

**SCARIFICATION ANALYSIS OF NORTH ATLANTIC
RIGHT WHALES (*EUBALAENA GLACIALIS*) AS A
METHOD OF ASSESSING HUMAN IMPACTS.**

A Report to:

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ABSTRACT

A 1990 analysis of photographs taken of North Atlantic right whales between 1959 and 1989 showed that 57% of the cataloged right whale population had scars from past entanglements in fishing gear and 7% had scars from ship-strikes propellers (Kraus, 1990). Since that analysis, a large amount of new photographic data has become available and there has been speculation that the rate of entanglements has been increasing. We describe and quantify the occurrence of scarring in right whales from the updated right whale photo-catalog, and where possible, determine the cause of such scars, in what place and time the scarring occurred, and whether specific age or sex classes are particularly vulnerable to certain types of injury. Two different techniques to investigate scarring trends are described and compared.

All photographs taken between 1935 and 1995 of each animal ($n=357$) in the catalog were analyzed for the presence of marks or scars on the skin. These photographs were organized chronologically and separated by geographic region, then carefully inspected for the occurrence of any visible marks. Although the primary intent of the analysis was to gather information on scarring caused by human activities, marks of unknown cause were also noted.

The results indicate that 61.6% of the population have scarring caused by entanglement and 6.4% carry ship-strike scars (primarily propeller wounds). Substantially more females have scars from ship-strikes, but males and females are apparently equally likely to be scarred by entanglements. Scars most commonly occurred on the dorsal tail stock

from entanglements and on the left side from ship-strikes. There has been a significant, increasing trend in entanglement events over the years and this increase cannot be fully attributed to increased effort or population growth.

INTRODUCTION

The population of North Atlantic right whales (*Eubalaena glacialis*) is one of the most endangered in the world. Although protected from hunting since the mid-1930's, the population has shown little sign of recovery. The population is growing at a third of the rate of southern right whale populations (*Eubalaena australis*) (Knowlton *et al.* 1994) and it appears that entanglements and ship-strikes are having a significant impact on the population (Kraus 1990).

Right whales are individually identifiable by the pattern of the callosity tissue on their heads; The pattern of these patches is unique to each individual. The New England Aquarium is the curator of a photo-identification catalog of 374 right whales. The catalog contains over 11,000 records of photographed sightings from 1935 to the present. In 1990, Kraus used this database to assess the anthropogenic causes of scarring, specifically from entanglement and ship-strikes. His analysis of photographs collected between 1959 and 1989 showed that 57% of the cataloged right whale population had scars from past entanglements in fishing gear and 7% had scars from ship's propellers. Since that analysis, there has been speculation that the rates of scarring on right whales has been increasing. Here we report on a more

comprehensive analysis of photographs from 1935 to 1995 (more than 100,000 photographs). Two different techniques to investigate scarring trends are described and compared. Trends in human-caused scarring rates, the persistence of those scars, and effects by gender and age classes were investigated. The limitations of this type of analysis for assessing the geographic location and season where scarring events occur are discussed.

METHODS

Background

Each whale in the catalog is assigned a four digit catalog number (referred to as the EGNO) and all photographs are filed according to that number. All identified sightings are entered into a dBase III database including the whales age at time of sighting if known and its sex as well as the sighting time, date, latitude/longitude, observer, geographic region and any comments. The majority of the photographed sightings have been collected from the five main high-use areas (southeastern U.S. during the winter, Massachusetts Bay primarily in the late winter and early spring, Great South Channel east of Cape Cod, MA in the spring, the Bay of Fundy and Browns Bank/Roseway Basin southeast of Nova Scotia in the summer and fall) with additional sightings collected for areas further to the north and in between the high-use areas. The first dedicated, long-term photographic effort began in 1980 in the Bay of Fundy with others starting after that.

In order to assess the age profiles of whales being scarred, all whales were categorized as juvenile, adult or unknown. Juveniles were defined as animals of known-age

who were less than nine years old (Payne *et al.* 1990, Hamilton *et al.* In press), including calves. Calves were considered calves for the calendar year of their birth (because peak calving for this population is in late December/ early January (Kraus *et al.* 1993)). Adults were defined in one of three ways: 1) whales of known-age who were at least nine years old, 2) whales of unknown-age whose sighting histories spanned eight years or more (because they were at least one year old when first sighted), and 3) any parturient female irrespective of the length of her sighting history. With the exception of these latter females, whales of unknown-age and with sighting histories spanning less than eight years were categorized as of unknown-age class.

Sex was determined in one of three ways: 1) a large whale associated with a calf over three sightings was considered a female, 2) photographs of the genital region, or 3) genetic analysis of collected skin samples (Brown *et al.* 1994).

Photographic Analysis

All photographs taken between 1935 and 1995 for each animal in the catalog were examined for the presence of marks and scars on the skin. Slides from 1996 were not included in this analysis as they are in various stages of being incorporated into the catalog. Image types included: slides, color prints, b/w prints, and newspaper photos, and were obtained from either a shipboard or aerial platform. Photographs were searched for the occurrence of *any visible* mark. Each type of scar/mark was defined and given a letter code (Figure 1). Although the primary intent of the analysis was to glean information on human-caused scarring, marks of unknown cause were also noted. The information on non-human

caused scars may prove useful in the future. For example, if information gathered in the future gives us insight into the cause of "rake marks" by the blow holes or white skin lesions, this database will be available for further analysis. In this paper, we report only on entanglement and ship-strike scars (examples of which can be seen in Figure 2) from 1980 through 1995.

All photographs of each animal were ordered chronologically by area and season, and were analyzed as one group (e.g. all photos from Massachusetts Bay during February and March in 1994 were analyzed together) with the scar information summarized in an entry for each individual whale. If a scar developed during the season, the whale would get two entries for that season- one coded without the scar, the second coded with the scar. A diagram of a whale body was divided into a 21 section grid (Figure 3) and each body section was coded for each group of photographs. If a portion of the body was not photographed in that geographic region during that season, an "X" was placed in the column. If a portion of the body was seen, it was either coded with an "N" (no scar) or with one or more scar codes. If that body portion was only partially seen, the "N" or scar codes were preceded by a "P". There were three body sections that were never fully seen because most of the area remained under water at all times; X1- the chin, X6 and X8- anywhere behind the blowholes and forward of the peduncle including the flippers. These sections were all coded with "P". Any new scar was denoted with an asterisk the first time it was seen and then without an asterisk in all subsequent sightings when that scar was observed.

Unwavering conservatism was applied to coding for the cause of a scar. Unless there was compelling evidence to assign a specific cause, it was coded as unknown. With some

entanglement scars, information over several years led the analyst to determine the cause of a scar. For example, the information collected during a given sighting or even a single season may not have been complete enough to ascertain the scarring pattern as entanglement. In these cases, photographs of the scar from all years were used to determine the cause. Because there were many scars that were probably human-caused but had to be coded as unknown because of the uncertainty, the number of probable entanglement or ship-strike scars were also tallied. We used the notebook described below to manually tally possible ship-strike or entanglement scars. Only scars were coded for; so even if a whale was photographed while still entangled in gear, if there was no scarring, the database would not register an entanglement scar (although the entanglement would be noted in the comments). The same was true for dead whales. Any whale that was photographed dead on the beach was also coded, but even if the cause of death was determined to be a ship-strike by a shattered skull, if there was no external scar or wound that fit the coding criteria, it was not coded as a ship-strike.

Because much of this analysis required detailed interpretation, several additional records were kept to document the process. First, a composite drawing of each whale was photo-copied and all scars were drawn on the composite with the date of their first sighting written next to them. Secondly, a notebook was kept with a narrative description of all important scars for each whale. For example, all entanglement and ship-strike scar codes required justification, so the entry included the reason a scar was coded as such, all the factors that went into making the determination, as well as which photos best showed the scar. When there was any doubt about the coding, the scar analyst consulted one or two, and

in some cases, three other experienced researchers, and the decision was made jointly. The analysis sheets were entered into a computer database in Microsoft Access 2.0 then proofed for errors.

Assigning Scarring Time

One of the primary intents of this analysis was to test the hypothesis that scarring events are occurring more frequently. To investigate this, it was necessary to determine the time period within which the scarring events occurred. Once the time period had been described, scarring could then be summarized by year to look for trends from year to year.

Scars were categorized as either known-year or unknown-year. They were determined to be known-year scars if they were: 1) on whales that had an entanglement scar on a region of the body that had been well-photographed (i.e. the area was fully seen, not just partly) without that scar earlier that same year or 2) on any calf of the year with a scar, regardless of whether or not the body region had been photographed without the scar earlier. These scars were given an annual scarring probability of one for the year they were detected.

It was more difficult to assign annual probabilities to unknown-year scars. To address this problem, we developed two different techniques to determine the likelihood of these scars occurring in any given year. The first analysis, which was performed primarily by the computer, assigned annual scarring probability indices based on all scars and was cruder but much more efficient and precise. The second technique assigned annual scarring probabilities to each scarring event and was presumably more accurate, but required detailed inspection of the sighting history of each scarred whale. Because of the volume of data, the former

technique is preferable. With this in mind, the results of both techniques were compared to determine the defendability of using the easier technique. Both are described in detail below.

Assessing Trends in Scarring with an Annual Scarring Probability Indices

For this analysis, the computer was programmed to locate every new, human-caused scar and then searched backward in the sightings record to determine whether or not that body part had been seen without the scar previously. If the body region had not been seen without the scar and the whale was not a calf, then that scar was eliminated from the analysis (there was no way for the computer to know when the scarring event may have occurred). If the scarred body part had been previously sighted without the scar, then we assumed that it was equally likely that the animal was scarred in any given month between sightings. For example, whale No. 1048 had new entanglement scars recorded in the regions X8, X9, and X10 (Table 1A). Because those body regions had previously been seen without the scars at varying times, each scarred body region was assigned different annual scarring probabilities for different years (Table 1B). These annual probabilities were calculated by the computer by dividing each scarred body region (i.e. one) by the total number of months between the sightings of that body region without the scar and the sighting with the scar, and then multiplying by the number of months during which the animal was available to be scarred in a given year.

Region (X) Scar Probability Year (Y) = $(1 / \text{No. of months between no scar and scar}) \times \text{No. of months available to be scarred in year (Y)}$

For example, prior to August, 1988, the X8 region on No. 1048 had last been well-photographed (i.e not an "X" and not a "P") without the scar in September of 1987. The entanglement scar could have occurred any time during the ten month period from October, 1987 to July of 1988. Because there were only three months in 1987 when No. 1048 was available to be scarred (i.e. October through December), the annual probability for the scar in X8 in 1987 is:

$$\text{X8 Scar Probability: 1987} = (1/10 \text{ mo.}) \times 3 \text{ mo.} = .3$$

For 1988, the probability is:

$$\text{X8 Scar Probability: 1988} = (1/10 \text{ mo.}) \times 7 \text{ mo.} = .7$$

Any scarring events that occurred in a given year received a probability of one for that year. Once the annual scarring probability for each body part for each whale was calculated, all probabilities were combined and summed by year to get a total annual probability for all scars for all animals. For example, No. 1048's 1988 probabilities (Table 2B) of .7 for X8, .31818 for X9 and .16901 for X 10 would be added to all the other probabilities for 1988 from all other whales.

Once this cumulative annual probability was determined, the next step was to calculate a scarring probability index since the cumulative figure alone over represented the scarring probability. For example, there were 85 body parts on a total of 42 whales in 1988 that received entanglement probability numbers. Because most whales had scars on many body parts from a single entanglement event, adding all the probabilities together makes the annual probability appear higher than it actually was. To account for this, we multiplied the total annual probability by the number of whales that were assigned probabilities for that year

and then divided by the number of records (i.e. body regions) to get a probability index.

$$\text{Scarring Probability Index Year (Y)} = \frac{\text{Total prob. for year(Y)} \times \text{No. of whales assigned prob. in year(Y)}}{\text{No. of records for year(Y)}}$$

For example, the total annual probability (i.e. all probabilities assigned to all body regions for all whales) for 1988 was 18.3982, so the index for that year was:

$$1988 \text{ Probability Index} = (18.3982 \times 42 \text{ whales}) / 85 \text{ body regions} = 9.0909$$

Assessing Trends in Scarring by Assigning a Single Scarring Probability to Each Event

To test the accuracy of the scarring probability index, we attempted to assign a probability to each scarring event rather than adjust the information from all scars. To do this, we reviewed the sighting histories of all whales with human-caused scarring to glean the most accurate information possible from the data set. This was time consuming and less precise as it allowed for greater human error, but enabled us to assign probabilities with more accuracy. To account for the problem of a single entanglement event causing scars on many different parts of the body, the first step was to determine the minimum number of different entanglement events that had caused all the scars on each whale. To do this, we assumed that if one body part on a whale showed an entanglement scar in a given year, and other body parts that had not been seen since before that year showed an entanglement scar two years later, then all those scars probably occurred at the same event. The earliest sighting of a new entanglement scar was considered to be the first sighting of that event. For example, whale No. 1048 was seen with new entanglement scars in August, 1988 (X8 and

X9) and September, 1992 (X10) (Table 1A). Because the body region of the latter sighting (X10) had not been photographed since before August, 1988, we assumed that they were all caused by one event and the first sighting of the event was considered August, 1988.

In order to assign a probability to that event, the next step was to determine the most recent time that scarring from that event had definitely not been seen. All the scarred body parts that had been photographed without the scar previously were inspected and the shortest time between no scar and scar was used to determine the best probability for that event. In the case of whale No. 1048 again, the information in region X8 gave us the most accurate period of when the scarring occurred (Table 1A). A probability was assigned for that body part for 1987 and 1988 and the probabilities for X9 and X10 were discarded.

In some cases, it was clear that a whale had been entangled by more than one event. In these cases, we reviewed all the information from all body parts to determine which scars most likely belonged to which events. During this process, some entanglement events may have been left out because we had no way of determining that they were separate events. For example, the review of whale No. 1622's history indicated that she was entangled at least three times (Table 2A). One entanglement event happened prior to August, 1986 as witnessed by the new entanglement scar in region X18. Looking at regions X8, X9 and X10, we can see that a second entanglement event happened between October, 1986 and August, 1988. This event has to be different from the first event because these regions had all been seen without entanglement scars at the same time that region X18 was seen with entanglement scars. Finally, region X10 shows that a third entanglement occurred sometime between February, 1989 and February, 1990. This event must be different than the previous two

because that body region was seen without a scar after the other two events had taken place. In this whale's case, probabilities could only be assigned to two of the three events (Table 2C). All we know about the first event is that it occurred before August, 1986, so that event is discarded from the probability analysis. The second two events could both be assigned probabilities from region X10, so the probabilities from regions X8 and X9 were discarded.

Additional Analyses

While manually inspecting the individual sighting histories for all scarred whales, four other analyses were performed to gather additional information that could not be collected from the computer.

- 1) We were able to assign annual probabilities for scarred, known-age whales that had never been seen without the scars. For these animals, we assigned an equal probability that the scar occurred during all months from January of their year of birth up until the first time the scarring was observed. For example, if No. 1622 had been born in 1985, her first entanglement event (see X18) could have been assigned a probability for 12 months in 1985 and seven months in 1986. Similar to the analysis of all scars, no probabilities were assigned for the unknown-age whales whose scarred areas had never been photographed without the scar (e.g. 1622's X18 scars).
- 2) Each scar that was recorded in X1, X6 or X7 was looked at individually to determine if the specific portion of each region with the scar had been photographed previously. Because many of the scars cataloged in X6 and X7 were on the flippers which are rarely seen, only a few probabilities could be manually assigned to this region during

this analysis.

- 3) The persistence of scars were analyzed to determine how many scars disappeared over time and whether the age of the whale when it was scarred played a factor in how the scar healed. Scars were determined to have disappeared if the scarred body part was well seen after scarring without the scar.
- 4) Finally, the minimum number of scarring events for each whale were added up to determine the minimum number for the population.

RESULTS

Of the 357 whales analyzed, 61.6% (n=220) had scars from entanglements and 6.4% (n=23) had scars from past ship-strikes (Figure 4A). When scars on all the different body regions for these whales were combined, there were a total of 1,002 body regions scarred by entanglements and 61 scarred by ship-strikes. In addition to these, there were another 125 possible entanglement scars and 17 possible ship-strike scars that were coded as of unknown origin to be conservative. Sixty-six entanglement scars disappeared over periods that ranged from five months to 15 years. Fifty-nine percent of those scars were first recorded when the whales were juveniles.

Of the 220 whales with entanglement scars, 28% (n=62) had been entangled more than once: 46 whales had been entangled at least twice, 15 whales at least three times, and one whale at least four times. Two whales that were carrying gear developed new scars over

time, but these new scars were considered to be from a single entanglement event to be conservative (i.e. the line they were carrying probably produced new scars periodically, but it was still just one entanglement event). When all the events were added up, there was an absolute minimum of 299 entanglement events for the entire population. There was only one whale that showed scars from being hit by a ship twice, making the absolute minimum for ship-strike events 24.

ENTANGLEMENTS

By Body Region

The dorsal peduncle was the most frequently scarred body region with 178 different entanglement scarring events in this region alone (Figure 5). Scarring events decreased by body region in the following order: either side of the fluke insertion (where the flukes meet the body): left (n=126) and right (n=134), the ventral peduncle (n=105), the leading edges of the flukes: left (n=90) and right (n=95), either side of the back: left (n=36) and right (n=33), lower lip leading edges: left (n=32) and right (n=30) and other body regions. Entanglement scars occurred on all body regions with at least two scarring events for each.

By Gender

Of the 220 whales with entanglement scars, 40.9% were males, 40.9% were females and 18.2% were of undetermined sex. When the 357 whales analyzed were separated by gender and scarred animals compared to the subset of their own gender, the scarring

percentages were 67.7% of all males, 65.7% of all females and 46.0% of all unknown genders (Figure 4B).

Known-Year Occurrences

There were 17 examples of whales who were well-photographed both before and after a scarring event in a single year and another 21 examples of calves that were not well photographed before scarring, but were photographed after scarring in their first year (Figure 6, Table 3). Because right whales are known to travel hundreds of miles in a matter of weeks, it was impossible to determine in what geographic region scarring events occurred. Only three whales were seen in the same region both before and after scarring, suggesting the scarring event may have occurred in that region. The events took place in: 1) the Bay of Fundy in 1983 involving a female calf, 2) the Bay of Fundy in 1993 involving another female calf and 3) Florida in 1994 involving a calf of unknown gender. Many of the other events occurred sometime between sightings in Massachusetts Bay and the Bay of Fundy, but could have happened anywhere, including Great South Channel and the Gulf of Maine.

Trends

Of the 220 whales with entanglements, only 146 had scars on parts of the body that had been photographed without the scars previously, were calves of the year, or were known-age animals. Only these whales were assigned probabilities for one or more event. The remaining 74 whales were of unknown-age and had never been seen without their scars.

The probability indices for all scars was remarkably similar to the probabilities assigned by individual scarring events, suggesting that the index is an effective way to determine overall trends without going through sighting histories whale by whale (Figure 7). Both techniques showed an increase in entanglement scars over time. A sharp decline in 1995 is most likely an artifact of it being the last year analyzed (i.e many of the scars that will be detected in 1996 and later years will be assigned a probability of having occurred in earlier years, including 1995). For this reason, the last year analyzed will always be under represented. A linear regression on the data from 1980 to 1995 shows that the increasing trend in entanglement events is significant ($F=80.921$, $p<0.001$). The slope of this regression is 1.099, indicating that the annual entanglement rate has been increasing at about one event per year for 15 years. If we assume that an increase in the population over the last 15 years has increased the probability of entanglement events, and we correct for the maximum population growth rate (an estimated annual increase of 0.025 per year (Knowlton *et al.* 1994)), the trend in entanglement events remains unaffected.

By Age

For this paper, because of the uncertainty of when most scarring events actually occurred, we did not assign probabilities for scarring by age class. Instead, we looked at ages in two ways: 1) the ages of the subset of whales whose year of scar occurrence was known, and 2) the number of scars that were first photographed when the whale was still a juvenile.

Of the whales involved in the 38 known-year scarring events, 86.8% ($n=33$) occurred

when the whales were juveniles, 5.3% (n=2) were adult and 7.9% (n=3) were of unknown age (Figure 6). This number is biased towards juveniles because calves' scarring could be assigned a year without being seen without the scarring in the same year. If we use the same criteria that we used for non-calves (i.e. the body region has to been seen earlier without the scar), then the percentages change to: out of 17 events, 70.6% (n=12) were juveniles, 11.8% (n=2) were adult and 17.6% (n=3) were of unknown age. These numbers contrast the age structure for the population of 20.8% juvenile, 74% adult and 5.2% of unknown age (Hamilton *et al.* In press). Of the total of 220 whales scarred by entanglements, 38.6% (n=85) experienced at least one scarring event while they were juveniles. This number may be low as many of the whales whose scars were first seen when they were adults may well have acquired those scars when they were juveniles.

SHIP-STRIKES

By Body Region

The left side of the body had the highest incidence of ship-strike scars with 13 events (Figure 5). After that, the regions most likely to be hit by ships were: the right side of the back (n=9) and the right fluke- dorsal, ventral and leading edge (n=4 ea.). The left insertion, dorsal peduncle, left dorsal fluke and right fluke tip all had equal numbers of scars (n=3 ea.). Scars were also observed on the rostrum, lip, peduncle and elsewhere on the flukes.

By Gender

Of the 23 whales with ship-strike scars, 21.7% were male, 60.9% were female and 17.4% were of unknown gender. Separating the analyzed population by gender and comparing the scarred animals to the catalog, the scarring percentages were 3.8% of all males, 10.2% of all females, and 4.6% of all unknown genders (Figure 4).

Known-Year Occurrences

There were six examples of known-year ship-strike scars or wounds: three were whales that were photographed before and after a ship-strike in a single year (one dead on the beach), one was a calf photographed with the scar within months of its birth and the remaining two whales were found dead within days of their collisions (Table 3). The geographic region and the time of year for all six of these events was known: three occurred off the coast of Florida during the winter, one occurred off Massachusetts in August, one occurred in the Bay of Fundy in October and one occurred off New Jersey in February.

Trends

Of the 23 whales with ship-strike scars, only 14 had scars on parts of the body that had been photographed without the scars previously, were calves of the year, or were known-age animals. Only this subset could be assigned annual probabilities for their scarring events (Figure 8). No trends were apparent. Unlike the entanglement analysis, the probabilities that resulted from the analysis of ship-strike scars by event differed substantially from the probability indices assigned from all scars. This is most likely due to stochasticity

caused by a much smaller sample size.

By Age

Similar to the entanglement analysis, we looked at the age of whales with ship-strike scars in two ways: 1) the ages of the subset of whales whose year of scarring occurrence was known and 2) the number of scars that were first photographed when the whale was still a juvenile. The ages of the six known-year ship-strikes were: calf (n=3), one year (n=1), two year (n=1) and one was of unknown age (Table 3). Of the total of 23 whales scarred by ship-strikes, at least 43.5% (n=10) were hit while they were juveniles.

DISCUSSION

This analysis was undertaken to test the hypothesis that the frequency of entanglement events was increasing. However, because anthropogenic mortalities are effecting this species' recovery, managers were also interested in the potential use of photo-identification for monitoring the effectiveness of future management policies designed to mitigate human/whale conflicts. Therefore, it is important to clearly outline the factors that may have biased these results. The following factors affected the analysis and made the numbers presented conservative.

- Interrupted survey efforts affected our ability to discern scarring time.
- Inconsistent sighting histories of individual whales affected our ability to discern scarring time.
- The photographic quality effected overall scar assessment. In particular, aerial

photographs were less useful at clearly discerning the presence or absence of scars.

- Photo-identification efforts tend to focus on the head, leaving many of the frequently scarred body regions unphotographed.
- Because right whales are known to travel great distances over short periods of time (Mate *et al.* 1997), it was difficult to determine the geographic location of scarring.
- Not all ship strikes leave visible external scars.
- Not all entanglement scars persist over time.
- Not all scars could be assigned a cause.
- Not all scars were white- some were grey indents that were difficult to see.
- Additional analyses will be necessary to address effort, taking into consideration that the number of whales captured does not represent the number of whales appropriately photographed to capture scars (i.e just the head may have been photographed) and that scarring was summarized from information on all body parts and probabilities were assigned accross years, further clouding the question of capture success and effort.

All of these factors played varying roles in determining the presence and or absence of scars as well as the timing of those scars. Some can be addressed (i.e. survey effort or thoroughness of body regions photographed) and others are inherent and cannot be changed.

With these limitations in mind, the analysis still proved to be quite powerful. The

system of using the computer to help assign annual scarring probability indices was remarkably effective for entanglement scarring, but was less effective for the less numerous ship-strike scars. Both the probability indices and the probabilities assigned by event showed an increasing trend in entanglement events. When compared to the number of whales photographically captured each year (Figure 7), at first glance this increasing trend looks like it may simply be an artifact of the number of whales identified each year. However, three years (1983, 1990 and 1992) have much higher scarring probabilities while the number of whales identified declined, and in 1988 the entanglement probability decreases while the number of whales identified increased substantially. These discrepancies suggest that the entanglement probabilities are not necessarily dependent on the number of whales identified.

Describing the geographic location of scar acquisition was more difficult for entanglements, but somewhat easier for ship-strikes. Of the 45 animals whose year of scarring was definitely known, only nine (3 entanglement and 6 ship-strike) could be assigned a geographic region for the scarring with any degree of certainty. The southeast is clearly one of the hot spots for ship-strike scars (50% of all known-year events) which is in contrast to the mortality data (only 20% of all known ship-strikes (Knowlton and Kraus, In prep)). Out of the 15 whales killed by ships, 25% showed no outward appearance of the strike indicating that, if not hit with a propeller or a sharp bow, a whale can sustain a damaging impact and show no scars. However, it is still interesting that the ship-strike scarring data conflicts with the ship-strike mortality information on *all* counts: more females are scarred whereas more males die; more whales are scarred in the southeast, but more die elsewhere; there were more scarring events in the 1980's, but more ship-strike deaths in the

1990's (three deaths in the 80's compared to eight so far in the 90's, although this increase could be caused by an increased effort to respond to mortalities). This contrast is primarily the result of different vessel strikes having different impacts. Most of the scarring data is probably the result of smaller vessels (with the exception of the three whales that were dead) where as the mortalities were from larger vessels. An analysis of the shipping industry has shown a trend towards increased ship size in the shipping industry (Knowlton, 1997).

In the age and gender analyses, when compared to the total population, the relative ratio of male to female whales with entanglement scars (40.9% ea.) mirrored the sex ratio for the entire population (37.3% male to 38.4% female (Hamilton *et al.* In press)). However, the ship-strike ratio of 21.7% males to 60.9% females showed a clear departure from parity. This could be attributed to the fact that females are predominant off the southeastern U.S. where many of the known location ship-strikes occurred. Other possibilities are that females are more coastal where vessel traffic is most focussed and/or they spend more time on the surface, particularly if they have calves. As for age class, juveniles are clearly more susceptible to both ship-strikes and entanglements. Initially, the high percentage of juveniles with known-year entanglement events seemed misleading because calves' scarring could be assigned to a particular year even if the scarred body part had never been seen without the scar. However, when we held calves to the same assignment criteria as other whales, still over 70% of known-year scar events occurred when whales were juveniles and a minimum of 39-44% of all scarred whales had some entanglement and ship-strike scarring respectively while they were juveniles.

The fact that a quarter of all whales with entanglement scars were entangled more

than once raises some intriguing questions. If whales know the gear is there, then it suggests that they may not learn from past mistakes. There have been a number of anecdotal accounts of young right whales playing with lines and sea weed. It may be during some of those explorations that they become entangled. Certainly the other, and probably more likely, explanation for multiple entanglements is that whales are simply unaware of the gear's presence and so could not avoid it even if they were cognizant of the threat it posed.

There were some interesting surprises during this analysis. Some scars that appeared like ship-strikes proved to be entanglements. For example, whale #1621, had a deep scar in its back that appeared too deep to be an entanglement and at first was suspected to be from the sharp bow of a ship. However, closer inspection showed less visible scars wrapping out of either side of the mouth and connecting with the back scar. There were also some scars that were only apparent from one very specific angle and only an extremely thorough analysis could have determined that the whale had been scarred. Perhaps the most interesting example of this was whale #2212 who had a very faint, but very clear, imprint of gillnet mesh imprinted on its side that was only visible in one photograph from one sighting. This was the only entanglement scar that could be attributed to a specific type of fishery.

This analytical process provides the only known method to monitor the rates and effects of entanglements on right whales. It therefore will be essential to maintain the photo-identification effort in order to monitor the effectiveness of any management actions regarding whale/fishing and whale/shipping encounters. To improve the effectiveness of this analysis, photographic effort has to be improved for all geographic regions other than Massachusetts Bay and the Bay of Fundy, equal photographic effort has to be made for

animals without scars (i.e. photograph unscarred flukes as well as scarred flukes), and survey effort has to be re-established in Great South Channel and the Nova Scotian Shelf.

ACKNOWLEDGMENTS

As with all analyses using the right whale photo-catalog, thanks go to all the contributors who make this detailed information possible. In particular, the Center for Coastal Studies and the University of Rhode Island have contributed especially vital information to the catalog. The Microsoft Access computer program was completed by Jim Hosey of Fulcrum Technologies in Providence, R.I. Comments from Amy Knowlton throughout the analysis and writing improved the overall project substantially. This project was made possible with funding from the National Marine Fisheries Service, the Island Foundation, and the New England Aquarium's Right Whale Sponsorship Program.

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FIGURE 1.

SCAR CODES

- * = NEW SCAR** -At the *first sighting* of a scar, place an asterisk next to the scar code; e.g. if a whale has a new orca scar on the left fluke tip, then you would write O* in column X14.
- B = BLISTERS** -Small patches of skin which are raised or bubble, then erupt and leave behind craters. Any of these conditions, if clearly seen, will be coded as "Blister". Distant, blurry or aerial photos will not allow for accurate assessment, therefore gray areas in such photos will be coded as "Gray", although some may actually be blisters.
- C = LARGE CIRCULAR** -Usually bigger and more persistent than "dots". Should show up in most photos, regardless of angle, glare, or focus.
- D = DOTS** -Tiny white spots which seem to come and go. May not show up in lesser quality photos. Not as persistent as "Large Circular".
- E = ENTANGLEMENT** -Partially influenced by location of scar - those on tail stock, flippers, leading edge of flukes and leading edge lower lips are particularly suspect. Any scars which appear to "wrap around" are coded as entanglement.
- F = FUNGUS** -Whitish or grayish areas with soft edges, as if out of focus.
- G = GRAY** -Irregularly shaped and spaced patches of gray sloughing. Area should be coded as "Gray" only if more than 50% of visible area has gray patches. If it is unclear, due to the quality of the photos, whether a gray area is raised or depressed (i.e. "Blistered"), code as gray.
- I = INDENT** -Indented narrow strip behind post-blowhole callosities. Can be either faint and gray, or deep, whitish and permanent-looking. Within two feet of blowholes. The faint ones sometimes disappear over time.
- N = NO SCAR** -Area was seen well enough to determine that no scars exist.
- O = ORCA** -Thin, white parallel lines, usually on flukes, especially the tips, made by any small odontocete, not just orcas. Apparent bite marks should not be coded as "Orca" *unless* there are visible parallel lines associated.
- P = PARTIALLY SEEN** -Area was only partially visible or photo was too dark or too distant to discern small scars. Any scar code is preceded by a "P" (except for sections X1, X6 and X7 since they cover a huge area and are rarely seen completely). Not used for aerial photos.

FIGURE 1 (cont).

SCAR CODES

- R = RAKE MARKS** -Two or more parallel lines near the blowholes. They look as though skin has been split open. Not persistent from year to year.
- S = SHIP-STRIKE** -Propeller wounds only (unless there is compelling evidence that a particular scar or wound is the direct result of a boat strike).
- T = TUBERCLES** -Describes the series of 'bumps' (usually 2 or 3) sometimes seen anterior to dorsal peduncle. If seen, they're coded in X9, even though they're usually forward of that section.
- U = UNKNOWN ORIGIN** -Any scars not clearly fitting into the other categories.
- X = NOT SEEN** -Indicates that a body region was not photographed at all, or that photos were too poor to code scars with confidence. For aerial photos, all regions are given an "X" unless there is a scar visible (no "N" or "P").
- Z = OTHER** -Scar or condition resulting from a particular event which we witnessed or were made aware of (e.g. satellite or radio tagging), but which does not fit into any of the above categories.

FIGURE 2A.

EXAMPLES OF ENTANGLEMENT SCARS

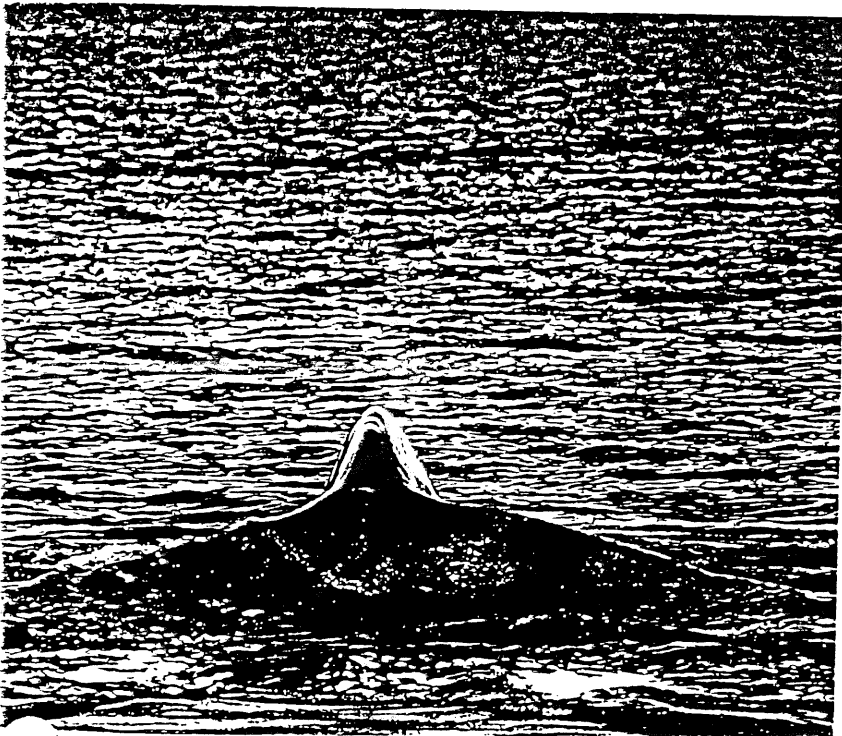
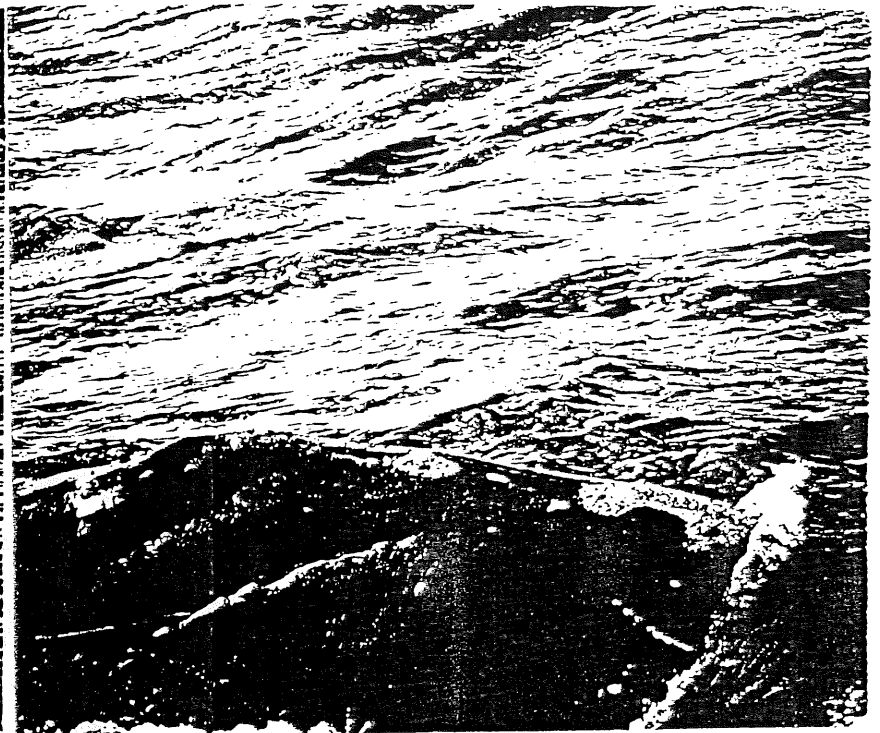
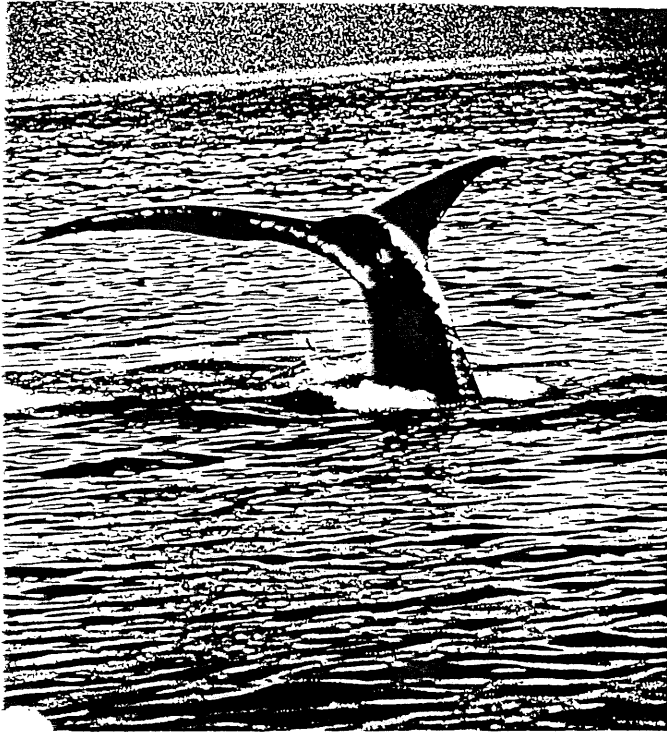


FIGURE 2B.

EXAMPLES OF SHIP-STRIKE SCARS

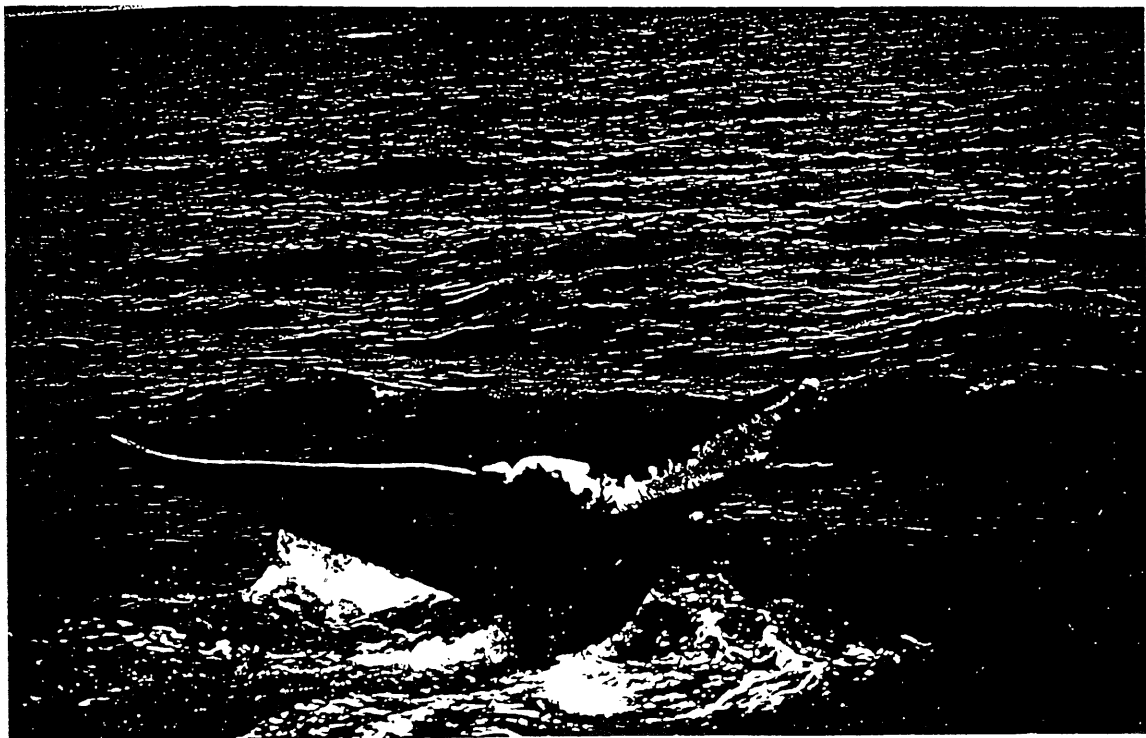
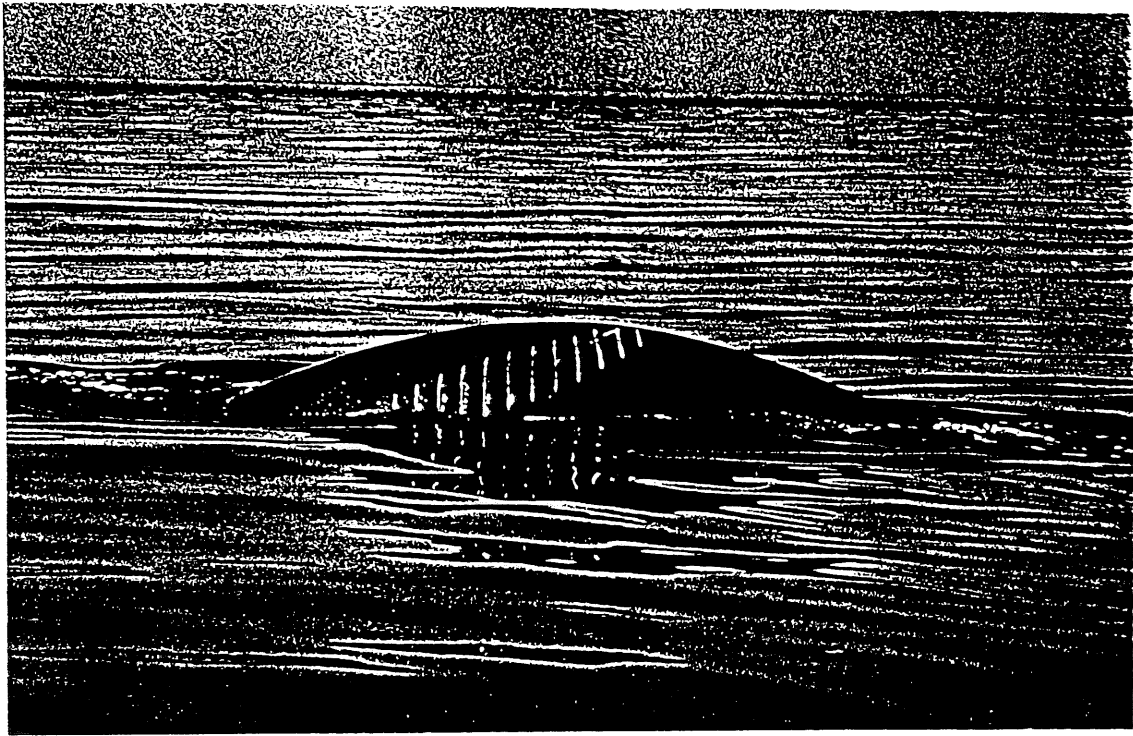


FIGURE 3.

WHALE DIAGRAM SHOWING BODY REGIONS

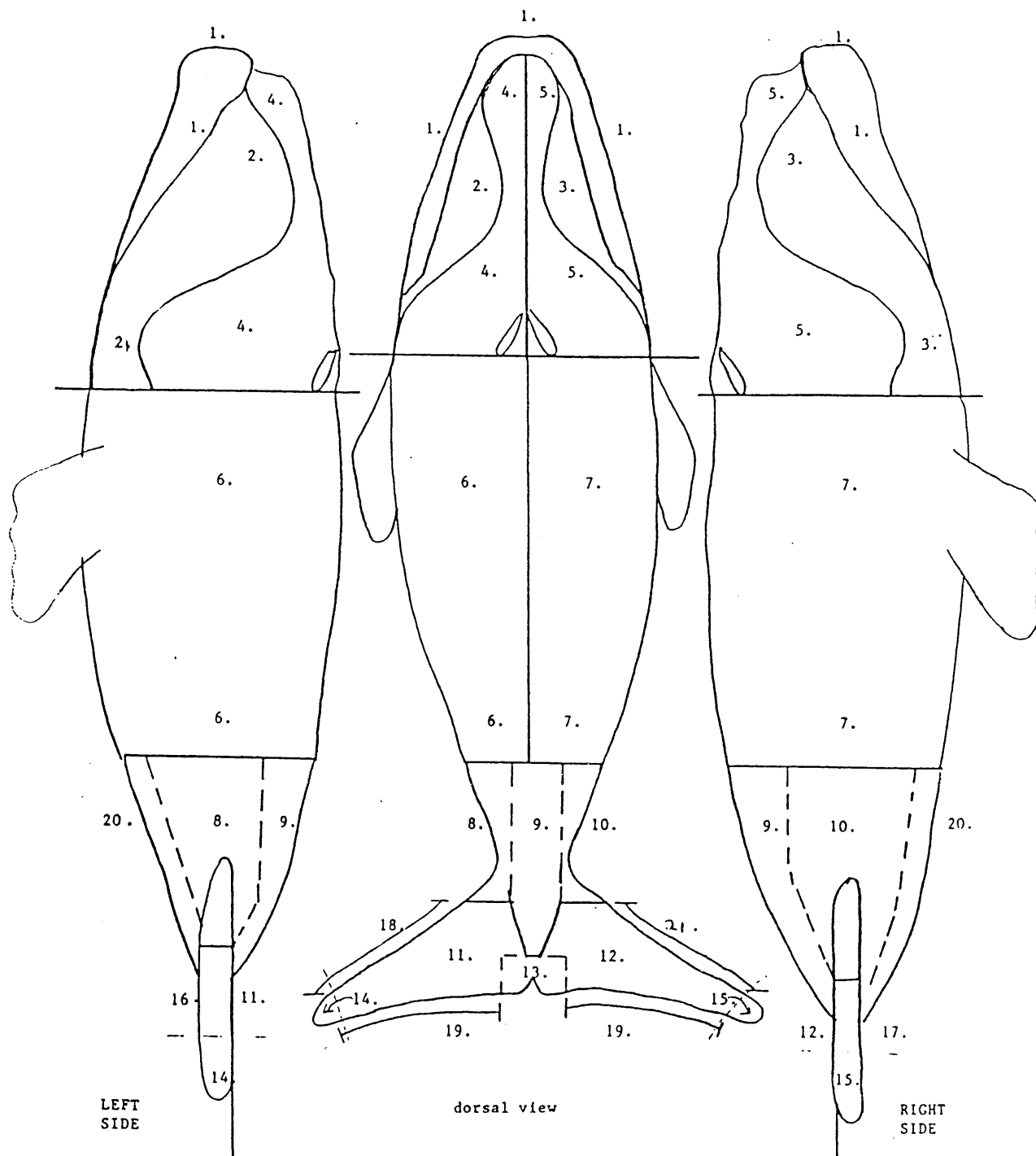


FIGURE 4A. PERCENTAGE OF TOTAL POPULATION THAT IS SCARRED

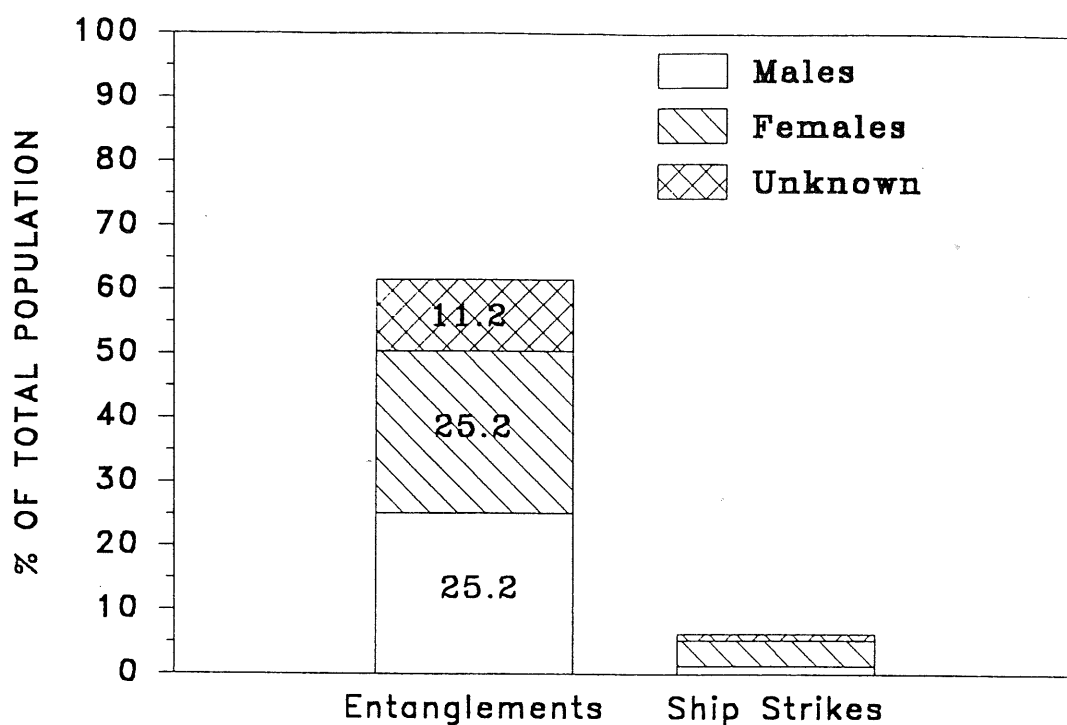


FIGURE 4B. PERCENTAGE OF SCARRED WHALES BY GENDER
(e.g. No. of Males Scarred/ No. of Males Analyzed)

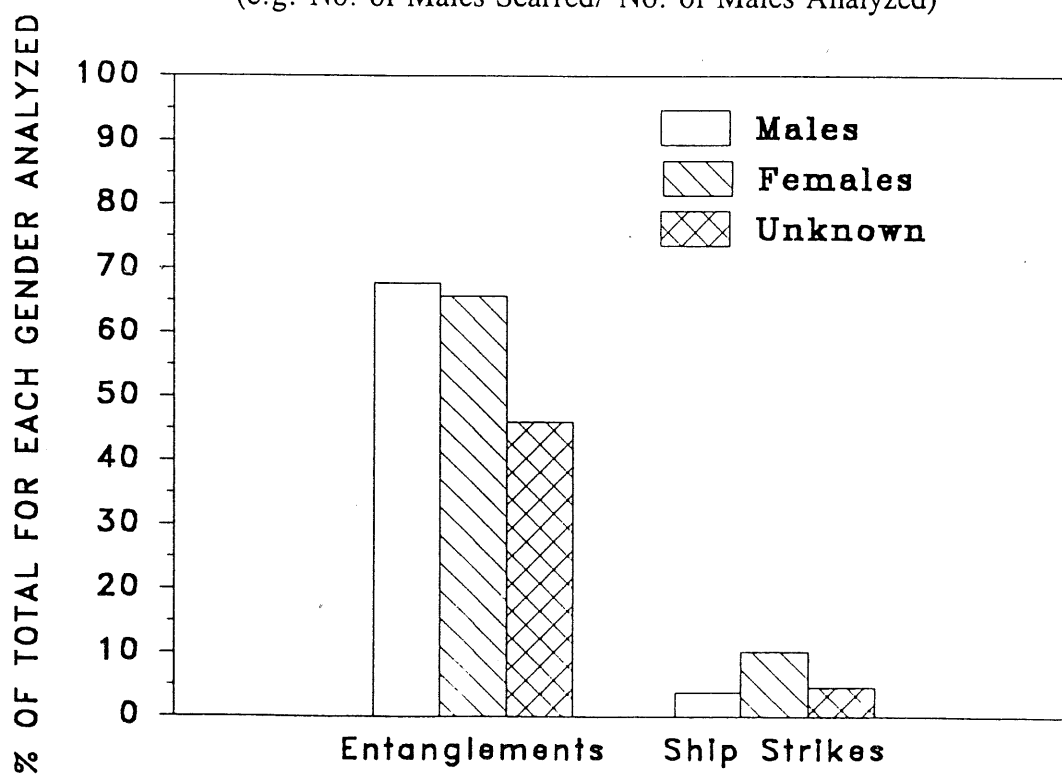
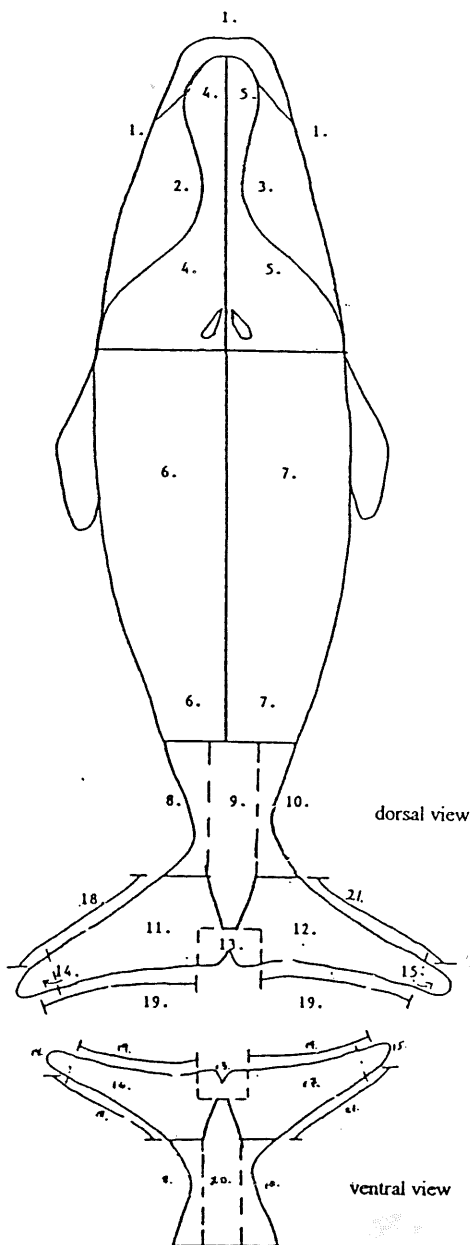


FIGURE 5. MOST FREQUENTLY SCARRED BODY REGIONS.



ENTANGLEMENTS	# OF SCARS left/right	SHIP-STRIKES	# OF SCARS left/right
1st Dorsal Peduncle (X9)-	178	The back (X6,X7)-	13/9
2nd Fluke insertion (X8,X10)-	126/134	Right fluke (X12,X17,X21)-	4 ea.
3rd Ventral peduncle (X9)-	105	Left insertion (X8), Dorsal	
4th Leading fluke edges (X18,X21)-	90/95	peduncle (X9), Left fluke (X11),	
5th The back (X6, X7)-	36/33	and Right fluke tip (X15)-	3 ea.
6th Lower lip (X2,X3)-	32/30		
Total for all 21 body regions	1,002		61

FIGURE 6. NUMBER OF ENTANGLEMENT EVENTS THAT DEFINITELY OCCURRED IN A GIVEN YEAR: 1980-1995.

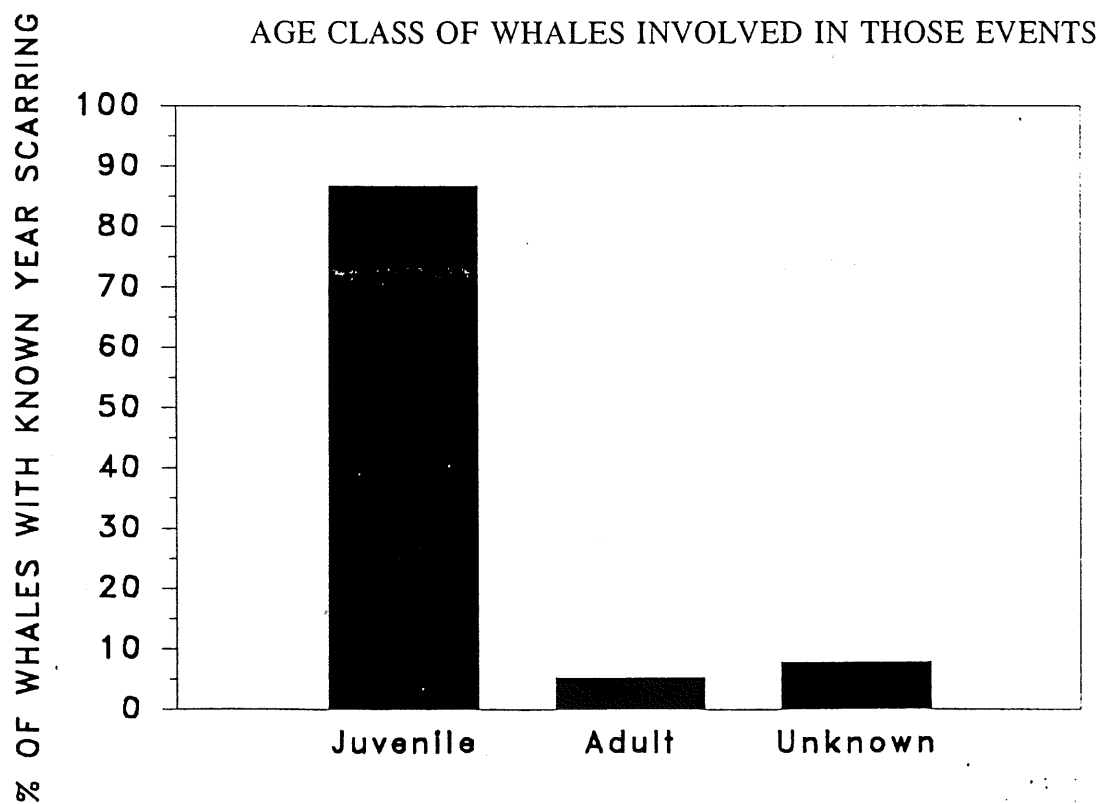
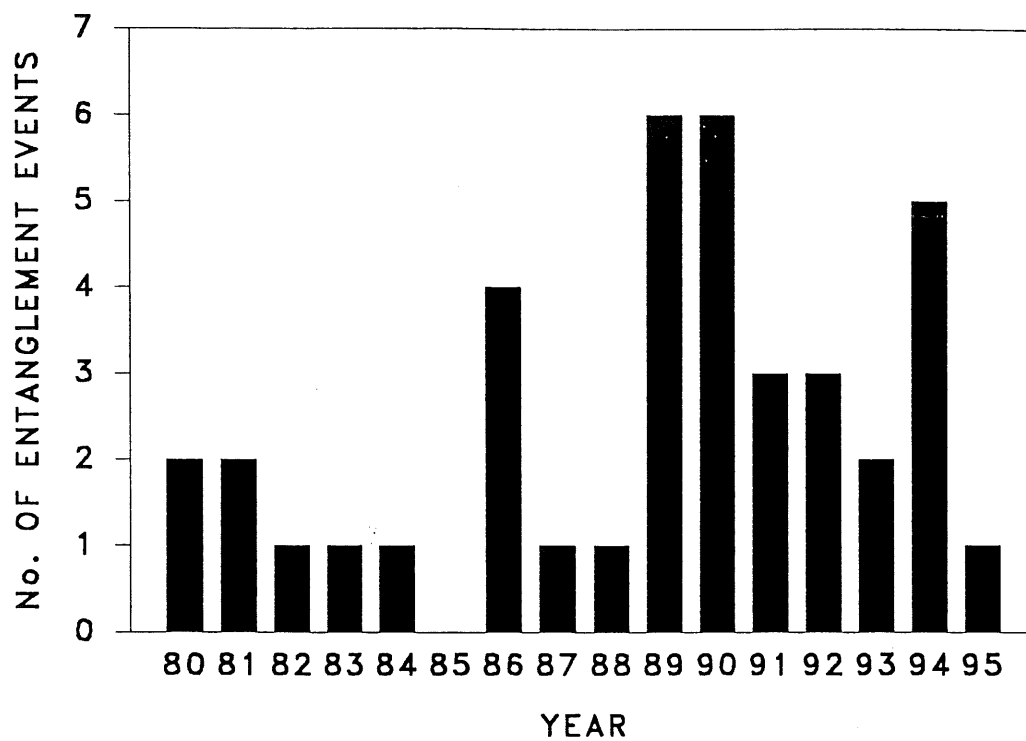


FIGURE 7. PROBABILITY OF ENTANGLEMENT SCARRING (TOP) AND TOTAL NUMBER OF WHALES IDENTIFIED (BOTTOM): 1980-1995.

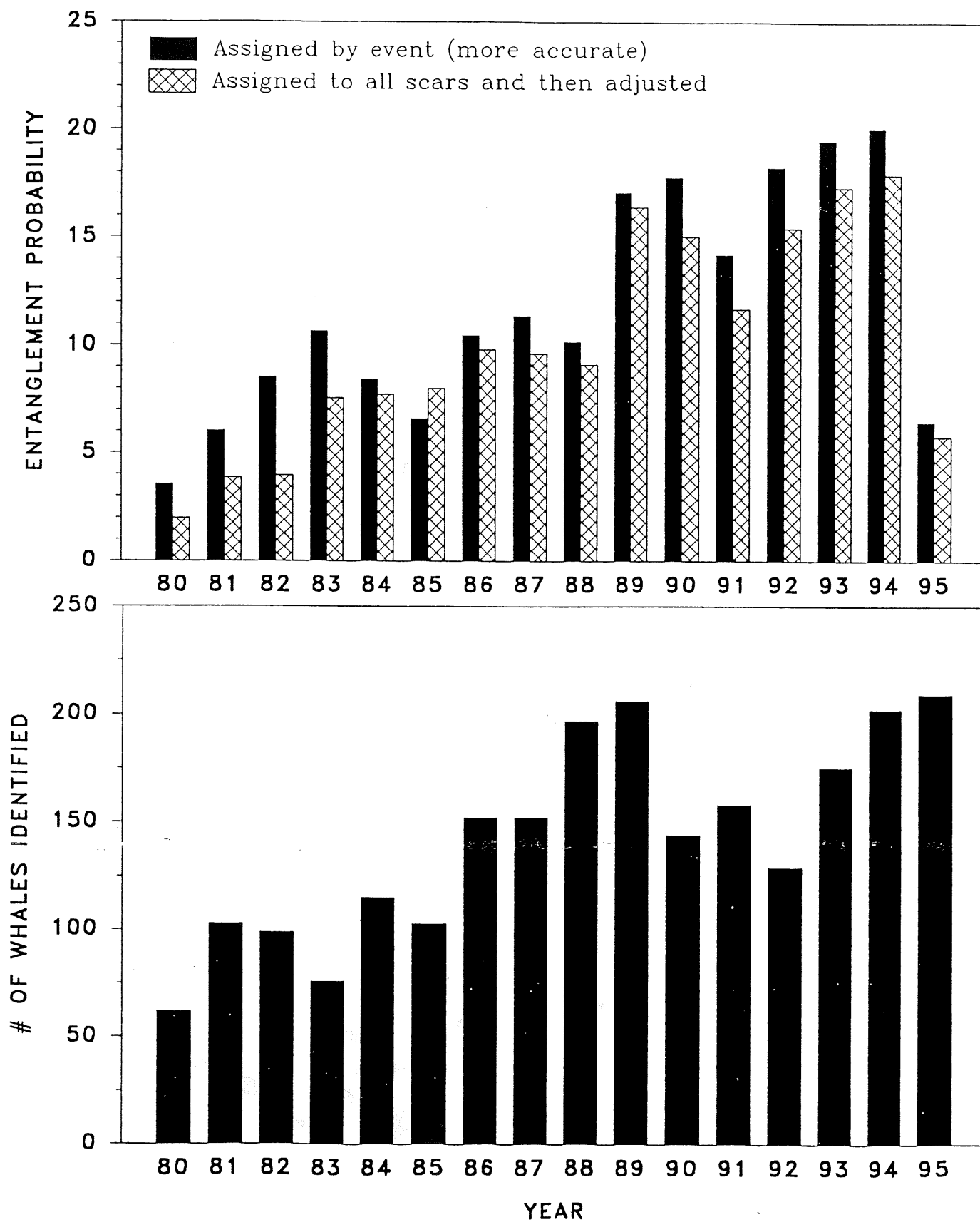


FIGURE 8. PROBABILITY OF SHIP-STRIKE SCARRING (TOP) AND TOTAL NUMBER OF WHALES IDENTIFIED (BOTTOM): 1980-1995.

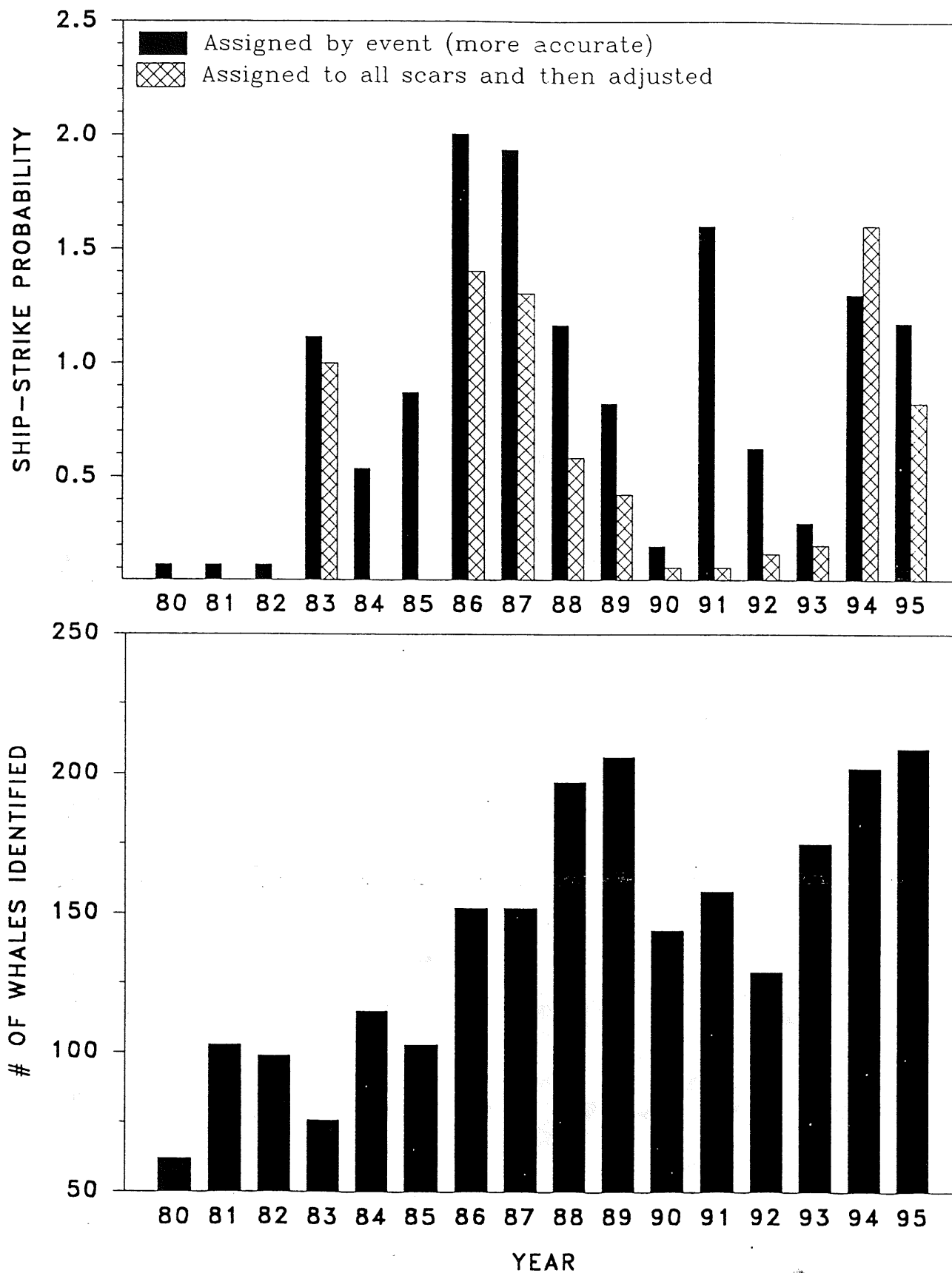


TABLE 1A. WHALE No. 1048 - SCARRING HISTORY AND ASSIGNED PROBABILITIES.

Date(s)	Area	Age	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21
Whale: 1048																							
8/80 - 8/80	BOF	U	X	X	X	X	X	X	U*	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5/81 - 5/81	MB	U	X	X	X	X	X	X	X	X	X	X	X	X	U*	X	X	X	U*	X	X	X	X
5/82 - 5/82	MB	U	U*	X	X	X	X	X	U	X	X	X	X	X	X	X	X	X	X	X	X	X	X
9/86 - 9/86	BB	U	X	X	X	D*	PG	D*	D*	X	U*	D*	X	X	X	X	X	U	U	X	X	PN	X
8/87 - 9/87	BB	U	U*	U*	D*G	DU*	U*	DU*	U*D*	D*	X	X	X	X	U	O*	X	U	U	U*	X	PN	X
3/88 - 3/88	MB	U	U	U	X	DG	UD*G	X	U	X	X	X	X	X	X	X	X	X	X	X	X	X	X
8/88 - 9/88	BB	U	U	PN	PN	D	U	DGU	UD	E'D*	E*	X	PN	U*	U	O	X	U	PN	U*	X	X	X
5/89 - 5/89	GSC	A	X	X	X	X	X	X	U	X	X	X	X	X	X	X	X	X	X	X	X	X	X
9/90 - 9/90	BB	A	X	X	X	X	U	X	U	X	X	X	X	X	X	X	X	X	X	X	X	X	X
9/92 - 9/92	BB	A	X	PN	X	D	D	D	X	X	E	D*E*	X	X	O	U*	U	U	U	X	X	X	X
8/95 - 10/95	BOF	A	U	D*G	PG	DU*	UDF*	C*D*	D*C*	X	X	X	X	X	U	O	U	U	U	X	X	X	U*

1B. ANNUAL PROBABILITIES ASSIGNED BY SCAR

Scar Region	Year	Probability
X8	1987	.3
X8	1988	.7
X9	1986	.13636
X9	1987	.54546
X9	1988	.31818
X10	1986	.04225
X10	1987	.16901
X10	1988	.16901
X10	1989	.16901
X10	1990	.16901
X10	1991	.16901
X10	1992	.11268

TABLE 2A. WHALE No. 1622 - SCARRING HISTORY AND ASSIGNED PROBABILITIES.

Date(s)	Area	Age	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21
Whale: 1622																							
3/86 - 3/86	MB	U	X	X	X	G	X	X	U*	X	X	X	X	X	X	X	X	X	X	X	X	X	X
8/86 - 10/86	MB	U	X	U*D*	D*	U*D*	U*	U*	U*	D*U*	U*	D*	N	N	N	N	N	X	X	E*	N	PN	U*
3/87 - 4/87	MB	U	X	X	X	DU*	D*	U*D1*	X	X	X	X	X	X	X	X	X	X	X	PE	X	X	X
5/88 - 5/88	GSC	U	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
8/88 - 9/88	BB	U	X	PN	PN	PN	N	U*1	U*1*	E*	E*	E*	N	N	U*	X	X	X	X	U*E	X	PE*	PN
12/88 - 2/89	FLG	U	X	U	X	D*	N	U	X	PE	E	E	X	X	X	X	X	X	X	PE	X	X	PU*
2/90 - 3/90	MB	U	X	X	X	N	N	I	B*1	X	E	E	E*	PN*	N	U*	X	N	N	X	N	U*E*	U*
8/90 - 8/90	MB	U	X	PG	X	PG	X	X	X	E	E	X	X	PN	X	X	X	X	X	PEU	X	X	X
1/91 - 1/91	FLG	U	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3/91 - 3/91	MB	U	X	X	X	U*	PN	I	X	X	PE	X	X	X	X	X	X	X	X	X	X	X	X
9/95 - 9/95	BOF	A	X	X	X	PN	U*	X	C*D*U*	X	X	X	X	X	X	X	X	PN	X	X	X	X	X

2B. ANNUAL PROBABILITIES ASSIGNED BY SCAR

2C. ANNUAL PROBABILITIES ASSIGNED BY SCAR

Scar Region	Year	Probability	Event #1. Prior to August, 86	Probability Assigned
X8	1986	.09524	Event #1. Prior to August, 86	None assigned
X8	1987	.57143		
X8	1988	.33333		
X9	1986	.09524	Event #2 October, 86 - July, 88	1986: .09524
X9	1987	.57143		
X9	1988	.33333		
X10	1986	.09524	Event #3 March, 89 - Feb. 90	1989: .90909
X10	1987	.57142		
X10	1988	.33333		
X10	1989	.90909		1990: .09090
X10	1990	.09090		

TABLE 3.

SCARS WHOSE YEAR OF OCCURRENCE IS KNOWN.

EGNO	SEX	AGE	YEAR	SEEN WITHOUT SCAR	SEEN WITH SCAR	COMMENTS
<u>Ship-Strike - 6</u>						
2404	U	0	1994	January: Florida	February: Florida	Flukes punctured
1704	F	0	1987	February: Florida	February: Georgia	Tail cut
2250	M	U	1995	October: B.O.F.	October: B.O.F.	Dead with slice down back
1128	F	2	1983	Not Seen	February: N.J.	Dead on beach with severed tail
2143	F	0	1991	Not Seen	February: Florida	Prop. wound left side
1504	F	1	1986	Not Seen	August: M.B.	Floating dead with deep prop. wound
<u>Entanglements - 38</u>						
2404	U	0	1994	January: Florida	February: Florida	
1135	F	A	1987	January: Florida	September: B.O.F.	Seen in M.B. in between- N.P.
1158	F	U	1989	January: Florida	September: B.O.F.	Seen in G.S.C. in between- N.P.
1621	U	U	1993	March: Florida	January: Florida	
1802	F	3	1991	March: M.B.	August: B.O.F.	
1426	F	6	1990	March: M.B.	August: B.O.F.	
2350	U	U	1995	March: M.B.	August: B.O.F.	
1025	F	A	1980	May: G.S.C.	October: M.B.	Seen in B.O.F. in between- N.P.
2123	F	0	1991	June: B.O.F.	August: B.O.F.	
1806	F	1	1989	June: M.B.	September: B.O.F.	
2027	M	0	1990	July: Jeffery's Ledge	August: B.O.F.	Entangled in July, scar showed in Aug.
2233	F	1	1993	July: George's Bank	August: M.B.	Line through mouth- December, 1993;
2158	M	1	1992	August: M.B.	September: B.O.F.	scarred by same line later. Dead- 1995.
2366	M	1	1994	August: M.B.	September: B.O.F.	
1301	F	0	1983	August: B.O.F.	September: B.O.F.	
2151	U	3	1994	August: B.O.F.	November: M.B.	Carrying line in the mouth in Nov.
2123	F	1	1992	September: B.O.F.	January: Florida	

TABLE 3 (cont.)

SCARS WHOSE YEAR OF OCCURRENCE IS KNOWN.

EGNO	SEX	AGE	YEAR	SEEN WITHOUT SCAR	SEEN WITH SCAR	COMMENTS
2145	F	0	1991	Not Seen	March: M.B.	
2406	U	0	1994	Not Seen	March: M.B.	
1804	M	0	1988	Not Seen	May: G.S.C.	
1909	F	0	1989	Not Seen	July: M.B.	
1610	M	0	1986	Not Seen	July: M.B.	
1123	F	0	1981	Not Seen	August: B.O.F.	
1138	M	0	1981	Not Seen	August: B.O.F.	
1153	F	0	1980	Not Seen	August: B.O.F.	
1245	F	0	1982	Not Seen	August: B.O.F.	
1404	M	0	1984	Not Seen	August: B.O.F.	
1608	F	0	1986	Not Seen	August: M.B.	
1931	F	0	1989	Not Seen	August: B.O.F.	
2018	M	0	1990	Not Seen	August: B.O.F.	
2048	U	0	1990	Not Seen	August: B.O.F.	
2057	M	0	1990	Not Seen	August: B.O.F.	
2212	M	0	1992	Not Seen	August: M.B.	
2223	F	0	1992	Not Seen	August: M.B.	
2425	F	0	1994	Not Seen	August: B.O.F.	
1607	M	0	1986	Not Seen	September: B.O.F.	
1609	M	0	1986	Not Seen	October: M.B.	

KEY: G.S.C = Great South Channel (east of Cape Cod, Massachusetts)

M.B. = Massachusetts Bay

B.O.F. = Bay of Fundy (between Maine and Nova Scotia)

N.P. = No Photo of Scarred Area