported in 41 accounts and ranged from 6 to 51 kn. Information on both vessel speed and condition of the whale after being hit was available in 33 cases (Fig. 2). Among collisions causing lethal or severe injuries, 89% (25 of 28) involved vessels moving at 14 kn or faster and the remaining 11% (3 of 28) involved vessels moving at 10–14 kn; none occurred at speeds below 10 kn. The three fatal or severe injuries caused by vessels moving slower than 14 kn involved a southern right whale killed by a ferry moving at 12–13 kn and two severely injured whales hit by small private vessels reportedly traveling at 10 kn. Of five collisions classified as causing no or minor injuries, three were traveling at less than 10 kn. In all cases where fate of a whale was unknown but vessel speed was reported ($n$ = 8), vessels were moving 14 kn or faster.

At least 53 of the 58 collision accounts occurred on the continental shelf or shelf slope. Exceptions included two collisions (October 1980 and March 1998) with blue whales where the location of the collision was not determined; a collision (mid-1930s) with an unidentified species "near Rarotonga" in the South Pacific; a collision (September 1961) at an unspecified location in the Caribbean Sea; and a collision with a sperm whale (29 November 1965) about 200 km west of San Francisco, California. Twenty-seven collisions occurred in daylight, nine at night, and one at dusk; for 20 accounts, the time was not reported.

*Historical Trends in the Number and Speed of Ships*

Trends in ship strikes may be affected by the number and speed of ships. Based on Lloyds Register of Shipping, the number of steam and motor vessels greater than 100 gross tons more than doubled between 1890 and 1920 when the first collision records were found. During this period the registered number of such ships increased from 11,108 to 26,513 (The Committee of Lloyds Register 1890 and 1950). Their numbers then remained relatively stable until 1950, when they again increased rapidly until 1980. Between 1950 and 1980, when the registry increased from 30,852 to 73,832 ships (The Committee of Lloyds Register 1992), documented ship strikes appear to have increased sharply. After 1980 the increase in vessel numbers slows substantially (the registry listed 78,336 ships in 1990) and the number of ship strikes has remained relatively stable or perhaps increased slightly.

Since 1819, when the first steam-powered ship (the *Savannah*) crossed the Atlantic, the speed of motorized oceangoing ships has increased substantially. Passenger vessels, along with warships, are among the fastest oceangoing ships. Based on the maximum sustained speeds of 1,422 steam-powered ships built since the 1830s for trans-Atlantic passenger service (Table 6), the average maximum sustained speed of the fastest ships began reaching 14–16 kn late in the 1800s and early in the 1900s when the first collisions fatal to whales were reported. Interestingly, many of the earliest collision records involved some of the fastest ships of the day. The earliest record (1885) involved a pilot boat reportedly moving at 13 kn (Allen 1916) and at least four of the eight other records before 1930 (Table 1) involved passenger vessels able to steam at over 14 kn. These included the *Kensington,* a 146-m ship built in 1894 and able to maintain speeds up to 16 kn; the *St. Louis,* a 162-m ship built in 1895 and capable of 21 kn; and the *Berengaria,* a 268-m ship built in 1912 and capable of 23.5 kn (Smith 1978). Although a maximum speed of the liner, *Seminole,* was not found, its sister ship could steam at 16 kn. The maximum speed and type of other vessels involved in collisions with whales before 1930 could not be found.

Most oceangoing vessels, however, are freighters, tankers, and other types of vessels whose maximum speed is considerably slower—perhaps 5–8 kn slower—than the passenger vessel speeds shown in Table 6. For example, based on a 1933 list of 3,126 merchant ships of all types (*i.e.*, passenger vessels and

*Table 6.* Maximum sustained speeds of ships engaged in trans-Atlantic passenger service built in decades from the 1830s to 1970s based on the vessels' fastest trans-Atlantic crossing.

| | 1830–1839 | 1840–1849 | 1850–1859 | 1860–1869 | 1870–1879 |
|---|---|---|---|---|---|
| Total number of ships entering service | 7 | 21 | 76 | 128 | 158 |
| Average maximum speed for all vessels (in knots) | 7.7 | 10.1 | 10.5 | 11.4 | 12.7 |
| Range of maximum average speeds (in knots) | 6–8.5 | 8.5–13 | 8.5–13.5 | 10–14 | 10–16 |
| No./% of ships >15 kt | 0 | 0 | 0 | 0 | 15 (10%) |
| No./% of ships >20 kt | 0 | 0 | 0 | 0 | 0 |

*Table 6.* Continued.

| | 1880–1889 | 1890–1899 | 1900–1909 | 1910–1919 | 1920–1929 |
|---|---|---|---|---|---|
| Total number of ships entering service | 163 | 164 | 263 | 96 | 142 |
| Average maximum speed for all vessels (in knots) | 13.8 | 14.5 | 15.0 | 16.8 | 16.6 |
| Range of maximum average speeds (in knots) | 10–22 | 11–22.5 | 11–26 | 12.5–24 | 11–28.5 |
| No./% of ships >15 kt | 45 (27%) | 52 (32%) | 136 (51%) | 81 (84.4%) | 111 (78.1%) |
| No./% of ships >20 kt | 3 (1.9%) | 10 (6.1%) | 10 (3.8%) | 11 (11.5%) | 12 (8.5%) |

*Table 6.* Continued.

| | 1930–1939[a] | 1940–1949[a] | 1950–1959[a] | 1960–1969[a] | 1970–1977[a] |
|---|---|---|---|---|---|
| Total number of ships entering service | 61 | 49 | 32 | 43 | 19 |
| Average maximum speed for all vessels (in knots) | 19.1 | 17.6 | 18.9 | 21.2 | 21.0 |
| Range of maximum average speeds (in knots) | 14–40 | 14–31 | 15–35.5 | 17–28.5 | 19–24 |
| No./% of ships | 57 (93.4%) | 47 (95.9%) | 101 (100%) | 43 (100%) | 19 (100%) |
| No./% of ships | 24 (39.3%) | 8 (16.3%) | 36 (35.5%) | 30 (69.8%) | 18 (95%) |

[a] For decades after the 1930s, data also include maximum speeds of passenger ships entering service in all parts of the world as listed in Supplement Part VIII of Smith 1978. Data extracted from data in Smith 1978.

other types of merchant ships) able to maintain speeds of 12 kn or faster (The Committee of Lloyds Register 1934), 71% (2,227) were limited to speeds of 12–14 kn when the maximum sustained speed of new passenger vessels averaged about 19 kn and nearly 40% could steam at 20 kn or faster (Table 6). A similar list for 1950 (The Committee of Lloyds Register 1950) indicated that most merchant ships (61%; 2,910 of 4,770) were still limited to maximum speeds of 12–14 kn. Thus, the apparent increase in the number of ship-struck whales between the 1950s and 1970s also corresponds with the period when the maximum speed of most large oceangoing ships began to exceed 14–15 kn and most new passenger vessels were exceeding 20 kn.

## Discussion

To date, stranding data and anecdotal accounts offer the only way to glean useful insights into the occurrence, frequency, and significance of vessel-related whale deaths and injuries. Although intriguing patterns and trends are suggested by these data, varying degrees of speculation are required to evaluate their validity because of inherent sampling biases and data limitations. For example, in almost half of the 57 anecdotal collision reports, the species of whale was not identified. This could bias our perception of which species are most often hit. With this in mind, we offer the following observations.

1. Ship collisions with motorized vessels appear to have begun late in the 1800s and to have remained relatively infrequent until the 1950s. From the 1950s through the 1970s they increased to approach current levels. In some areas ship strikes are now responsible for a substantial proportion of large-whale strandings.

Accounts of ship collisions before 1950 may be scarce because they went unnoticed or unrecorded. It seems more likely, however, that their scarcity reflects a genuine rarity compared to the number of events in recent decades. Many ship strikes leave obvious signs on whales (*e.g.*, severed tails and large propeller slashes) that one would expect to be noted. Yet, while early stranding records mention other types of injuries and human interactions, injuries and interactions attributable to ships are absent or infrequent. Also, ship-strike accounts before the 1950s were treated as great curiosities. The whale carried into Baltimore harbor by a tanker in 1940 attracted a crowd of 10,000 people (Burgess 1940). Therefore, we assume that a relatively large proportion of such events would have been reported in local newspapers or otherwise come to the attention of whale scientists. A low number of collision records before the 1950s also might be expected, given the depleted status of many large whale populations early in the 1900s due to commercial whaling and the small number of large ships. As noted below, the slow speed of ships early in the 1900s also could be a factor.

Between the 1950s and 1970s ship collision anecdotes become more common. Since the 1970s, stranding records indicate that ship strikes have been responsible for a substantial proportion of whale strandings and that the fre-

quency of such events has been relatively stable or increasing slowly. For example, although nine ship-struck whales were found along the U.S Atlantic coast between 1975 and 1979 compared to 16 between 1990 and 1994, the same number of ship-struck right whales, fin whales, and minke whales were found in both five-year periods (Table 2).

In some cases the proportion of ship strikes in stranding records is surprisingly high (*e.g.*, one-third of stranded northern right whales and fin whales along the U.S. east coast). Inherent biases and data limitations make it difficult to evaluate the significance of such proportions. On the one hand, several factors may artificially inflate the proportion of ship-struck whales. Some deaths may be attributed erroneously to ships due to collisions with floating whales already dead. Also, disease, parasites, entanglement, or other factors may cause whales to spend more time at the surface and predispose them to being hit. Some whales struck by ships also are carried into port where they are more likely to be found.

Other factors could lead to underestimating vessel collisions in stranding records. Some collisions inflict only internal injuries, such as fractured vertebrae and skulls, with no obvious external damage. These injuries can only be identified by flensing carcasses to the bone, a practice not done for most large whale strandings. Thus, some deaths caused by ships undoubtedly go unrecognized. Flensing right whale carcasses to the bone, which became routine along the eastern United States and Canada in the 1990s, has resulted in identifying some ship strike victims that otherwise would not have been identified. Thus, while 29% of the 24 documented right whale deaths in both countries was attributed to ship collisions between 1970 and 1990, 47% of the 17 carcasses found between 1990 and 1998 was linked to this cause (Knowlton and Kraus, in press). Some ship-strike injuries also may be masked by advanced carcass decomposition, and some documented carcasses are never examined (*e.g.*, unretrieved floaters and whales disposed of before they can be examined).

Also, although some whales may be hit after they are already dead, it is possible to distinguish between pre- and post-mortem injuries. Large hematomas indicating a functioning circulatory system at the time of death provide evidence that a whale was alive when struck. Because dead whales tend to float ventral side up, the location of observed injuries also can help distinguish between pre- and post-mortem wounds. Finally, although some rorquals are carried into port on ship bows, one would think that hitting a whale such that it becomes pinned to a ship's bow would occur only in a small fraction of collision incidents and that, for every whale carried into port, many more may be struck and mortally wounded but not caught. In this regard, small rorquals, such as minke, Bryde's, and sei whales found only occasionally on ship bows, could be underrepresented compared to large rorquals because their small size may reduce the likelihood of being caught and remaining on a bow.

Considering all of these factors, it seems likely that more vessel-related deaths have gone unrecognized or unrecorded than have been mistakenly ascribed to post-mortem ship collisions, and that the recorded number of strand-

ings attributed to ship strikes is probably lower than the actual number of such deaths.

2. Although all types and sizes of vessels may hit whales, most lethal and serious injuries to whales are caused by relatively large vessels (*e.g.*, 80 m or longer).

Collision accounts found in this study likely are biased towards vessel types whose passengers and crew are more likely to report such events to resource managers or scientists. For example, the relatively large number of accounts involving whale-watching boats (11) and Coast Guard or Navy ships (12) probably reflects a high level of awareness about marine conservation issues among their passengers and crew rather than a greater chance of such vessels hitting whales. Nevertheless, accounts compiled in this study provide useful information on the range of vessel types involved in collisions with whales.

The broad array of vessels included in Appendix 1, ranging from small outboards to aircraft carriers, suggests that virtually all types of vessels may hit whales, but that small vessels are less likely to do so. This conclusion appears valid for several reasons. One would expect operators of small vessels (*e.g.*, less than 20 m) to notice collisions with whales because small vessels would receive a significant jolt from such collisions. Also, they tend to operate in good weather when objects struck would be easier identify, and operators of small vessels close to the water would have good visibility all around the vessel. A relatively low number of accounts involving small vessels also would be expected due to their shallow draft and perhaps because of their superior maneuverability, which could allow operators to avoid whales in many cases.

Conversely, the crews of larger vessels (*e.g.*, vessels more than 100 m long) may be less likely to see and report collisions because visibility immediately in front of the ship where whales may first appear is more limited (*e.g.*, large ships have higher bows with bridges farther astern) and because the greater mass of large ships makes collision impacts less likely to be felt. In 8 of 21 collisions involving vessels 120 m or longer, crew members were unaware that a whale was struck until the ship arrived at port with a whale on the bow. Thus, the disparity in collision records for small and large vessels may actually be greater than that reflected in accounts presented in Appendix 1. The massive nature of most blunt trauma and propeller injuries observed on dead ship-struck whales also suggests that most, if not all, lethal collisions are caused by large ships rather than small vessels.

3. A great majority of ship strikes seem to occur over or near the continental shelf.

With some caveats, collision accounts seem useful for determining general areas where collision risks are relatively high. The high percentage of collision accounts in Appendix 1 over or near continental shelves probably reflects greater concentrations of vessel traffic and whales in these areas. Stranding records also seem to support this trend.

As noted above, rorquals can be caught and transported long distances on

ship bows. In some cases the precise time and location of these collisions have been determined by examining ship logs for sudden unexplained changes in vessel speed or propeller pitch caused by the added drag of a bow-pinned whale. From this evidence, the longest transport distance we found was a fin whale struck 50 km southeast of Cape Cod, Massachusetts, by a cruise ship on 1 August 1995 and carried to St. George, Bermuda, a distance of at least 1,100 km (Anonymous 1995). Because of such transport distances, stranding sites for species potentially caught on ship bows may not reflect actual collision sites. However, for all cases in Appendix 1 where the collision location of bow-caught whales was determined, whales were hit over or near the continental shelf.

For species rarely caught on ship bows, stranding data may be more useful for assessing where collision risks may be relatively high. Massive injuries from vessel collisions may reduce a victim's mobility and cause rapid death, leaving them to drift from impact sites with prevailing winds and currents. Thus, stranding sites for these species may be relatively close to impact positions. From dead northern right whales found along eastern North America, Knowlton and Kraus (in press) note that whales killed by ships tend to be closer to major shipping lanes than whales with no evidence of vessel-related injuries. Similarly, the high proportion of stranded humpback whales struck by ships off the U.S. mid-Atlantic states since 1990 suggests that shipping lanes off Chesapeake Bay may constitute an area where humpback whales are likely to be hit. Regular reports of collisions by local vessel traffic, such as recurring reports of ferries hitting fin whales off Corsica and Sardinia in the Mediterranean Sea and sperm whales near the Canary Islands, also may suggest relatively high-risk collision areas. The captain of one ferry operating between France and Corsica estimated that they hit whales at least once a year.

The high proportion of calves and juveniles among stranded ship-struck right whales and humpback whales indicates that young animals may be more vulnerable to being hit by ships. This could be caused by the relatively large amount of time that calves and juveniles spend at the surface or in shallow coastal areas where they are vulnerable to being hit. It also may indicate that whales learn to avoid vessels as they mature. In either case, habitats preferred by nursing or juvenile right whales or humpback whales could be areas where collision risks are greater.

4. The behavior of whales in the path of approaching ships is uncertain but, in some cases, last-second flight responses may occur.

Because whales rely on sound to communicate and because vessels produce loud sounds within the hearing range of whales (Richardson *et al.* 1995), one would think whales could detect and avoid approaching vessels. Reports of abrupt whale responses to noises much quieter than ships, such as a shutter click from an underwater camera, bolster this supposition (Caldwell *et al.* 1966). At times, however, whales seem oblivious to vessel sound. Slijper (1979) refers to "many stories of ships colliding with sleeping sperm whales" and reports similar sleeping behavior in Greenland (bowhead) whales, hump-

back whales, and right whales. In one case he reports a ship came upon a "Biscayne Right Whale sleeping at the surface (that) woke up only when the ship's bow waves lapped over its head."

Whales engaged in feeding also may be less responsive to approaching ships. Chatterton (1926) noted that in the 1920s, when whalers began seeking rorquals in the Antarctic, they were hunted only when feeding. Similarly, Horwood (1981) noted that minke whales feeding at the surface in the Antarctic were easily approached and usually ignored the ship. Right whales may be more vulnerable to ship strikes than other species because of behaviors, such as skim feeding, nursing, and mating, which occur at the surface and may make whales less attentive to surrounding activity and noise.

Underwater pathways through which ship noises move also may affect the ability of whales to detect and avoid approaching vessels. Terhune and Verboom (1999) suggest that the failure of right whales to react to vessel noise may be caused by difficulty in locating approaching vessels due to underwater sound reflections, confusion from the sound of multiple vessels, hull blockage of engine and propeller noise in front of vessels, and a phenomenon known as the Lloyd mirror effect which reduces sound levels at the surface where resting or feeding whales may occur.

Although few collision accounts found in this review provide information on whale behavior immediately before being hit, a last-second flight response was suggested in some cases. Considering the ability of startled whales to flee threatening situations with bursts of speed and the added push it would receive from the bow wave of a large vessel, seconds or even fractions of seconds may determine whether or not some whales are hit. The success of last-second flight responses may therefore depend in part on the swimming speed of whales relative to the speed of approaching ships. Right whales, bowhead whales, gray whales, humpback whales, and sperm whales are among the slowest swimming whales. Slijper (1979) cites a usual swimming speed for these species at 3.5–4.3 kn, with sperm whales able to make an "occasional sprint" of 13.9 kn and humpback whales reaching speeds of 8.6 kn. Tomilin (1957) cites a slower top speed (8–10 kn) for sperm whales, a higher top speed (14.7 kn) for humpback whales, and a top speed of 7 kn for right whales "when they are frightened." For gray whales, Tomilin (1957) cites a top speed of 8.6 kn for "frightened" animals. Rorqual whales (other than humpback whales) have higher swimming speeds, an ability Slijper (1965) attributes to their thinner blubber layers. For blue and fin whales, Slijper (1965) and Tomilin (1957) cite cruising speeds of 8.7–10.4 kn and sprint speeds of 15.6–17.4 kn, while sei whales, perhaps the fastest of the great whales, may reach a top speed of 26 kn.

5. Most severe and lethal injuries caused by ship strikes appear to be caused by vessels traveling at 14 kn or faster.

Because the probability of a vessel hitting and killing a whale must increase as its speed increases from zero, it follows that the hazard posed by ships is at least partly a function of their speed. As a vessel begins to pick up speed,

one would expect such probabilities to increase slowly at first as most whales are pushed out of the way unharmed or able to take evasive action. At higher speeds the probabilities of lethal or serious injuries likely would increase more rapidly as impact forces reach a point where serious injuries are possible and whales have less time to avoid moving ships. At even higher speeds, increases in the probability of serious injuries would likely level out and become a virtual certainty as all whales struck would be seriously injured or killed and time for startled whales to avoid a vessel no longer exists.

Although correlations between collision probabilities and specific vessel speeds are unknown and may vary by vessel type, collision accounts appear to provide some insights. As noted above, 89% of collision accounts found in this review in which whales were killed or severely injured and vessel speed was reported involved vessels moving at 14 kn or faster and none occurred at speeds of less than 10 kn. Also, collision records first appear late in the 1800s when the fastest vessels began attaining speeds of 14 kn, and then increased sharply in the 1950s–1970s when the average speed of most merchant ships began to exceed about 15 kn.

The scarcity of collision accounts below 14 kn could be an artifact of the small sample size of collision records found in this study; however, the absence of accounts involving severe or lethal whale injuries at speeds below 10 kn, and the low number of such collisions below 14 kn, seems significant. Since the 1970s, when most collision accounts occur and most ships have been capable of 15 kn or faster, vessels traveling at 14 kn or slower presumably have done so principally when there was a special need to be alert for navigation hazards. Thus, one might expect there would have been a greater chance of noticing and reporting collisions at speeds below 14 kn since the 1970s, yet there are few such records.

6. Ship collisions probably have a negligible effect on the status and trend of most whale populations, but for very small populations or discrete groups, they may have a significant effect.

A crude measure of the importance of ship strikes on whale populations can be obtained by comparing data on ship strikes and the size and trend of affected whale populations. For example, eastern North Pacific gray whales and western Arctic bowhead whales, estimated to number 22,571 and 8,200, respectively, have been increasing steadily for two decades or more (International Whaling Commission 1997). For gray whales, Patten *et al.* (1980) refer to records of 12 collisions and six deaths off southern California between 1975 and 1980, and Heyning and Dahlheim (in press) report only 7 of 489 gray whales stranded between Mexico and Alaska from 1975 to 1989 with apparent propeller injuries. For bowhead whales, no records were found of whales killed by ships and George *et al.* (1994) report propeller scars on only 2 of 236 (0.8%) carefully examined whales landed by Alaska Native whalers between 1976 and 1992. Even if vessel-related deaths were several times greater than observed levels, it would still be a small fraction of their total populations.

This also appears to be the case for humpback whales and fin whales in the

North Atlantic where ship collisions constitute a higher proportion of strandings. With North Atlantic populations of humpback whales and fin whales estimated at 10,600 whales (Smith *et al.* 1999) and more than 20,000 whales (International Whaling Commission 1992), respectively, vessel-related deaths several times higher than numbers reported in this paper would still constitute a small portion of their total populations. However, in combination with other causes of human-related mortality (*e.g.*, entanglement in fishing gear and whaling), vessel-related deaths may warrant consideration in relevant population models and management programs. Also, high numbers of ship strikes in some areas, such as collisions with humpback whales off U.S. mid-Atlantic coastal states and fin whales in the western Mediterranean Sea, could be a source of concern for some local population segments.

For highly endangered populations numbering in the low hundreds of animals, where the loss of even a few individuals can be significant, ship collisions can be a major recovery obstacle. This certainly is true for northern right whales in the western North Atlantic, and also could be true for western North Pacific gray whales, which may be near the minimum number necessary for recovery (Rice *et al.* 1984), and for northern right whales in the western North Pacific, which may number in the low hundreds (Perry *et al.* 1999). The small population of blue whales that feed in the Gulf of St. Lawrence, Canada, also may warrant concern. Although highly endangered bowhead whale populations off northeastern Canada, Greenland, northern Europe, and Russia are well removed from most ship traffic, they too could be at risk if year-round northern sea routes develop in their Arctic habitats.

### *Conclusions*

For some small whale populations or population segments, ship collisions can pose a substantial threat. Massive injuries on stranded ship-struck whales suggest large vessels are the principal source of severe injuries to whales. Currently, anecdotal records provide the only information for evaluating vessel operating factors related to ship strikes. Although such records have significant weaknesses, they merit consideration absent other data. Accounts found in this review suggest that most whales hit by ships are not seen beforehand or seen only at the last moment. Collision avoidance strategies dependent on detecting and avoiding whales therefore may be ineffective for large ships with limited maneuverability. Where steps are needed to reduce collision risks, advanced planning to avoid or minimize travel distances through high-use whale habitats or to reduce vessel speed in waters where whales are likely to occur may be more effective. Collision accounts compiled here suggest that serious injuries to whales may occur infrequently at vessel speeds below 14 kn and rarely at speeds below 10 kn. Therefore, there may be benefit in management actions designed to reduce vessel speed below at least 14 kn to reduce the impact of vessel collisions on large cetaceans.

Further research is needed to identify areas where collisions between ships and whales are most frequent and to help further evaluate and improve upon

mitigation measures. To assess the frequency, location, and circumstances of such collisions, vessel operators, port pilots, and other port officials should be asked to record and immediately report any collisions with whales or whales carried into port on bows of ships. Reports should be made promptly to resource management officials or marine mammal stranding coordinators so that involved vessel crews can be interviewed, and navigation and engine logs can be examined for information on when, where, and at what speed the collision occurred and the behavior of whales before and after being hit. Also, stranding program participants should routinely look for and record injuries caused by ships on all beach-cast whales. For whales belonging to small populations or population segments that may be affected by low levels of human-related mortality, it would be prudent to flense stranded whale carcasses to the bone to look for internal injuries caused by ship collisions.

Further research also is needed to better assess whale behavior and responses near transiting ships of different types and sizes. Studies of the frequency and intensity of sound produced by different types of ships at different depths, distances, and directions (particularly in front of vessels), and the responses of whales engaged in different behaviors to those signals would be helpful for determining whether or at what distance whales may be able to detect and avoid ships. Studies to document and assess other ship-generated signals that might cause a startle response in whales directly in front of approaching ships, such as low amplitude, high-intensity hull vibrations, and bow wave effects, also should be made. Studies also should be undertaken to better identify habitat-use patterns of whales and correlations between environmental parameters and whale distribution to improve advice to mariners on when and where whales are most likely to occur.

Research on alternative management actions also should be considered. Potential studies include periodic review of the feasibility of evolving technologies to provide vessel operators with real-time data on the presence and location of whales along navigation routes. Possible options might include bottom-mounted sonobuoys along established vessel traffic lanes through important whale habitats to relay information on whale locations to ships, and further research similar to that by André *et al.* (1997) on the possible use of sound to alert whales to approaching ships.

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*Appendix 1.* Anecdotal descriptions of collisions between self-propelled ships and whales.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|
| May 1885 | Unknown | Minor injury | Pilot boat; *Alexander M. Lawrence, No.4*; Size unknown | 13 kn | 32 km east of Nantucket, MA, USA | The vessel's port bow suddenly collided with a large whale. The vessel dipped until water nearly reached her hatches and seemed in such imminent danger of capsizing that those below rushed on deck. Looking back they saw the whale rolling about as if in distress. (No reference was made as to whether or not blood was seen.) The vessel sustained no damage. | Nantucket Inquirer and Mirror 65(48), May 30, 1885 cited in Allen 1916 |
| Mid-1930s | Unknown | Killed | Steamer, *Maunganui*; 131 m | 15 kn | Near Raratonga, South Pacific | While steaming from New Zealand, the ship collided with a large whale which was cut almost in half. Impaled across the ship's bow below the water line, it was necessary to stop and run astern for a few minutes to remove the carcass. | W. Cummings[a] |
| August 1952 | Unknown | Unknown | Navy destroyer, *USS Tweedy*; 93 m | 14 kn | 139 km off Montauk, Long Island, New York, U.S.A. | At 1300 in fine weather and calm seas enroute from Guantanamo, Cuba, to Boston, Massachusetts, a large whale about 15 m long was seen awash and swimming slowly about 90 m ahead and 18 m to port. A few seconds before impact it submerged to a shallow depth. The impact was not felt, but it caused severe damage to the sonar dome necessitating drydocking in Boston. | W. Cummings[a] |
| Fall 1953 | Unknown | Killed | Aircraft carrier; *USS. Sicily*; 169 m | ~20 kn | Northern Yellow Sea | After midnight under a full moon and in calm seas a sudden shudder was felt throughout the ship. The bow lookout reported something on the bow. The engines were stopped and the object on the bow was identified as a whale. The ship had to back full to dislodge the whale, which then sank. There was no damage to the ship. | W. Cummings[a] |
| 12/25/54 | Unknown | Unknown | Passenger ship; *Maori*; 133 m | 18 kn | 11 km off Kaikoura, South Island, New Zealand | Very early in the morning while steaming northward, the vessel collided with a large whale and incurred damage to the stem bar protecting the rudder. The bar was twisted to port about two feet out of plumb. | W. Cummings[a] |
| 3/22/55 | Sperm whale | Killed | Steamship; *Amerskerk*; 144 m | 17 kn | 89 km west of Cape Gardafui, Canary Islands | After a mysterious jolt, the crew found that a 10-m sperm whale had been struck on the head and body and become lodged on the bow below the water line. The ship was stopped and the engines were reversed to remove the whale's carcass from the bow. It was thought the whale was struck while it was sleeping. | Slijper 1979 |

*Appendix 1.* Continued.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|
| February 1960 | Unknown | Severe injury | Passenger ship; name unknown; 13,000 tons | Unknown | West of Cape Reinga, North Island, New Zealand | At about 1100 a large school of whales crossed ahead of the vessel. Before evasive action could be taken, the vessel's propeller struck a whale causing the vessel to shudder and the engine speed to slow noticeably. The whale was seen thrashing with its back sliced by the propeller and bleeding. The other whales in the school circled about the injured animal. | W. Cummings[a] |
| September 1961 | Unknown | Severe injury | Cargo vessel; name unknown; ~8,000 tons | 14 kn | Caribbean Sea | At about 1500 a whale was sighted lying at the surface just prior to the collision in a light sea and good visibility. After the collision, the whale was seen thrashing in the wake with blood in the water. | W. Cummings[a] |
| 1963 | Unknown | Severe injury | Passenger ship; name unknown; 14,000 tons | 18 kn | Equatorial Pacific | Numerous whales, possibly including cow-calf pairs, were in the vicinity. In midafternoon, with good visibility and low swell, a whale thought to be surfacing in front of the vessel was struck. A small amount of blood was seen in the water; the whale appeared to swim away slowly. The ship sustained no damage. | W. Cummings[a] |
| 11/29/65 | Sperm whale | Minor injury | Whale catcher boat; *Sioux City*; 41 m | Unknown | ~200 km W of San Francisco, California, USA; 37°30′N, 123°31′W | While on a whale-marking research cruise amid a harem school of about 50 sperm whales, the vessel approached a cow-calf pair. The female dove while the calf played at the surface alongside the boat as it passed. When the female was seen surfacing, the vessel's engine was immediately disengaged, but there was a strong thump as the whale was struck. The thrashing whale and feces-filled water was seen in the boat's wake. The starboard propeller was bent necessitating drydock repair. | W. Cummings[a] |
| July 1967 | Unknown | Killed | Navy cruiser; *USS Newport News*; 219 m | Unknown | South of Halifax, Canada | After dark enroute to San Juan, Puerto Rico, it was determined the vessel's speed was too slow for the number of propeller revolutions being registered. A crewman was sent to look for obstructions on the bow and reported a whale was stuck to the bow. The ship had to be stopped and backed down to remove the whale which then sank unidentified. | W. Cummings[a] |

*Appendix 1.* Continued.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|
| 10/9/67 | Unknown | Killed | Passenger ship; *SS Brazil*; 232 m | Unknown | Approaching Gaspé, Quebec, Canada | At about 0700 a crewman reported hearing a flapping noise on the ship's bow. A large whale 15–18 m long was observed impaled on the bow. Before entering Gaspé harbor, the vessel had to use reverse thrust to dislodge the whale. A passenger filmed the animal, which was nearly cut in half, as it was dislodged. | W. Cummings[a] |
| March 1972 | Unknown | Severe injury | Boston whaler; name unknown; 4 m | >25 kn | Las Perlas Islands, Panama, Pacific Ocean | At about 1000 while running at top speed, a small whale surfaced directly in front of the boat. The boat struck the whale and went right over the animal breaking off the tow ring fitting in the animal's flesh. After the collision, the animal was seen thrashing with blood coming from the wound. | W. Cummings[a] |
| Between 11/72 and 2/73 | Unknown northern right whale? | Killed | Bulbous bow container ship; *Young America*; 207 m | 21–23 kn | ~97 km east of Boston, Massachusetts, USA | Upon arriving at the Boston harbor pilot station from Cadiz, Spain, the crew of the harbor pilot boat noticed a whale lying across the ship's bulbous bow. Prior to that time the crew was unaware they had struck a whale. The whale had no apparent propeller wounds or signs of bleeding. Reverse engine thrust was used to remove the whale from the bow. Based on an unexplained decrease in ship speed, it was thought the whale had been hit at night about 3–4 h before reaching the pilot station. | J. Murphy II[b] |
| October 1973 | Unknown | Killed | Navy destroyer; *USS Whipple*; 133 m | Unknown | Bay of Bengal, Indian Ocean | At around midnight the vessel struck and killed a large unidentified whale. The collision caused no damage to the vessel. | W. Cummings[a] |
| 12/26/73 | Killer whale | Severe injury | Commercial ferry; *Comex Queen*; 152 m | 15–18 kn | Strait of Georgia, British Columbia, Canada | At 1545 a crunch was heard at the ship's stern and blood was seen in the wake. A bull, a cow, and two calf killer whales surfaced off the stern and the ship circled back to within a few feet of the whales. A calf was seen bleeding profusely from visible propeller slashes. The bull and cow cradled the calf between them to prevent it from turning upside down. The ship stayed with the animals for 10–15 min before leaving. The ship sustained no damage. | Ford *et al.* 1994 |

*Appendix 1.* Continued.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|
| 4/23/74 | Unknown, gray whale? | Severe injury | Private motor yacht; *Brynette*; 18 m | 10.5 kn | <2 km off Baja Peninsula, Mexico | At 1530, while on auto pilot, the boat suddenly veered to port and started shaking. The engines were stopped immediately and a large whale surfaced at the stern with deep propeller gashes down the mid section. A large pool of bloody water soon formed. It was thought the whale must have come up directly under the boat because passengers on the bow at the time were looking down at the water and saw no whale before the collision. The boat sustained no damage. | W. Cummings[a] |
| Late 1974 | Unknown | Severe Injury | Commercial ferry; name unknown; 4,000 tons | 17 kn | Cook Strait, New Zealand | During the afternoon in moderate seas and good visibility, the twin screw ferry struck and possibly killed a whale. Blood was noticed in the water after the vessel passed. The ship sustained no damage. | W. Cummings[a] |
| 1/22/75 | Gray whale | Killed | Navy hydrofoil; *Flagstaf*; 72 tons | 51 kn | Off Pt. Loma, California, USA | At 0728 about 2.4 km south of Point Loma, the ship hit a whale while foil-borne returning to San Diego. The vessel came to a dead stop within about 30 m, but no injuries to the 18-member crew were reported. The vessel sustained considerable damage to its rear struts. The crew lost sight of the whale but the next day a dead whale with a severed tail stranded near the collision site. | Anonymous 1975 |
| 7/5/80 | Blue whale | Killed | Tanker; *Baldbutte*; 203 m | 21 kn | 64 km west of Ensenada, Mexico | Upon entering Los Angeles harbor a dead whale floated to the surface near the ship. The crew was unaware of the collision until then. The collision location was inferred from notes in the ships log about a sudden decrease in speed from 39 to 35 km/h and a change in the bow wake. The whale's spine was broken. | Patten **et al.** 1980, Alexander 1980 |
| 10/24/80 | Blue whale | Killed | Bulbous bow freighter; *Evershine*; 174 m | Unknown | North Pacific | Upon arriving in Seattle, Washington, from Taipei with an intermediatee call at Port Angeles, California, a 18-m blue whale drifted free of the ship's bow. It was not known when the whale was hit, but it was thought to have been on the bow for at least five days given the slow ship speed enroute from Port Angeles. | Norris 1980 |
| August 1984 | Fin whale | Severe Injury | Whale-watching vessel; name unknown; 28 m | 16 kn | Stellwagen Bank Massachusetts, USA | At dusk while returning to port at full speed, a fin whale surfaced immediately in front of the vessel. There was no time to take evasive action. After the collision the whale was not resighted but blood was seen in the water around the vessel. | M. Weinrich[c] |

*Appendix 1.* Continued.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|
| 10/16/84 | Southern right whale | Killed | Hopper dredge; *D.E. Patterson*; 110 m | Unknown | East London Harbor, South Africa | At 0730 after receiving a report of right whales in the area and advice to be alert for them, a cow-calf pair suddenly surfaced directly in front of the dredge as it passed a breakwall. The calf took the full brunt of the impact and as the vessel passed over it, the calf was struck by the propeller. After attempts by the cow to support its bleeding calf, the calf crossed the waterway, stranded on a small beach and died. The cow remained in the area several hours. | Best *et al.*, in press |
| 1/24/85 | Unknown | Severe injury | Navy frigate; *USS Hepburn*; 126 m | Unknown | Off Southern California, USA | While underway with a bridge watch posed, crew on the fantail/flight deck noted a large pool of blood astern and the back and tail of a large whale. Although the watch did not see the whale and there was no noticeable bump, the ship's hydrophone operator detected an increase in the ship's radiated noise astern. An increase in vibration in the aft part of the ship also was noted. Divers sent down to survey the hull reported significant damage (a 1.6-m tear) in the leading edge of a propeller blade. The propeller had to be replaced at a cost of $125,000. | T. Tucker[d] |
| 3/5/88 | Gray whale | Unknown | Tanker; name/size unknown | Unknown | Outside Los Angeles Harbor, Southern California, USA | A small pod of migrating whales was seen directly ahead of a tanker bearing down on them. The whales seemed unaware of the approaching ship until it was about 30 m away when the pod suddenly increased speed and dove to avoid the ship. The last whale to dive was hit. The ship continued on without changing course or speed. The event was video taped from a nearby whale-watching vessel. | Heyning and Dahleim, in press |
| 9/7/88 | Southern right whale | Killed | Twin screw ferry; *Barrier*; 171 m | 12–13 kn | 7 km outside Port Elizabeth Harbor, South Africa | The ferry was accelerating on leaving the port at 1653 when nine whales were seen ahead of the vessel crossing the bow. They failed to dive, an impact with at least one animal was felt, and blood was seen in the water immediately thereafter behind the ship. Three days later two dead right whales stranded nearby, one with propeller gashes and a damaged rostrum, the other with no external wounds | Best *et al.*, in press |

*Appendix 1.* Continued.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|
| 4/16/91 | Unknown | Unknown | Navy hydrofoil; *Aquila*; 24 m | >40 kn | Off Key West, USA | At ~0900 while foil-borne, the ship struck a whale causing a rapid landing threw the crew forward. Port and starboard aft strut actuators were severely damaged, port and starboard steering arms broke, ruptured seawater piping caused flooding of the gas turbine, the hull was warped in numerous places, and starboard diesel engine shifted forward off its mounts. Repairs cost $1 million. | T. Tucker[d] |
| 6/21/91 | Humpback whale | Minor injury | Whale watching Vessel; *Mary Elizabeth*; 14 m | 5–10 kn | Stellwagen Bank, Massachusetts, USA | At about 1700, the vessel and another whale-watching boat were alternately observing a mother-calf pair and a single animal. The *Mary Elizabeth* left the cow-calf pair to move to the single animal about 90 m away. While doing so, the whale, a photo-identified animal named "Rocker," surfaced a few yards off the starboard bow, apparently lunging to avoid the vessel. The engine was immediately disengaged, but the bow struck and rode up over the whale. It resurfaced off the stern. The vessel's naturalist observed the whale and reported no injuries and normal swimming behavior. However, observers on a third whale watching boat approaching from about a mile away photographed the animal with a fresh shallow nick between its nares and dorsal fin. Over the next six years, the animal was resighted annually (except 1996) at Stellwagen Bank. Photos show the wound healed with no apparent effect to the whale. | K. Sullivan[e]; S. Young[f] |
| 7/6/91 | Unknown | Killed | Coast guard cutter; *Chase*; 84 m | 22 kn | >185 km E of Delaware Bay, USA; 38°21.5′N, 73°06.5′W | At ~1845 in calm seas and clear weather, two large whales, possibly sperm or right whales, were seen by the bridge watch surfacing 46 m ahead crossing the bow. They dove quickly perhaps trying to avoid the ship. A few seconds later the ship vibrated and the engine was disengaged. As the ship slowed, a calf about 4.6 m long rolled from under the stern bleeding profusely from large propeller gashes on its side. It rolled a few times, settled nose up for a few minutes, and sank "obviously dead." The two large whales surfaced, circled back to the ship, lingered a while, and then left. Both propellers were damaged. | U.S. Coast Guard 1991 |

*Appendix 1.* Continued.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|
| February 1992 | Sperm whale | Killed | High-speed ferry; name unknown; ~20 m | 45 kn | Canary Islands; 27°56′N, 14°34′W | A description of the event is not available, however the collision reportedly resulted in the death of one passenger. | André *et al.* 1997 |
| 4/4/92 | Unknown | Severe injury | Research vessel; *Surveyor*; 89 m | 14 kn | ~19 km W of Callao, Peru | In late morning, a biologist on the bridge saw a large whale surface a few hundred yards ahead of the ship. A few minutes later, a shudder was felt throughout the ship. Immediately afterward, blood was seen in the ship's wake from which it was concluded that a whale had been struck. Numerous whales were seen shortly before the event. The vessel sustained no damage. | D. Ainley[g] |
| 5/15/92 | Bryde's whale | Killed | Bulbous bow container ship; *City of Burnie*; 121 m | ~14 kn | Bass Strait, Australia | Upon entering the port of Burnie, Tasmania, a dead 12-m whale was found draped over the ship's bulbous bow. Based on a sudden unexplained decrease in vessel speed, the Captain presumed the whale was hit at 0400, about 4 h before entering port. A necropsy indicated the whale was alive when struck. The event was the first record of a Bryde's whale from Tasmanian waters. | H. Wapstra[h] |
| 6/20/92 | Fin whale | Minor injury | Whale-watching vessel; name/size unknown | Unknown | Tadoussac, St. Lawrence Estuary, Canada | The vessel collided with the fin whale while whale watching. After the collision a wound was visible on the animal's back in front of the dorsal fin. | N. Menard[i] |
| 1/5/93 | Northern right whale | Killed | Coast Guard cutter; *Point Francis*; 25 m | 15 kn | 6 km off St. Augustine, Florida, USA, 30°02′44″N, 81°16′04″W | At ~1515 in heavy fog, a whale surfaced off the bow and was struck before evasive action could be taken. The whale, a calf, was badly lacerated by the propellers. Two bumping sounds were heard during the event. The ship stayed with the calf for two hours; the calf's mother stayed ~275 m away occasionally slapping the water with her pectoral fin. Three days later the calf was found floating dead offshore and was towed ashore for necropsy. The ship sustained no damage. | National Marine Fisheries Service 1995; Bonde[j] |
| 7/29/93 | Fin whale | Minor injury | Whale-watching vessel; name/size unknown | Unknown | Bergeronnes, St. Lawrence Estuary, Canada | While moving toward a humpback whale and letting another boat pass, a fin whale surfaced and struck the bow of the vessel. A wound was subsequently oberved on the animal's back. | N. Menard[i] |

*Appendix 1.* Continued.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|
| 9/9/93 | Fin whale | Killed | Bulbous bow ferry; *Ile de Beaute*; 159 m | ~20 kn | Mediterranean; Toulon harbor, France | At 0200, the crew felt a shock followed by strong vibrations and a 4-km/h decrease in vessel speed. The cause of shock and strong vibrations was unknown until the ferry entered port three hours later and the port pilot advised the captain a whale was caught on the bow of the vessel. | A. Collet[k] |
| 10/7/93 | Humpback whale | Severe injury | Private sport fishing vessel; name unknown 10 m | >10 kn | 2 km off Atlantic City, New Jersey, USA | The animal was hit at 1030 as the vessel was accelerating but not yet on plane. About 15 min later the animal was observed "wobbling" as it attempted to dive and blood was seen in the water. The animal also was observed on its side and moving slowly from a Coast Guard helicopter. Rough weather prevented a determination of the extent of the injury. The vessel's propeller, propeller shaft, and rudder were damaged. | MME15658, Cetacean Distributional Database, Smithsonian Institution |
| 8/14/94 | Fin whale | Minor injury | Whale-watching vessel; name/size unknown | Unknown | Tadoussac, St. Lawrence Estuary, Canada | The vessel called to report colliding with a fin whale while whale watching. The impact was hard enough to make the hull vibrate. A wound was subsequently seen on the whale. | N. Menard |
| 10/31/94 | Unknown | Severe injury | High-speed jetfoil ferry; *Suisei*; 31 m | Unknown | 22 km W of Niigata, Japan, Sea of Japan | Following a collision with an object in the water, a 193-g sample of bone and muscle tissue was removed from the left waterjet suction pipe at the stern of the ferry and examined microscopically. Tissue examination strongly indicated it was from a large marine mammal. | Honma*et al.* 1997 |
| 2/1/95 | Unknown, right whale? | Unknown | Navy submarine; name/size unknown | Unknown | Off North Carolina, USA | After leaving port and while on the surface, a small black whale breached in front of the submarine, struck the bow, and slid down the starboard side of the vessel The whale may have received injuries to its right side, mid-length. No other whales were observed in the area. | U.S. Navy 1995 |
| 6/1/95 | Unknown, humback whale? | Minor injury | Fishing vessel; *Lady Kath*; ~27 m | 9 kn | Summer Sound, Southeast Alaska, USA | The captain of the fishing vessel reported that, while moving at 17 km/h, the vessel struck what was believed to be a humpback whale. The report indicated the whale was struck almost head-on along the port bow. After striking the whale, it was observed swimming in circles before contact with the animal was lost. There was no damage to the vessel. | M. Sternfeld[l] |

*Appendix 1.* Continued.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|
| 8/1/95 | Fin whale | Killed | Bulbous bow passenger ship; *Royal Majesty*; 173 m | Unknown | 48 km SE of Cape Cod, Massachusetts, USA | Upon arriving in St. George, Bermuda, a 17-m fin whale was discovered on the ship's bow. Based on a major vibration of unknown cause felt about 30 miles southeast of Cape Cod, the captain concluded the whale was struck at that location and carried to Bermuda, a distance of at least 2,037 km. The whale had a broken spine and extensive bruises. | MME12124, Cetacean Distributional Database, Smithsonian Institution |
| 9/26/95 | Minke whale | Unknown | Whale-watching vessel; name unknown; 11 m | >30 kn | Bergeronnes, St. Lawrence Estuary, Canada | The vessel, a pneumatic rigid-hulled craft capable of 74 km/h, collided with a minke whale while traveling at speed. The operator could not see directly in front of the craft due to its high bow. | N. Menard[1] |
| 10/9/95 | Unknown, humpback whale? | Unknown | Coast Guard cutter; *Reliance*; 64 m | 15 kn | >185 km E of Cape Cod, Massachusetts, USA | Whales were observed in the area and the watch on the starboard bridge wing was instructed to look for whales. He subsequently reported a whale directly off the bow. At about the same time, another seaman saw a whale surface 5–6 m off the starboard bow. Before a warning could be issued, a thud was heard and a shudder felt. The ship stopped to search the area but no injured animal was found. The ship sustained no damage. | National Marine Fisheries Service 1996 |
| 5/16/96 | Unknown | Severe injury | Coast Guard cutter; *Jarvis*; 115 m | 15 kn | Southeast Coast of Kenai Peninsula, Alaska, USA | An unidentified large whale surfaced ~46 m ahead of the vessel at ~1630. An attempt was made to avoid the whale, but a shudder was felt throughout the ship indicating a collision. The ship circled back and found blood in the water, but no dead or injured whale. No ship damage was reported. | M. Sternfeld[1] |
| 5/30/97 | Unknown | Unknown | Whale-watching vessel; *Kenai Fjords*; ~18 m | 22 kn | Resurrection Bay, Prince William Sound, Alaska, USA | Early in the afternoon in clear, calm weather, the vessel was moving at speed towards a group of humpback whales seen in the distance. The captain on the bridge and passengers at the bow suddenly saw a large whale surface immediately ahead of the vessel. The captain immediately throttled down to avoid a collision, but the whale was hit hard. Hull damage was suspected and passengers were asked to don life vests. The port stabilizer was subsequently found to have been lost in the collision. No injured animal was seen after the strike or in searches of the area in the following days. | M. Sternfeld[1] |

*Appendix 1.* Continued.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|
| 7/20/97 | Humpback whale | Unknown | Coast Guard cutter; *Campbell*; 82 m | 18 kn | 40 miles east of Cape Cod, Massachusetts, USA; 42°09′06″N, 69°12′09″W | Between 1143 and 1225 up to seven humpback whales were seen along the ship's track. At one point two whales were seen 3.7 km ahead. The course was altered and the speed reduced from 33 km/h to 5 km/h to avoid the whales. After passing them 914 m to starboard, a speed of 33 km/h was resumed. At 1415 in clear weather, visibility 16 km, the watch reported a whale 15.3 m below the surface immediately ahead of the ship. Almost immediately, a shudder was felt and the whale was struck a glancing blow on the starboard side. Despite a several hour search immediately after the collision, the whale was not resighted and no evidence of an injured whale was found. The vessel sustained no damage. | D. Hirman[m] |
| 9/27/97 | Humpback whale | Minor injury | Whale-watching vessel; name/size unknown | Unknown | St. Lawrence Estuary, Canada | At 1400, while approaching a site where two other boats and three or four zodiacs were already watching a whale, the vessel, a pneumatic rigid-hulled vessel, struck a humpback whale. The whale surfaced just in front of the vessel before the operator could stop or avoid the animal. After the collision, the whale was much less active and seemed to be injured. | N. Menard[i] |
| 10/12/97 | Sperm whale | No apparent injury | Fishing vessel; *Aleutian Isle*; size unknown | ~6 kn | Southern Prince William Sound, Alaska, USA | While longline fishing for black cod, the vessel's bow struck the whale's tail. At the time, several whales were following the vessel feeding on black cod caught on lines. The captain reported that the whale seemed unaffected by the collision and resumed feeding on black cod after being hit. The vessel sustained no damage. | M. Sternfeld[l] |
| 1997 | Sperm whale (cow-calf pair) | Killed | Commercial ferry; name unknown; 100 m | 25 kn | Canary Islands; 28°11′N, 15°32′W | A sperm whale cow-calf pair was observed resting on the surface as the ship approached the animals. The captain saw no movement by the animals to avoid the vessel. A loud sound was heard and the bodies of both animals were observed behind the vessel amidst blood. Subsequent necropsies determined that the animals went through the propellers. | M. André[n] |

*Appendix 1.* Continued.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|
| 3/3/98 | Blue Whale | Killed | Bulbous bow tanker; *Botany Triumph*; 148 m | Unknown | North Atlantic | A juvenile blue whale was found draped across the ship's bulbous bow by a port pilot on 3 March as the ship approached Narragansett Bay on route from northern Europe. Before then the crew was unaware a whale had been struck and caught on the bow. To remove the whale from the bow, reverse engine thrust was needed. The precise time and location of the event are unknown. Date of death and the animal's age were estimated by the necropsy team. | National Marine Fisheries Service 1998 |
| 8/5/98 | Unknown | Unknown | High-speed ferry; *Asco*; Size unknown | ~30 kn | Mediterranean; Nice Harbor, France | At about 2230 offshore Ajaccio (west of Corsica) the vessel hit an unidentified whale. A T-foil on the vessel was broken and the ferry arrived in Nice harbor two hours late as a result of the collision. | A. Collet[j] |
| August 1998 | Humpback whale | Severe injury | Whale-watching vessel (high-speed catamaran); *Millennium*; 36 m | 18 kn | Stellwagen Bank, Massachusetts Bay, USA | At ~1300 in good weather, the vessel was leaving two humpback whales under observation. About 450–900 m away from the two whales, a third whale surfaced immediately in front of the vessel. The captain turned to starboard to avoid the whale, but it went between the two hulls and was struck by the port hull about two-thirds of the way down the hull. The whale did not resurface after being hit, but a humpback whale with a deep bleeding wound about one foot wide across the back was seen in the same area about one hour later. | M. Weinrich[c] |
| 9/12/98 | Minke whale | Killed | Whale-watching vessel; *Whale Watcher*; 24 m | 25 kn | Stellwagen Bank, Massachusetts Bay, USA | While returning from an afternoon whale watching trip, a 6-m minke whale surfaced about 14 m in front of the vessel's bow and dove quickly. The vessel lurched and the whale came up immediately behind the vessel with a deep bleeding gash believed to be mortal. At least one propeller was damaged. | M. Weinrich[c] |
| 9/24/98 | Humpback whale | No apparent injuries | Charter whale-watching vessel; name unknown; 7 m | 15–18 kn | North Pass, Southeast Alaska, USA | The vessel reportedly ran up on the dorsal surface of the animal behind the blowhole, tipped the boat, and dove. Other whales in the area came and circled the struck whale and all swam off together. Other charter boats in the area observed no apparent change in whales behavior or any injuries. Vessel sustained a cracked hull. | Cetacean Distribution Database, Smithsonian Institution |

*Appendix 1.* Continued.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|
| 7/28/99 | Humpback whale | Killed | Bulbous bow passenger ship; *Westerdam*; 730 m | 19 kn | Stephens Passage, Southeast Alaska, USA | At ~0900 while traveling the mid-channel route through the passage, there was a slight vibration. It was felt by the chief engineer, but not the crew on the bridge. Shortly there after, a passenger on the bow reported a dead whale, estimated at 11–12 m long, draped over the ships bulbous bow at the water line. It remained there until the ship slowed and the whale slipped off and sank down. The vessel sustained no damage. | J. Straley[o] |
| 1/11/00 | Bryde's whale | Killed | Bulbous bow passenger ship; *Nieuw Amsterdam*; 214 m | 22 kn | Southwest of Bonaire, Caribbean Sea | Upon arriving at Bonaire, the harbor master noticed a whale on the ship's bulbous bow. Until then, the crew was unaware a whale had been hit. From an unexplained decrease in speed to 35 km/h noted in the vessel log, it was determined that the whale was struck in darkness at 0430 about 100 km southwest of Bonaire. The crew did not feel the impact and there was no damage to the ship. | K. De Meyer[p] |
| 2/1/00 | Humpback whale | Severe injury | Passenger ship; *Akademik Sergey Vavilov*; 118 m | 14.3 kn | Off the Antarctic Peninsula, Southern Ocean | At about 1930 in good visibility with a 37-km/h wind and 4-m seas, two whales were seen surfacing about 3 km and again about 1.6 km ahead of the ship. Officers on the flying bridge then saw two whales surface about 14 m off the port bow, alter course, and swim directly in front of the ship. One whale, with its mouth wide open, came up directly before the bow and was hit. There was a loud thud and a shudder. Both whales resurfaced about 183 m off the stern, one with blood behind it. Both whales were seen breathing at the surface for 5–10 min as the ship proceeded on course. The ship sustained no damage. | J. Wikander[q] |

*Appendix 1.* Continued.

| Date | Species struck | Fate of whale | Vessel type, name/size | Speed | Location | Description of event | Source |
|---|---|---|---|---|---|---|---|

[a] William C. Cummings, unpublished data held by the Marine Mammal Commission, 4340 East-West Highway, Rm. 905, Bethesda, Maryland, 20814, U.S.A., 28 April 1999.

[b] Personal communication, Captain Joseph. S. Murphy, II, Massachusetts Maritime Academy, 101 Academy Drive, Buzzards Bay, Massachusetts 02532 U.S.A., 6 July 1999.

[c] Personal communication, Mason T. Weinrich, Cetacean Research Unit, P.O. Box 159, Gloucester, Massachusetts 01930 U.S.A., 1 August 1998.

[d] Personal communication, T. J. Tucker, unpublished data, Head, Information Management Systems Department, Naval Safety Center, Department of the Navy, 275 A Street, Norfolk, Virginia 23511-4399 U.S.A., 24 November 1999.

[e] Personal communication, Kevin R. Sullivan, unpublished data, Office of Enforcement, National Marine Fisheries Service, 53 North 6th Street, Room 214, New Bedford, Massachusetts 02740 U.S.A., 15 June 1999.

[f] Personal communication, Sharon Young, Humane Society of the U.S., 22 Washburn Street, Bourne, Massachusetts 02523 U.S.A., 16 July 1999.

[g] Personal communication, David G. Ainley, H. T. Harvey & Associates Ecological Consultants, 906 Elizabeth Street, P.O. Box 1180, Alviso, California 95002 U.S.A., 16 July 1998.

[h] Personal communication, Hans Wapstra, Australian Parks and Wildlife Service, Tasmania, Australia, 6 August 1998.

[i] Personal communication, Nadia Menard, unpublished data, Saguenay-St. Lawrence Marine Park, Quebec, Canada, 19 November 1998.

[j] Personal communication, Robert K Bonde, Necropsy Examination Report RKB-1424, Sirenia Project, U.S. Geological Survey, 412 NE 16th Street, Gainseville, Florida 32601 U.S.A.

[k] Personal communication, Anne S. Collet, Center for Marine Mammal Research, Museum of Oceanography, La Rochelle 17000, France, 30 April 1999.

[l] Personal communication, Mary Sternfeld, unpublished Investigation Report Nos. 95010, 96006, 97025, and 97056, Office of Enforcement, National Marine Fisheries Service, Juneau Alaska 00802 U.S.A., 30 July 1998.

[m] Personal communication, LTJG Diane Hirman, unpublished Incident Report, August 18, 1997 Fisheries Law Enforcement, U.S. Coast Guard, 2100 Second Street, S.W., Washington, DC 20593 U.S.A., 30 March 1999.

[n] Personal communication, Michel André, c/o Suarex Calvan 24, Santa Maria de Guia, Gran Canaria, Canary Islands 35450, Spain, 8 July and 18 August 1999.

[o] Personal communication, Janice M. Straley, University of Alaska, Southeast, 1332 Seward Avenue, Sitka, Alaska 99835 U.S.A., 29 July 2000.

[p] Personal communication, Kalli De Meyer, Manager, Bonaire Marine Park, Netherlands Antilles, 20 January 2000.

[q] Personal communication, Jonas Wikander, Expedition Leader, Quark Expeditions, 980 Post Rd, Darien, CT 06820 U.S.A., 14 February 2000.