Visual health assessment of North Atlantic right whales (*Eubalaena glacialis*) using photographs

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Abstract: Although trends in reproduction, mortality, and entanglement events have been analyzed for the endangered North Atlantic right whale (*Eubalaena glacialis*) population, no method has been available to assess individual right whale health. Here, we describe a technique for assessing health based on evaluation of selected physical parameters from archived photographs of right whales. A scoring system was developed to assess body and skin condition, blowhole cyamids, and rake marks in over 200 000 photographs. Comparison of body condition scores of females during calving and noncalving years found that females were significantly thinner in calving years and in the year after calving compared with the year before calving, showing that changes in body condition known to occur during the reproductive cycle can be successfully evaluated from photographs. Comparison of scores for all parameters between living whales and whales with more than a 5-year gap in sighting history ("presumed dead") found that presumed dead whales received health assessment scores indicating compromised health with body condition emerging as a key visual indicator. This health assessment method provides a new tool to monitor health trends in right whales at individual and population levels and may provide a model for assessments of other well-photographed cetaceans.

Résumé : Alors qu'il a été possible d'analyser les tendances de la reproduction, de la mortalité et des incidents d'enchevêtrement chez la population menacée de la baleine franche de l'Atlantique Nord (*Eubalaena glacialis*), il n'y a pas de méthode disponible pour évaluer la santé des baleines individuelles. On trouvera ici une technique pour juger de l'état de santé des baleines franches d'après l'évaluation de paramètres physiques sélectionnés sur des photographies d'archive. Le développement d'un système d'attribution de points permet d'estimer la condition du corps et de la peau, la présence de cyamidés sur l'évent et celle éraflures sur plus de 200 000 photographies. La comparaison des points obtenus par les femelles pour leur condition corporelle les années de mise bas et les années sans mise bas montre qu'elles sont significativement plus maigres l'année de la mise bas et l'année suivante, en comparaison avec l'année qui précède la mise bas; il est donc possible de suivre les changements de condition corporelle qui surviennent durant le cycle reproductif à partir de photographies. La comparaison des points obtenus pour toutes les caractéristiques entre les baleines vivantes et les baleines qui n'ont pas été observées durant plus de 5 ans et qui sont présumées être mortes montre que les baleines « présumées mortes » ont obtenu des rangs plus faibles d'évaluation de santé, ce qui laisse croire à un état de santé détérioré dont le principal indicateur visuel est la condition corporelle. Cette méthode d'évaluation de la santé fournit un nouvel outil pour suivre l'évolution de la santé chez les baleines franches, tant chez l'individu que chez la population et peut fournir un modèle pour l'évaluation d'autres cétacés fréquemment photographiés.

[Traduit par la Rédaction]

Introduction

Population growth of the North Atlantic right whale (*Eubalaena glacialis*) has been compromised by high levels of human-induced mortality (Kraus 1990; Kenney and Kraus 1993; Knowlton and Kraus 2001) and decreased reproduction over the past decade (Kraus et al. 2001). Recent population modeling by Caswell et al. (1999) and Fujiwara and Caswell (2001) suggests that if current trends continue, extinction of the population is likely within 200 years. Recovery efforts have focused on reducing anthropogenic mortality and identifying the potential cause(s) of the recent reproductive decline.

Over the past decade, calving intervals of North Atlantic right whale cows have increased from 3.67 years to over 5 years, the mean age at first parturition has increased, calves per mature female per year have decreased, and yearly calf production has been extremely variable (Kraus et al. 2001). Population growth is substantially lower than that of southern right whale populations (*Eubalaena australis*) (International Whaling Commission 2001). Specific causes for the decline in reproduction have not yet been identified, but potential contributing factors include effects of environmental contaminants or marine biotoxins, nutritional stress, genetic influences, and infectious diseases (Reeves et al.

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2001). Development of methods to monitor the health of North Atlantic right whales was identified as essential to understanding the reproductive decline in this population (International Whaling Commission 2001; Reeves et al. 2001).

Health is a relative term, defined as "the state of the organism when it functions optimally without evidence of disease or abnormality" (Stedman 2000). Methods for assessing health in free-ranging wildlife include tracking population abundance, tracking rates of reproduction and mortality, and assessing key physical parameters in individuals (Fowler and Siniff 1992). Measurement and (or) estimates of body fat stores, or body condition, have been used as one indicator of health status in both terrestrial and marine mammals and have been associated with reproductive success and survivorship (Young 1976; Lockyer 1986, 1993; Guinet et al. 1998; Schulte-Hostedde et al. 2001). Body condition of wild giraffes has been evaluated visually based on the prominence of the ribs and skin folds (van der Jeugd and Prins 2000). In wild Assateague ponies, visual body condition scores were found to differ by gender and by food availability (Rudman and Keiper 1991).

Assessing the health of free-ranging cetaceans is inherently difficult because of the limited visibility of an animal's entire body while in the water, their wide distribution, and sighting variability. While harvested cetaceans have provided information on various aspects of health for some species, such data have not been useful for evaluating trends over time or for assessing health in living cetaceans (Lockyer et al. 1985; Beck et al. 1993; Gales and Renouf 1994; Pitcher et al. 2000; Nilssen et al. 2001). Stranded and captive cetaceans have provided valuable information on the health of individuals (Beckmen et al. 1997; Jauniaux et al. 1998; Cornaglia et al. 2000) but are unlikely to be representative of the entire population (Wilson et al. 1997).

A few studies have applied visual assessment criteria to evaluate relative health status in free-ranging cetaceans. Length and width measurements of gray whales (*Eschrichtius robustus*) using vertical aerial photogrammetry reliably detected changes in body condition associated with fasting during winter migration (Perryman and Lynn 2002). Although seasonal fluctuation in blubber fat reserves is normal for baleen whales, these results demonstrate that it is possible to visually detect changes in body condition that correspond to known physiological events. Therefore, it follows that loss of fat reserves due to disease or starvation, for example, could likewise be evaluated visually. Thompson and Hammond (1992) monitored the prevalence of skin lesions on the dorsal fins of wild bottlenose dolphins (*Tursiops truncatus*) using photographs routinely taken for photo-identification purposes. Lesion type and prevalence were analyzed in relationship to age, sex, habitat usage, and the influence of specific environmental parameters such as temperature and salinity (Wilson et al. 1997, 1999). These studies suggested a positive correlation between low temperature and salinity of water and prevalence and severity of lesions and showed that photographic evaluation of skin condition may be a useful health indicator. While trends in reproduction, mortality, and entanglement events for North Atlantic right whales have been analyzed based on individual photo-identification (Knowlton and Kraus 2001; Kraus et al. 2001), no method has been available to assess individual right whale health.

A collection of right whale photographs from the North Atlantic Ocean dating as far back as 1935 is curated by the New England Aquarium in Boston, Mass., and access is managed by the North Atlantic Right Whale Consortium (Hamilton and Martin 1999). For most right whales, aerial and shipboard photographs from several different locations and years have been collected (primarily since the late 1970s), allowing for a longitudinal examination of selected physical parameters based on visual assessment. This photographic database presented a unique opportunity to determine if the external appearance of individual right whales could be used to assess their health.

Here, we report on a method for assessing right whale health based on photographs using four parameters. The objectives of this study were to (*i*) develop a visual health assessment technique using photographs taken and archived routinely for photo-identification, (*ii*) assess the health of individual North Atlantic right whales over their entire sighting history, and (*iii*) evaluate the validity of this technique by testing the predictive capabilities of the health assessment in relation to life-history parameters including calving history and survivorship.

Methods

Photographic database

Systematic photo-identification surveys of the North Atlantic right whale population have been carried out since 1980 and presently include annual surveys of four of the five identified "critical habitats", habitats deemed essential to the survival of the species (Endangered Species Act of 1973. 16 U.S.C. 1531–1544 (ESA sec.3); National Marine Fisheries Service 1991). Whales are individually identifiable using the unique patterns of raised epithelium (called "callosities") on their heads, lips, and chins along with unique body scars (Payne et al. 1983; Kraus et al. 1986), making it possible to track individuals over time. The photographic database contains over 200 000 slide, print, and digital images representing 26 654 sightings of 435 individual whales photographed between 1935 and 2002. For this study, data on 410 different individual whales photographically identified through the year 2000 were used.

Health assessment parameters

Four visual health assessment parameters were identified and scoring criteria were developed by four experienced right whale biologists, a statistician, and a veterinarian. The parameters were selected based on detectable changes visible in photographs of whales in extremely poor health (e.g., whales severely and chronically entangled in fishing gear) and the availability of photographs routinely taken for photo-identification. All parameters were scored on a numerical scale, with lower scores indicating less severe or better health. Any parameter for which a reliable score could not be assigned with the available photographs was scored as "X". The four health assessment parameters and the scoring criteria used were as follows.

Body condition

The body condition score was based on estimation of the relative amount of subcutaneous fat. Because the area behind

Fig. 1. Body condition was scored from the profile of the right whale's (*Eubalaena glacialis*) back. (*a* and *b*) A score of 1 was assigned to whales with fat rolls or a flat back behind the nuchal crest. The arrow in Fig. 1*a* shows the placement and appearance of the fat roll. (*c* and *d*) A score of 2 was assigned to whales that exhibited a slight to moderate dip, as noted by arrows. (*e*–*g*) A score of 3 was assigned to whales with significant dips in their backs and (or) sides and those that exhibited a hump behind the nuchal crest. Large arrows indicate dip areas and small arrows identify the hump often observed in severely thin whales. (All photographs presented in this paper were contributed by the North Atlantic Right Whale Consortium.)

the blowholes is usually visible in lateral photographs taken for whale identification, this was used to evaluate body condition in right whales. Accumulation of fat in this neck area ("neck roll") has been described in southern right whales (Rowntree 1999) and the same area is evaluated during necropsies of small cetaceans to evaluate relative body condition (S. Rommel, personal communication). The body condition score was determined by the degree of convexity or concavity just posterior to the blowholes, also referred to as the nuchal crest (cervical region). Right whales typically display a flat or slightly rounded profile caudal to the nuchal crest when viewed laterally, and some whales exhibit a fat roll (convexity) in this area. In contrast, whales that are in poor condition have a dip (concavity) in this area. Whales that appear to be extremely thin may also exhibit "humps" behind the blowholes that are distinguishable from typical fat rolls because there is a visible dip caudal to the hump.

The angle of the photograph was an important consideration when assessing this parameter, as oblique images were difficult to evaluate. Additionally, whales that were engaged in skimfeeding or headlifting behaviors arched their backs, creating a temporary concavity. Therefore, body position had to be evaluated when scoring for this parameter. Body condition was scored on a scale of 1–3: whales that were scored as 1 had flat or rounded backs (good condition), whales scored as 2 exhibited a slight to moderate concavity, and a score of 3 was assigned to whales that were characterized by marked concavity (poor condition) (Fig. 1).

Skin condition

Evaluation of skin condition included assessment of the number and severity of lesions, the area of skin sloughing, and the appearance of cyamids (probably *Cyamus ovalis*) on the body, as this organism often colonizes wounds and appears in areas of skin damage (Rowntree 1996). Epidermal lesions of unknown origin have been previously described for North Atlantic right whales and have been classified based on color and morphology (Hamilton et al. 1998, M. Marx, unpublished data). Lesions may appear as white or grayish plaque-like patches with indistinct edges and include circular, outline, and swath types. Lesions may also appear as areas of erupting blisters resulting in crater-like patches. It is important to note that these lesions are distinct from scars resulting from entanglements, shipstrikes, and other sources. Scars were not scored during this assessment. Small patches (<5 cm) of skin with lesions, sloughing, or cyamids were not weighed heavily if the remainder of the visible skin was in good condition. This parameter was scored on a scale of 1 or 2: whales with apparently good skin condition (i.e., smooth, black skin with no epidermal lesions) were scored as 1 and those with poor skin condition were scored as 2 (Fig. 2). A two-point scoring system was used for this parameter because during the development of the criteria, it became apparent that classification in a moderate category was highly subjective.

Rake marks forward of the blowholes

Rake marks were defined as two or more parallel lines in the epidermis that sometimes occur anterior to the blowholes. The term "rake mark" used in this study should not be confused with tooth rake marks described for other cetaceans (George et al. 1994), as the marks described here are definitely not predatory in origin. The lines vary in color intensity (bright white to gray) and the degree to which they radiate around the blowholes. Neither the significance nor the origin of rake marks is known, but they often become more prominent on whales in poor health (chronically entangled, for example). These marks appear only forward of the blowholes and their parallel and regular spacing distinguishes them from scrape marks described in Payne and Dorsey (1983). Rake marks were scored independently for the left and right blowholes, as they were often not symmetrical. Scoring criteria included the presence–absence of marks, the number of marks, the brightness and depth of the marks, and the area covered around the blowholes. Whales possessing zero to few rake marks were scored as 1, a score of 2 was assigned to whales with several radiating lines, and whales with many radiating rake marks that appeared to be deeply furrowed and (or) bright white were assigned a score of 3 (Fig. 3).

Cyamids around blowholes

The presence of cyamids around the blowhole region of whales has been associated with long-term entanglement events and other injuries (Osmond and Kaufman 1998). This parameter was scored on a scale of 1 or 2 (a two-point system was used for the same reasons stated for skin condition); whales with zero to few cyamids (individuals or small aggregates) were scored as 1, and whales whose blowholes were largely or completely covered with cyamids were scored as 2 (Fig. 4).

Parameter scoring and consistency analysis

Over 200 000 photographs of right whales from 1935 through 2000 were examined and scored for this study. Photographs from both vessels and aircrafts were analyzed according to individual whale, habitat, and year. All sightings of a given whale in each habitat were evaluated together, resulting in a score for that habitat and year. If the available photographs were of sufficient quality for assessment, scores were assigned to each of the four parameters. For consistency, all scoring was performed by one primary researcher (researcher 1). Rake marks, body condition, and cyamids around the blowholes were difficult to detect from aerial photographs, and therefore, when only aerial shots were

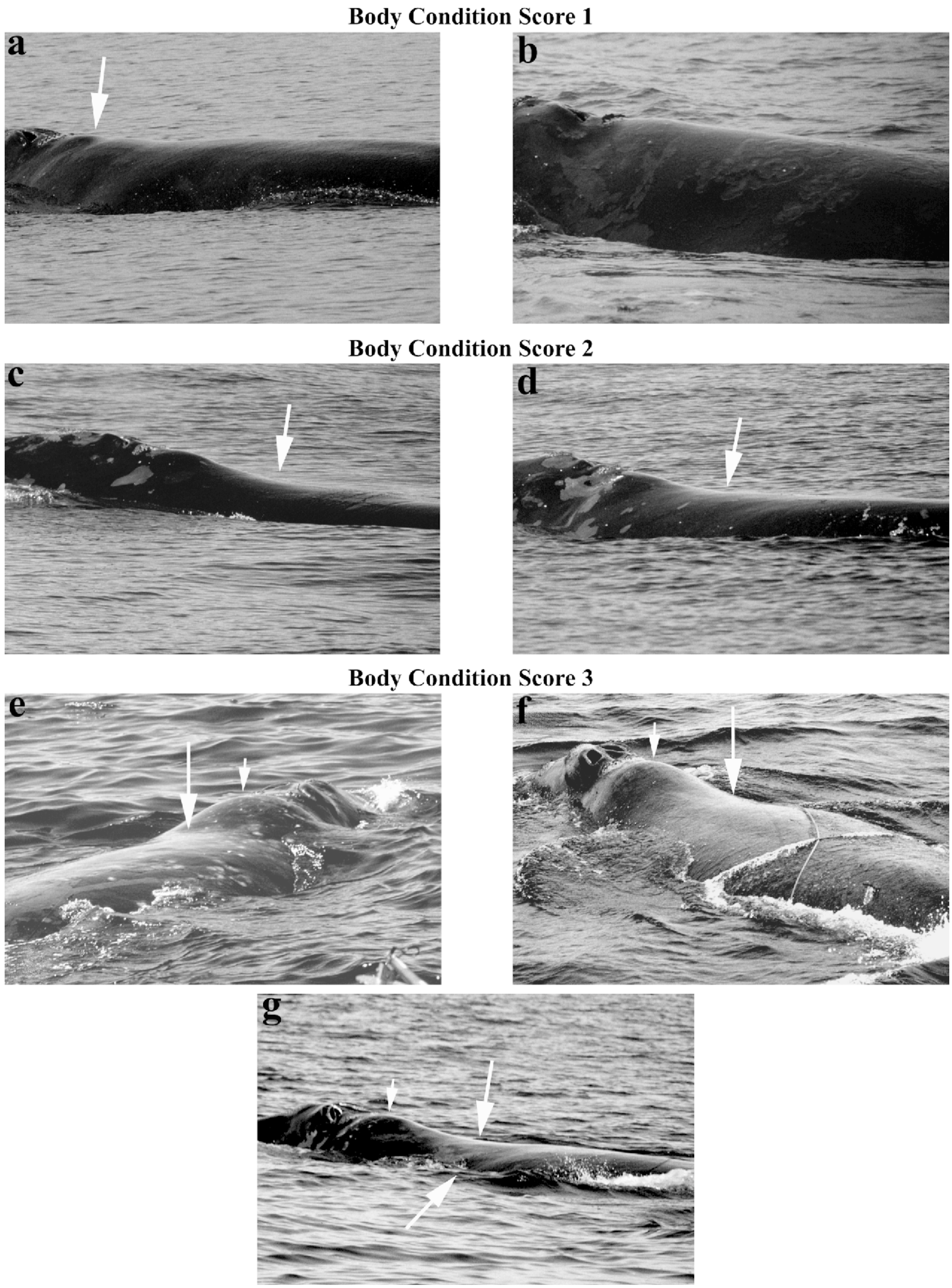

Body Condition Score 1
a
b
Body Condition Score 2
c
d
Body Condition Score 3
e
f
g

Fig. 2. Right whale (*E. glacialis*) skin condition was scored based on the absence–presence of skin lesions, blisters, excessive sloughing, and coverage of cyamids on large areas of the body. (*a*–*c*) Whales with black skin that showed limited sloughing were scored as 1. (*d*–*g*) Whales with swath lesions (*d*), significant lesion coverage (*e* and *f*), blisters (*g*), extensive sloughing, and (or) a large area of the body covered with cyamids were scored as 2. Arrows for whales in Figs. 2*d*–2*g* identify areas of the body with poor skin condition.

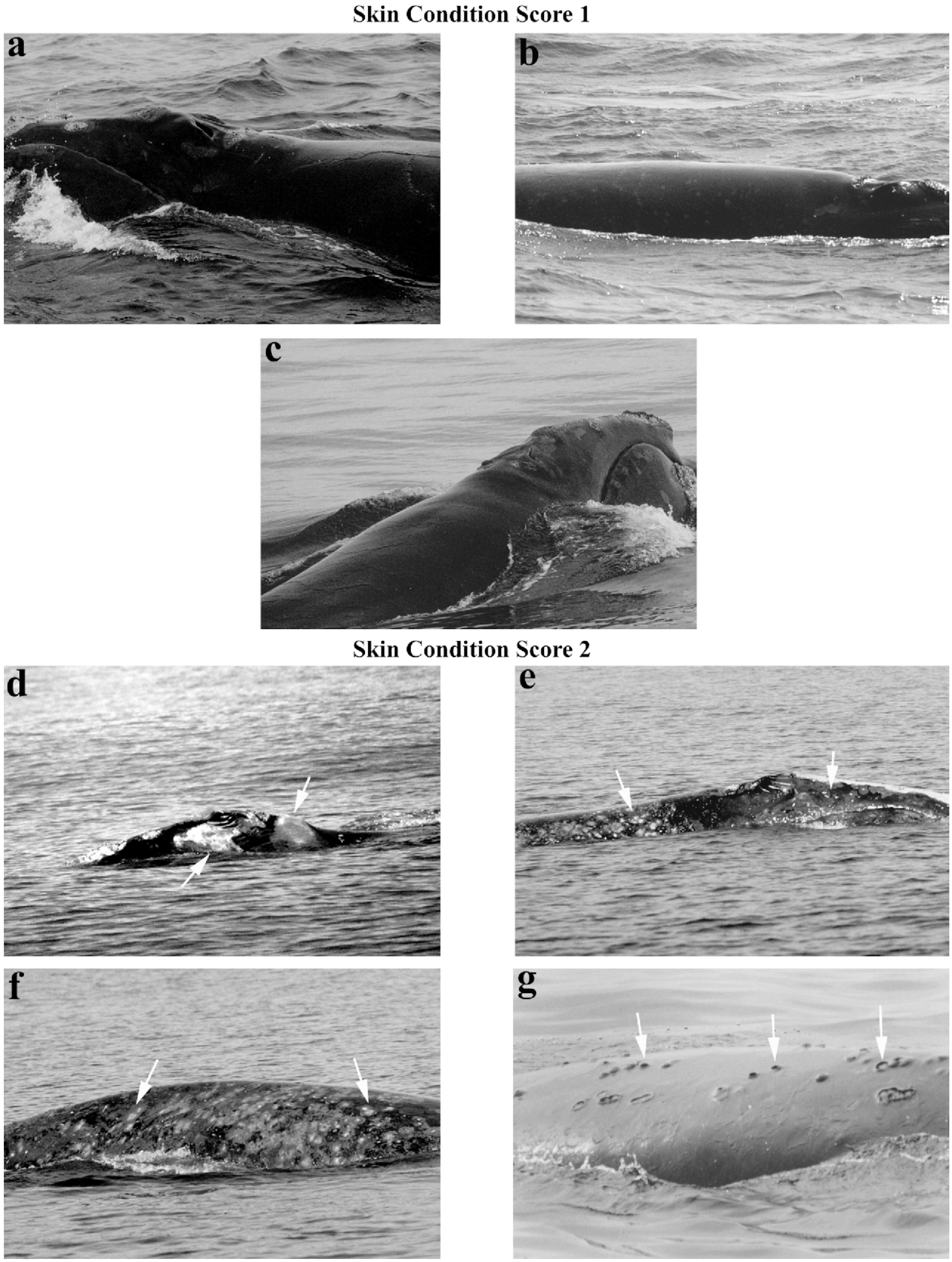
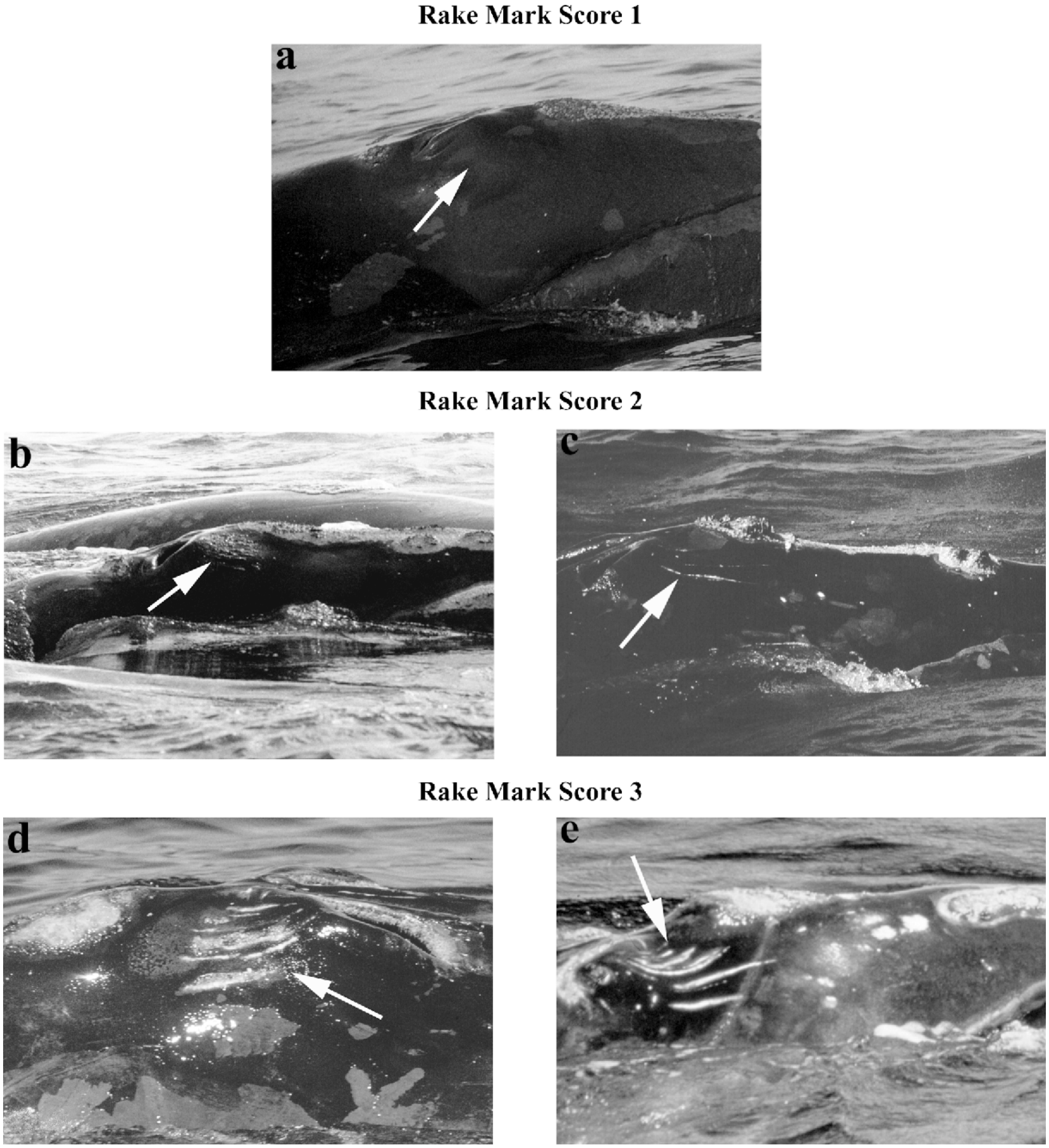


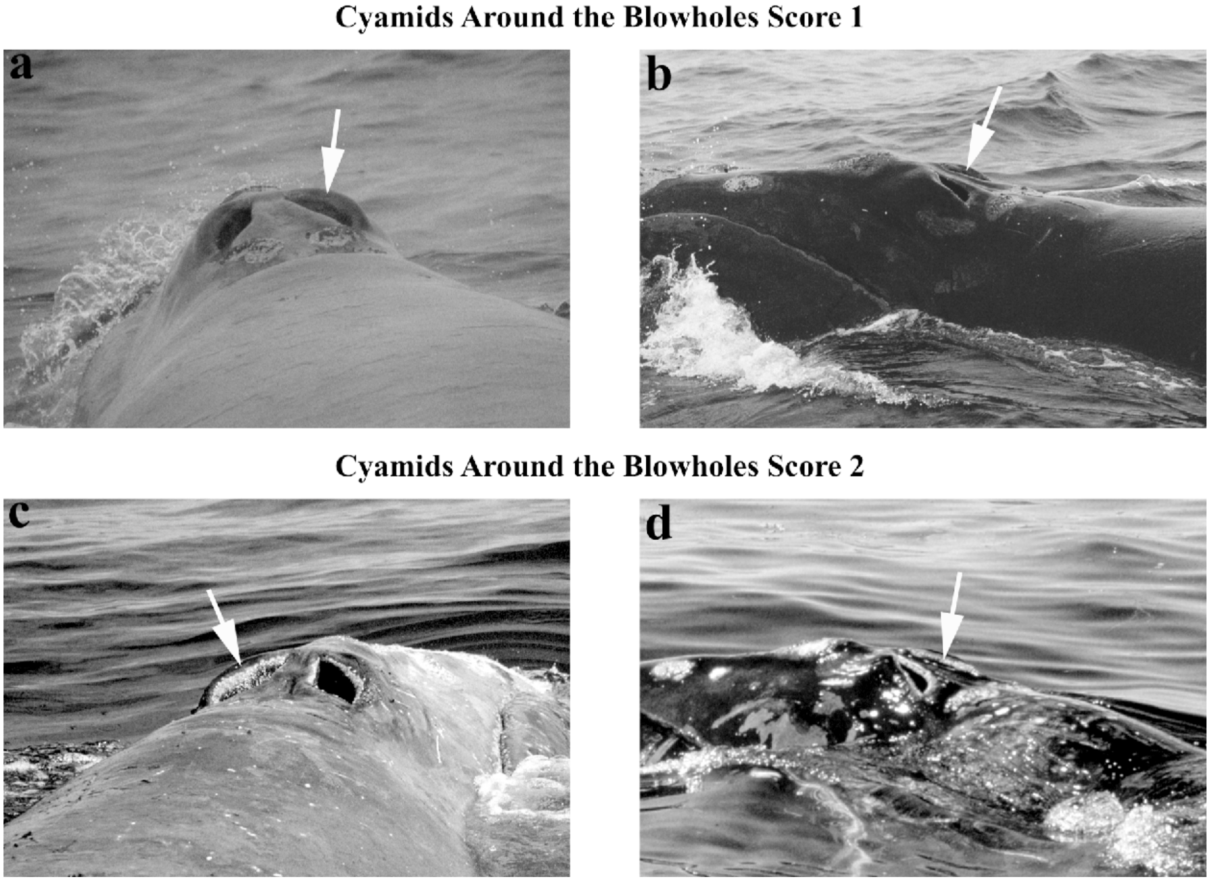
Fig. 3. Right whale (*E. glacialis*) rake marks, defined as two or more parallel lines forward of each blowhole, were scored independently for the right and left sides of the heads. Arrows identify the area inspected for this parameter. (*a*) Whales with zero to few parallel lines extending from the blowholes forward to the rostrum were scored as 1. (*b* and *c*) Whales with several parallel lines in this area that appeared to radiate around the blowhole but were not significantly deep or long were scored as 2. (*d* and *e*) A score of 3 was assigned to whales with many lines radiating around the blowholes that appeared to be deep and (or) long.



available, these parameters were scored only if the parameter area was clearly visible, resulting in a conservative estimate. In contrast, skin condition was routinely assessed from aerial photographs when large portions of the whale were clearly visible because skin lesions, presence of large patches of cyamids on the body, and extensive epidermal sloughing were readily visible.

To determine the consistency of the scoring among different observers, a double-blind study was conducted. Two additional experienced right whale biologists (researchers 2 and 3) independently examined and scored 100 randomly selected collections of photographs of individual whales grouped by habitat and year. There were variable numbers of photographs in each of the 100 collections of individual whale sightings. As photographs were grouped by habitat and year and then analyzed as a set, a whale could have one sighting or multiple sightings in a given habitat per year. Parameter entries that were scored as non-X (i.e., photographs were of sufficient quality to score the parameter) by the primary researcher and a second researcher were compared for interresearcher consistency using Kappa’s weighted test for agreement (Cohen 1968).

Fig. 4. Cyamids (probably *Cyamus ovalis*) around the blowholes of right whales (*E. glacialis*). (*a* and *b*) Whales with no or few cyamids (individuals or small aggregates) were assigned a score of 1. (*c* and *d*) Whales whose blowholes were significantly covered with cyamids were scored as 2. Arrows in these photographs illustrate the area inspected for this parameter.



Analysis of health assessment scores in relation to reproductive events and survivorship

Two sets of analyses were conducted to assess the usefulness of the visual health assessment technique for evaluating right whale health and predicting survivorship. The first set of analyses tested the ability of body condition scores to detect known physiological variations in body fat that occur during the reproductive cycle of cows (females who have calved at least once). In the second set of analyses, parameter scores were compared between whales known to be living and whales presumed to be dead (as described by Knowlton et al. 1994) to assess whether the health assessment criteria could be used as a predictor of presumed mortality. These analyses are described in detail below.

Effect of calving on cow body condition scores

Energy requirements of mammals, including large whales, are known to be high during pregnancy and particularly during lactation (Young 1976; Lockyer 1981). Historical whaling data indicate that females with calves produced much lower oil yields than whales without calves, reflecting a depletion of body fat stores (Rice and Wolman 1971; Reeves and Mitchell 1986). Therefore, if the health assessment technique is accurate, cows should be scored as thinner in years that they are supporting a calf than in years that they are not. To test this, the body condition scores of cows in years with a calf and in years without a calf were compared. Sighting data for cows with and without calves spanned the years 1935–2000. For each cow, an average body condition score was calculated for each year the whale was seen following its first calving event. The scores were averaged for all calving years, and then again for all noncalving years for each cow, resulting in a data set consisting of paired data points for individual cows. Pregnant females were included in the noncalving year category. Calving year was defined as the calendar year of a calving event. A nonparametric Wilcoxon paired sample test was used to compare cow body condition in calving and noncalving years. All tests were considered significant at $P < 0.05$.

To investigate changes in cow body condition over multiple years and to determine if the health assessment scoring technique could detect the recovery of cow body condition following calving events, individual cow body condition scores were compared for the years before, during, and after calving. This analysis differs from the previous one, which combined all noncalving years (i.e., not just pre- and postcalving years). An average body condition score for each cow and year was calculated. Three paired data sets were created: one comparing body condition in the year before with that in the year during calving, one comparing the year during with the year after calving, and one comparing the year before with the year after calving. If a cow had more than one paired record for an analysis, then a single record was randomly selected and included. Wilcoxon paired sample tests were performed for each paired set of data.

Controlling for population-wide interannual body condition variation

Annual population-wide variation in body condition of right whales, caused by changes in the availability or nutritional content of copepod prey, potentially exists (International Whaling Commission 2001) and could confound the body condition analyses. Because the body condition of adult males would not be affected by reproductive events as that of cows is, we reasoned that adult males probably provide the most representative measure of population-wide annual variation in body condition. To control for this potential confounder, the above analyses were repeated using cow body condition scores "standardized" to adult male scores by year. There were no significant differences between the nonstandardized and standardized analyses, and therefore, only the nonstandardized results are presented in this paper.

Health assessment scores of presumed dead compared with known living whales

Right whales that are not sighted and photographically identified for 5 consecutive years are presumed dead during the sixth year (Knowlton et al. 1994). Although some whales that are subsequently presumed dead are entangled in fishing gear or severely wounded at their last sighting, most show no signs of physical trauma before disappearing. However, field observations suggest that some of the presumed dead whales appeared to be in poor health at their last sighting (i.e., they were thin, had skin lesions, had large portions of body covered with cyamids, etc.). To test the significance of these observations, the health assessment scores of presumed dead whales were compared with those of known living whales. Since a 5-year sighting gap is required for a whale to be classified as presumed dead, the data set for this analysis included sighting data only for the years 1981–1995 (at the time of analysis, whales last sighted in 1996–2000 had not yet been classified as presumed dead). To ensure large enough sample sizes for statistical analyses and to account for potential yearly variations in health assessment parameters, presumed dead and living whale health score data were grouped into 5-year periods for analysis: 1981–1985, 1986–1990, and 1991–1995. Presumed dead whales in each year were those last sighted in that year, while living whales were those seen the same year but that were also resighted in later years. The potential for finer year-to-year variations in health parameter scores exists, but limited sample sizes precluded analysis of such variations.

Presumed dead and living whale health assessment scores were compared using both cumulative health scores (summed scores of all four parameters) and individual parameter scores to investigate their predictive potential. As cumulative health score analyses required that all four parameters were adequately photographed and scored as non-X for each entry, the resulting sample size was smaller than that of the individual parameter analyses. To eliminate unequal weighting by the original scoring system (because the scales varied between 1 or 2 and 1–3 for different parameters), cumulative health assessment scores were compared by first rescaling all parameter scores for completely scored entries from a two- or three-point scale to a six-point scale. Cumulative and individual parameter scores of presumed dead and living whales for each 5-year period were compared using the Mann–Whitney test. Additionally, the fate of whales scored as severely thin (body condition score 3) was investigated using body condition scores for all sightings from 1935 to 2000.

Table 1. Weighted kappa values (K_w) for the double-blind study comparing right whale (*Eubalaena glacialis*) parameter scoring by different researchers.

	K_w	
Parameter	Research 1 vs. researcher 2	Researcher 1 vs. researcher 3
Rake marks left	0.61	0.64
Rake marks right	0.61	0.54
Body condition	0.86	0.87
Skin condition	0.88	0.83
Cyamids around blowholes	1.00	—[a]

Note: Cohen's K_w scale: >0.80, strong; >60 and <80, good; >40 and <60, moderate; >20 and <40, fair; <20, poor. This test examines agreement along the diagonal of a square table of the primary researcher values by secondary researcher values. In this case, 30 entries were assigned a score of 1 by both researchers and 2 were scored as 2 by the primary researcher (1) and 1 by researcher 3. Since there were no entries scored as 2 by both researchers, it was not possible to calculate a K_w value.

[a]There was 94% agreement between researchers 1 and 3 for cyamids around the blowholes; however, a K_w value could not be determined.

Results

Parameter scoring and consistency analysis

More than 200 000 slide, print, and digital images of 410 individual whales were analyzed, resulting in 5149 scored entries for the four parameters. Of these entries, 2002 (38.9%) were completely scored (non-X) for all four health assessment parameters. The following numbers were scored as non-X for each individual parameter: rake marks left, 3323 (64.5%); rake marks right, 3273 (63.6%); body condition, 3520 (68.4%); skin condition, 4737 (92%); and cyamids around the blowholes, 2505 (48.7%). The comparatively high percentage of scoring for skin condition reflects the ability to evaluate this parameter from aerial and other photographs that are not always adequate for assessment of other parameters.

The results of the universal comparative scoring study showed strong agreement between the primary researcher (1) and researchers 2 and 3 for body condition, skin condition, and cyamids around the blowholes (for researchers 1 and 2) and moderate agreement for both right and left rake marks (Table 1).

Analysis of health assessment scores in relation to reproductive events and survivorship

Effect of calving on body condition scores of cows

The median body condition score for all cows in years without a calf was 1.08, while the median body condition in years with a calf was 1.67. A pairwise Wilcoxon comparison showed that cows were significantly thinner in years with a

Table 2. Results of Wilcoxon one-tailed comparison of health assessment scores between presumed dead and living right whales (*E. glacialis*).

	1981–1985		1986–1990		1991–1995	
Parameter	*n* presumed dead/living	*P*	*n* presumed dead/living	*P*	*n* presumed dead/living	*P*
Cumulative scores	7/195	**0.0003**	16/402	0.0531	11/489	**0.0046**
Rake marks left	12/298	0.1921	27/624	0.7663	21/683	**0.0004**
Rake marks right	13/294	**<0.0001**	25/615	0.4733	21/679	**0.0203**
Body condition	15/329	**0.0064**	29/704	**0.0141**	24/707	**<0.0001**
Skin condition	19/429	0.2923	31/764	0.2637	31/804	**<0.0001**
Cyamids around blowholes	10/233	0.0589	21/471	**0.0198**	16/557	**<0.0001**

Note: H_0: scores of presumed dead whales are less than or equal to those of living whales. Bold values are significant at $P < 0.05$.

Table 3. Right whales (*E. glacialis*) with body condition scores of 3 between 1935 and 2000 and their present status (as of 2002).

Whale ID No.	Sex	Year of birth	Year scored body condition 3	Years since last sighted	Present status	Comments
1163	F	1981	1991	11	Presumed dead	Calving year, previously entangled
1907	F	1989	1991	na	Dead in 1991	Entangled
2233	F	1992	1993	9	Presumed dead	Entangled
1135	F	Unknown	1996	6	Presumed dead	Calving year
2557	F	1995	1997	5	Unknown	Entangled
1333	M	Unknown	1998	na	Dead in 1998	
1617	M	Unknown	1994, 1998	0	Alive	Sighted in 2002
2212	M	1992	1998	4	Unknown	Entangled
1014	F	Unknown	1999	na	Dead in 1999	Shipstrike
1505	M	1985	1999	3	Unknown	

Note: Right whales are presumed dead following a 5-year sighting gap. The status of whales that have not been seen in <5 years is considered unknown. na, not applicable.

calf than in those without, as indicated by the higher score (T = 46, P < 0.0001, n = 57). Body condition scores increased (whales scored thinner) during years with a calf compared with years without a calf for 42 of the 57 (73.7%) cows in this analysis. Body condition scores remained unchanged for 12 (21.0.%) cows and decreased (whales scored fatter) for 3 (5.3%) cows in years with a calf.

The body condition scores of cows were significantly lower (better condition) in the year before calving than in the year of calving (T = 0, P < 0.0001, n = 46), higher (poorer condition) in the year of calving than in the year after calving (T = 127, P = 0.0058, n = 34), and lower in the year before calving than in the year after calving (T = 0, P = 0.0011, n = 26).

Comparison of health scores between presumed dead and living whales

Cumulative health parameter scores differed significantly between presumed dead and living whales for 1981–1985 and 1991–1995 (U = 1082.5, P = 0.0003, and U = 3735.5, P = 0.0019, respectively; see Table 2 for sample sizes) but just missed statistical significance for 1986–1990 (U = 3654.5, P = 0.0531). In both cases where there was a statistical difference, the parameter scores of the presumed dead whales were significantly higher (poorer condition) than those of living whales (Table 2).

All of the individual parameters were scored significantly higher for presumed dead whales than for living whales for 1991–1995. Additionally, scores were significantly elevated in presumed dead whales for rake marks on the right side of the blowholes for 1981–1985 (U = 2413, P < 0.0001), for cyamids around the blowholes for 1986–1990 (U = 5149.5, P = 0.0198), and for body condition for 1981–1985 and 1986–1990 (U = 3005, P = 0.0064, and U = 11137.5, P = 0.0141, respectively; see Table 2 for sample sizes). Body condition scores were significantly elevated in presumed dead whales over all years (Table 2).

Severely thin whales

Ten right whales were scored with a body condition of 3 (severely thin) for the years included in this assessment. Three of these whales are known to have died, and six others have not been sighted since they were classified as severely thin (three of those are presumed dead). The tenth whale had a body condition of 3 in 1994 and was resighted in 1998, still with a body condition of 3. This whale was recently sighted in 2002, but body condition assessment was not possible. Of these 10 whales, 4 were entangled in fishing gear at the last sighting, 1 had been previously entangled, and 1 had been struck by a vessel an estimated 10 days prior to death (Table 3).

Discussion

The technique described in this paper is the first visual criteria based system developed to assess the health of individual right whales using photographs. Comparisons of parameter scoring by multiple researchers indicated that the scoring methodology in this assessment is sufficiently objective and can be utilized by any experienced right whale biologist. The fact that archived data can be used increases the utility of this technique for retrospective analyses related to reproduction and survivorship.

Analysis of the body condition scores of right whale cows indicated that cows are significantly thinner during years in which they are supporting a calf. The impacts of the female reproductive cycle on body condition are well documented for large whale species (Rice and Wolman 1971; Lockyer 1981, 1984). Our results concur with previous work that outlines the high energetic costs of lactation in which the blubber layer of females is thickest during the year of pregnancy and is depleted throughout lactation (Lockyer 1984, 1986; Reeves and Mitchell 1986). Once weaning occurs, females begin to replenish blubber reserves. In this study, pairwise analyses of the body condition scores of individual cows in the year before, the year during, and the year after a calving event follow closely these known trends in body condition. This suggests that the scoring criteria for this parameter are sensitive enough to discern the annual fluctuations in blubber reserves experienced by cows during gestation and lactation. Since reproductive success for many mammals, including large whales, is heavily influenced by body condition, this method provides a new opportunity to examine the relationship between calving success and body condition at both individual and population levels.

Cumulative health assessment scores were significantly higher (poorer condition) for presumed dead whales compared with living whales for two out of three 5-year periods investigated. Currently, there is no way to monitor right whale mortality accurately, as many carcasses are probably lost at sea and never detected. The presumed dead classification was developed to provide an indication of which whales may have died, but it is based solely on gaps in sighting history and is not statistically rigorous (Caswell et al. 1999). Indeed, some presumed dead whales are later resighted alive. The health assessment technique's ability to detect significant differences between presumed dead and living whales suggests that including health data will improve estimation of resighting probabilities and thus provide better estimates of right whale mortality resulting from chronic health effects (old age, disease, starvation, etc.). Body condition was consistently scored higher for presumed dead whales than for living whales for all three time periods. This result, coupled with the observation that only 1 of the 10 whales coded as severely thin has ever been resighted, suggests that the body condition parameter in itself may serve as a useful predictor of mortality in right whales.

Body condition has long been known to affect survival and reproduction in both terrestrial and marine mammals (Young 1976; Pitcher et al. 2000; Shulte-Hotedde et al. 2001). For example, it has been hypothesized that the recent decline of Steller sea lions (*Eumetopias jubatus*) in the western Pacific Ocean has been caused by nutritional stress resulting in a decline in reproductive success (Calkins et al. 1998; Pitcher et al. 1998). Nutritional stress has also been hypothesized as a factor reducing reproductive success in the North Atlantic right whale population (International Whaling Commission 2001; Kraus et al. 2001). Recently, amplitude-mode ultrasound has been used to measure dorsal blubber thickness to investigate the possible link between body condition and reproduction in right whales (Moore et al. 2001). The visual body condition assessment described here complements that approach because it can be used to monitor long-term trends at the individual level as well as population-wide body condition.

Whales last seen and presumed dead for 1991–1995 were scored in significantly poorer health than living whales for all four parameters. Additionally, all of the whales that were scored as severely thin were from sightings between 1991 and 1999. These observations could be indicators of a population-wide disease or starvation event during the 1990s. This same time period coincides with a significant decline in measures of reproductive success in this population (Kraus et al. 2001), suggesting a causal relationship that needs to be investigated further.

Several factors complicated the visual health assessment analyses. This study relied upon well-photographed sightings, in terms of both the quality and the number of photographs. Since evaluating health parameters relies upon images of several parts of the body, sightings for which only a few or poor-quality photographs were available were not useful for the assessment. Additionally, skin condition is the only parameter that could be routinely scored from aerial photographs, so for right whales seen in areas where only aerial surveys are conducted (Great South Channel, southeastern United States), most health parameters could not be assessed. Sighting heterogeneity of right whales, particularly adult females, may also complicate the analysis of health scores. Brown et al. (2001) found that the sighting rates of adult noncalving females were significantly lower than those of other age classes and sexes and that sighting rates of calving females were significantly higher than expected when they were lactating. This suggests that monitoring the health of adult females, both calving and noncalving, may be difficult. Lastly, the sample size of presumed dead whales is considerably smaller than that of living whales. We compensated for this by pooling data into 5-year groups; however, this pooling potentially masks intergroup health-score variation that needs to be addressed in future analyses.

This visual health assessment method provides a new tool with which to monitor health-related trends in right whales at both the individual and population levels. Population-wide health assessment scores can be coupled with the results from ongoing studies of right whale genetics, blubber thickness, and reproductive and stress hormone levels to give a more accurate picture of the relationships between right whale health, reproductive success, and survivorship. This approach may also be used as a model for application to other well-photographed whale species such as gray whales (*Eschrichtius robustus*), humpback whales (*Megaptera novaeangliae*), and killer whales (*Orcinus orca*). Long-term photographic documentation, combined with appropriate statistical methods, may provide useful insights to support the management and conservation of several cetacean species.

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