# Morphometric analysis on stock structure in the Antarctic minke whale based on JARPA samples.

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**Abstract**

In 1997 the IWC Scientific Committee listed up several tasks that could assist the interpretation of the results on stocks structure of Antarctic minke whales in the JARPA research area. One of these tasks was the conduction of morphological and morphometric analyses. In response to that task I conducted a morphometric analysis using JARPA data of this species obtained in the period 1987/88 and 2004/05. Samples were grouped into the six primary longitudinal strata used by JARPA surveys. The analysis was confined to mature animals. First the estimated marginal mean length of each measurement in each longitudinal sector for average body length was estimated using analysis of covariance (ANCOVA). Second cluster analysis is applied to the estimated marginal mean length to examine relationships in morphometric characters among whales in the six longitudinal sectors. Males and females were separated into two groups at 130°E and 165°E, respectively. Results of the morphometric analysis are consistent with the results of the genetic analysis.

KEY WORDS: STOCK IDENTITY, ANTARCTIC, FEEDING GROUNDS, ANTARCTIC MINKE WHALES, MORPHOMETRICS

## INTRODUCTION

The study on stock structure in the Antarctic minke whale is conducted under the JARPA research objective titled 'Elucidation of the stock structure of the Southern Hemisphere minke whales to improve stock management'. Information on stock structure is important for a) the estimation of biological parameters, which should ideally be carried out on the basis of biologically identified stocks and b) the future application of the multi-stock rules of the Revised Management Procedure (RMP) (IWC, 1994). Several genetic analyses have been conducted under the JARPA with the aim to investigate stock structure in the feeding grounds of Areas IIIE-VIW, and results have suggested substantial genetic heterogeneity, which is consistent with a multiple stock scenario in these areas (see SC/D06/J9 and a review of the studies on stock structure in SC/D06/J9).

In reviewing the results on stock structure derived from JARPA in 1997, the IWC Scientific Committee (SC) has noted that only preliminary conclusions can be drawn at this stage and that more concrete conclusions will be able to be made following the completion of different analyses. It further supported the suggestion that additional analyses using alternative groupings and analytical methods should be conducted (IWC, 2004). These suggestions are related to the widely accepted concept that the most effective way to address questions on stock identity is to consider results from several techniques, genetics and non-genetics (Donovan, 1991; Pastene *et al*., 2000; Perrin, 2001; Rugh *et al*., 2003). In the case of the Antarctic minke whale the application of multi-approaches to investigate stock identity is particularly desirable because previous genetic analysis suggested that the effect size in this species is low and then, results obtained by a single genetic marker should be checked using independent markers. Consequently the study on stock structure under the JARPA was extended by the use of several biological markers, both genetics and non-genetics and more detailed grouping of samples (Pastene *et al*., 2005).

Morphological and morphometric analyses are useful tools to examine questions on stock structure as demonstrated in the case of the North Atlantic common minke whale (*Balaenoptera acutorostrata*) (Christensen *et al*., 1990). Some morphological and morphometric studies were conducted on the Antarctic minke whale in the past using data obtained during commercial pelagic operations (Doroshenko, 1979; Wada and Numachi, 1979; Bushuev, 1990). However results of these analyses provided no evidence of unambiguous genetic differences between Areas in the Antarctic. Although some of these studies showed some differentiation among longitudinal sectors in the Antarctic (Doroshenko, 1979), the analyses were restricted to some few Areas and the issue of the criteria classification technique among investigators participating in different whaling expeditions was a common problem in these studies.

Morphometric data obtained from Antarctic minke whales sampled during JARPA surveys provide a valuable opportunity to examine stock structure questions in a more reliable way. Antarctic minke whales are taken randomly through systematic surveys and a team of whale specialists are in charge to get the samples and measurement of the animals sampled. A preliminary study on morphometry using JARPA data was carried out by Fujise (1996).

In 1997 the IWC Scientific Committee listed up several tasks that could assist the interpretation of the results on stocks structure of Antarctic minke whale under JARPA. One of these tasks was the conduction of morphological and morphometric analyses. In response to that task I conducted a morphometric analysis using JARPA morphometric data of this species obtained in the period 1987/88 and 2004/05. Results of this analysis could assist the interpretation of the results of genetic analysis conducted on the same Antarctic minke whale samples.

## MATERIALS AND METHODS

### Samples

Minke whales sampled by JARPA surveys in Areas IIIE (35°-70°E), IV (70°-130°E), V (130°E-170°W) and VIW (170°-145°W) between 1987/88 and 2004/05, were used in the analysis. All samples were taken randomly along pre-defined track-lines. In the analysis I used only mature animals because body proportion could be different between mature and immature animals (see Document SC/D06/J17 by Bando *et al*. for details of determination of sexual maturity)

### External measurements

In order to eliminate the effect of bias due to difference among researchers, the measurements that were less susceptible to such differences were selected for the analysis. Selection of these measurements took into consideration the opinion of experienced researchers. I also excluded girth because they are likely to change according sampling date in the feeding season. The ten external measurements used are shown in Figure 1.

### Grouping of samples

For the analysis the six longitudinal sectors used during JARPA surveys, were considered: IIIE (35°-70°E), IVW (70°-100°E), IVE (100°-130°E), VW (130°-165°E), VE (165°E-170°W), VIW (170°-145°W). Initially whales in sectors IVW and VE sector were sub-divided into southern and northern strata and compared between them. Because no substantial latitudinal differences occurred (except in the case of a few measurements for males in VE), samples in north and south strata were pooled for subsequent analyses.

### Analytical approach

*ANCOVA*

The ten measurements used in this analysis are dependent of body length of the animals. The first step was to estimate the average of the measurements in each sector allowing the body length to be different among six longitudinal sectors. For this purpose I used analysis of covariance (ANCOVA). First I examined if there is significant interaction between body length and sectors. If not, I took body length (V1) as a covariate and fit a linear model in formula (1) to exclude the effect of growth on measurements (V*x*).

$$\log(Vx) = \alpha \log(V1) + \beta_i + \varepsilon \qquad (1)$$

where $\beta_i$ is the intercept of sector *i*. There was no significant interaction between body length and sector so I assumed a common slope $\alpha$ for all sectors (Table 2). Logarithm of estimated marginal mean length of V*x* (denoting this estimate $\overline{\log(Vx)}$ ) for average body length was estimated for each sector.

*Cluster analysis*

Cluster analysis was applied to the estimated marginal mean to examine relationships in morphometric characters among the six longitudinal sectors. A total of 100 bootstraps were conducted. Resamples were generated assuming log (*Vx*) for average body length is normally distributed with mean of $\overline{\log(Vx)}$ and variance of $se\left(\overline{\log(Vx)}\right)$ in Table 3. For each longitudinal sector *i*, 100 resamples were generated by

$$\log(Vx)_i \sim N(\overline{\log(Vx)}_i, se(\overline{\log(Vx)})_i) \qquad (2).$$

Then cluster analysis was applied to each resamples.

## RESULTS

### ANCOVA

Results of the tests conducted to investigate interaction between body length and sectors are shown in Table 2. There was no significant interaction between body length and sector for all measurement used in this analysis. This justified statistically that a common slope $\alpha$ can be used for all sectors in formula (1) (i.e. ANCOVA can be applied). Table 3 shows the estimated marginal mean length of measurements by sex and sector for average body length over six sectors. From these results length of skull and length from tip to somewhere became larger for their body length from west to east.

### Cluster analysis

Figure 2 shows the results of the cluster analyses for sexual mature males and females. For mature males, six sector were separated into two groups, west (Areas IIIE, IVW and IVE) and east (Areas VW, VE and VIW) of 130°E. For mature female, six sectors were separated into west (Areas IIIE, IVW, IVE and VW) and east (Areas VE and VIW) of 165°E. For both sexes whales in Areas VE and VIW comprised a single group.

## DISCUSSION

In previous studies ANCOVA and discriminant analysis were applied to examine JARPA morphometric data for the study of stock structure of Antarctic minke whale (e.g. Fujise, 1996; Pastene *et al*., 2005). In the present study ANCOVA was used in a different way, only to estimate average length of each measurement. Furthermore cluster analysis was used to classify estimated marginal mean length of measurements in each sector. The reason for this new application was because the sample size used is large and then ANCOVA detects small differences in measurements (at most only 2 or 3% of measured length) as significant. The cluster analysis used in the present analysis is preferred.

Genetic analysis based on mtDNA suggested a separation of two stocks in the longitudinal range 150°-160°E, which is broadly consistent with this morphometric results, which suggest a division at 130°E and 165°E for males and females, respectively. The division for males in the morphometric analysis seems to occur more to the west in comparison with the genetic data. However there is the possibility that two stocks mix to each other in the longitudinal sector between 130°E and 165°E, which could explain the apparent differences.

The cluster analysis was well supported by the bootstrap values demonstrating that the estimated dendrogram is reliable. I also conducted a similar analysis using animals with body length larger than 760cm for males and larger than 800cm for females. These lengths were chosen based on the distribution of body length for each sex. Data of shorter animals were omitted so that distribution of body lengths looks like normal distribution. Results were almost the same as those obtained for the criterion of mature animals. This also suggests that the cluster analysis is reliable.

Fujise (1996) estimated marginal mean length of measurements for mean body length among eastern early, western early and western late group by ANCOVA using samples in Area IV during 1989/90 JARPA. In this study, the estimated marginal mean length of V4, V6-V9 were larger in eastern early than in western early and late for males and V3-V9 for females. The tendency that the measurements were longer in eastern longitudinal sector for their body length found in this study agrees with the results of Fujise (1996).

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Table 1. The number of Antarctic minke whales (mature males and females) used in this study by sex, year and longitudinal sector.

| | Longitudinal sector | | | | | | |
|---|---|---|---|---|---|---|---|
| sex | 3E | 4W | 4E | 5W | 5E | 6W | Combined |
| Male | 125 | 219 | 633 | 492 | 523 | 561 | 2629 |
| Female | 105 | 369 | 302 | 308 | 655 | 64 | 1803 |

Table 2. Results of the statistical test to investigate the interaction between body length and sector, for males and female.

Male

| measure ment | sum of squere | DF | mean squere | F statisitcs | p values |
|---|---|---|---|---|---|
| lnv3 | 0.004 | 5 | 0.001 | 0.492 | 0.782 |
| lnv4 | 0.003 | 5 | 0.001 | 0.601 | 0.700 |
| lnv5 | 0.002 | 5 | 0.000 | 0.499 | 0.777 |
| lnv6 | 0.006 | 5 | 0.001 | 1.610 | 0.154 |
| lnv7 | 0.001 | 5 | 0.000 | 0.484 | 0.789 |
| lnv8 | 0.001 | 5 | 0.000 | 0.848 | 0.515 |
| lnv9 | 0.001 | 5 | 0.000 | 1.309 | 0.257 |
| lnv19 | 0.003 | 5 | 0.001 | 0.575 | 0.719 |
| lnv20 | 0.007 | 5 | 0.001 | 0.975 | 0.432 |

Female

| measure ment | sum of squere | DF | mean squere | F statisitcs | p values |
|---|---|---|---|---|---|
| lnv3 | 0.004 | 5 | 0.001 | 0.489 | 0.785 |
| lnv4 | 0.006 | 5 | 0.001 | 1.018 | 0.405 |
| lnv5 | 0.003 | 5 | 0.001 | 0.807 | 0.544 |
| lnv6 | 0.004 | 5 | 0.001 | 1.182 | 0.316 |
| lnv7 | 0.002 | 5 | 0.000 | 1.009 | 0.411 |
| lnv8 | 0.001 | 5 | 0.000 | 0.760 | 0.578 |
| lnv9 | 0.001 | 5 | 0.000 | 0.838 | 0.523 |
| lnv19 | 0.012 | 5 | 0.002 | 1.817 | 0.106 |
| lnv20 | 0.001 | 5 | 0.000 | 0.079 | 0.995 |

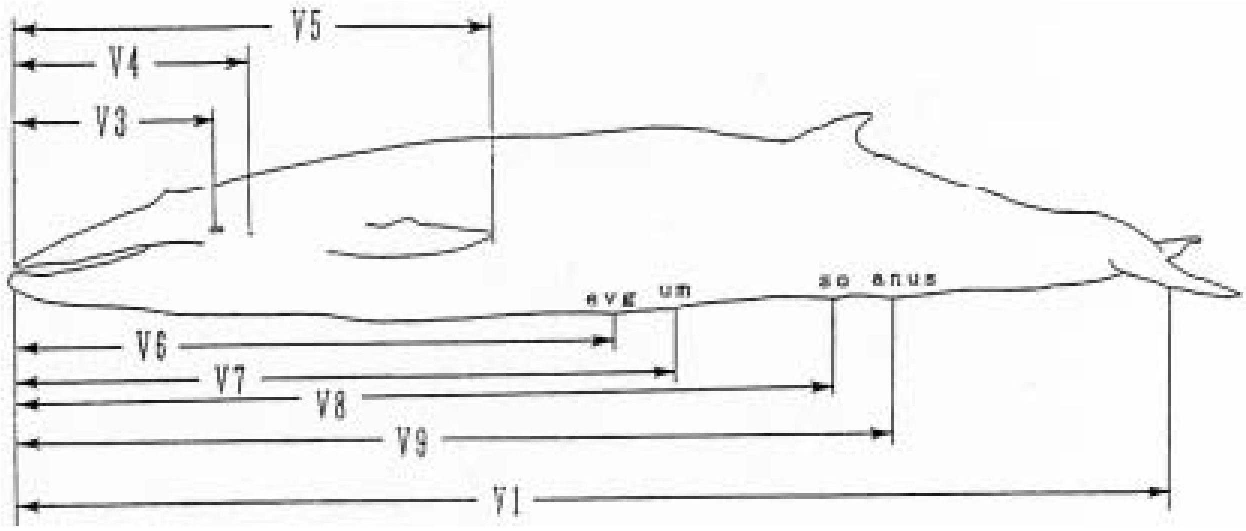
Table 3. Estimated marginal mean length of measurement for average body length (833.4cm for males and 887.9cm for females) in each sector by sex, derived from ANCOVA.

male

| measurement | sector | mean | se |
|---|---|---|---|
| V3 | IIIE | 5.036 | 0.003 |
| | IVW | 5.044 | 0.002 |
| | IVE | 5.051 | 0.002 |
| | VW | 5.057 | 0.002 |
| | VE | 5.069 | 0.002 |
| | VIW | 5.072 | 0.003 |
| V4 | IIIE | 5.273 | 0.002 |
| | IVW | 5.280 | 0.001 |
| | IVE | 5.286 | 0.002 |
| | VW | 5.293 | 0.001 |
| | VE | 5.301 | 0.001 |
| | VIW | 5.304 | 0.002 |
| V5 | IIIE | 5.906 | 0.002 |
| | IVW | 5.910 | 0.001 |
| | IVE | 5.912 | 0.001 |
| | VW | 5.920 | 0.001 |
| | VE | 5.927 | 0.001 |
| | VIW | 5.927 | 0.002 |
| V6 | IIIE | 6.017 | 0.002 |
| | IVW | 6.021 | 0.001 |
| | IVE | 6.023 | 0.001 |
| | VW | 6.031 | 0.001 |
| | VE | 6.036 | 0.001 |
| | VIW | 6.036 | 0.002 |
| V7 | IIIE | 6.098 | 0.001 |
| | IVW | 6.100 | 0.001 |
| | IVE | 6.104 | 0.001 |
| | VW | 6.107 | 0.001 |
| | VE | 6.111 | 0.001 |
| | VIW | 6.109 | 0.001 |
| V8 | IIIE | 6.322 | 0.001 |
| | IVW | 6.322 | 0.001 |
| | IVE | 6.323 | 0.001 |
| | VW | 6.326 | 0.001 |
| | VE | 6.326 | 0.001 |
| | VIW | 6.327 | 0.001 |
| V9 | IIIE | 6.419 | 0.001 |
| | IVW | 6.421 | 0.000 |
| | IVE | 6.423 | 0.001 |
| | VW | 6.425 | 0.001 |
| | VE | 6.424 | 0.001 |
| | VIW | 6.424 | 0.001 |
| V19 | IIIE | 5.262 | 0.002 |
| | IVW | 5.270 | 0.001 |
| | IVE | 5.274 | 0.002 |
| | VW | 5.279 | 0.002 |
| | VE | 5.286 | 0.001 |
| | VIW | 5.280 | 0.002 |
| V20 | IIIE | 4.674 | 0.003 |
| | IVW | 4.678 | 0.001 |
| | IVE | 4.680 | 0.002 |
| | VW | 4.690 | 0.002 |
| | VE | 4.689 | 0.002 |
| | VIW | 4.677 | 0.003 |

female

| measurement | sector | mean | se |
|---|---|---|---|
| V3 | IIIE | 5.135 | 0.004 |
| | IVW | 5.138 | 0.002 |
| | IVE | 5.149 | 0.002 |
| | VW | 5.154 | 0.002 |
| | VE | 5.169 | 0.002 |
| | VIW | 5.169 | 0.005 |
| V4 | IIIE | 5.363 | 0.003 |
| | IVW | 5.368 | 0.002 |
| | IVE | 5.375 | 0.002 |
| | VW | 5.382 | 0.002 |
| | VE | 5.394 | 0.001 |
| | VIW | 5.395 | 0.004 |
| V5 | IIIE | 5.988 | 0.003 |
| | IVW | 5.992 | 0.001 |
| | IVE | 5.995 | 0.002 |
| | VW | 6.003 | 0.002 |
| | VE | 6.012 | 0.001 |
| | VIW | 6.013 | 0.004 |
| V6 | IIIE | 6.099 | 0.003 |
| | IVW | 6.101 | 0.001 |
| | IVE | 6.101 | 0.002 |
| | VW | 6.110 | 0.002 |
| | VE | 6.118 | 0.001 |
| | VIW | 6.121 | 0.003 |
| V7 | IIIE | 6.170 | 0.002 |
| | IVW | 6.172 | 0.001 |
| | IVE | 6.176 | 0.001 |
| | VW | 6.179 | 0.001 |
| | VE | 6.184 | 0.001 |
| | VIW | 6.189 | 0.003 |
| V8 | IIIE | 6.440 | 0.001 |
| | IVW | 6.441 | 0.001 |
| | IVE | 6.442 | 0.001 |
| | VW | 6.444 | 0.001 |
| | VE | 6.447 | 0.001 |
| | VIW | 6.447 | 0.002 |
| V9 | IIIE | 6.485 | 0.001 |
| | IVW | 6.485 | 0.001 |
| | IVE | 6.486 | 0.001 |
| | VW | 6.489 | 0.001 |
| | VE | 6.491 | 0.000 |
| | VIW | 6.490 | 0.002 |
| V19 | IIIE | 5.348 | 0.004 |
| | IVW | 5.355 | 0.002 |
| | IVE | 5.363 | 0.002 |
| | VW | 5.365 | 0.002 |
| | VE | 5.376 | 0.001 |
| | VIW | 5.369 | 0.005 |
| V20 | IIIE | 4.751 | 0.004 |
| | IVW | 4.749 | 0.002 |
| | IVE | 4.760 | 0.002 |
| | VW | 4.766 | 0.002 |
| | VE | 4.769 | 0.002 |
| | VIW | 4.761 | 0.005 |

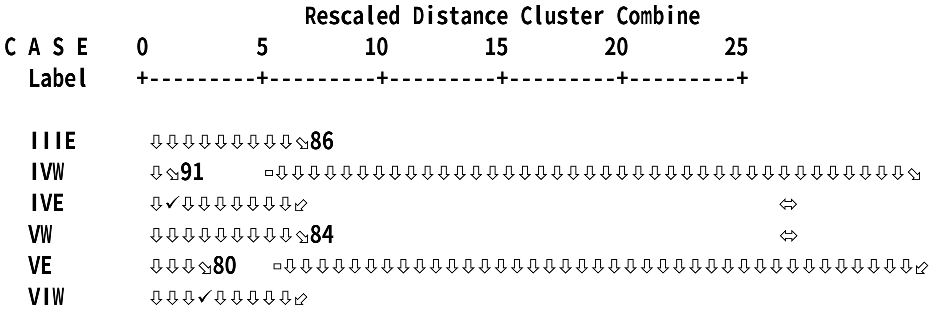



V1: Body length
V3: from the tip of snout to center of eye
V4: from the tip of snout to ear
V5: from the tip of snout to tip of flipper
V6: from the tip of snout to end of ventral gloves
V7: from the tip of snout to center of umbilicus
V8: from the tip of snout to sexual apparatus
V9: from the tip of snout to anus
V19: length of skull
V20: width of skull

Fig. 1. External measurements of the Antarctic minke whale used in this study.

Figure 2. Dendrogram based on the estimated marginal mean of length of measurements for males and females. Number is probability (%) estimated by bootstrap (out of 100 resamples).

Male




Female