Spatial and temporal variation in body mass and the blubber, meat and visceral fat content of North Atlantic minke whales

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ABSTRACT

The exponent for predicting total weight from length has been studied in many species and here data on minke whales from areas in the North Atlantic is added from both Icelandic and Norwegian research catches. In addition changes in partial weights of blubber, meat and visceral fat are studied. In all cases a significant increase over the season, in particular for the mature animals, is found and also in girth measurements, more so aft on the body. Pregnant females have significantly more blubber. These results agree with studies on blubber thickness measurements and tissue energy content and observed changes in the ecosystem around Iceland during the research period.

INTRODUCTION

Migratory baleen whales (mysticetes) are capital breeders and cover the costs of reproduction at the winter breeding grounds from the blubber that is deposited at the summer feeding grounds and by lipid accumulation in muscle and internal organs (Lockyer, 1987b, 2007; Kasuya, 1995; Armstrong and Siegfried, 1991; Nordøy *et al*., 1995). Temporal trends in blubber storage can provide important insights into the behavioural ecology of these species (Haug *et al*., 2002; Konishi *et al*., 2008, 2009; Miller *et al*., 2011). Lockyer (1987a) and Víkingsson (1995) estimated the total energy content of fin whale carcasses and absolute seasonal energy storage from weighings and chemical analysis of different organs and tissues. In this study we look at seasonal trends in total weights, meat, visceral fat and blubber storage of Icelandic minke whales (*Balaenoptera acutorostrata acutorostrata*), caught under the special permit research programme between 2003 and 2007 (Marine Research Institute 2003). We also compare these with previous Norwegian research catches. The Icelandic minke whale research catch is studied in a separate papers for blubber thickness (SC/F13/SP8) and tissue energy content (SC/F13/SP10), where in both cases a linear increase is found over the season in mature animals.

MATERIAL

All the weight data are plotted in fig 2.

Total weights

During the Icelandic research catch in 2004 and 2005, 10 whales were towed to shore at Sandgerði (Reykjanes peninsula) and weighed in parts, except one that was weighed whole. The towing was generally short and no loss of tongue (a potential problem in heavy seas) was observed. In 2006 and 2007 11 whales were weighed in parts on board the largest vessel, Dröfn RE-35 (25.92m, 154.6 Br.tons). The total weights (n=21, mean 4083 kg) therefore does not include blood. The whales were caught westerly south to westerly north off Iceland in late May to early September. In total, the Icelandic material include total weights from two immature males and one female and seven mature males and 11 females who all were pregnant. Six girths measurements were available (Fig 1).

From previous Norwegian research catch under special permit (Lydersen *et al.* 1991) total weight, length and one comparable girth measurement (G2, axillary under flipper, Fig 1) was available for 11 males (six mature) and one immature female, caught in the Lofoten and Vesterålen area in August

1988, and six females (two pregnant) caught west off Svalbard in July 1989. The Norwegian whales were weighed whole with stomach content, but had been bled.

These data from Iceland and Norway are the only total weights obtained of North Atlantic Minke Whales that we are aware of.

Blubber meat and visceral fat weights

In addition to total weights from the Icelandic catch five mature males and one immature female had been weighed in parts except for bones and these whales were included in the analysis of meat (n=27) and blubber. However one of the males had to be excluded as the blubber weight was not clearly separated (n=26). For 80 animals visceral fat measurements were available.

The Norwegian data with total weights from 1988 and 1989 also had the partial weights. In addition partial weights (missing total weights) for one mature male and two immature females in 1988 and one mature and one immature male and one immature and one pregnant female in 1989.

Weights of body parts, blubber (n=222), meat (n=224) and visceral fat (n=114) were also available from Norwegian research catch under special permit in 1992-94 (Næss *et al.* 1998). These animals were caught in the Lofoten (n=55), Finmark (n=52), Björnöja (n=53), Spitsbergen (n=46) and Kola (n=19) areas. These data have girth measurements G2 and G4 (Fig 1) for most of the whales and G5 in 1993 and 1994.

Sexual condition was not available for a few of the Icelandic animals and most the 1992-1994 Norwegian except those observed with a foetus so this had to be assigned based on length. Males above 6.75 and females above 7.15 m were considered mature (Christensen 1981).

In the Icelandic data 90% of the females and 80% of the males were mature. The Norwegian data shows signs of segregation. The Spitsbergen animals (n=46) were all but one females, and out of 32 caught there in 1992 and 1993, 27 were mature by length, however only four of these were observed pregnant. Whereas in 1994 only two out of 12 were mature by length and both pregnant. In the Kola area (all taken midsummer 1992) seven of the eight females were mature thereof six observed pregnant. In data from other Norwegian areas about 40% are females that are 50% mature and there of 2/3 pregnant, while 2/3 of the males were mature.

METHODS

Measurements

Stomach content was subtracted from the total weights of the animals weighted as whole (foetuses are included). No data were available to quantify for fluid loss in the total weights that were based on partial weighings. The length measurement is made with a straight line from tip of snout to the notch of fluke (standard length). Girth measurements were taken at six points along the body (Fig 1): G1 axillary in front of flipper, G2 axillary under flipper at insertion, G3 at end of longest ventral grooves, G4 in front of fin, G5 behind fin and G6 midways between G5 and anterior edge of tail insertion. Norwegian girth measurements in 1988 and 1989 were taken whole, but other girth measurements were taken by measuring from center of back (dorsal) to abdominal center (ventral) and multiplied by two.

Analyses

Log-normal stepwise regression was performed where an exponent on length (and potentially the six girth measurements) predict the total weight, along with day of year as well as sex, sexual condition, area and year, and interactions of these with the day of year.

The same regression was performed with the meat and the blubber separately.

Visceral fat was regressed both directly and on the logarithm of visceral fat + 0.1 kg as 6 of the Icelandic measurements were 0.

RESULTS

Total weights

The regression with length (and no girth), including the day of the year (table 1), was significant (20% fattening over 100 days) and pregnancy implies a significant 26% more weight for a given length. Males are 19% heavier than females of the same length, and although not significantly different, this was included in the model as a difference is supported by the other data. There was little interaction of these factors with the length or the day within year. Year is not significant but 2003 is the heaviest. The CV of predicted weights is 0.103. Fixing the exponent on weight at 3 gives the same results for day within year.

If the regression is reversed (predicting length by weight) the exponent on total weight is 0.307, corresponding to an exponent on length of 3.2.

Including all the six girth measurements in the regression leads to nonsensical results. The best girth measurement is G4 (Fig 1), but this may be a sampling artefact. Fitting all or selecting the best girth measurements out of six given only 21 observations is questionable, so instead we tried averaging all the girth measurements. The exponent on length then became 1.734 and exponent on average girth 1.183. The effect of maturity becomes 0.14 and as expected the effect of day within year falls to 0.12%, both just significant. The CV of predicted weights is 0.0812.

When G4, the best girth measurement, is used instead of the average of the girths, the effect of maturity and the day within season is further halved (and not significant), implying that the seasonal fattening is better reflected there than at the tail or closer to the head. The CV of predicted weights is 0.078.

Adding the Norwegian data on total weights with a factor for area gives very similar results, but a more precise exponent on length of 2.91 (S.E. 0.15). There is a significant area effect as the Norwegian caught whales are 15% heavier (S.E. 5%), while interaction of area and length is insignificant (in different directions for the two Norwegian catch areas). Including the available G2 girth measurement (see Lydersen *et al.* 1991) increases the difference of the areas.

Including the 5 heaviest foetuses in the Icelandic data with the Icelandic data in the regression of length on weight was also tested and this gave the exponent 2.915 (S.E. 0.04).

Blubber and meat weights

The same regression model that was used on total weights was also used on blubber (mean weight 603 kg) and gave an increase with day of the year of 0.33% (S.E. 0.13%) both with the exponent on length estimated and fixed at 3 (*Condition Index* in Næss *et al.* 1998). For meat (mean weight 1,429 kg) the increase with day is 0.16% (S.E. 0.07%). When the Norwegian data were included precision was higher, but results were similar. Blubber increases with day by 0.35% (S.E. 0.03%) and meat by 0.13% (S.E. 0.05%). The increase is the same for all categories. Pregnant females are significantly higher in blubber by 17% (S.E. 3%) but females in general are significantly lower in meat. There are significant differences between areas, the Kola area is (by length) 17% higher in blubber and 18% in meat than the Icelandic area that is similar to other Norwegian areas in blubber, but lowest in meat. There are also significant differences by years where 2005 (Iceland) is lowest and 1988 (Lofoten) highest in blubber and differ by over 50%. Meat is also highest in 1988 and Iceland lowest and lower each year, the difference 1988 to 2007 is 30%.

Girths

The girths at position G2 (axillary under flipper), in the combined data set increase by 0.08% per day, 0.10% at position G4 (in front of fin) and 0.13% at G5 behind fin (CV 0.1 in all cases). The increase in the cross sectional area is more than double (squared) that of the increase in the circumference (girth). As the girth is increasing over the season, including girth measurements in the model reduces the estimated increase, but by less than half for blubber. If the exponent on girth is fixed at 2 the increase in blubber is estimated lowest with girth G5, but still 0.09% per day.

Visceral fat weights

Visceral fat in the Icelandic data (mean 38 kg) increases by 0.59 kg (SE 0.10) or 2.6% (S.E. 0.54%) per day. Mature animals have 16 kg more fat or 10% more than immature (when corrected for length), females have 20 kg more fat than males or 10% more and mature females extra 26 kg. When the Norwegian data are included results are more precise but very similar, the increase is 0.55 kg (S.E. 0.08) or 2.8% (S.E. 0.32%) per day. Females have 8 kg or 9% more and pregnant significantly 19 kg or 25% on top of that. The power on log(length) is significantly larger than 3 implying that larger animals have proportionately more fat, but droping length has no effect on the increase over the season. Differences are significant by year and area where the Björnöya area and Iceland in 2005 and 2006 are lowest while Iceland in 2007 and the Lofoten area are highest. Including girth G4 also gives an exponent significantly larger than 3 and lowers the estimated daily increase significantly to 1.8% or 0.35 kg per day.

DISCUSSION

Considerations of area and other factors

In spite of the clear segregation in the Norwegian data, in general, sex, sexual condition and area had little effect on the within year effect on either total or partial weights. The lower weights (by length) in the Icelandic data might be real as there are other indications that conditions around Iceland were poor during this period (SC/F13/SP2 & SC/F13/SP10; Ástþórsson *et al.* 2007), but some difference due to how the weightings in Iceland and Norway were conducted can not be excluded. That should not, however, affect the trend over the season. The Norwegian dataset of total weights is smaller and very unbalanced by sex and each year coming from a different area and month, so not surprisingly they add little to the precision in the day within year effect.

Pampoulie *et al.* (2013) found no genetic structure on the feeding grounds. It is therefore unlikely that the observed differences between areas are of genetic origin, but rather coincidental, segregation or reflecting feeding conditions at the areas at the time of sampling. Some of the areas were only sampled in a single year. Changes have been observed in minke whale distribution around Iceland in recent years (Gunnlaugsson *et al.* 2013=SC/F13/SP6).

Including the available girth measurement (G2, axillary under flipper) in the regression on total weight increased the difference of the areas implying that the difference in fat deposition is not well reflected at this position (assuming that the difference is real). This might also imply that the difference was due to factors such as fluid loss in the Icelandic total weightings. The G5 (behind dorsal fin) measurement is about 10% less in the Icelandic data, but this may be due to some difference in the measurement. In their studies of seasonal variations in minke whale body condition in Norwegian waters, Næss *et al.* (1998) observed that the deposition of fat over the summer varied with position on the whale body, e.g., with more depositions on the dorsal and lateral than on the ventral sides. Also, they observed an increase in blubber thickness from snout to tail. Such variations will certainly affect development in girth measurements, and further analysis of girth and blubber thickness should include all measurements in the Icelandic data, not just those minke whales with parts weighted that were considered here. Due to the limited information on sexual condition, pubertal animals could here not be assigned to a separate category. The immature size limit is including pubertal. There are indications (SC/F13/SP10) that pubertal are more like mature animals and this will therefore have blurred the differences of these categories.

Exponent on length

When girth is included it is natural to expect the exponent on length to be close to 1 and the exponent on girth close to 2, since the girth is reflecting two dimensions (breath and height). The best fit is however obtained with this almost reversed, that is exponent on length close to 2 and girth close to 1. This is likely a function of less precision in the girth measurements where both the point of measurement along the body is uncertain and the top dorsal and ventral points in the half-girth measurements are unclear. When the length was dropped from the regression, but retaining girth, the fit was poorer than in the model above with length and no girth. The sum of the exponents on length and girth (2.83) is however as expected close to 3.

Hauksson *et al.* (2013=SC/F13/SP 8) found an exponent on length of 2.758 (s.e. 0.2) for the weighted minke foetuses. The exponent reported here on length when some foetuses were included was close to 3 as expected since the girth to length ratio in large foetuses is very similar to the ratio in adults, indicating that little morphometric change is taking place from foetus to adult. Morphing into a more flattened or elongated form would take the exponent on length closer to 2 or even 1.

Model considerations

A regression such as presented here will always give the best prediction of weight for a data set similar to the one used, but if there are errors in the explanatory variables the exponent (slope) will not reflect the true exponent in the population, but be biased towards zero as also evident when the regression is reversed. In other words, if there is substantial error in the length measurements, it is better to assume that the animal is closer to the average weight than what the length measurement implies. Since the data set is small and certainly the length measurements have some error, that has not been quantified, we do not attempt here any inter species comparison such as Lockyer (1976). This also implies that any obtained formula is not optimal for length measurements that have a different range or with a different precision.

CONCLUSION

Similar to observations made in Norwegian waters in 1992-1994 (Næss *et al.* 1998), both total minke whale body weights and weights in parts of the visceral fat, blubber and meat show a significant increase for a given length over the Arctic summer in Icelandic waters. The predicted increase in weight over the season would be in addition to any increase in weight due to growth (lengthening) or maturation of the animals. The increase in weight is not fully explained by the increase in the available girth measurements. The girth measurements show more fattening towards the caudal part of the body. Immature animals show less fattening than mature. Pregnant females show rather less fattening than other mature animals but are heavier and therefore must have gained weight sooner in the season and/or only those females with good reserves did become pregnant. These results confirm the findings from blubber thickness measurements (SC/F13/SP8) and the increased energy content (SC/F13/SP10) comes on top of this increased mass/volume.

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Table 1. Regression on total weight of 21 minke whales caught off Icland in 2004 and 2005. The intercept is at the mean length of 7.5m (ln=2.012) in mid summer (day 180).

Coefficients	Estimate	Std.Error	t-value	Pr(>ltl)	
Intercept: ln(kg)	8.02	0.12	3.56	0.002	**
Day of year -180	0.0022	.00064	3.38	0.0038	**
ln(length in m) – 2.012	2.82	0.32	8.85	0.0001	***
pregnant	0.26	0.118	2.20	0.043	*
male	0.19	0.119	1.60	0.13	

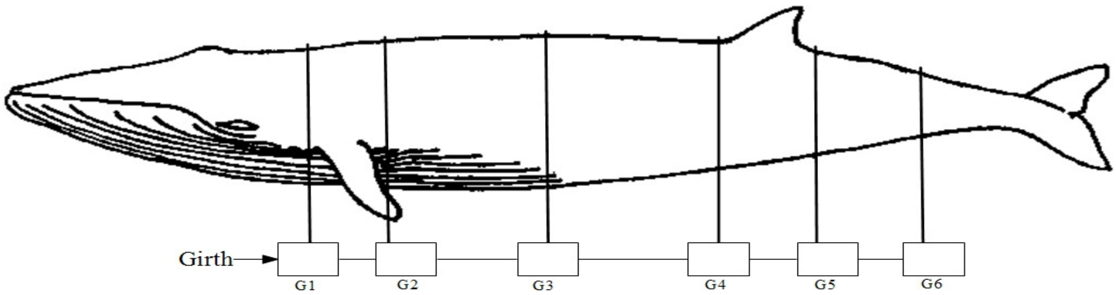

Fig. 1. Sites of girth measurements along the whale body.

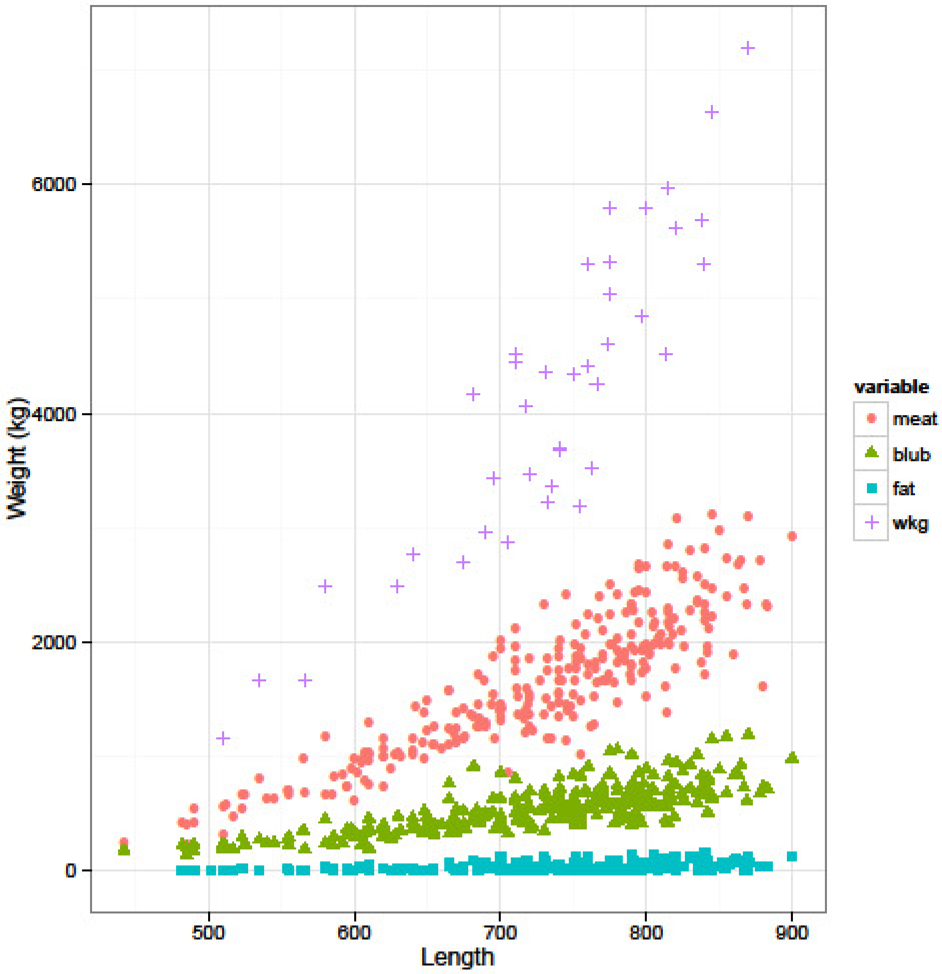

Fig 2. Icelandic and Norwegian weight data of North Atlantic minke whales 1988-2007. Total weights (wkg), meat, blubber (blub) and visceral fat (fat).