# Analysis of the body condition of gray whales (*Eschrichtius robustus*) photographed in Northwest Washington, 2004-2010

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**ABSTRACT**

Gray whales that feed in Northwest Washington (NWA) waters during the summer and fall show variability in their fidelity to the region, with annual variations in the total number of whales observed, the length of time within a year that an individual whale uses the area, and the likelihood that an individual whale will return to the area in future years. In order to determine whether body condition could reflect this annual variability in whale sightings, we used methods developed by Bradford et al. (2012) to evaluate the body condition of individually identified gray whales photographed in NWA between 2004 and 2010. Body condition of NWA whales generally improved over the duration of the June to November feeding season, but was highly variable between years. Whales in good body condition were more likely to return the next year, and years with low total counts of whales observed correlated to lower average body condition. When compared to the body condition reported for whales feeding off Sakhalin Island, Russia, gray whales observed in NWA appear to be in worse body condition more often than Sakhalin Island whales. This report is the first to address in-season changes in body condition of Eastern North Pacific gray whales.

KEYWORDS: GRAY WHALE; NUTRITION; PHOTOGRAMMETRY; FEEDING GROUNDS; SITE FIDELITY; PACIFIC OCEAN

## INTRODUCTION

In Washington State (USA), research on gray whales (*Eschrichtius robustus*) has primarily focused on photo-identification, distribution, and behavior of Eastern North Pacific (ENP) gray whales that feed in Northwest Washington (NWA) waters during the summer and fall. Individual whales show varying degrees of fidelity to NWA both in the length of time within a year that a whale uses the area and the likelihood that the whale will return to the area in future years (Scordino et al. 2011). Further, the total number of whales sighted in NWA is also variable between years (Calambokidis et al. 2012; Scordino et al. 2011). This variability in use of NWA waters may be related to the overall health of the individual whales and reflect both foraging success in the region and annual changes in ecosystem productivity (Scordino et al. 2011).

A whale's health, as shown by its body condition, changes throughout the year depending on factors such as reproductive status or fasting during migration and breeding (Bradford et al. 2012) and has been positively correlated with greater food availability (Lockyer et al. 1986). In order to determine whether body condition could reflect the variability of whale sightings in NWA, we evaluated the body condition of individually identified gray whales photographed in the region between 2004 and 2010. A method for visually assessing the body condition of gray whales was developed by Bradford et al. (2012) to evaluate the health of gray whales feeding at Sakhalin Island, Russia. Bradford et al. (2012) noted that whale body condition differed over the duration of the feeding season, between years, and by reproductive status. A similar though less extensive method of photographic health assessment was developed by Newell (2009) to evaluate annual differences in the numbers of feeding gray whales on the Oregon coast (USA) observed in poor body condition.

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The primary goal of this project was to use the methods developed by Bradford et al. (2012) to determine body condition of whales feeding in NWA and to assess how the body condition of these whales changes over the feeding season and between years. Our secondary goal was to determine how a whale's body condition affects its fidelity to the NWA region within and between years, and to determine whether total numbers of whales sighted in a given year corresponds to the collective health of the whales sighted in that year (i.e. a year with fewer total whales sighted might show more whales in poor health than a year with more total whales sighted). Our final goal was to compare the findings of Bradford et al. (2012) from whales feeding at Sakhalin Island to the body condition of gray whales feeding in NWA. This would allow comparison of a) whether whales in these two regions exhibit similar patterns in seasonal and annual changes in individual health, and b) whether a particular year of overall reduced or improved body condition (where most whales in a given year show a similar body condition pattern) correlates between regions to examine regional similarities or differences in ecosystem productivity.

## MATERIALS AND METHODS

### Photographs and sighting data

Photographs and sighting data were contributed from gray whale surveys conducted in NWA by researchers from the Makah Tribe's Fisheries Management department (MFM) and NOAA's National Marine Mammal Laboratory (NMML) from 2004 to 2010. These surveys consisted of nearshore, small-boat surveys targeting photo-identification of gray whales in a research area extending from Cape Flattery to Sekiu, WA in the Strait of Juan de Fuca and from Cape Flattery south to Sea Lion Rock, WA in the Eastern North Pacific (ENP) Ocean (Figure 1). Each gray whale sighted during these surveys was photographed using a digital SLR camera with a 70-300 mm lens, and the time and location of the sighting was recorded. Photographs of gray whales were sent to Cascadia Research Collective (CRC) for comparison to, and inclusion in, their catalog of individually identified gray whales from the US West Coast. Each whale photographed was either matched to an existing whale and identification number, assigned a new identification if no match could be made, or left unidentified if the photo was of insufficient quality (Calambokidis et al., 2012).

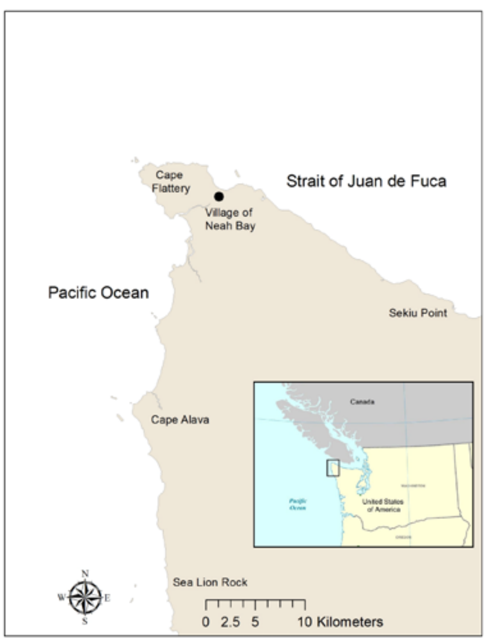



Figure 1. Map of the study area extending from Cape Flattery east to Sekiu, WA and south to Sea Lion Rock, WA, in the Eastern North Pacific Ocean.

In order to look at changes in body condition over the feeding season, we used photographs and sighting data spanning from June through November over the 7-year time period. To further evaluate how body condition affects gray whale use of NWA waters, we only evaluated the body condition of whales meeting the IWC definition of Pacific Coast Feeding Group (PCFG) whales. These whales are defined as whales seen between 41˚N and 52˚N (northern California to southeast Alaska) during the feeding season of June to November in more than one year (IWC 2011). This subset consisted of a total of 573 sightings where gray whales were successfully photographed, including over 23,300 photographs of 125 individually identified whales. Each individual whale evaluated for body condition was referred to by the identification number provided by CRC (e.g. CRC 42).

**Body condition evaluation**

We used methods developed by Bradford et al. (2012) to visually assess the body condition of individual gray whales by evaluating the amount of visible depression (or lack thereof) as a measure of the whale's subcutaneous fat stores in the post-cranial, scapular, and lateral regions of the body. Each body region was scored to provide a quantitative measurement of whether the whale was in good, fair, or poor condition. The post-cranial region was scored on a 3-point scale based on the degree of depression behind the blowholes and skull, where a score of 3 indicates good condition and 1 indicates poor condition. The scapular region was similarly scored on a 2-point scale based on the visible subdermal protrusion of the scapula. The lateral flank was also scored on a 2-point scale where the lateral flank of a whale in good body condition is rounded from the post-cranial region to the start of the knuckle ridge, and a whale with obvious depression along the flank is considered in poor condition. An overall body condition score would thus read "322" for a whale in good body condition.

For a given sighting, the photographs required to assign an overall (or complete) body condition score were not always available. When performing photo-ID of gray whales, the lateral flank is used to identify individual whales. It is more likely, therefore, that the researcher took a photo of the lateral flank than of the post-cranial or scapular areas of the whale. In the case where a photo was not available or was of poor quality, that particular body region was scored as an X. Bradford et al. (2012) found that the area most indicative of overall health was the post-cranial region, therefore a whale for which a post-cranial score could not be assigned (e.g. "X22") was considered an incomplete body condition score. If at least a post-cranial score could be assigned (e.g. 3XX), then the score was considered complete. Following their methods, we created monthly composite scores of each individual whale to increase the likelihood of having a complete body condition score by pooling scores for that whale from all sightings in a given month (Bradford et al. 2012). If whales were sighted on more than one occasion within a month, then the composite was based on the most frequent body score given or the score with the most confidence (e.g. 322, 3X2, and XX2 would yield a 322 composite score; 221, 321, 3X1, and X21 would yield a 321 composite score).

Photos that were given a score were selected based on their general quality, the amount of the body region showing, and their adherence to the angles and regions defined and displayed in Bradford et al. (2012) figures 1, 2, and 3. Photographs that were blurry, too grainy, or with glare and extreme exposures were not scored to reduce bias towards inconsistent scoring or towards scoring skinny whales that may be more obvious to detect in cases of poor photo quality. Photographs that did not display the full body region (e.g. head just starting to come out of the water; very close up photo of flank) were not scored. Photographs were also selected for scoring based on their angle to the camera and body position of the whale. For example, in post-cranial photographs it was necessary to evaluate whether the whale was lifting its head in the photograph, which would affect whether or not we could detect a visible depression behind the blowholes. We did our best to adhere to the methods used by Bradford et al. (2012) to select photographs of suitable quality that were most comparable to their study and engaged in multiple conversations with the lead author to assure consistency with their methods (pers. comm. Amanda Bradford).

**Lateral flank scores**

When this study was initially conducted using MFM photos (NMML photographs were added later), the authors misinterpreted the language in the study by Bradford et al. (2012) describing the body region defined as the lateral flank. The lateral flank was defined as the body region extending from the post-cranial region to the caudal peduncle, which the authors interpreted to mean the caudal region before the flukes rather than start of the knuckle ridge (or dorsal fin in other species). As such, when we initially scored the lateral flank of the whale, we utilized photographs more typically used for gray whale photo-identification, centered around the dorsal lateral flank and knuckle ridge (here after referred to as "dorsal lateral flank"). After further discussion with the authors of Bradford et al. (2012), we realized our misinterpretation, and went back through each sighting to attempt to find photographs to more accurately adhere to the area defined by Bradford et al. (hereafter referred to as the “Bradford et al. flank”), which extended from the post-cranial region to the start of the knuckle ridge.

Our initial mistake led us to a unique opportunity, that of evaluating whether a score assigned to a dorsal lateral flank (more available in photo-identification studies) was comparable to that of a Bradford et al. flank and whether lateral flank scores (of either variety) could be used to reflect the overall body condition of a whale when a post-cranial photograph was unavailable. In an earlier publication of the their study, Bradford et al. (2007) reported that they did not use dorsal lateral flank photographs due to uncertainty about whether a visible depression was in fact due to the visible skinniness of the whale or due to flexing or other body movements. The authors felt that evaluating the lateral region between the post-cranial region and start of the knuckles, which would be visible before the whale significantly lowered its head or went into a roll, more accurately reflected the overall condition of the lateral flank (pers. comm. Amanda Bradford). Because our scoring of the lateral flanks initially used the dorsal lateral flank photo and then used the Bradford et al. flank, rather than vice versa, we feel that our scores of the dorsal lateral flanks were unbiased by any additional information about the whale’s condition (skinniness or lack thereof) that we would have gained from looking at the Bradford et al. flank.

**Statistical analysis**

In order to better compare our results to those of Bradford et al. (2012), we employed similar statistical tests with our data. Only complete body condition scores, containing at minimum a post-cranial score, were used for analysis of changes by month, year, and minimum tenure. Incomplete scores, primarily consisting of ones for which only a lateral score is available (XX1 or XX2), were only used in comparisons between the dorsal lateral flank and Bradford et al. flank and in considerations of using lateral scores to represent overall whale health. All statistical tests were performed in the program R.

We used a multinomial logistic regression to determine the effects of month and year on NWA gray whale body condition and used the Akaike Information Criterion (AIC) to select the most parsimonious model to represent the observed changes. Using body condition as an ordinal response variable, we compared a constant slope model (intercept = 1) to models with month, year, or month and year combined. Year was employed as a categorical variable. Month was modeled both as a continuous variable (constant rate of change in body condition through the feeding season) and as a categorical variable (each month has a unique multiplier for body condition as compared to a reference month). Because individual whales could be represented multiple times within the model, we made whale ID (CRC ID) a normally distributed random effect variable within the models using the Ordinal package in R.

## RESULTS

**Individual and composite scores**

From the 125 whales identified in the subset of photographs used in this study, we were only able to evaluate body condition from 119 whales due to being unable to make any monthly composite scores for 6 whales. Out of 472 total monthly composite scores, only 58% (276 total) contained a post-cranial score (Figure 2). Therefore of those 119 whales, we could only assign complete monthly composite scores for 94 individuals. From those composites containing a post-cranial score, 49% (135 total) represented good body condition, 35% (97 total) represented fair body condition, and 16% (44 total) represented poor body condition (Figure 2).

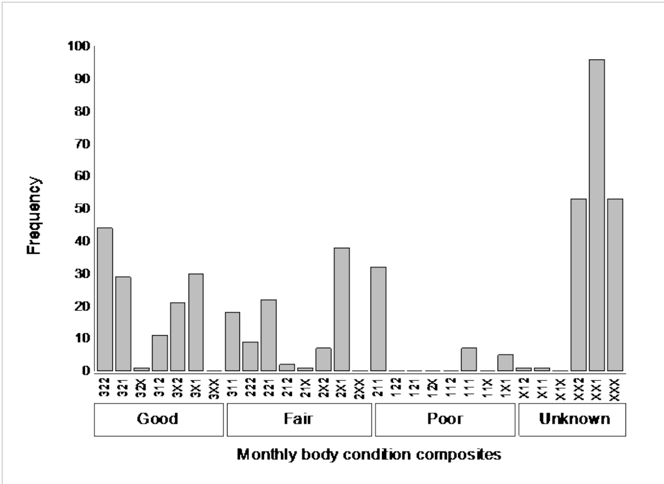



Figure 2. Frequency of body condition monthly composite scores. Each bar represents the number of scores assigned using each monthly composite and does not represent the number of individual whales having each score. A single line visible for some composites (e.g. 3XX) represents zero. Individual whales are represented in the figure as many times as they were sighted within the 7-year period.

**Dorsal lateral flank vs Bradford et al. flank**

We were able to compare scores from the dorsal lateral flank photographs to the Bradford et al. flank for 494 total sightings. Although we did not find a statistical difference between scores assigned to the dorsal lateral flank and the Bradford et al. flank (Paired t-test, two-tailed, df=496, p=0.165), the lateral score in 29% of sightings changed when using the Bradford et al. flank rather than the dorsal lateral flank. For laterals initially scored in poor condition (lateral score of 1), 21% were later scored in good lateral condition (lateral score of 2) using the Bradford et al. flank. For those initially scored in good condition, 36% were later scored in poor lateral condition using the Bradford et al. flank. Laterals in 2% of sightings initially could not be assigned a lateral score (and were given a score of X) when using the dorsal lateral flank photograph, but were assigned a 1 or 2 lateral score when using the Bradford et al. flank photograph. A small number of 1 and 2 lateral scores (1% of each) were changed to X and discarded from analysis during selection of an appropriate Bradford et al. flank photograph, primarily due to cases where the correct body region was showing (post-cranial region to start of the knuckle ridge) but the photo was of poor quality.

**Using lateral flanks to represent overall body condition**

Due to a bias in photo-identification studies towards photographs of the lateral region of the whale as opposed to the post-cranial or scapula portion, we sought to test whether the lateral flank condition could be used as an indicator of the overall health of a whale. We compared the chances of assigning a lateral score of either good (2) or poor (1) with differing post-cranial and scapula scores. With declining post-cranial condition, a whale was significantly more likely to show a compromised lateral condition (Fisher's exact test, p<0.000). In cases where the post-cranial region was scored in fair condition (2), 84% of laterals were scored in poor condition, and in cases where the post-cranial region was scored in poor condition (1), 100% of laterals were scored in poor condition. Still, the lateral scoring scale appears an inaccurate predictor of overall health given that in cases of good post-cranial condition (3), lateral scores were split nearly in half, with 51% of the cases scored in poor condition and 49% scored in good condition.

The chance of scoring the lateral region in either good or poor condition also differed with the availability of and score given to the scapula region. For 37% of all cases where a post-cranial score was available, no score could be assigned to the scapula region. When both the post-cranial and scapula regions were visible for scoring, a poor scapular score was more likely to correspond to a poor lateral score (Figure 3). When the post-cranial and scapula regions were both scored in good condition (3 for post-cranial and 2 for scapula), only 40% of laterals were scored in poor condition (321), compared to 62% of laterals scored in poor condition when the scapula was also in poor condition (311). In cases where the post-cranial region was scored in fair condition and the scapular was scored in good condition, 70% of laterals were scored in poor condition (221), compared to 94% when the scapula was also scored in poor condition (211). For whales with a poor post-cranial condition, if the scapula region was visible, both the scapular and lateral regions were always scored in poor condition (111).

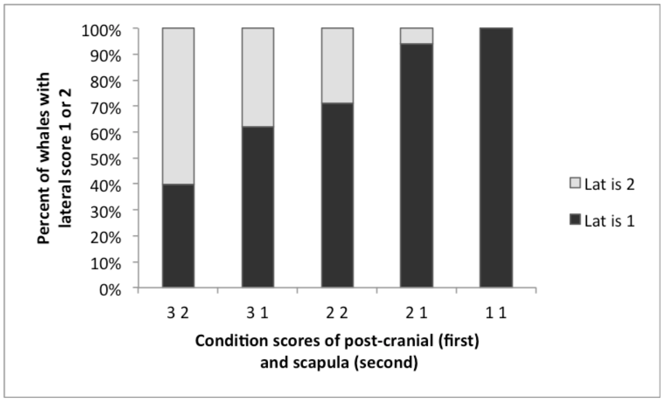
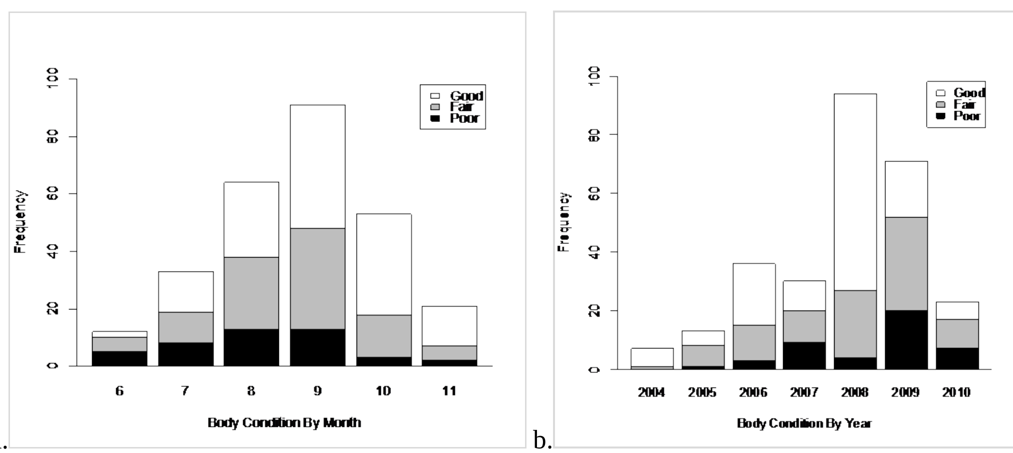



Figure 3. Percent of whales in good (2) or poor (1) lateral condition based on condition score of post-cranial and scapula regions.

**Body condition model by month and year**

We had a temporal bell shaped trend in the number of assigned monthly composite scores with a peak in late summer and early fall (Figure 4a) and greater number of scores in some years compared to others (Figure 4b). In general, body condition of whales increased over the duration of the feeding season (Figure 5a), while the number of individual whales that could be assigned a complete body condition score increased from the start of the feeding season in June to a peak in September, and then decreased through November (Table 1). Body condition of whales varied between years (Figure 5b) as did the number of whales that could be assigned a complete body condition score (Table 1), with the highest number of whales scored in 2008 and the lowest number scored in 2004.

a.




b.

Figure 4. Temporal trend in the number of monthly body condition composites we were able to determine from photographs by a) month and b) year.

a. b.

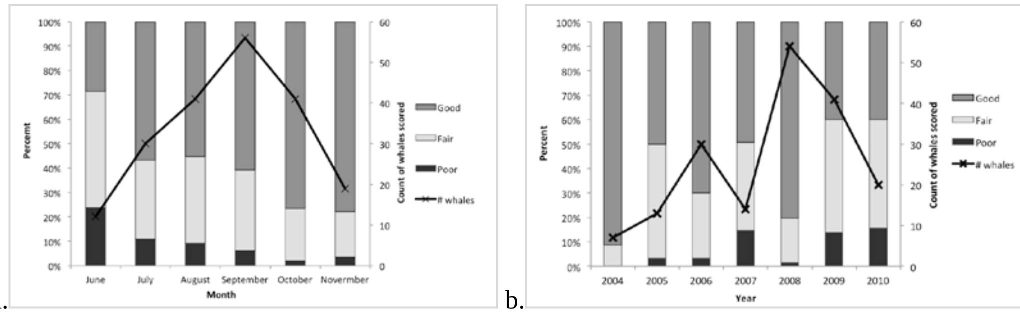



Figure 5. Percent of body condition scores in good, fair, or poor condition relative to the total number of whales in known body condition by a) month and b) year. Total numbers of individual whales (# whales) are provided in Table 1.

Table 1. Total number of known body condition scores (monthly composites) versus total number of individual whales with known body condition scores in each month and year of the study period. Each whale (Total individual whales) is counted in each month-year combination (Total composite scores) in which it was assigned a known body condition.

| Year (Y) | June | July | Aug | Sep | Oct | Nov | Total composite scores | Total individual whales |
|---|---|---|---|---|---|---|---|---|
| 2004 | 0 | 0 | 1 | 2 | 3 | 2 | 8 | 7 |
| 2005 | 1 | 4 | 2 | 6 | 0 | 0 | 13 | 13 |
| 2006 | 2 | 3 | 7 | 22 | 2 | 0 | 36 | 30 |
| 2007 | 0 | 7 | 9 | 8 | 2 | 4 | 30 | 14 |
| 2008 | 2 | 11 | 19 | 18 | 30 | 14 | 94 | 55 |
| 2009 | 7 | 6 | 21 | 21 | 16 | 1 | 72 | 41 |
| 2010 | 0 | 3 | 5 | 14 | 1 | 0 | 23 | 20 |
| Total composite scores | 12 | 34 | 64 | 91 | 54 | 21 | 276 | |
| Total individual whales | 12 | 30 | 41 | 56 | 41 | 19 | | 94 |

Based on model selection using the Akaike Information Criterion, we determined that the best model for representing NWA gray whale body condition was a combined model including year plus month, with month as a continuous variable (Table 2). The results of the multinomial logistic regression of month plus year confirm that whale body condition changes over the feeding season and is variable by year (Table 3). Compared to the reference year (2004), whales in all other years had lower average body conditions, represented by negative Wald *z* statistics where 2004 is equal to zero (Table 2). Only three years (2007, 2009, 2010) were significantly different from 2004 ($p<0.05$), having lower average body condition scores than any other years. For further comparability with the study by Bradford et al. (2012), we investigated the model where both month and year are categorical variables (model 4). In this model, a significant difference in body condition (from reference month June) did not occur until September, and continued through November (Table 4).

Table 2. Model selection using Akaike Information Criterion. Model "0" represents a constant slope model where the intercept = 1. Month with a lowercase "m" (month) refers to month as a categorical variable. Month with an uppercase "M" (Month) refers to month as a continuous variable where June (6) is set to 0. Year (lowercase "y") was treated as a categorical variable in all models. The selected model (5) is in bold.

| Model# | Model | *d.f.* | AIC |
|---|---|---|---|
| 0 | ~1 | 3 | 554.5699 |
| 1 | ~month | 8 | 543.984 |
| 2 | ~year | 9 | 505.6641 |
| 3 | ~Month | 4 | 539.3543 |
| 4 | ~month+year | 14 | 504.3577 |
| **5** | **~Month+year** | **10** | **498.5218** |
| 6 | Month*year | 16 | 508.4148 |

Table 3. Results from multinomial logistic regression maximum likelihood estimates of the selected model (model 5), using month as a continuous variable, year as a categorical variable, and body condition as an ordered ordinal response variable (Poor, Fair, Good). The first two rows represent model intercepts. Year = 2004 is used as a reference year. *P*-values for month and year represent a difference from a slope = 0 (month) and from the reference year (year), where p<0.05 is considered significant.

| Variable | Estimate | SE | Wald *z* | *p*-value |
|---|---|---|---|---|
| Poor\|Fair | -3.132 | 1.273 | -2.461 | 0.014 |
| Fair\|Good | -0.809 | 1.252 | -0.646 | 0.518 |
| **Month** | **0.347** | **0.116** | **2.985** | **0.003** |
| Year = 2005 | -1.637 | 1.303 | -1.256 | 0.209 |
| Year = 2006 | -1.319 | 1.236 | -1.067 | 0.286 |
| **Year = 2007** | **-3.014** | **1.254** | **-2.404** | **0.016** |
| Year = 2008 | -0.815 | 1.206 | -0.676 | 0.499 |
| **Year = 2009** | **-2.982** | **1.221** | **-2.443** | **0.015** |
| **Year = 2010** | **-2.930** | **1.267** | **-2.313** | **0.021** |

Table 4. Results from maximum likelihood estimates of model 4, using month and year as categorical variables and body condition as an ordered ordinal response variable (Poor, Fair, Good). The first two rows represent model intercepts. *P*-values (where p<0.05) represent a significant difference from reference month (June) and year (2004).

| Variable | Estimate | SE | Wald *z* | *P*-value |
|---|---|---|---|---|
| Poor\|Fair | -2.697 | 1.353 | -1.994 | 0.046 |
| Fair\|Good | -0.353 | 1.341 | -0.263 | 0.792 |
| Month = July | 0.995 | 0.749 | 1.327 | 0.184 |
| Month = August | 1.123 | 0.691 | 1.624 | 0.104 |
| **Month = September** | **1.489** | **0.686** | **2.170** | **0.030** |
| **Month = October** | **2.081** | **0.734** | **2.834** | **0.005** |
| **Month = November** | **1.697** | **0.863** | **1.966** | **0.049** |
| Year = 2005 | -1.665 | 1.302 | -1.279 | 0.201 |
| Year = 2006 | -1.301 | 1.234 | -1.054 | 0.292 |
| **Year = 2007** | **-3.001** | **1.244** | **-2.412** | **0.016** |
| Year = 2008 | -0.837 | 1.194 | -0.701 | 0.483 |
| **Year = 2009** | **-2.989** | **1.209** | **-2.473** | **0.013** |
| **Year = 2010** | **-2.970** | **1.269** | **-2.340** | **0.019** |

Using the coefficients from model 5 (month as continuous), we used odds ratios and confidence intervals to predict the probability of a whale being in better or worse condition in different months or years. With each increasing month in the feeding season, whales were 1.4 times more likely to have improved their overall body condition (95% CI [1.1, 1.8]). Compared to years that were significantly different from 2004 (i.e. 2007, 2009, and 2010), whales from 2004 were 18 to 20 times more likely to be in better body condition, however the confidence intervals for these years were broad. To further investigate difference between years, we computed the predicted probabilities of an average whale being in poor, fair, or good body condition in each year of the study (Figure 6). Although body condition improved each feeding season, the starting body condition of observed whales differed between years (Figure 6). Whales in 2004 appeared to start and end the season in better body condition than other years, however data collection in that year was limited and did not begin until August (Table 1), therefore predictions for June and July are estimates. In 2007, 2009, and 2010, whales started the feeding season in worse body condition than in other years, equally likely to be in poor as in fair condition, and were equally likely to end the season in fair as in good condition. The slight bell-curve observed (Figure 6) for whales in fair condition in these three years likely reflects the decline of whales in poor condition leading to an increase in whales in fair condition and the simultaneous decrease in whales in fair condition as some whales improve to good condition.

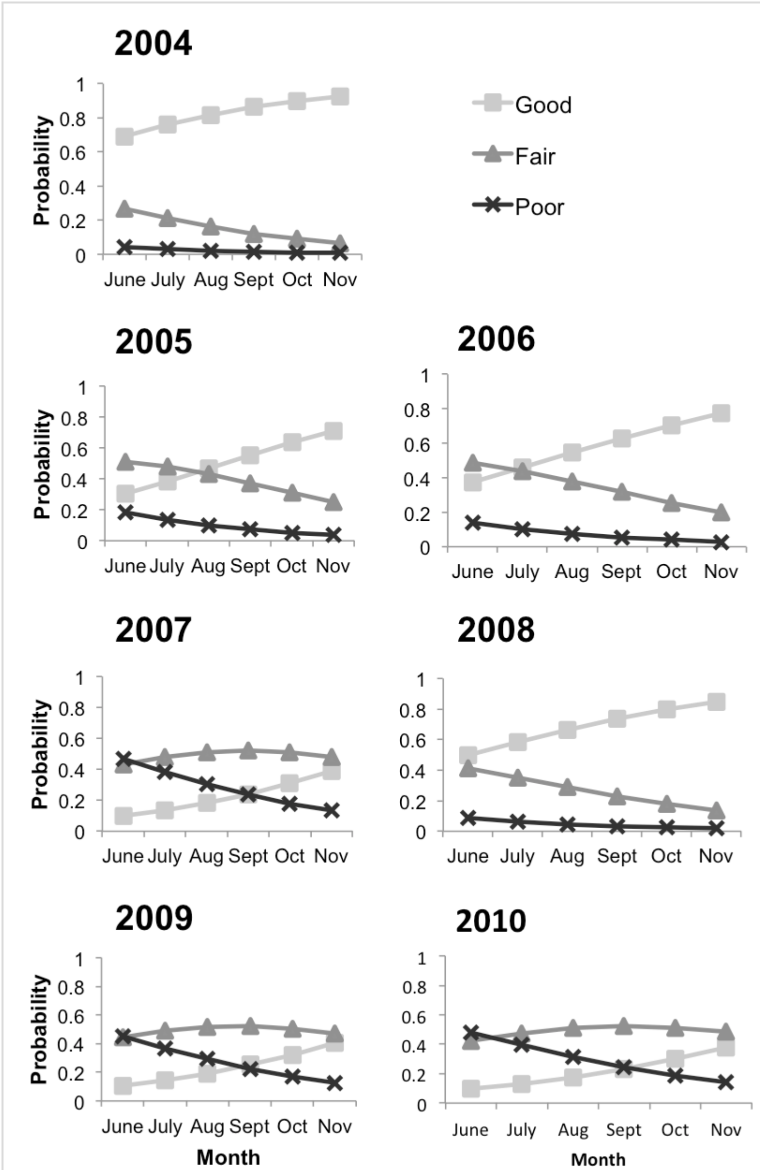



Figure 6. Predicted probabilities of an average NWA gray whale (random effect = 0) of being in poor, fair, or good body condition in each month and year of the study period. Predicted values were calculated from the selected model (model 5 ~Month+year) and estimate predictions for month and year combinations where no data was available.

**Influence of body condition on fidelity to the study area**

To evaluate the influence of body condition on the probability that an individual whale is seen in the next feeding season, we compared body condition in the last month that a whale was sighted in a given year (year Y) to whether or not the whale was seen the next year (year Y+1). The probability that a whale observed in year Y was also observed in year Y+1 differed significantly by body condition ($\chi^2$ = 1.3653, df = 2, p-value = 0.00), where whales in good body condition were more likely to be observed in year Y+1 than whales in fair or poor body condition (Figure 7).

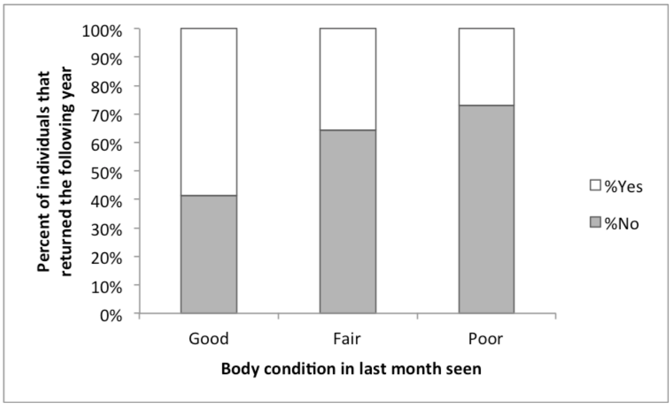



Figure 7. Percent of individual whales observed in year Y that returned (yes = returned, no = not returned) in year Y+1 relative to their last known body condition.

To evaluate the influence of body condition on a whale's use of the study area within a feeding season, we compared a whale's body condition in the first month it was seen to its minimum tenure, defined as the individual's possible length of stay in NWA based on the date of its first and last sightings. There were 167 cases, comprising 92 individual whales, where known body condition was determined at first sighting in a given year. For these individuals, body condition at first sighting did not significantly affect minimum tenure in the study area (One-Way ANOVA, df=1, p=0.68). Still, whales in poor body condition appeared more likely to stay in the study area for shorter periods (>0-5 and >5-10 days) than whales in good and fair condition (Figure 8).

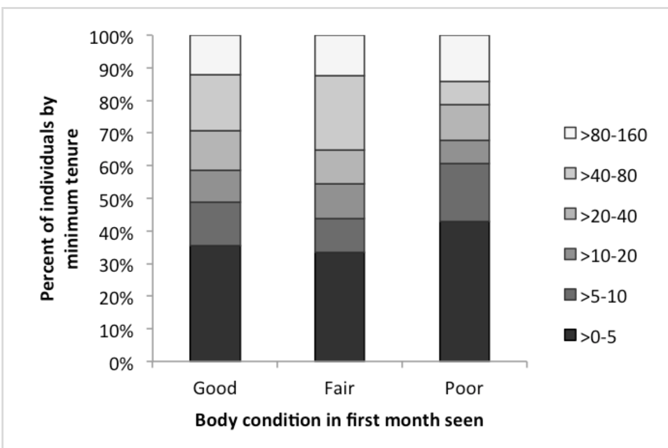



Figure 8. Percent of individual whales by length of minimum tenure (days) compared to their body condition at first sighting.

The total number of whales sighted in NWA appears to mirror years of collective good, fair, or poor condition. When initially comparing average body condition to the total number of whales sighted in a given year, we found little correlation including all years of the study period (R=0.21). Due to very low survey effort in 2004 (Scordino et al. 2011) and correspondingly low number of whales sighted, we tested the correlation without 2004 and found a high correlation between total number of whales and average body condition (R=0.71).

## DISCUSSION

### Using Bradford et al. methods to assess body condition of NWA gray whales

Our evaluation of using methods established by Bradford et al. (2012) to assess the body condition of gray whales feeding in NWA fell into three categories: 1) for how many whales were we able to detect a known body condition, 2) how do lateral scores using the lateral flank region as defined by Bradford et al. (Bradford et al. flank) compare to the dorsal lateral flank more typical of photo-identification, and could the more typical dorsal lateral flank photograph be a substitute in body condition studies, and 3) due to a bias in photo-identification studies and the relatively low proportion of known conditions detected in #1, how well does the lateral flank alone represent overall body condition.

We were only able to detect known body condition scores for 58% of all total monthly composites and for only 94 out of 119 individual whales. In comparison, Bradford et al. (2012) were able to assign known body conditions for 73.6% of their total monthly composite scores and for 165 out of 168 individual whales. Although Bradford et al. (2012) used photographs and video from a longer time period (10 years compared to 7 in this study), our study included over 23,300 photographs from 573 sightings, compared to 34,000 photographs from 5,173 sightings in their study. In an earlier version of their publication, Bradford et al. (2007) reported that collection of photographs from the post-cranial and scapula regions was implemented into their photo-identification protocols. As such, it is expected that researchers who do not focus on collecting photographs of these regions would be less likely to be able to assign known monthly composite scores (Figure 1). In addition to photographs, Bradford et al. (2012) also used video footage from sightings to help confirm the body condition from photographs, a tool which we did not have available.

We found that scores from the lateral flank alone, at least based on a 2-point scale, could not accurately detect the whales overall body condition. Comparisons of the dorsal lateral flank with Bradford et al. flank suggest that the two photographs are not interchangeable, as 29% of scores changed between photograph types. Due to a degree of uncertainty about how a whale's body movement influences the appearance of a depression on the lateral flank, we agree that the lateral flank used by Bradford et al. (2012) appears the more defensible predictor of lateral condition. The lateral flank photograph utilized by Bradford et al. (2012) includes the head before or just after lowering, creating the assumption that the whale is not rolling or flexing its body into a dive. The number of scores that were changed from poor to good condition when using the Bradford et al. flank (21%) suggests that instances of flexing or other body shape changes were causing whales to appear in compromised condition in the dorsal lateral flank photograph. Conversely, the number of good lateral scores that were changed to poor (34%) demonstrates that body movements or photo angle can also create false positives and suggests that the Bradford et al. flank represents a more unbiased position for scoring.

The number of scores changed when looking at the two photograph types may also reflect of a lack of sensitivity in the 2-point lateral score in general. Although the lateral score decreased with declining post-cranial and scapula condition, half of whales in good post-cranial condition showed poor lateral condition. Because the lateral flank is scored on a 2-point scale, a poor lateral score (score of 1) could refer to whales with a slight depression, in recovering condition or at the start of declining health, as well as to those in very adverse health (i.e. very skinny whales). An analysis of creating a lateral scoring system on a 3-point scale was not done in this study but could warrant further investigation. A drawback to creating a more extensive lateral scoring system would be keeping the scoring from becoming overly subjective, and would likely still require strict rules as to area of the lateral flank being evaluated, the amount of body region showing, and photo quality. In a study on North Atlantic right whales, the authors sought to develop a visual health assessment technique using photos routinely collected during photo-identification studies, in that case the whale's head (Pettis et al., 2004). Although some researchers may routinely collect the photographs necessary in this analysis, work to develop methods that apply to more typical gray whale photo-identification photographs should be considered for use on long-term, retrospective datasets.

Our inability to compute known body condition for individual whales over each feeding season also results from the restricted spatial scale of our study area. A high degree of overlap between whales sighted in our study area and around Vancouver Island, BC suggests that, at a minimum, expanding this analysis to include photographs from both NWA and southwest Vancouver Island would likely be more informative of the whales' condition (Calambokidis et al., 2012). Because we know that summer and fall gray whales in NWA also use areas ranging from northern California to southeast Alaska (Calambokidis et al., 2012), an even larger spatial scale may be necessary to detect other factors affecting body condition, such as sex, reproductive status, or age class. This study included 10 whales identified as reproductive females, having been previously sighted with a calf (Calambokidis et al., 2012). For only one of these females could we assign a known body condition (fair) in a single month of a known calving year, and for only one other female could we assign a known body condition (fair) in a single month of a post-calving year. This is in sharp contrast to whales at Sakhalin Island for which extensive analysis has been done to identify genetics, reproductive status, and age class of individuals (e.g. Weller et al. 2009, Bradford et al. 2010, Bradford et al. 2012).

**Changes in NWA gray whale body condition within and between years, 2004-2010**

We found that NWA gray whale body condition likely changes at a constant rate throughout each feeding season (Table 2), but that average body condition starts and ends at different conditions between years (Figure 6). For example, most whales in 2005 and 2006 started the season in fair or good body condition with few in poor condition, and in both years the majority of whales improved to good condition by the end of the feeding season (Figure 6). At the beginning of 2007, however, the majority of whales were instead in fair and poor condition, and by the end of the season were still equally likely to be in fair as in good condition (Figure 6). At first glance, this may appear as though the winter migration from 2006 to 2007 was somehow more strenuous than other migrations, causing poorer condition for whales at the start of 2007. A more likely explanation is the yearly turnover of individuals in the NWA region. Although some whales return to NWA in subsequent years, the proportion of returning whales varies each year (Scordino et al. 2011), therefore the whales that improved to good condition in 2006 may not be sighted at all in NWA in 2007, or if sighted may not be sighted at the start of the feeding season. Because in-season turnover also occurs, whales observed in good condition at the end of a given feeding season might not reflect actual food availability or productivity of NWA.

Gray whales feeding around Vancouver Island, BC, have been documented to feed on a variety of species of mysid shrimp and crab larvae and this diversity in prey species is thought to allow whales to change foraging behavior or habitats within the feeding season to forage on the most optimal prey (Darling et al. 1998, Nelson et al. 2008, Feyrer 2010). This ability to forage on multiple species and to engage in different foraging behaviors is consistent with gray whale body condition changing at a constant rate over the duration of the feeding season. Although a yearly difference in average body condition can be observed in NWA, gray whale body condition in NWA does not reflect the health of the greater PCFG or ENP ecosystem. It is evident that NWA gray whales feed in areas ranging from at least northern California to southeast Alaska (Calambokidis et al. 2012). Although our analysis provides insight into the productivity of the NWA ecosystem, further analysis of feeding gray whales from the larger PCFG range could help to illuminate how oceanographic factors affect annual changes in gray whale foraging and health in the greater California Current or Alaska Current ecosystems.

**Body condition as a predictor of NWA use and apparent survival to the region**

Body condition does not appear to significantly influence how long a whale uses the NWA study area within a given season, however it does appear to have some influence on resight rate in a following year (Figure 7). We hypothesized that a year of good body condition and high abundance of whales may reflect a year of high food availability in the region, with individual whales returning to the area the next year because of the good foraging conditions the previous year. Whales in poor and fair condition were less likely to be seen in the next year than whales in good condition, suggesting that if a whale is in compromised condition at the end of the feeding season, it may choose to forage at a different location in the following year. Although the total number of whales sighted in a given year may be influenced by survey effort, we did find a correlation between average body condition and total number of whales.

The year with the greatest number of whales (2008) was also a year of better average body condition. The two successive years had decreasing numbers of whales and corresponding decreased average body condition (Figure 5b). If in 2009 the food availability was lower than in 2008, either due to different habitat conditions or due to overexploitation of resources in 2008, we could expect a lower number of whales to return in 2009 or for whales in 2009 to stay for shorter tenure periods (Feyrer 2010). Feyrer (2010) found that the number of whales sighted off Vancouver Island was correlated to mysid densities and was noticeably lower in years of low mysid availability. Similarly, Newel (2009) found that years of low mysid densities on the Oregon coast corresponded to lower numbers of feeding gray whales and to more whales being sighted in poor condition.

**Initial comparison of NWA gray whales to Sakhalin Island gray whales**

In cases where we were able to determine a known monthly body condition, whales in NWA appear to be in compromised health more often and to not recover from compromised condition as quickly as whales observed at Sakhalin Island. In Bradford et al. (2012), the majority of total monthly composites were assigned as being in good condition (mostly 322 composites). All composites were recorded between

July and September, suggesting that by September, the majority of whales photographed at Sakhalin Island had reached optimal condition (good condition in all body regions). In our study, there was a much smaller difference in the number of monthly composites assigned in good or fair condition (Figure 2) compared to Sakhalin Island whales, and in September more than 40% of NWA whales were still in fair and poor condition (Figure 5a). Due to the number of unknown monthly composites in this study (42% of the total) and differences in sample size between the two studies, the full implications of this difference are unclear. At a minimum, these findings suggest that Sakhalin Island is a better foraging habitat than NWA. Alternatively, because NWA is only a small portion of the true feeding range of the whales sighted, our study may have been unable to track changes over the feeding season due to in season turn-over of individuals. Another possibility is that despite our concerted effort to follow the protocols established by Bradford et al. (2012), it is possible that some difference in scoring occurred. Based on an interrater agreement study performed by Bradford et al. (2012) used to test the efficacy of their methods, we feel it is unlikely that differences in photo-selection or scoring would lead to the degree of difference observed between results from the two studies.

To further investigate these differences, we modeled month as a categorical variable for more direct comparison to the results in Bradford et al. (2012). At Sakhalin Island, body condition of whales in August was significantly different from those photographed in reference month July ($p<0.000$), where no significant difference in NWA gray whale body condition from the reference month June was detected until September (Table 4). This result could support the idea that Sakhalin Island is better foraging habitat than NWA, where whales at Sakhalin Island are able to recover their body condition after migration more quickly than whales feeding in NWA. In this study, body condition of whales in October was most different from June (Table 4). Although no data is available after September from Sakhalin Island for comparison, we could expect body condition to continue to improve from the reference month through the end of the feeding season.

Due to having different reference years (1997 versus 2004), it is difficult to compare findings from the two studies between years. In both studies however, whales in 2004 appeared to be in the best body condition compared to all other years (Table 3, compare to Table 3 Bradford et al. 2012). Unfortunately, low survey effort in NWA in 2004 (Scordino et al. 2011) and the corresponding small sample size of whales in known condition (Table 1), confounds this comparison. It is unknown how these results would differ had survey effort in 2004 been greater. Although fitted with different models (month as continuous versus month as categorical), the predicted probability plots are nearly identical when comparing 2004 in this study (Figure 6) with their 2004 plot for Other Whales, or whales other than lactating females and calves (Figure 5 Bradford et al. 2012). Although our model does not take into account reproductive status or age class, for 2004 it does not include any known lactating females (Calambokidis et al. 2012) and only includes one known calf. Whales at Sakhalin Island appeared to be in worse condition in 2007 than any other year, however the probability plot for Other Whales (Figure 5 Bradford et al. 2012) shows that whales still started and ended the year in better condition than whales from NWA (Figure 6). In 2007, none of the known reproductive females in this study were recorded to have calved (Calambokidis et al. 2012) and no whales evaluated were recorded as being a calf in that year.

Future comparisons of ecosystem productivity and gray whale vital rates between Sakhalin Island and NWA could be possible through targeted analysis of known reproductive females. Bradford et al. (2012) found that lactating, postpartum females were unable to fully recover their body condition by the next breeding opportunity, which may correspond to the varying calving intervals observed. Studies on Atlantic right whales suggest that body condition and blubber thickness is significantly better in the feeding season leading up to calving than in post-calving years of anestrous (Pettis et al., 2004; Miller et al. 2011). A noticeable difference in the girth of pregnant females compared to other whales was also detectable in aerial survey photographs of both gray whales and right whales (Perryman and Lynn, 2002; Miller at al. 2012). An analysis specifically tracking the body condition of known reproductive females could shed light on calving intervals by looking at body condition changes in between known calving years. Relatively few cow-calf pairs have been identified in the PCFG (Calambokidis et al. 2012) and an analysis of body condition could help to estimate additional years of parturition in known reproductive females in years when no calf was sighted. Because reproductive females are not always resighted in successive years (Calambokidis et al. 2012), however, the sample size for this analysis would likely be small. Evaluating the body condition of known reproductive females in NWA or the greater PCFG during known parturient or anestrous years would then allow for a comparison of calving rates between the two regions. Further, comparing the length of anestrous between parturition years could also provide insight into the productivity of the two regions, where longer or shorter periods of recovery (anestrous) between parturition events might signal differences in food availability.

**CONCLUSIONS**

Annual differences in body condition with respect to the total number of gray whales sighted in NWA in a given year reflects annual variability in the productivity of NWA foraging locations. Some of the observed variability in body condition is likely due to both in-season and annual turnover of individuals and may in part be due to the relatively small sample size of known body condition scores. Still, a high correlation between total number of whales sighted and average body condition coupled with evidence that whales in good body condition are more likely to return to NWA the following year suggests that low use years are likely correlated to reduced food availability in NWA. Future examination of photographs from a larger regional scale would help provide larger sample sizes and better track the changes of individual whales, but could also be used to examine regional ecosystem differences in productivity. Future work to examine the body condition of known reproductive females from the PCFG may aid in understanding calving rates and may be useful for further comparison to gray whales from Sakhalin Island.

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