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Amanda L. Bradford
alb992@u.washington.edu

David W. Weller
Washington Cooperative Fish and Wildlife Research Unit, School of Aquatic and Fishery Sciences, University of Washington

Yulia V. Ivashchenko
Kamchatka Branch of Pacific Institute of Geography, Far East Branch of the Russian Academy of Sciences, Pr. Rybakov, 19-a, Petropavlovsk-Kamchatsky, 683024, Russia

Alexander M. Burdin
Kamchatka Branch of Pacific Institute of Geography, Far East Branch of the Russian Academy of Sciences, Pr. Rybakov, 19-a, Petropavlovsk-Kamchatsky, 683024, Russia

Robert L. Brownell Jr.
Southwest Fisheries Science Center, NMFS, NOAA, rlbcetacea@aol.com

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Amanda L. Bradford[*], David W. Weller[+], Yulia V. Ivashchenko[#], Alexander M. Burdin[#†§], and Robert L. Brownell, Jr.[¥]

Contact e-mail: *alb992@u.washington.edu*

ABSTRACT

The western gray whale population (*Eschrichtius robustus*) is critically endangered and its potential for recovery is uncertain. Along with other natural and anthropogenic threats, western gray whales are susceptible to nutritional stress, known from regular observations of individual whales in compromised body condition. Thus, the ability to visually quantify the relative body condition of free-ranging western gray whales and evaluate how this condition varies seasonally and annually is needed. A photo-identification study of western gray whales on their feeding ground off the northeastern coast of Sakhalin Island, Russia, produced a large dataset of digital, film, and video images of 150 identified individuals from 1994 to 2005. These images were utilized to visually assess the body condition (i.e., good, fair, poor) of western gray whales by evaluating the relative amount of subcutaneous fat in three body regions presumed to reflect reductions in body condition. Multinomial logistic regression for ordinal responses was used to evaluate the effects of year, month, whale class, and sex on the body condition of western gray whales. Although the correlation between observations of individual whales has not yet been accounted for, significant findings of the analysis indicate that: 1) the body condition of whales varied annually and seasonally; 2) the body condition of whales improved as each feeding season progressed; and 3) lactating females were in relatively poorer body condition nursing calves in comparatively better body condition. Additional work is needed to refine the statistical analysis. Investigating the causes and consequences of compromised body condition in western gray whales is important for understanding the health and viability of this population.

KEYWORDS: BODY CONDITION; HEALTH; NUTRITION; PHOTO-IDENTIFICATION; SAKHALIN ISLAND; SPECIES CONSERVATION; WESTERN GRAY WHALE; *ESCHRICHTIUS ROBUSTUS*

INTRODUCTION

The population of gray whales (*Eschrichtius robustus*) in the western North Pacific is critically endangered (Hilton-Taylor, 2000; Weller *et al.*, 2002), numbering on the order of 100 individuals in recent assessments (Cooke *et al.*, 2007; Bradford *et al*. In Press). Among other natural and anthropogenic threats (Weller *et al.*, 2002; Reeves *et al.*, 2005), western gray whales are vulnerable to nutritional stress, as evidenced by regular observations of individual whales in compromised body condition, which have been

[*] Washington Cooperative Fish and Wildlife Research Unit, School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195-5020, USA.
[+] Southwest Fisheries Science Center, NMFS, NOAA, 8604 La Jolla Shores Drive, La Jolla, CA 92037-0271, USA.
[#] Kamchatka Branch of Pacific Institute of Geography, Far East Branch of the Russian Academy of Sciences, Pr. Rybakov, 19-a, Petropavlovsk-Kamchatsky, 683024, Russia.
[†] Alaska SeaLife Center, 301 Railway Avenue, Seward, AK 99664, USA.
[§] University of Alaska Fairbanks, P.O. Box 757500, Fairbanks, AK 99775, USA.
[¥] Southwest Fisheries Science Center, NMFS, NOAA, 1352 Lighthouse Avenue, Pacific Grove, CA 93950, USA.

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referred to as 'skinny' whales (Brownell and Weller, 2001; Weller *et al.*, 2002). The causes for this reduction in body condition, as well as the consequences for the population are unknown, but are of interest given the conservation status of western gray whales. Thus, developing a method to quantify the relative body condition of free-ranging western gray whales is needed, as is evaluating how this condition changes over time and within different population segments. A long-term photo-identification study of western gray whales on their summer feeding ground off the northeastern coast of Sakhalin Island, Russia, resulted in a large dataset of digital, film, and video images of 150 identified individuals between 1994 and 2005. Bradford *et al.* (2007) detailed how these images were used to visually assess the body condition of western gray whales. Findings from a qualitative exploration of the resulting body condition determinations indicate that: 1) the body condition of whales varied annually and seasonally throughout the study period; 2) the body condition of whales generally improved during each field season; 3) lactating females were typically in compromised body condition nursing calves that were almost always in good condition; and 4) individual variation in the body condition of both male and female whales is high (Fig. 1; Bradford *et al*. 2007). The objective of this follow-up report is to present results from the ongoing quantitative analysis of western gray whale body condition.

METHODS

Since 1997, western gray whale photo-identification surveys have been conducted annually during summer months off Piltun Lagoon, located on the northeastern coast of Sakhalin Island, Russia, following an opportunistic effort in 1994 and a pilot study in 1995 (Weller *et al*. 2008). Detailed information about the study area and the photo-identification data collection and analysis protocols can be found in Weller *et al.* (1999). From 1994 to 2005 during months ranging from June to October, 307 photo-identification surveys were carried out, producing 4,547 sightings of 150 identified whales. Note that the sex of 127 of these individuals is known from genetic analyses of biopsy samples collected in coordination with photo-identification efforts. A sighting consisted of at least one high quality photo-identification image, although several photo and simultaneous video images were usually collected during each sighting. Fourteen additional sightings of 12 of these individuals were obtained during a survey of an ephemeral feeding area approximately 60 km southeast of Piltun Lagoon (Burdin *et al.*, 2002). In total, 28,274 film and digital photos and 33 hours of digital video from 4,561 sightings of 150 photo-identified individuals were examined in order to assess western gray whale body condition. However, only data collected during July through August of 1997 to 2005 are being utilized in the quantitative analysis of body condition, so that seasonal and annual comparisons can be made. The analysis subset involves 4,385 sightings of 149 individual whales.

A protocol adapted from North Atlantic right whale (*Eubalaena glacialis*) researchers (Pettis *et al.*, 2004) was used to quantify the body condition of western gray whales. In a retrospective analysis of photo-identification data, Pettis *et al.* (2004) visually assessed the relative amount of subcutaneous fat in the post-cranial area of North Atlantic right whales. This index of body condition was evaluated with three other parameters (i.e., skin condition, blowhole rake marks, and blowhole cyamids) as a means of assessing the health of individual right whales (Pettis *et al.*, 2004). The body condition of western gray whales was quantified using a similar scoring approach as that of Pettis *et al*. (2004), although two additional body regions that are also regularly captured during photo-identification efforts were examined. That is, the relative amount of subcutaneous fat was visually assessed in three body regions: 1) the post-cranial area, 2) the scapular region, and 3) the lateral flanks. Apparent reductions in body mass in these regions lead to three diagnostic features, respectively: 1) a post-cranial depression, 2) a subdermal protrusion of the scapula, and 3) a depression along the dorsal aspect of the lateral flanks (Brownell and Weller, 2001). Although the underlying physiological mechanisms are not well understood, whales exhibiting these features are considered to be in compromised body condition (Brownell and Weller, 2001).

All available digital, film, and video images of individual western gray whales were examined in the assessment of body condition. Specifically, for each survey sighting of a whale, the three body regions of interest were assigned a numerical score, with higher values corresponding to better condition (Figs. 2-4). If a body region could not be assigned a reliable numerical score (e.g., no images were taken of the body region, body region condition confounded by body position), the region was coded as X. All scoring was executed by one analyst (ALB) to maintain consistency in the analysis (Pettis *et al*., 2004). However, an inter-rater agreement study was performed to demonstrate that the western gray whale body condition protocol can be used by more than one researcher (A. L. Bradford, unpublished data). The scored data for each whale were then collapsed into monthly composites of post-cranial, scapular, and lateral flank condition for each year of the study. Bradford *et al*. (2007) details how these composites were classified into overall determinations of body condition (i.e., good, fair, poor, or unknown) for use in the subsequent analysis. Note that individual whales are thus represented by a body condition category in as many months as the individual was sighted.

Multinomial logistic regression for ordinal responses was employed in the quantitative analysis of western gray whale body condition. Specifically, the proportional odds model (McCullach 1980, Agresti 2002) was used to evaluate the effect of four categorical variables (year, month, whale class, and sex) on body condition as a multinomial response (good, fair, poor), where: 1) year is 1997 to 2005; 2) month is July, August, or September; 3) whale class is lactating female, calf, or other whale; and 4) sex is male, female, or unknown. The correlation between observations of individual whales was not yet accounted for in the analysis, which was conducted using the Design Package (Harrell 2007) within the program R (R Development Core Team 2008).

RESULTS

The 4,561 survey sightings between 1994 and 2005 were collapsed into 1,360 monthly body condition composites representing 150 photo-identified western gray whales. The numbers of composites in each body condition category are: good – 590 (43.4%), fair – 254 (18.7%), poor – 123 (9.0%), and unknown – 393 (28.9%). Lactating females (n = 23) represented 114 of these composites, which are distributed primarily in the compromised body condition (i.e., fair and poor) categories: good – 3 (2.6%), fair – 32 (29.8%), poor – 64 (56.1%), and unknown – 13 (11.4%). The 4,385 survey sightings between 1997 and 2005 representing the analysis subset were collapsed into 1,269 monthly body condition composites of 149 individuals. The distribution of composites within each body condition category is: good – 566 (44.6%), fair – 242 (19.1%), poor – 114 (9.0%), and unknown – 347 (27.3%). Within this subset, known body condition determinations (i.e., good, fair, or poor) are represented by 145 whales, with a median of five determinations per whale (range = 1-22). A summary of how these observations were distributed within the analysis framework is shown in Table 1.

Table 1. Summary of observations used in the quantitative analysis of western gray whale body condition. Note that individual whales are represented once in the annual numbers of whales in known body condition and within each month, but are represented in as many months and years as the individual was sighted. Further, individual whales can be represented multiple times in the annual numbers within each whale class and sex category, depending on the number of known monthly body condition determinations for the individual.

	Whales in	Month			Whale Class			Sex		
Year	Known BC[1]	Jul	Aug	Sep	LF[2]	Calf	Other	Male	Female	Unknown
1997	37	16	24	22	5	5	52	29	28	5
1998	48	33	28	22	16	15	52	35	41	7
1999	64	42	54	35	4	7	120	70	46	15
2000	54	7	50	38	3	5	87	58	34	3
2001	63	42	53	46	16	17	108	78	59	4
2002	70	38	47	50	16	16	103	68	62	5
2003	65	16	50	41	20	20	67	56	51	0
2004	55	22	50	1	11	12	50	31	37	5
2005	67	18	41	36	9	8	78	48	42	5

[1]Body Condition
[2]Lactating Female

Results from fitting the proportional odds model to the western gray whale body condition determinations (Table 2) are consistent with findings from the qualitative exploration of the data (Fig. 1, Bradford *et al*. 2007). Specifically, compared to the reference year of 1997, whales were in poorer body condition during the years of 1999 through 2001 and 2005, as evidenced by the negative values of the predictor coefficients, although only 1999 was statistically significant (Table 2). The coefficient for 2004 was only marginally significant, but suggests that whales were in relatively better body condition during that year. Whales were in significantly better body condition in August and September relative to July, with the magnitude of the coefficients suggesting an improvement in body condition as the season progressed. Lactating females were in significantly poorer body condition relative to other whales, nursing calves that were in significantly better condition. The body condition of females was comparatively poorer than that of males; however, the associated coefficient was only marginally significant. Predicted probabilities of whales being in poor, fair, and good body condition according to various combinations of the covariates are illustrated in Fig. 5.

Table 2. Maximum likelihood parameter estimates and standard errors resulting from fitting the proportional odds model to the western gray whale body condition determinations, with the first two rows representing model intercepts and the rest predictor coefficients. Note that Year = 1997, Month = Jul, Class = Other, and Sex = Male served as the reference categories. Significant predictor coefficients ($p < 0.05$) are shown in bold.

Variable	Estimate	SE	*p* Value
$Y \geq$ Fair	2.22	0.349	<0.001
$Y \geq$ Good	-0.08	0.331	0.819
Year = 1998	0.22	0.399	0.585
Year = 1999	-0.83	0.349	**0.018**
Year = 2000	-0.41	0.379	0.282
Year = 2001	-0.48	0.351	0.176
Year = 2002	0.12	0.363	0.743
Year = 2003	0.15	0.382	0.694
Year = 2004	0.77	0.426	0.069
Year = 2005	-0.45	0.375	0.226
Month = Aug	0.91	0.184	**<0.001**
Month = Sep	1.81	0.213	**<0.001**
Class = LF[1]	-3.42	0.280	**<0.001**
Class = Calf	4.14	1.013	**<0.001**
Sex = Female	-0.31	0.169	0.068
Sex = Unknown	1.16	0.480	**0.016**

[1]Lactating Female

DISCUSSION

Additional work is needed in the ongoing quantitative analysis of western gray whale body condition. Primarily, the correlation between observations of individual whales (Table 1) should be accounted for either through the use of a generalized estimating equation or, preferably, a random effects model. Appropriate software to utilize either of these methods with the proportional odds model has not yet been identified. Additionally, model diagnostics to assess the fit of the model and model building to examine the importance of the predictor variables should be conducted.

Although the variance has not been properly estimated in the current analysis, the parameter estimates reveal sources of variation in the body condition of western gray whales from 1997 to 2005 (Table 2). First, the body condition of western gray whales varied annually, with whales in relatively poorer condition in 1999 and to some degree in 2000 and 2001. As indicated by Brownell and Weller (2001), the reduced body condition of western gray whales during this time period overlaps with and may have been linked oceanographically to an unusual mortality event in the eastern gray whale population (LeBoeuf *et al*., 2000; Moore *et al*., 2001). That is, Brownell and Weller (2001) suggested that the mechanisms underlying the mortality event in the eastern population and the concurrent observations of poor body condition in the western population may have been ocean-wide in nature, changing the availability of food resources for both populations in the same way, rather than being regional and population specific. In terms of seasonal variation, body condition was compromised toward the beginning of each field season and generally improved as the season progressed. However, the predicted probabilities indicate that not all whales were in good body condition by the end of the field season (Fig 5). Lactating females were expected to be in compromised body condition (Perryman *et al.*, 2002; Pettis *et al.*, 2004) due to the energy expenditure required to support a calf. This assumption was supported in the analysis, which found lactating females in relatively poorer body condition. This transfer of energy is indirectly evident in the comparatively better body condition of western gray whale calves.

The mechanisms regulating body condition in western gray whales are not well understood. Thus, the cause of compromised body condition in these whales cannot be specified. This nutritional stress could be caused directly by natural or human-caused changes in prey availability or habitat quality, indirectly by disease or stress-related physiological responses, or by some combination of these factors (Weller *et al.*, 2002). For instance, annual variation in seasonal sea ice may influence the summer abundance and density of prey or limit the time western gray whales can spend feeding (Brownell and Weller, 2001). Likewise, intensive oil and gas development off the northeastern coast of Sakhalin Island could negatively affect the habitat quality of feeding whales (Reeves *et al.*, 2005). More effort is needed to evaluate associated environmental and anthropogenic properties (e.g., prey abundance and density, climatic indices, oil and gas disturbance) and relate them to western gray whale body condition and, ultimately, health. Over the short-term, western gray whales seemingly recover from periods of compromised body condition. However, the long-term consequences (e.g., reduced survival or recruitment) are unknown, but are important for evaluating the viability of the critically endangered western gray whale population.

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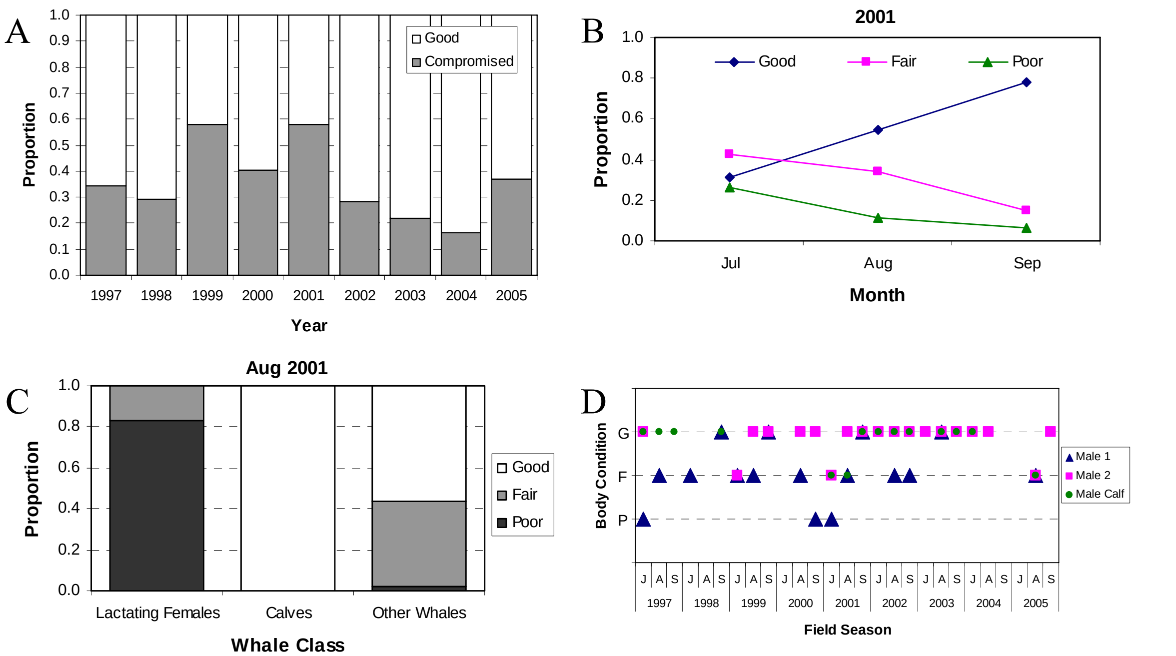
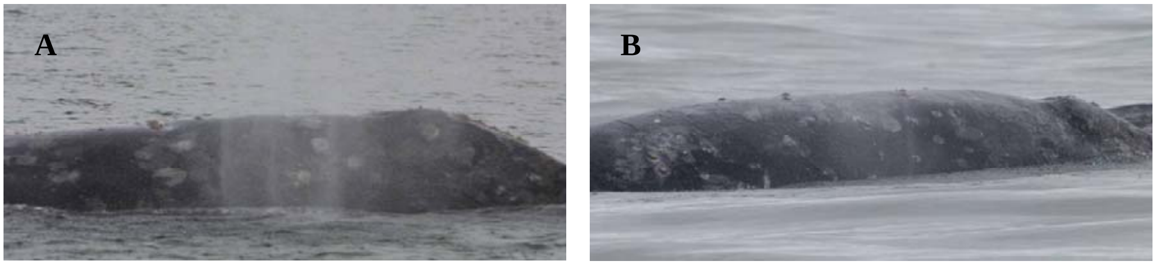
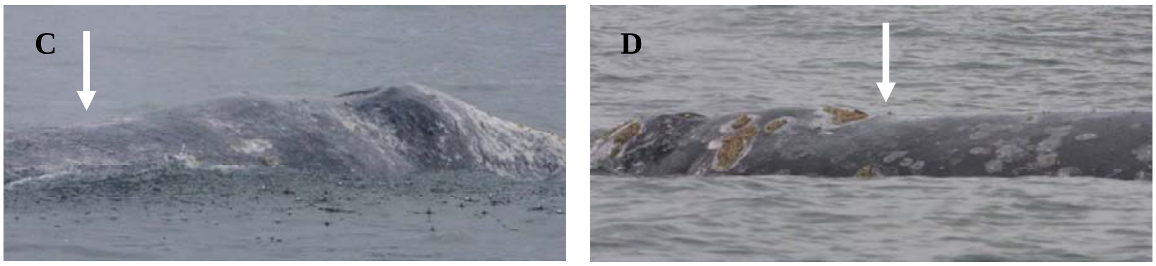


Fig. 1. Graphic summary from Bradford *et al*. (2007) of the qualitative exploration of western gray whale body condition determinations (analysis subset) suggesting: A) *annual variation* – proportion of whales of known body condition (excluding lactating females) found to be in compromised body condition (i.e., fair and poor) at some point during each field season; B) *seasonal variation* – proportion of all whales of known body condition found to be in good, fair, and poor body condition during July through September of the 2001 field season (representative of the trend in all years); C) *whale class variation* – proportion of lactating females, calves and other identified whales of known body condition found to be in good, fair, and poor body condition during August of the 2001 field season (representative of the trend in all years); and D) *individual variation* – schematic depicting the known body condition (G = good, F = fair, P = poor) of two male non-calf whales (Male 1 and Male 2) and one male calf weaned during the 1997 field season.

Post-Cranial Condition Score 3



Post-Cranial Condition Score 2



Post-Cranial Condition Score 1

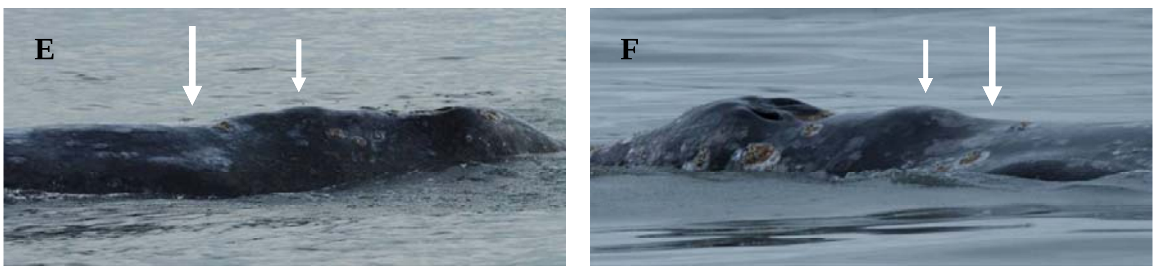


Fig. 2. Example images depicting the three-point scale used to assess the post-cranial condition of western gray whales. A score of 3 was assigned to whales with flat or rounded backs (A-B), a score of 2 was be assigned to whales with a slight to moderate post-cranial depression, indicated by an arrow (C-D), and a score of 1 was assigned to whales with a significant post-cranial depression such that a pronounced 'hump' was visible posterior to the blowholes, noted by large and small arrows, respectively (E-F).

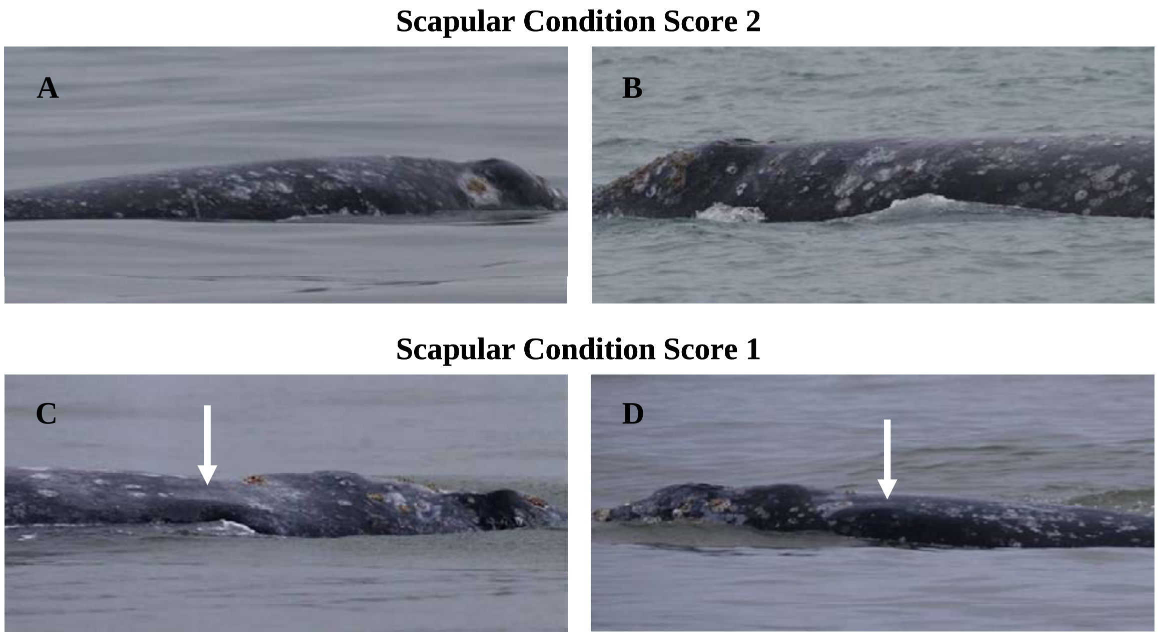


Fig. 3. Example images showing the two-point scale utilized to evaluate the scapular condition of western gray whales. A score of 2 was assigned to whales with rounded sides over the shoulder blades (A-B), and a score of 1 was assigned to whales with a subdermal protrusion of the scapula, identified by an arrow (C-D).

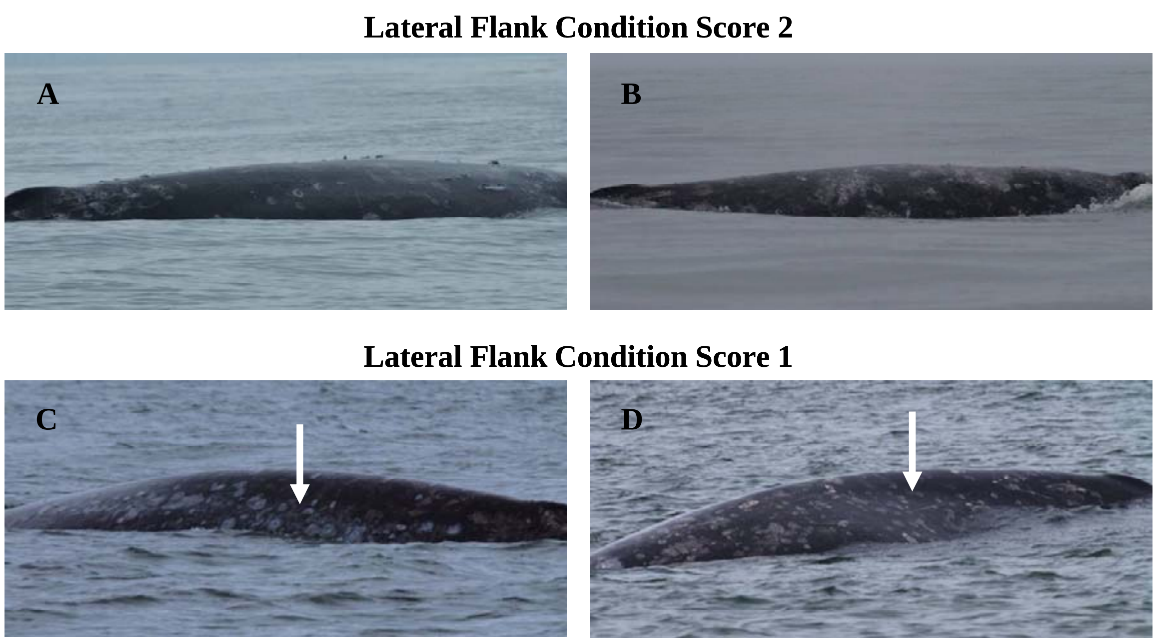


Fig. 4. Example images showing the two-point scale employed to rate the lateral flank condition of western gray whales. A score of 2 was assigned to whales with rounded sides from the post-cranial area to the start of the caudal peduncle (A-B), and a score of 1 was assigned to whales with a depression along the dorsal aspect of the lateral flanks, indicated by an arrow (C-D).

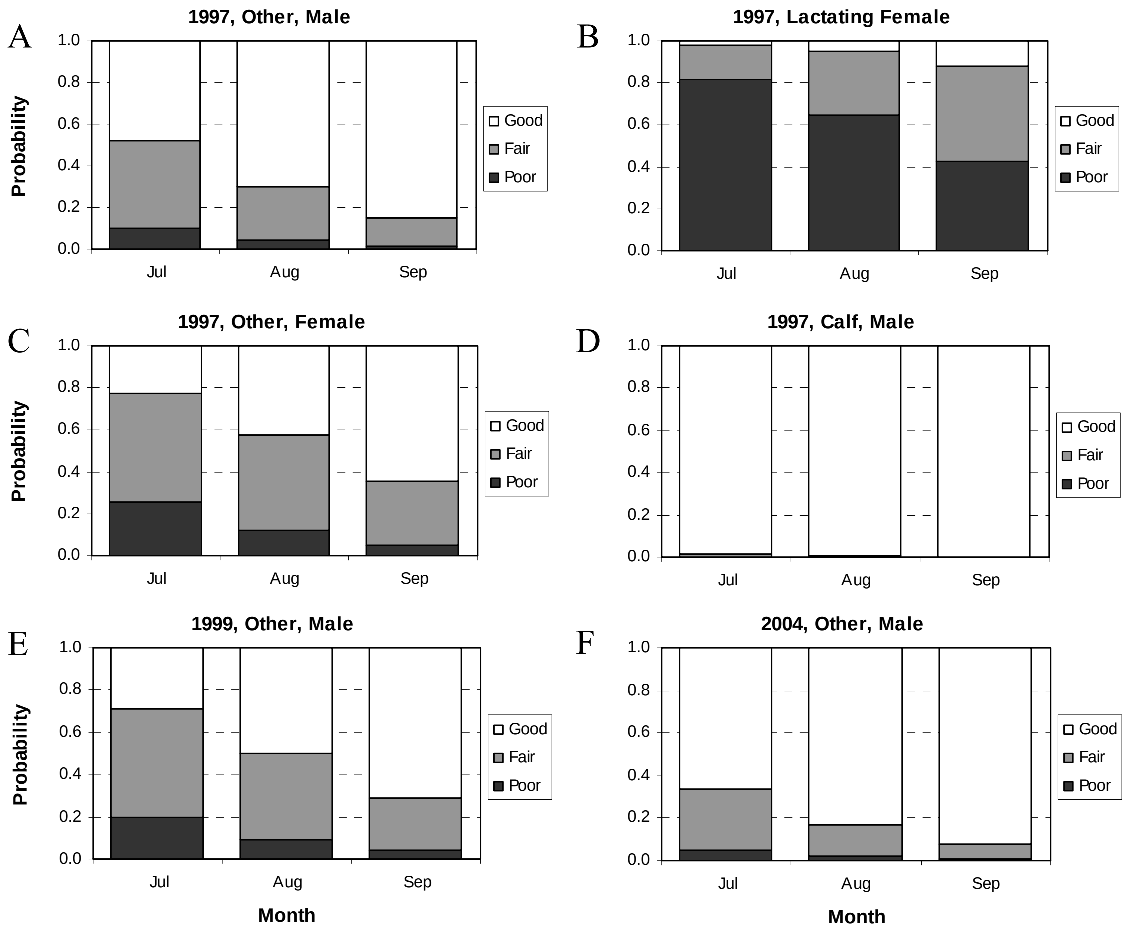


Fig. 5. Predicted monthly probabilities of being in poor, fair, and good body condition for six example combinations of the three remaining predictor variables (i.e., year, whale class, sex): A) other male whales in 1997, B) lactating females in 1997, C) other female whales in 1997, D) calf male whales in 1997, E) other male whales in 1999, and F) other male whales in 2004.