ATTACHMENT E.2

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 Penninsula	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

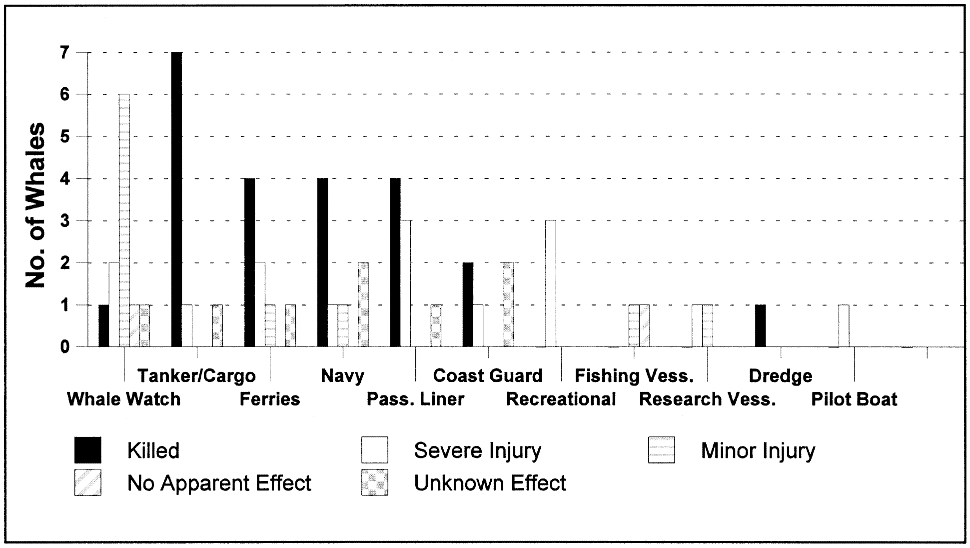

Figure 1. Number and fate of whales struck by different vessel types from collision accounts found in this study. Killed = observed carcass; Severe Injury = report of bleeding wounds or observation of blood in the water; Minor Injuries = visible non-bleeding wound or sign of distress with no report of 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

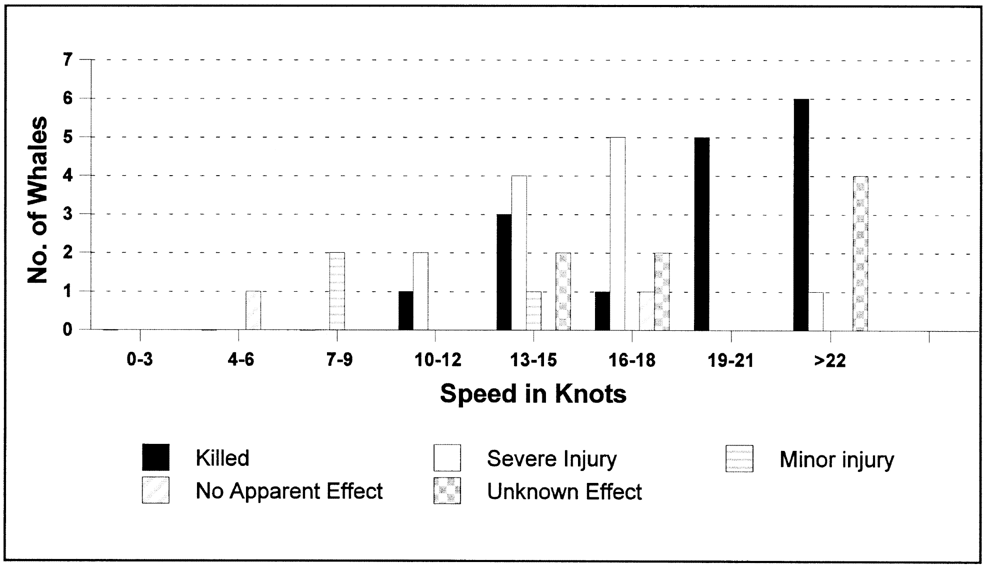

Figure 2. Severity of injuries to whales struck by vessels traveling at known speeds. Killed = observed carcass; Severe Injury = report of bleeding wounds or observation of blood in the water; Minor Injuries = visible non-bleeding wound or sign of distress with no report of blood; No Apparent Effect = 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 frequency 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 strandings 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, humpback 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