Time trends in the storage of energy in the Antarctic minke whales during the JARPA and JARPA II research periods

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ABSTRACT

Yearly changes in the energy stores of sexually mature Antarctic minke whales were studied over the 24 years of the JARPA and JARPA II research programmes by examining five variables which are, or could be, indices of storage of energy. These variables are the total fat weight in the whale body, blubber thickness at two lateral measurement points and girth measured at two specified positions. Three of these variables are available from almost all whales sampled, but girth at axilla was measured over 20 years and fat weight was only measured over 17 years of the JARPA programme, and only for the first whale sampled on each day. A number of covariates were also recorded. A large number of linear mixed-effects statistical models were investigated for each of the dependent variables, and the Bayesian Information Criterion (BIC) was used to select the best model. All models examined had 'year' as a possible explanatory variable.

The results show that all five measures of energy storage declined substantially over time during the JARPA period, with a more than 10% decline in total fat weight. For all five dependent variables the values for energy stores are higher for females than for males. The values increase during the feeding season and are higher for higher body coverage of diatoms. This is assumed to be a measure of how long the animal has spent in Antarctic waters. The results are similar when each sex is analysed separately, but the decrease in energy stores was somewhat larger in females than in males. The results from the JARPA II period are very different from the JARPA period. There is no clear trend towards increase, or further decrease, in any of the four measures of energy storage. The results suggest that fundamental changes have taken place in the eastern part of the Antarctic marine ecosystem during the 1990's. These changes have resulted in less optimal feeding conditions for minke whales.

KEY WORDS: ANTARCTIC, ANTARCTIC MINKE WHALE, ENERGETICS, TREND, FOOD/PREY

INTRODUCTION

At the JARPA Review meeting in 2006 the authors presented a paper which indicated that blubber thickness measured at one lateral point in the middle of the body (directly below the centre of dorsal fin) had declined over the 18 year JARPA period from 1987/88 to 2004/05 (Konishi, Tamura and Walløe, 2006), taking into account other variables which could influence blubber thickness. An improved and extended manuscript was later discussed at the IWC-SC meeting in 2007 and later published in Polar Biology (Konishi et al, 2008). In the published paper the girth at the level of the umbilicus and the total fat weight in the whale body were used as response variables which could be used as indices of energy storage in addition to the blubber thickness. Blubber thickness and girth were available from nearly all whales taken, while fat weight was measured only from the first whale caught at each day in JAPRA period. Only sexually mature animals were included in the study to avoid problems connected with the growth of immature animals. The method used in these studies was simple multiple linear regression with either blubber thickness (cm), girth (cm) or fat weight (tons) as the dependent variable, and with date (Dec 1st = 1), year (1987/88 = 1), longitude (°E), latitude (°S), the extent of diatom adhesion on the skin (1 to 5), and body length (m) as independent variables. For some analyses body weight (tons), whale age (years) and foetus length (cm) were also used, but these variables were not available for all whales.

Some analyses were carried out separately for each sex; other analyses were carried out with both sexes combined and then with sex as an additional independent variable. In all regression runs the minimum BIC models included "year", "date", "diatom", and "sex", some also "longitude" and "latitude". "Year" was always highly significant different from zero with the regression coefficient ranging from -0.018 to -0.028 cm per year. "Fat weight" was found to decrease by approximately 17 kg per year and "girth" by approximately 0.92 cm per year (Konishi et al. 2008).

In the IWC-SC meeting in 2011 William de la Mare presented a paper claiming that the particular multiple regression model used by Konishi et al (2008) could have been inappropriate (de la Mare, 2011), and in the SC meeting he suggested that mixed-effects models should be fitted to the data to account for various forms of heterogeneity. During the meeting Hans J. Skaug fitted six such models which arose from the discussion, including all mixed-effects models suggested by de la Mare. In all models except one the coefficients for year were statistically significant and with values ranging from -0.017 to -0.026 cm/year. The model with the lowest AIC value had coefficient for year – 0.019 which was very close to the value in the best model published by Konishi et al. (2008), but the SE was three times larger than the value published by Konishi et al. (an increase from 0.0022 to 0.0068 cm/year), but the slope was still significantly different from zero at the 5% level. A jack-knife analysis by Lars Walløe with one year as the sampling unit to subsume the consequences of lack of independence in the data gave similar results (regression slope -0.0213 cm/year, SE 0.00836). The text of the Working Paper by Skaug is attached as an appendix (Appendix 1). De la Mare was offered the data file under the IWC Data Availability Agreement to explore other models himself, but he did not accept the conditions specified in the agreement. In the IWC-SC meeting in 2012 de la Mare presented a paper which argued that the transect sampling of JARPA and JARPA II precludes reliable and appropriate analysis of the data collected (de la Mare, 2012). He argued that that the transects could in reality have been the basic sampling unit in the analyses by Konishi et al (2008), not the individual whales, because whales taken on the same transect could have highly correlated properties. The discussion continued at the SC in 2013 with a reanalysis by mixed effect models by Hiroko Kato Solvang and Lars Walløe of the decrease in minke whale fat stores during the 17 JARPA years (Appendix 2). Since only one whale was dissected each day, de la Mare's argument about correlation between neighbouring whales in the data file should at least be less relevant, if relevant at all, for this statistical analysis. The results were similar to the results obtained by Skaug (Appendix 1) on blubber thickness, a largely unchanged and statistically significant decline compared to the results of the simple linear regression analysis of Konishi et al (2008), but a higher SE (0.0041 compared to 0.0025). The SC did not conclude the issue, however, requested further analyses of the data, including:

(1) determining whether the models fitted so far capture all the main features of the data,
(2) determining whether the estimate of trend could be made more precise,
(3) analysing the two sexes separately,
(4) including the interaction of slopes by latitudinal band with year as a random effect, and
(5) investigating independence issues by using mixed-effects models with track line as a random effect.

The SC encouraged additional analyses to be undertaken on both the blubber thickness and body fat data and noted that papers should ideally be submitted to the forthcoming JARPA II review. This is part of the background for the present paper.

MATERIALS AND METHODS

The present investigation has been expanded in two ways compared to the analyses carried out by Konishi et al. (2008) and the reanalyzes of these data carried out by Skaug (2011, Appendix 1) and Solvang and Walløe (2013, Appendix 2): The set of dependent variables has been increased from the three used by Konishi et al. (2008) and now also includes girth at level of the axilla and blubber thickness at a lateral point at the level of the umbilicus. Three of these five dependent variables were measured on most whales during the JARPA period and the measurement series were continued in the JARPA II period. Girth at level of the axilla was measured during 20 years of JARPA and JARPA II, Fat weight was only measured during 17 of the JARPA years and the measurements were not continued in JARPA II. In the current analyses we have fitted a large number of linear models to the data, both simple models with and without interaction terms and mixed models with random effects. For all dependent variables we have first analyzed the JARPA data only to try to resolve the disagreements expressed in the meetings of the IWC-SC from 2010 to 2013. We have then repeated the analyses for only the data from first six years of the JARPA II period (2005/06-2010/11) and finally analyzed the total JARPA + JARPA II period (1987/88-2010/11) for four of the dependent variables.

Samples and measurements

During all years from 1987/88 to 2010/11 blubber thickness at two lateral points under the dorsal fin (BT11) and level of umbilicus (BT7) were carefully measured to the nearest mm on a most whales on the left side of the body, but in several cases they were made on the right side, mainly because of damage to the left side caused by the harpoon. Measurements are missing from 16 whales in "BT11" and 4 whales in "BT7". The reasons for choosing this particular lateral point for blubber thickness measurements were that skin surface and muscle fascia are parallel in this area, and blubber thickness is close to constant in an area around the measurement site. Dorsal blubber, such as anterior and posterior to the dorsal fin, is highly variable in thickness along the axis of the body and has been shown difficult to measure consistently by different researchers. Therefore measurements of blubber thickness at the lateral positions are the only measurement positions which can be used to obtain reliable long time series of data. A small area of skin and blubber around the measurement points was also dissected free from surrounding skin and blubber to avoid stretch or pressure from surrounding areas before the measurements were obtained. The resulting variables were called "BT11" and "BT7" in the equations and in the Results section below. The distance between the dorsal mid-line and the ventral mid-line was measured to the nearest cm at two positions at umbilicus ("HalfGirth-u") and axillary ("HalfGirth-a") levels. In the first animal caught each day, all the blubber including the ventral groove and visceral fat was also removed from the body and weighed to the nearest kilogram during the last 17 years of the JARPA period. Since the total weight of the whale body was also available, the difference between these two weights for each whale has been called "lean body weight" and has been used as a predictor variable in some of the statistical analyses. These variables are only available for the JARPA period. Other predictor variables available for each whale include position of catch (latitude, longitude), time (year, date and local time) and a track line identifier. Fetus length was measured in the same way as adult body length. In addition to using continuous variables, some variables were split into categories and included in regression analyses. For some of the analyses, "latitude" and "longitude" were divided into eleven categories ("LatCat11" and "LongCat11"), and "year" into separate categories for each survey year ("YearCat"), to see if there were non-continuous effects of any of these explanatory variables. The study area includes the Ross Sea down to about 78^{o}S. Since the research area covered a wide range of latitudes and longitudes, extending as far south as the Ross Sea, geographical variables separated for lower and higher latitude areas with 70°S as the dividing line ("Lat70") and longitudinal areas as the dividing line 155°E ("LongWE") has also been used in the statistical analyses.

Statistical analysis

All statistical analyses were conducted in R environment version 3.0.2 (R Core Team 2013) using package "lme4" version 1.0-5 (Bates et al. 2013) for mixed effects models, and "stats" (R Core Team 2013) for other regression models.

In the R formulas the symbol ':' indicates an interaction between parameters. In mixed effects models left side of vertical bar '|' is fixed effect and right side grouping factor to which the random effect applies. The abbreviations 'lm' means linear model and 'lmer' means linear model with random effects.

There are different opinions among statisticians how to select the best model from a range of possibilities. The question is how to balance model fit with complexity. Akaike's information criterion (AIC) is currently much used. A related criterion, the Bayesian information criterion (BIC) usually selects the same model as AIC, but if there is a difference, BIC usually selects a simpler model. We have presented the values of both criteria in this paper, but generally we have a preference for BIC which was also the criterion used in Konishi et al. (2008). As can be seen from the results section, the two criteria have in most cases selected the same model, and when they have selected different models the coefficients for the change of blubber thickness with time are usually about the same. This is usually also the case when some models have about the same value for BIC. In both these situations it would have been possible to use the focused information criterion (FIC) (Claeskens and Hjort, 2008) and average the decline in blubber thickness over the best models with weights dependent on the fit, since the discussion so far has mainly been focused on the time trend in blubber thickness. It has so far not been necessary to use FIC, since models with close values of BIC have similar coefficients for year. If new models are suggested during the discussion of our results during the review meeting or in the IWC-SC, we may choose to use the FIC with averaging. The other four dependent variables can of course be dealt with in a similar way.

RESULTS

The output from all model runs can be found as pdf-files in an electronic attachment to this paper. A large number of different models have been explored, but the number is still small compared to the near infinite number of possible models. To make it easier to refer to the different models in the attachment, the models have been numbered consecutively. As an example Table 1 shows the different models which have been used in the analyses of the lateral blubber thickness at the level of the dorsal fin (called BT11) for both sexes combined. The log likelihood, number of parameter, AIC and BIC values and the coefficients for year with its SEs and t-values are also given. The models fall in four groups: simple linear models, linear models with categorical terms, linear models with interaction terms and finally mixed-effects models with random effect terms. The best model in each group according to the BIC criterion is shown in bold, and the best model of all are shown in bold italics. The models include models with random effect of track lines.

The JARPA period:

Blubber thickness "BT11":
For all models investigated (except one) the results show a decline in blubber thickness over the 18 JARPA years ranging from -0.0196 to -0.0299 cm/year (Table 1). The model with the lowest BIC value has a decline of -0.0203 cm/year (SE=0.0024). All the random-effects models have higher BIC values than the best linear model:
lm(BT11 ~ YearNum + BLm^3 + DateNum + Diatom + LongCat11 + Sex + DateNum:LongNum) ..(#BT11jarpa17)

The best model with random effects was:
lmer(BT11 ~ YearNum + BLm^3 + DateNum + Diatom +LatNum +LongNum + LongCat11 + Sex + DateNum:LongNum) + (DateNum | YearCat)) ..(#BT11jarpa18)

The total printouts of the results from the fitting of these two models are shown in Appendix 3 and 4 (and they can of course also be found in the electronic attachment as models # *BT11jarpa17* and #*BT11jarpa18*). The AIC preferred a model with three additional random effect terms in addition to the last model above. The two random effect models gave a decline in blubber thickness of -0.0189 and -0.0197 cm/ year, respectively. In addition to a decline in blubber thickness BT11 over the 18 JARPA years, the blubber thickness increased from west to east and from north to south. It also increased with the body length, diatom coverage and from December to March (Appendix 3 and 4). The scatterplot of residuals in BT11jarpa17 shows that the distribution of residuals is close to a normal distribution (Figure 1).

When the two sexes were analyzed separately, the results were largely the same as when the sexes were analyzed together. The decline over the JARPA period was somewhat larger for females than for males (-0.0297 cm/year versus -0.0176 cm/year for the models (#BT11jarpa15females and #BT11jarpa15male) with the lowest BIC values; see electronic attachment).

Blubber thickness "BT7":
The analyses of BT7 show a similar pattern, although the decline in blubber thickness is not quite as large as for BT11 (Table 4a). All models except two have negative coefficient for "YearNum", and the model with lowest BIC is a linear model (#BT7jarpa17):
lm(BT7 ~ YearNum + BLm^3 +DateNum +Diatom + LatNum + Lat70 + Sex + YearNum:LongCat11 + DateNum:LongNum) which has slope -0.011cm/year. The BIC values in the all mixed effects modes are all larger than in #BT7jarpa17.

Girth "HalfGirth-u":
All models except one have negative coefficient for "YearNum" ranged from -0.464 cm/year to -0.075cm/year, and the model with lowest BIC is mixed-effects model with coefficient -0.34 cm/year (SE=0.12) (#HGirth-Ujarpa25)(Table 4b):
lmer(UnbilicusGirth ~ YearNum + BLm +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine)). In the regression trial with "HalfGirth-u", linear effect of "BLm" was preferred both by the variance of residuals and BIC.

Girth "HalfGirth-a":
The analyses of HalfGirth-a show a similar pattern to those of HalfGirth-u. The point estimates of coefficients for "YearNum" are also similar, although the time series is a little shorter in HalfGirth-a since it is only available from the 1991/92 survey season. Interestingly, the model with lowest BIC is a simple linear model with coefficient for year -0.46 cm/year (SE=0.054) (#HGirth-Ajarpa6) (Table 4c):
lm(AxillaryGirth ~ YearNum + BLm +DateNum +Diatom + Sex)

Fat weight "FatWeight":
All models have negative coefficient for "YearNum" ranged from -0.014 to -0.006 (tons/year), and the model with lowest BIC is linear model has coefficient -0.011 tons/year (SE=0.0012) (#FatWjarpa5)(Table 4d):
lm(FatWeight ~ YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongWE + Sex + LeanBW) In the different regression runs, the large majority had coefficients for "YearNum" very close to 0.011 tons/year.

The JARPA II period:

Blubber thickness "BT11":
The analyses of BT11 did not show any clear decline of blubber thickness. None of the models explored had coefficients for "YearNum" which were statistically significant different from zero. In this group of regressions, complicated models tend to have lower BIC than simple models. The coefficient for "YearNum" in the model with lowest BIC (#BT11jarpaII17) was not statistically significant from zero at 5% level (-0.006, t-value -0.562)(Table 2).

Blubber thickness "BT7":
The analyses of BT7 show a similar pattern to those of BT11, and change of BIC between models are small. The model with the lowest BIC value (#BT7jarpaII18) has a positive coefficient for "YearNum", significant at the 5% level (0.661 cm/year) (Table 5a).
lm(BT7 ~ YearNum + BLm^3 +Date.quad +Diatom + LatNum + LongNum + Sex + YearNum:LatNum + Date.quad:LongNum)

Girth "HalfGirth-u":
All of the coefficients for "YearNum" have positive values and the model with the lowest BIC (#HGirth-UjarpaII19) shows significant and large increase of the girth per year (2.036 cm/year) (Table 5b).
lm(UnbilicusGirth ~ YearNum + BLm +Diatom + LongCat11 + Sex + YearNum:LongCat11 + I(DateNum^2):LongNum)

Girth "HalfGirth-a":
The analyses of HalfGirth-a show a similar pattern to those of HalfGirth-u, and all models except two have positive coefficient for "YearNum". The coefficient for "YearNum" in the linear model (HGirth-AjarpaII 14) with lowest BIC is 0.363 cm/year while the coefficient is not significant at 5% level(Table 5c).

The JARPA + JARPA II period:

Blubber thickness "BT11":
All models have negative coefficient for "YearNum" but the decline were smaller than those in the only JARPA period ranged from -0.1063 to -0.0056. The mode with lowest BIC is mixed effects model #BT11jarpa&II18 (Table 3):
lmer(BT11 ~ YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat))

Blubber thickness "BT7":
All models except one have negative coefficient for "YearNum" ranging from -0.073 cm/year to -0.006 cm/year, and the model with lowest BIC is mixed-effects model (coefficient of "YearNum" -0.010 cm/year, t=-2.165) (#BT7jarpa&II22)(Table 6a):
lmer(BT7 ~ YearNum + BLm +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine))

Girth "HalfGirth-u":
All models except one have negative coefficient for "YearNum" ranged from -0.616 cm/year to -0.198 cm/year, and the model with lowest BIC is mixed-effects model (coefficient of "YearNum" -0.258 cm/year, t=-2.900) (#HGirth-Ujarpa&II24)(Table 6b):
lmer(UmbilicusG ~ YearNum + BLm +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine))

Girth "HalfGirth-a":
The analyses of HalfGirth-a show a similar pattern to those of HalfGirth-u and all models have negative coefficient for "YearNum" The model with lowest BIC is mixed-effects model (coefficient of "YearNum" -0.321 cm/year, t=-3.080)is #HGirth-Ajarpa&II23 (Table 6c)

lmer(UmbilicusA ~ YearNum + BLm +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine))

DISCUSSION

The discussion in the IWC-SC during the last three years has mainly been about whether the decline during the JARPA period of blubber thickness BT11has been demonstrated with sufficient statistical significance to justify its acceptance, although the decline in girth at the level of umbilicus and the decline in total fat weight have also been questioned (Konishi et al. 2008, de la Mare 2011, 2012). The results presented here clearly show that all five measures of energy storage declined substantially during the JARPA years, and that the declines in all five variables are statistically significant at the 5% level, in four of them highly significant. The point estimates of the decline of BT11 is the same as reported in Konishi et al 2008, and that is also the SE of the estimate (0.0024). The jack-knife reanalysis by Walløe and the simple mixed model runs by Skaug (Appendix 1) both overcompensated for the heterogeneity. Also for the decline of girth at the level of umbilicus and the decline in total fat weight the point estimates in the best mixed models are about the same as in Konishi et al (2008). For all five dependent variables the values are higher for females than for males, the values increase during the feeding season and are higher for higher body coverage of diatoms which is assumed to be a measure of how long time the animal has spent in Antarctic waters.

The results are about the same when each sex is analysed separately, but the decline is somewhat larger for females than for males. The decline in blubber thickness for females does not change to any large degree when foetal length is included as an additional independent variable.

De la Mare suggested in the IWC-SC meeting in 2013 that for each whale the distance to the ice edge should be used as an independent variable in the analyses. The ice edge changes considerably from year to year and changes also within each research season. It will therefore be an insurmountable task to assign these distances to all whales in the database. As a proxy for the distance to the ice edge we have analysed separately the whales taken west of 155°E. In this area the coast goes roughly at a constant latitude, and the ice edge could perhaps as a first approximation also be regarded as being at a constant latitude, but possibly vary from year to year. We have analysed the blubber thickness at the level of umbilicus also for these whales with all the models with interaction terms and including random effects of latitude category for year category (LatCat | YearCat). The results remained the same as without these terms in the model with a strong and significant decline in blubber thickness. The BIC and AIC were also higher in these models than for models without these terms.

In the IWC-SC de la Mare (2012) has argued that whales taken on the same transect most likely would have highly correlated properties, and for this reason were far from independent of each other. To investigate this possibility we included random-effects analyses with transects (track lines) as the sampling unit in the mixed-effects models. All of the five models with lowest BIC values for the JARPA period and all models including random effects with track line as sampling unit still show a decline of coefficient of year similar to that in Konishi et al. (2008) and Sag (2011; Appendix 1). Our interpretation of these results is that the correlation between whales on the same track line is small or is covered by including spatial explanatory variables as we have done. Thus whales sampled on the same transect can be regarded as independent of each other. This finding could be of importance also for other types of investigations.

The results from the JARPA II period are very different from the JARPA period. There is no clear tendency of increase or decrease in any of the four measures of energy storage.

When the two periods are analysed together, the results are in general a significant decline of the four variables we have used as proxies for energy storage, but the absolute value of the coefficients with time is smaller than for the JARPA period. This could of course be expected.

The decline of energy storage during the 18 years JARPA period is substantial, close to 10% for fat weight and for the blubber thickness under the dorsal fin (BT11). Approximately at the end of the JARPA period the decline came to an end, and there is no further decline during the JARPA II period, nor an increase. The interpretation must be that there was a substantial decline in food availability during the JARPA period. This interpretation is supported by the finding of a decrease in stomach contents weights during the JARPA and JARPA II periods 1990/91 to 2009/10 (Konishi et al 2013).

What could be the explanation of the large decline in food availability during the 1990-ies and the following few years, followed by a constant food availability during the next years. One possibility is that the decline is caused by competition with rapidly growing humpback stocks during the JARPA period, and that this growth later has slowed down to a level which did not cause further difficulties for minke whale foraging. Another possibility is that some fundamental changes in the production of krill took place during these years, for instance caused by climatic changes, with the production decreasing from one level and levelling off at another lower level

The increase in the five proxies for energy storage from west to east is in need of an explanation. It could be a reflection of a better production of krill in the eastern JARPA area which is the one region of the Antarctic where the ice krill *E crystallorophus* dominates *E. superba*. It could also be explained if the I-stock and P-stock of minke whales had different feeding conditions north of the Antarctic feeding area. The gradient could then have been caused by the mixing of whales from the two stocks in the JARPA research area, as Kitakado et al (2013) have shown take place.

Conclusions:

On the statistical methods: De la Mare was right when he pointed out that simple multiple linear regressions could be dangerous when the multidimensional material could contain various forms of heterogeneity. However, when ordinary linear regressions are carried out on different subsets of the total material resulting in approximately the same results, as in Konishi at al. (2008), although not all regression runs were published, the point estimates of the regression coefficients are likely to be correct. The most dangerous part of the results is likely to be the SE of the coefficients. A jack-knife analysis can often take care of that problem, but may overcompensate for the heterogeneity, as has happened in the present example.

On the substance: In this paper and in a parallel paper (Konishi et al 2013) from the JARPA and the JARPA II programmes we have shown that fundamental changes have taken place in the eastern part of the Antarctic marine ecosystem during the 1990-ies resulting in worsened feeding conditions for minke whales.

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Table1 Model selection for the trend of BT11 in JARPA period (1987/88-2004/05) 18 years

<table>
<tr><th>Model No.</th><th>Var. of resid.</th><th>LogLik</th><th>No. of parameter</th><th>AIC</th><th>BIC</th><th>Year Effects</th><th>t-value</th><th>Models</th></tr>
<tr><td>BT11jarpa1</td><td>0.5795507</td><td>-5267.378</td><td>9</td><td>10552.76</td><td>10610.65</td><td>-0.0196</td><td>-8.715</td><td>YearNum + BLm +DateNum +Diatom + LatNum + LongNum + Sex)</td></tr>
<tr><td>BT11jarpa2</td><td>0.5870889</td><td>-5297.075</td><td>9</td><td>10612.15</td><td>10670.05</td><td>-0.0211</td><td>-9.358</td><td>YearNum + BLm +Date^2 +Diatom + LatNum + LongNum + Sex)</td></tr>
<tr><td>BT11jarpa3</td><td>0.579474</td><td>-5267.073</td><td>9</td><td>10552.15</td><td>10610.04</td><td>-0.0196</td><td>-8.721</td><td>YearNum + BLm^2 +DateNum +Diatom + LatNum + LongNum + Sex)</td></tr>
<tr><td>BT11jarpa4</td><td>0.5794055</td><td>-5266.802</td><td>9</td><td>10551.6</td><td>10609.5</td><td>-0.0196</td><td>-8.726</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + Sex)</td></tr>
<tr><td>BT11jarpa5</td><td></td><td>-5264.549</td><td>10</td><td>10549.1</td><td>10613.43</td><td>-0.0198</td><td>-8.795</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongWE + Sex)</td></tr>
<tr><td>BT11jarpa6</td><td></td><td>-5223.732</td><td>19</td><td>10485.46</td><td>10607.69</td><td>-0.0225</td><td>-9.587</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex)</td></tr>
<tr><td>BT11jarpa7</td><td></td><td>-5220.485</td><td>20</td><td>10480.97</td><td>10609.63</td><td>-0.0231</td><td>-9.811</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Lat70 + Sex)</td></tr>
<tr><td>BT11jarpa8</td><td></td><td>-5207.125</td><td>29</td><td>10472.25</td><td>10658.8</td><td>-0.0220</td><td>-9.192</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + LatCat11 + Sex)</td></tr>
<tr><td>BT11jarpa9</td><td></td><td>-5220.293</td><td>22</td><td>10484.59</td><td>10626.11</td><td>-0.0231</td><td>-9.805</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Area4 + Sex)</td></tr>
<tr><td>BT11jarpa10</td><td></td><td>-5196.793</td><td>29</td><td>10451.59</td><td>10638.14</td><td>0.0296</td><td>1.118</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + YearNum:LongCat11)</td></tr>
<tr><td>BT11jarpa11</td><td></td><td>-5223.098</td><td>20</td><td>10486.2</td><td>10614.85</td><td>-0.0252</td><td>-7.424</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + YearNum:Sex)</td></tr>
<tr><td>BT11jarpa12</td><td></td><td>-5223.709</td><td>20</td><td>10487.42</td><td>10616.08</td><td>-0.0299</td><td>-0.848</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + YearNum:LatNum)</td></tr>
<tr><td>BT11jarpa13</td><td></td><td>-5223.648</td><td>20</td><td>10487.3</td><td>10615.95</td><td>-0.0251</td><td>-3.701</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + YearNum:DateNum)</td></tr>
<tr><td>BT11jarpa14</td><td></td><td>-5200.599</td><td>29</td><td>10459.2</td><td>10645.75</td><td>-0.0198</td><td>-7.714</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongCat11)</td></tr>
<tr><td>BT11jarpa15</td><td></td><td>-5213.326</td><td>20</td><td>10466.65</td><td>10595.31</td><td>-0.0206</td><td>-8.670</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum)</td></tr>
<tr><td>BT11jarpa16</td><td></td><td>-5213.790</td><td>19</td><td>10465.58</td><td>10587.81</td><td>-0.0205</td><td>-8.631</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongCat11 + Sex + DateNum:LongNum)</td></tr>
<tr><td>BT11jarpa17</td><td></td><td>-5214.572</td><td>18</td><td>10465.14</td><td>10580.94</td><td>-0.0203</td><td>-8.564</td><td>YearNum + BLm^3 +DateNum +Diatom + LongCat11 + Sex + DateNum:LongNum)</td></tr>
<tr><td>BT11jarpa18</td><td></td><td>-5206.531</td><td>23</td><td>10459.06</td><td>10607.020</td><td>-0.0189</td><td>-2.853</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat))</td></tr>
<tr><td>BT11jarpa19</td><td></td><td>-5282.577</td><td>23</td><td>10611.15</td><td>10759.11</td><td>-0.0203</td><td>-8.165</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|LongCat11))</td></tr>
<tr><td>BT11jarpa20</td><td></td><td>-5222.711</td><td>23</td><td>10491.42</td><td>10639.38</td><td>-0.0230</td><td>-7.212</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|TrackLine))</td></tr>
<tr><td>BT11jarpa21</td><td></td><td>-5204.465</td><td>26</td><td>10460.93</td><td>10628.19</td><td>-0.0188</td><td>-2.850</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11))</td></tr>
<tr><td>BT11jarpa22</td><td></td><td>-5234.472</td><td>29</td><td>10526.94</td><td>10713.5</td><td>-0.0203</td><td>-3.062</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine))</td></tr>
<tr><td>BT11jarpa23</td><td></td><td>-5188.787</td><td>32</td><td>10441.57</td><td>10647.43</td><td>-0.0197</td><td>-3.139</td><td>YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine) + (DateNum|LatCat11))</td></tr>
<tr><td>BT11jarpa24</td><td></td><td>-5228.864</td><td>29</td><td>10515.73</td><td>10702.28</td><td>-0.0201</td><td>-3.060</td><td>YearNum + BLm +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine))</td></tr>
</table>

Table2 Model selection for the trend of BT11 in JARPA II period (2005/06-20010/11) 6 years

Model No.	Var. of resid.	LogLik	No. of parameter	AIC	BIC	Year Effects	t-value	Models
BT11jarpaII1	0.6849413	-2837.711	9	5693.422	5745.119	-0.0042	-0.373	YearNum + BLm +DateNum +Diatom + LatNum + LongNum + Sex)
BT11jarpaII2	0.673836	-2818.847	9	5655.694	5707.391	-0.0027	-0.246	YearNum + BLm +Date^2 +Diatom + LatNum + LongNum + Sex)
BT11jarpaII3	0.6846725	-2837.258	9	5692.516	5744.213	-0.0042	-0.373	YearNum + BLm^2 +DateNum +Diatom + LatNum + LongNum + Sex)
BT11jarpaII4	0.6844461	-2836.876	9	5691.753	5743.45	-0.0042	-0.375	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + Sex)
BT11jarpaII5	0.6735788	-2818.407	9	5654.813	5706.51	-0.0027	-0.246	YearNum + BLm^2 +Date^2 +Diatom + LatNum + LongNum + Sex)
BT11jarpaII6	**0.673358**	-2818.028	9	**5654.056**	**5705.754**	**-0.0027**	**-0.248**	**YearNum + BLm^3 +Date^2 +Diatom + LatNum + LongNum + Sex)**
BT11jarpaII7		-2818.001	10	5656.001	5713.442	-0.0030	-0.269	YearNum + BLm^3 +Date^2 +Diatom + LatNum + LongNum + LongWE + Sex)
BT11jarpaII8		-2785.355	19	**5608.709**	5717.848	0.0022	0.160	YearNum + BLm^3 +Date^2 +Diatom + LatNum + LongNum + LongCat11 + Sex)
BT11jarpaII9		-2817.898	10	5655.796	**5713.238**	**-0.0024**	**-0.213**	**YearNum + BLm^3 +Date^2 +Diatom + LatNum + LongNum + Lat70 + Sex)**
BT11jarpaII10		-2810.677	16	5653.355	5745.261	-0.0014	-0.122	YearNum + BLm^3 +Date^2 +Diatom + LatNum + LongNum + LatCat11 + Sex)
BT11jarpaII11		-2815.446	12	5654.892	5723.822	-0.0008	-0.071	YearNum + BLm^3 +Date^2 +Diatom + LatNum + LongNum + Area4 + Sex)
BT11jarpaII12		-2785.404	19	**5608.809**	5717.947	0.0000	0.001	YearNum + BLm^3 +Date^2 +Diatom + LatNum + LongNum + Sex + YearNum:LongCat11)
BT11jarpaII13		-2817.898	10	5655.796	5713.237	-0.0084	-0.536	YearNum + BLm^3 +Date^2 +Diatom + LatNum + LongNum + Sex + YearNum:Sex)
BT11jarpaII14		-2816.784	10	5653.568	5711.009	0.3267	1.560	YearNum + BLm^3 +Date^2 +Diatom + LatNum + LongNum + Sex + YearNum:LatNum)
BT11jarpaII15		-2816.377	10	5652.754	5710.196	-0.0319	-1.636	YearNum + BLm^3 +Date^2 +Diatom + LatNum + LongNum + Sex + YearNum:Date^2)
BT11jarpaII16		-2789.279	19	5616.558	5725.697	0.0090	0.638	YearNum + BLm^3 +Date^2 +Diatom + LatNum + LongNum + Sex + Date^2:LongCat11)
BT11jarpaII17		-2813.200	10	5646.399	***5703.841***	***-0.0065***	***-0.586***	***YearNum + BLm^3 +Date^2 +Diatom + LatNum + LongNum + Sex + Date^2:LongNum)***
BT11jarpaII18		-2840.053	23	5726.105	5858.221	0.0754	1.568	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat))
BT11jarpaII19		-2848.721	23	5743.441	5875.556	-0.0031	-0.210	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|LongCat11))
BT11jarpaII20		-2838.729	23	**5723.457**	**5855.572**	**-0.0336**	**-1.945**	**YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|TrackLine))**
BT11jarpaII21		-2839.581	26	5731.162	5880.51	0.0440	0.831	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11))
BT11jarpaII22		-2836.100	29	5730.199	5896.779	0.0193	0.379	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine))
BT11jarpaII23		-2836.134	32	5736.267	5920.08	0.0550	1.236	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine) + (DateNum|LatCat11))
BT11jarpaII24		-2833.198	29	5724.397	5890.977	0.0768	1.462	YearNum + BLm +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine))

Table3 Model selection for the trend of BT11 in JARPA and JARPA II period (1987/88-20010/11) 24 years

Model No.	Var. of resid.	LogLik	No. of parameter	AIC	BIC	Year Effects	t-value	Models
BT11jarpa&II1	0.6245668	-8171.005	9	16360.01	16421.57	-0.0092	-6.232	YearNum + BLm +DateNum +Diatom + LatNum + LongNum + Sex)
BT11jarpa&II2	0.6275089	-8187.228	9	16392.46	16454.02	-0.0095	-6.415	YearNum + BLm +Date^2 +Diatom + LatNum + LongNum + Sex)
BT11jarpa&II3	0.624445	-8170.333	9	16358.67	16420.22	-0.0092	-6.238	YearNum + BLm^2 +DateNum +Diatom + LatNum + LongNum + Sex)
BT11jarpa&II4	**0.6243397**	-8169.750	9	**16357.5**	**16419.06**	**-0.0093**	**-6.244**	**YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + Sex)**
BT11jarpa&II5		-8169.650	10	16359.3	16427.7	-0.0093	-6.245	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongWE + Sex)
BT11jarpa&II6		-8124.932	19	16287.86	**16417.82**	**-0.0091**	**-5.608**	**YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex)**
BT11jarpa&II7		-8124.929	20	16289.86	16426.66	-0.0091	-5.594	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Lat70 + Sex)
BT11jarpa&II8		-8105.081	29	**16268.16**	16466.52	-0.0074	-4.455	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + LatCat11 + Sex)
BT11jarpa&II9		-8123.366	22	16290.73	16441.21	-0.0086	-5.238	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Area4 + Sex)
BT11jarpa&II10		-8063.484	29	16184.97	16383.32	-0.0290	-2.984	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + YearNum:LongCat11)
BT11jarpa&II11		-8063.444	30	16186.89	16392.08	-0.0285	-2.888	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + YearNum:LongCat11 + YearNum:Sex)
BT11jarpa&II12		-8061.378	30	16182.76	16387.95	-0.0951	-2.821	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + YearNum:LongCat11 + YearNum:LatNum)
BT11jarpa&II13		-8061.451	29	16180.9	16379.26	-0.1057	-5.511	YearNum + BLm^3 +DateNum +Diatom + LongNum + LongCat11 + Sex + YearNum:LongCat11 + YearNum:LatNum)
BT11jarpa&II14		-8060.166	30	16180.33	16385.53	-0.1063	-5.543	YearNum + BLm^3 +DateNum +Diatom + LongNum + LongCat11 + Sex + YearNum:LongCat11 + YearNum:LatNum + YearNum:DateNum)
BT11jarpa&II15		-8025.809	39	**16129.62**	16396.37	-0.0538	-2.456	YearNum + BLm^3 +DateNum +Diatom + LongNum + LongCat11 + Sex + YearNum:LongCat11 + YearNum:LatNum + DateNum:LongCat11)
BT11jarpa&II16		-8025.809	39	**16129.62**	16396.37	-0.0538	-2.456	YearNum + BLm^3 +Diatom + LongNum + LongCat11 + Sex + YearNum:LongCat11 + YearNum:LatNum + DateNum:LongCat11)
BT11jarpa&II17		-8045.970	30	16151.94	**16357.14**	**-0.0782**	**-3.958**	**YearNum + BLm^3 +DateNum +Diatom + LongNum + LongCat11 + Sex + YearNum:LongCat11 + YearNum:LatNum + DateNum:LongNum)**
BT11jarpa&II18		***-8044.414***	***23***	16134.83	***16292.14***	***-0.0078***	***-1.554***	***YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat))***
BT11jarpa&II19		**-8178.390**	**23**	16402.78	16560.10	-0.0063	-3.694	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|LongCat11))
BT11jarpa&II20		**-8073.202**	**23**	16192.4	16349.72	-0.0111	-4.740	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|TrackLine))
BT11jarpa&II21		-8036.293	26	**16124.59**	16302.42	-0.0072	-1.388	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11))
BT11jarpa&II22		-8058.704	29	16175.41	16373.76	-0.0091	-1.817	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine))
BT11jarpa&II23		-8080.035	32	16224.07	16442.95	-0.0069	-1.321	YearNum + BLm^3 +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine) + (DateNum|LatCat11))
BT11jarpa&II24		-8067.573	29	16193.15	16391.50	-0.0056	-0.928	YearNum + BLm +DateNum +Diatom + LatNum + LongNum + LongCat11 + Sex + DateNum:LongNum + (DateNum|YearCat) + (DateNum|LongCat11) + (DateNum|TrackLine))

Bold Best three models, Italic the best model among each group

Table 4 Regression results of four response variables for only JARPA period

a) Blubber thickness at the level of umbilicus (BT7)

Models	Var. of resid.	LogLik	No. of parameter	AIC	BIC	Year Effects	t-value
BT7jarpa1	0.41182	-4493.924	9	9005.85	9063.77	-0.015	-8.162
BT7jarpa2	0.41672	-4521.180	9	9060.36	9118.28	-0.017	-8.786
BT7jarpa3	0.41174	-4493.477	9	9004.95	9062.87	-0.015	-8.170
BT7jarpa4	**0.41167**	-4493.066	9	**9004.13**	**9062.05**	**-0.015**	**-8.177**
BT7jarpa5		-4491.517	10	9003.03	9067.39	-0.016	-8.235
BT7jarpa6		-4454.353	19	**8946.71**	9068.98	-0.018	-8.857
BT7jarpa7		-4486.970	10	8993.94	**9058.30**	**-0.016**	**-8.552**
BT7jarpa8		-4466.689	19	8971.38	9093.65	-0.016	-8.276
BT7jarpa9		-4483.777	12	8991.55	9068.78	-0.017	-8.698
BT7jarpa10		-4426.920	20	8893.84	9022.55	-0.008	-1.256
BT7jarpa11		-4426.893	21	8895.79	9030.93	-0.008	-1.244
BT7jarpa12		-4426.920	20	8893.84	9022.55	-0.008	-1.256
BT7jarpa13		-4426.896	21	8895.79	9030.94	0.000	-0.007
BT7jarpa14		-4425.689	21	8893.38	9028.53	-0.014	-1.891
BT7jarpa15		-4406.409	30	**8872.82**	9065.89	0.033	2.003
BT7jarpa16		-4418.531	21	8879.06	9014.21	-0.017	-2.558
BT7jarpa17		-4419.658	20	8879.32	***9008.03***	***-0.011***	***-2.074***
BT7jarpa18		-4430.359	23	**8906.72**	**9054.74**	**-0.018**	**-2.975**
BT7jarpa19		-4517.981	23	9081.96	9229.98	-0.016	-7.721
BT7jarpa20		-4463.336	23	8972.67	9120.69	-0.018	-6.806
BT7jarpa21		-4427.865	26	8907.73	9075.05	-0.019	-3.043
BT7jarpa22		-4470.212	29	8998.43	9185.06	-0.019	-2.871
BT7jarpa23		-4428.872	32	8921.74	9127.68	-0.016	-3.378
BT7jarpa24		-4457.480	29	8972.96	9159.59	-0.019	-3.119

b) Half Girth at the level of umbilicus (HalfGirth-u)

Models	Var. of resid.	LogLik	No. of parameter	AIC	BIC	Year Effects	t-value
Hgirth-Ujarpa1	**142.04890**	-17879.050	9	**35776.09**	**35833.98**	**-0.418**	**-11.867**
Hgirth-Ujarpa2	142.44810	-17885.490	9	35788.97	35846.85	-0.434	-12.317
Hgirth-Ujarpa3	142.29950	-17883.090	9	35784.18	35842.06	-0.418	-11.863
Hgirth-Ujarpa4	142.68840	-17889.350	9	35796.70	35854.58	-0.418	-11.845
Hgirth-Ujarpa5		-17891.290	8	35798.58	35850.03	-0.432	-12.267
Hgirth-Ujarpa6		-17879.000	10	35778.01	35842.32	-0.427	-12.104
Hgirth-Ujarpa7		-17834.770	19	35707.54	35829.73	-0.464	-12.626
Hgirth-Ujarpa8		-17833.940	20	35707.88	35836.50	-0.467	-12.699
Hgirth-Ujarpa9		-17823.480	29	35704.95	35891.46	-0.451	-12.041
Hgirth-Ujarpa10		-17827.590	22	**35699.17**	35840.66	-0.456	-12.410
Hgirth-Ujarpa11		-17834.810	18	**35705.62**	**35821.38**	**-0.458**	**-12.473**
Hgirth-Ujarpa13		-17819.370	28	35694.75	35874.82	-0.286	-0.688
Hgirth-Ujarpa14		-17831.090	19	35700.19	35822.38	-0.562	-10.577
Hgirth-Ujarpa15		-17832.770	19	35703.54	35825.74	0.653	1.183
Hgirth-Ujarpa16		-17830.120	19	35698.25	35820.44	-0.154	-1.452
Hgirth-Ujarpa17		-17811.120	29	35680.25	35866.75	-0.099	-0.840
Hgirth-Ujarpa18		-17817.010	20	**35674.02**	**35802.64**	**-0.075**	**-0.706**
Hgirth-Ujarpa19		-17786.440	23	35618.87	35766.79	-0.328	-2.710
Hgirth-Ujarpa20		-17852.660	23	35751.32	35899.24	-0.420	-10.870
Hgirth-Ujarpa21		17814.890	23	35675.79	35823.71	-0.445	-8.890
Hgirth-Ujarpa22		-17784.670	26	35621.33	35788.54	-0.306	-2.530
Hgirth-Ujarpa23		-17827.150	29	35712.30	35898.80	-0.312	-2.420
Hgirth-Ujarpa24		-17771.360	32	35606.71	35812.51	-0.337	-2.760
Hgirth-Ujarpa25		*-17758.220*	*29*	***35574.44***	***35760.94***	***-0.340***	***-2.800***

c) Half Girth at the level of axilla (HalfGirth-a)

Models	old name	Var. of resid.	LogLik	No. of parameter	AIC	BIC	Year Effects	t-value
Hgirth-Ajarpa1	LinearModel.1	**170.09770**	-14939.260	9	29896.51	29952.57	-0.462	-8.457
Hgirth-Ajarpa2	LinearModel.2	170.57240	-14944.480	9	29906.96	29963.02	-0.459	-8.403
Hgirth-Ajarpa3	LinearModel.3	170.59760	-14944.750	9	29907.51	29963.57	-0.465	-8.505
Hgirth-Ajarpa4	LinearModel.4	171.39000	-14953.440	9	29924.87	29980.93	-0.468	-8.539
Hgirth-Ajarpa5	LinearModel.1.1		-14939.740	8	29895.47	29945.30	-0.457	-8.405
Hgirth-Ajarpa6	***LinearModel.1.2***		*-14940.140*	*7*	***29894.29***	***29937.89***	***-0.464***	***-8.592***
Hgirth-Ajarpa7	**LinearModel.5**		-14939.290	8	29894.58	**29944.41**	**-0.451**	**-8.239**
Hgirth-Ajarpa8	LinearModel.6		-14923.430	17	**29880.86**	29986.75	-0.463	-8.111
Hgirth-Ajarpa9	LinearModel.7		-14939.550	8	29895.10	29944.93	-0.459	-8.472
Hgirth-Ajarpa10	LinearModel.8		-14930.190	16	29892.39	29992.05	-0.458	-8.297
Hgirth-Ajarpa11	LinearModel.9		-14938.800	10	29897.60	29959.88	-0.447	-8.117
Hgirth-Ajarpa12	LinearModel.1.2.I1		-14923.760	17	**29881.53**	29987.41	-0.297	-2.660
Hgirth-Ajarpa13	LinearModel.1.2.I2		-14939.880	8	29895.75	29945.58	-0.235	-0.745
Hgirth-Ajarpa14	LinearModel.1.2.I3		-14939.860	8	29895.73	29945.56	-0.547	-4.408
Hgirth-Ajarpa15	LinearModel.1.2.I4		-14928.090	17	29890.19	29996.07	-0.490	-8.819
Hgirth-Ajarpa16	**LinearModel.1.2.I5**		-14938.240	8	29892.48	**29942.31**	**-0.472**	**-8.726**
Hgirth-Ajarpa17	LMER.6.I6.1		-14917.820	23	29881.64	30024.90	-0.389	-2.600
Hgirth-Ajarpa18	LMER.6.I6.2		-14950.360	23	29946.72	30089.98	-0.436	-7.270
Hgirth-Ajarpa19	LMER.6.I6.3		-14927.080	23	29900.16	30043.42	-0.483	-6.870
Hgirth-Ajarpa20	**LMER.6.I6.4**		*-14917.320*	*26*	29886.64	**30048.59**	**-0.391**	**-2.520**
Hgirth-Ajarpa21	LMER.6.I6.5		-14907.680	29	29873.36	30053.99	-0.410	-2.620
Hgirth-Ajarpa22	LMER.6.I6.6		-14920.730	32	29905.46	30104.78	-0.432	-2.650
Hgirth-Ajarpa23	LMER.6.I6.5.1		-14887.950	29	**29833.91**	30014.54	-0.405	-2.560

d) Fat Weight (ton)

Models	old name	Var. of resid.	LogLik	No. of parameter	AIC	BIC	Year Effects	t-value
FatWjarpa1	LinearModel.1	0.02312	322.421	10	-624.84	-579.43	-0.011	-9.027
FatWjarpa2	LinearModel.2	0.02312	322.391	10	-624.78	-579.37	-0.011	-9.275
FatWjarpa3	LinearModel.3	0.02307	323.146	10	-626.29	-580.88	-0.011	-9.049
FatWjarpa4	**LinearModel.4**	**0.02303**	323.798	10	**-627.60**	**-582.19**	**-0.011**	**-9.070**
FatWjarpa5	***LinearModel.5***		*329.077*	*11*	***-636.15***	***-586.20***	***-0.011***	***-9.067***
FatWjarpa6	LinearModel.6		**334.038**	**21**	-626.08	-530.71	-0.012	-9.160
FatWjarpa7	LinearModel.7		330.001	12	-636.00	-581.51	-0.011	-9.116
FatWjarpa8	LinearModel.8		337.113	21	-632.23	-536.86	-0.011	-8.832
FatWjarpa9	LinearModel.9		330.657	13	-635.31	-576.28	-0.011	-9.129
FatWjarpa10	LinearModel.5.I1		337.098	21	-632.20	-536.83	-0.014	-3.580
FatWjarpa11	LinearModel.5.I2		329.096	12	-634.19	-579.70	-0.011	-5.920
FatWjarpa12	LinearModel.5.I3		329.083	12	-634.17	-579.67	-0.009	-0.501
FatWjarpa13	**LinearModel.5.I4**		331.208	12	**-638.42**	**-583.92**	**-0.006**	**-1.875**
FatWjarpa14	LinearModel.5.I5		338.925	21	-635.85	-540.49	-0.012	-8.994
FatWjarpa15	LinearModel.5.I6		330.655	12	-637.31	-582.82	-0.011	-8.858
FatWjarpa16	**LMER.6.I6.1**		272.224	24	-496.45	**-387.46**	**-0.010**	**-4.021**
FatWjarpa17	LMER.6.I6.2		246.047	24	-444.09	-335.11	-0.012	-9.201
FatWjarpa18	LMER.6.I6.3		258.512	24	-469.02	-360.04	-0.011	-8.018
FatWjarpa19	LMER.6.I6.4		272.559	27	-491.12	-368.51	-0.010	-4.277
FatWjarpa20	LMER.6.I6.5		279.065	30	-498.13	-361.90	-0.010	-4.231
FatWjarpa21	LMER.6.I6.6		240.504	33	-415.01	-265.15	-0.009	-3.484
FatWjarpa22	LMER.6.I6.5.1		283.057	30	**-506.11**	-369.88	-0.010	-4.201

Table 5 Regression results of three response variables for only JARPA II period

a) Blubber thickness at the level of umbilicus (BT7)

Models	Var. of resid.	LogLik	No. of parameter	AIC	BIC	Year Effects	t-value
BT7jarpaII1	0.47026	-2403.760	9	4825.52	4877.22	-0.032	-3.453
BT7jarpaII2	0.46275	-2385.182	9	4788.36	4840.06	-0.031	-3.353
BT7jarpaII3	0.46997	-2403.030	9	4824.06	4875.76	-0.032	-3.454
BT7jarpaII4	0.46970	-2402.389	9	4822.78	4874.48	-0.032	-3.457
BT7jarpaII5		-2384.466	9	4786.93	4838.63	-0.031	-3.354
BT7jarpaII6		-2383.828	9	**4785.66**	**4837.35**	**-0.031**	**-3.356**
BT7jarpaII7		-2383.103	10	4786.21	**4843.65**	**-0.032**	**-3.457**
BT7jarpaII8		-2363.147	19	**4764.29**	4873.43	-0.026	-2.248
BT7jarpaII9		-2383.356	10	4786.71	4844.15	-0.030	-3.226
BT7jarpaII10		-2377.531	16	4787.06	4878.97	-0.026	-2.627
BT7jarpaII11		-2378.572	12	4781.14	4850.07	-0.029	-3.144
BT7jarpaII12		-2364.191	19	**4766.38**	4875.52	-0.018	-1.204
BT7jarpaII13		-2383.315	10	4786.63	4844.07	-0.040	-3.081
BT7jarpaII14		-2380.023	10	4780.05	4837.49	0.446	2.575
BT7jarpaII15		-2377.720	11	4777.44	4840.63	0.481	2.766
BT7jarpaII16		-2363.708	20	4767.42	4882.30	0.298	1.373
BT7jarpaII17		-2373.976	11	4769.95	***4833.14***	***0.661***	***3.599***
BT7jarpaII18		-2419.309	23	4884.62	5016.73	-0.028	-0.951
BT7jarpaII19		-2431.611	23	4909.22	5041.34	-0.021	-1.684
BT7jarpaII20		-2417.846	23	4881.69	**5013.81**	**-0.051**	**-3.304**
BT7jarpaII21		-2417.868	26	4887.74	5037.08	0.010	0.345
BT7jarpaII22		-2413.665	29	4885.33	5051.91	0.005	0.231
BT7jarpaII23		-2420.586	32	4905.17	5088.98	0.011	0.550
BT7jarpaII24		-2409.356	29	**4876.71**	5043.29	0.006	0.261

b) Half Girth at the level of umbilicus (HalfGirth-u)

Models	Var. of resid.	LogLik	No. of parameter	AIC	BIC	Year Effects	t-value
HGirth-UjarpaII1	151.47040	-8930.420	9	17878.84	17930.40	0.421	2.503
HGirth-UjarpaII2	**150.56520**	-8923.608	9	**17865.22**	**17916.78**	**0.432**	**2.577**
HGirth-UjarpaII3	151.89160	-8933.576	9	17885.15	17936.71	0.418	2.484
HGirth-UjarpaII4	152.46150	-8937.833	9	17893.67	17945.23	0.414	2.459
HGirth-UjarpaII5		-8926.748	9	17871.50	17923.06	0.429	2.558
HGirth-UjarpaII6		-8930.969	9	17879.94	17931.50	0.426	2.533
HGirth-UjarpaII7		-8923.310	9	17866.62	17923.91	0.444	2.638
HGirth-UjarpaII8		-8857.565	18	17753.13	17861.98	0.516	2.479
HGirth-UjarpaII9		-8856.718	19	17753.44	17868.01	0.559	2.653
HGirth-UjarpaII10		-8841.066	25	**17734.13**	17883.08	0.699	3.256
HGirth-UjarpaII11		-8851.187	21	17746.37	17872.41	0.561	2.657
HGirth-UjarpaII12		-8858.807	17	17753.61	**17856.73**	0.498	2.397
HGirth-UjarpaII13		-8814.566	27	17683.13	17837.81	0.480	0.526
HGirth-UjarpaII14		-8814.565	28	17685.13	17845.54	0.486	0.525
HGirth-UjarpaII15		-8814.485	28	17684.97	17845.38	0.315	0.315
HGirth-UjarpaII16		-8813.393	28	17682.79	17843.19	0.028	0.030
HGirth-UjarpaII17		-8798.053	37	17670.11	17882.07	0.557	0.144
HGirth-UjarpaII18		-8807.017	28	17670.03	17830.44	2.209	2.182
HGirth-UjarpaII19		-8807.084	27	***17668.17***	***17822.85***	***2.036***	***2.278***
HGirth-UjarpaII20		-8831.733	23	17709.47	**17841.23**	**0.631**	**1.202**
HGirth-UjarpaII21		-8858.305	23	17762.61	17894.37	0.466	2.101
HGirth-UjarpaII22		-8841.682	23	17729.36	17861.13	0.097	0.351
HGirth-UjarpaII23		-8830.472	26	17712.94	17861.89	0.745	1.550
HGirth-UjarpaII24		-8829.475	29	17716.95	17883.09	0.693	1.356
HGirth-UjarpaII25		-8826.679	32	17717.36	17900.68	0.721	1.482
HGirth-UjarpaII26		-8813.655	29	**17685.31**	17851.45	0.690	1.312

c) Half Girth at the level of axilla (HalfGirth-a)

Models	old name	Var. of resid.	LogLik	No. of parameter	AIC	BIC	Year Effects	t-value
HGirth-AjarpaII1	LinearModel.1	170.01230	-9001.861	9	18021.72	18073.22	0.267	1.494
HGirth-AjarpaII2	**LinearModel.2**	**169.29180**	**-8997.066**	**9**	**18012.13**	**18063.63**	**0.273**	**1.531**
HGirth-AjarpaII3	LinearModel.3	170.83360	-9007.302	9	18032.60	18084.10	0.262	1.461
HGirth-AjarpaII4	LinearModel.4	172.01210	-9015.064	9	18048.13	18099.63	0.256	1.421
HGirth-AjarpaII5	LinearModel.2.1	170.10770	-9002.494	9	18022.99	18074.49	0.268	1.498
HGirth-AjarpaII6	LinearModel.2.2	171.27680	-9010.227	9	18038.45	18089.95	0.261	1.458
HGirth-AjarpaII7	LinearModel.5		-8995.672	10	18011.34	18068.57	0.300	1.677
HGirth-AjarpaII8	LinearModel.6		-8961.914	19	17961.83	18070.55	0.400	1.796
HGirth-AjarpaII9	LinearModel.7		-8961.362	20	17962.72	18077.17	0.438	1.940
HGirth-AjarpaII10	LinearModel.8		-8945.307	26	17942.61	18091.39	0.625	2.715
HGirth-AjarpaII11	LinearModel.9		-8955.813	22	**17955.63**	18081.51	0.449	1.984
HGirth-AjarpaII12	**LinearModel.6.1**		-8963.023	18	17962.05	**18065.05**	**0.422**	**1.894**
HGirth-AjarpaII13	LinearModel.6.1.I1		-8952.585	27	**17959.17**	18113.67	0.122	0.122
HGirth-AjarpaII14	***LinearModel.6.1.I1.1***		*-8964.480*	*17*	17962.97	***18060.25***	***0.363***	***1.726***
HGirth-AjarpaII15	LinearModel.6.1.I1.2		-8962.914	18	17961.83	18064.83	0.040	0.142
HGirth-AjarpaII16	LinearModel.6.1.I1.3		-8961.627	18	17959.25	18062.25	-0.507	-1.204
HGirth-AjarpaII17	LinearModel.6.1.I1.4		-8963.191	18	17962.38	18065.38	0.815	2.318
HGirth-AjarpaII18	LinearModel.6.1.I1.5		-8954.665	27	17963.33	18117.83	0.247	0.952
HGirth-AjarpaII19	LinearModel.6.1.I1.6		-8963.443	18	17962.89	18065.89	0.413	1.938
HGirth-AjarpaII20	AxillaryLMER.6.I6.1		-8968.984	23	17983.97	18115.58	0.029	0.033
HGirth-AjarpaII21	AxillaryLMER.6.I6.2		-8980.465	23	18006.93	18138.54	0.298	1.264
HGirth-AjarpaII22	AxillaryLMER.6.I6.3		-8970.076	23	17986.15	18117.76	0.357	1.202
HGirth-AjarpaII23	AxillaryLMER.6.I6.4		-8968.611	26	17989.22	18138.00	0.118	0.128
HGirth-AjarpaII24	AxillaryLMER.6.I6.5		-8965.314	29	17988.63	18154.57	0.089	0.109
HGirth-AjarpaII25	AxillaryLMER.6.I6.6		-8965.892	32	17995.78	18178.90	-0.143	-0.191
HGirth-AjarpaII26	**AxillaryLMER.6.I6.5.1**		-8945.467	29	**17948.93**	**18114.88**	**0.107**	**0.127**

Table 6 Regression results of three response variables for JARPA and JARPA II period

a) Blubber thickness at the level of umbilicus (BT7)

Models	Var. of resid.	LogLik	No. of parameter	AIC	BIC	Year Effects	t-value
BT7jarpa&II1	0.43692	-6949.657	9	13917.31	13978.89	-0.007	-6.013
BT7jarpa&II2	0.43854	-6962.446	9	13942.89	14004.47	-0.008	-6.177
BT7jarpa&II3	0.43679	-6948.590	9	13915.18	13976.75	-0.007	-6.020
BT7jarpa&II4	**0.43667**	-6947.626	**9**	**13913.25**	**13974.83**	**-0.007**	**-6.028**
BT7jarpa&II5		-6947.453	10	13914.91	13983.32	-0.007	-6.029
BT7jarpa&II6		-6912.576	19	**13863.15**	13993.14	-0.007	-5.420
BT7jarpa&II7		-6946.106	10	13912.21	**13980.63**	**-0.008**	**-6.181**
BT7jarpa&II8		-6925.016	19	13888.03	14018.02	-0.006	-5.042
BT7jarpa&II9		-6945.859	12	13915.72	13997.82	-0.008	-6.077
BT7jarpa&II10		-6876.779	20	13793.56	13930.39	-0.016	-5.256
BT7jarpa&II11		-6876.720	21	13795.44	13939.11	-0.015	-4.468
BT7jarpa&II12		-6873.510	21	13789.02	13932.69	-0.073	-3.224
BT7jarpa&II13		-6873.071	21	13788.14	13931.82	-0.023	-5.735
BT7jarpa&II14		-6843.052	30	**13746.10**	13951.35	0.011	1.704
BT7jarpa&II15		-6865.831	21	13773.66	**13917.34**	**-0.017**	**-5.650**
BT7jarpa&II16		-6847.282	23	13740.56	13897.92	-0.008	-1.585
BT7jarpa&II17		-6974.155	23	13994.31	14151.67	-0.006	-3.943
BT7jarpa&II18		-6881.731	23	13809.46	13966.82	-0.009	-4.500
BT7jarpa&II19		-6833.623	26	13719.25	13897.13	-0.009	-1.967
BT7jarpa&II20		-6832.767	29	13723.53	13921.94	-0.008	-1.776
BT7jarpa&II21		-6912.868	32	13889.74	14108.67	-0.008	-1.727
BT7jarpa&II22		*-6818.411*	*29*	***13694.82***	***13893.23***	***-0.010***	***-2.165***

b) Half Girth at the level of umbilicus (HalfGirth-u)

Models	Var. of resid.	LogLik	No. of parameter	AIC	BIC	Year Effects	t-value
HGirth-Ujarpa&II1	**148.04160**	-26878.740	**9**	53775.48	53836.98	-0.334	-14.576
HGirth-Ujarpa&II2	148.18740	-26882.120	9	53782.23	53843.73	-0.336	-14.686
HGirth-Ujarpa&II3	148.37150	-26886.370	9	53790.75	53852.25	-0.334	-14.598
HGirth-Ujarpa&II4	148.84530	-26897.310	9	53812.63	53874.13	-0.335	-14.613
HGirth-Ujarpa&II5		-26879.390	8	**53774.79**	**53829.46**	-0.339	-15.110
HGirth-Ujarpa&II6		-26877.200	9	53772.40	53833.90	-0.335	-14.863
HGirth-Ujarpa&II7		-26820.670	18	53677.34	53800.35	-0.336	-13.725
HGirth-Ujarpa&II8		-26819.750	19	53677.51	53807.34	-0.340	-13.793
HGirth-Ujarpa&II9		-26801.660	28	53659.32	53850.66	-0.317	-12.457
HGirth-Ujarpa&II10		-26796.980	21	53635.96	53779.46	-0.309	-12.255
HGirth-Ujarpa&II11		-26797.270	20	**53634.54**	**53771.21**	**-0.307**	**-12.231**
HGirth-Ujarpa&II12		-26743.000	30	53546.00	53751.01	-0.582	-3.846
HGirth-Ujarpa&II13		-26742.130	31	53546.25	53758.09	-0.616	-4.013
HGirth-Ujarpa&II14		-26740.870	31	53543.74	53755.58	0.179	0.448
HGirth-Ujarpa&II15		-26742.030	31	53546.07	53757.91	-0.522	-3.314
HGirth-Ujarpa&II16		-26703.710	40	**53487.41**	53760.76	-0.586	-2.643
HGirth-Ujarpa&II17		-26724.950	31	53511.89	**53723.73**	**-0.369**	**-2.375**
HGirth-Ujarpa&II18		-26677.940	23	53401.88	53559.05	-0.229	-2.490
HGirth-Ujarpa&II19		-26825.730	23	53697.47	53854.64	-0.262	-9.990
HGirth-Ujarpa&II20		-26714.600	23	53475.20	53632.37	-0.350	-9.360
HGirth-Ujarpa&II21		-26721.770	26	53495.53	53673.21	-0.198	-2.010
HGirth-Ujarpa&II22		-26653.200	29	53364.40	53562.58	-0.265	-3.050
HGirth-Ujarpa&II23		-26762.900	32	53589.80	53808.48	-0.228	-2.200
HGirth-Ujarpa&II24		-26623.460	29	***53304.91***	***53503.09***	***-0.258***	***-2.900***

c) Half Girth at the level of axilla (HalfGirth-a)

Models	old name	Var. of resid.	LogLik	No. of parameter	AIC	BIC	Year Effects	t-value
HGirth-Ajarpa&II1	**LinearModel.1**	**172.34170**	**-23981.540**	**9**	**47981.07**	**48041.38**	**-0.366**	**-11.551**
HGirth-Ajarpa&II2	LinearModel.2	172.43630	-23983.180	9	47984.37	48044.67	-0.360	-11.346
HGirth-Ajarpa&II3	LinearModel.3	172.99800	-23992.950	9	48003.90	48064.20	-0.370	-11.635
HGirth-Ajarpa&II4	LinearModel.4	173.97510	-24009.860	9	48037.72	48098.02	-0.373	-11.712
HGirth-Ajarpa&II5	**LinearModel.5**		-23974.180	10	47968.36	**48035.37**	**-0.363**	**-11.457**
HGirth-Ajarpa&II6	LinearModel.6		-23942.450	20	**47924.90**	48058.91	-0.355	-10.530
HGirth-Ajarpa&II7	LinearModel.7		-23972.580	11	47967.16	48040.86	-0.360	-11.350
HGirth-Ajarpa&II8	LinearModel.8		-23959.570	19	47957.15	48084.46	-0.331	-9.985
HGirth-Ajarpa&II9	LinearModel.9		-23965.620	12	47955.25	48035.65	-0.332	-10.201
HGirth-Ajarpa&II10	LinearModel.5.I1		-23915.370	20	47870.74	48004.75	-0.388	-5.534
HGirth-Ajarpa&II11	LinearModel.5.I2		-23915.320	21	47872.63	48013.34	-0.375	-4.669
HGirth-Ajarpa&II12	LinearModel.5.I3		-23910.060	21	47862.13	48002.83	-2.294	-3.889
HGirth-Ajarpa&II13	LinearModel.5.I3.1		-23909.850	22	47863.70	48011.11	-2.144	-3.385
HGirth-Ajarpa&II14	LinearModel.5.I3.2		-23891.480	31	**47844.97**	48052.68	-2.586	-3.947
HGirth-Ajarpa&II15	LinearModel.5.I3.3		-23903.290	22	47850.58	47997.99	-2.472	-4.181
HGirth-Ajarpa&II16	**LinearModel.5.I3.3.1**		-23903.290	21	47848.59	**47989.29**	**-2.477**	**-4.214**
HGirth-Ajarpa&II17	AxillaryLMER.6.I6.1		-23926.130	23	47898.26	48052.37	-0.341	-3.260
HGirth-Ajarpa&II18	AxillaryLMER.6.I6.2		-23992.800	23	48031.60	48185.70	-0.329	-9.450
HGirth-Ajarpa&II19	AxillaryLMER.6.I6.3		-23933.580	23	47913.17	48067.28	-0.382	-8.260
HGirth-Ajarpa&II20	AxillaryLMER.6.I6.4		-23925.480	26	47902.95	48077.16	-0.331	-3.110
HGirth-Ajarpa&II21	AxillaryLMER.6.I6.5		-23902.230	29	47862.46	48056.77	-0.324	-3.110
HGirth-Ajarpa&II22	AxillaryLMER.6.I6.6		-23921.570	32	47907.14	48121.55	-0.077	-0.430
HGirth-Ajarpa&II23	***AxillaryLMER.6.I6.5.1***		-23867.890	29	***47793.78***	***47988.09***	***-0.321***	***-3.080***

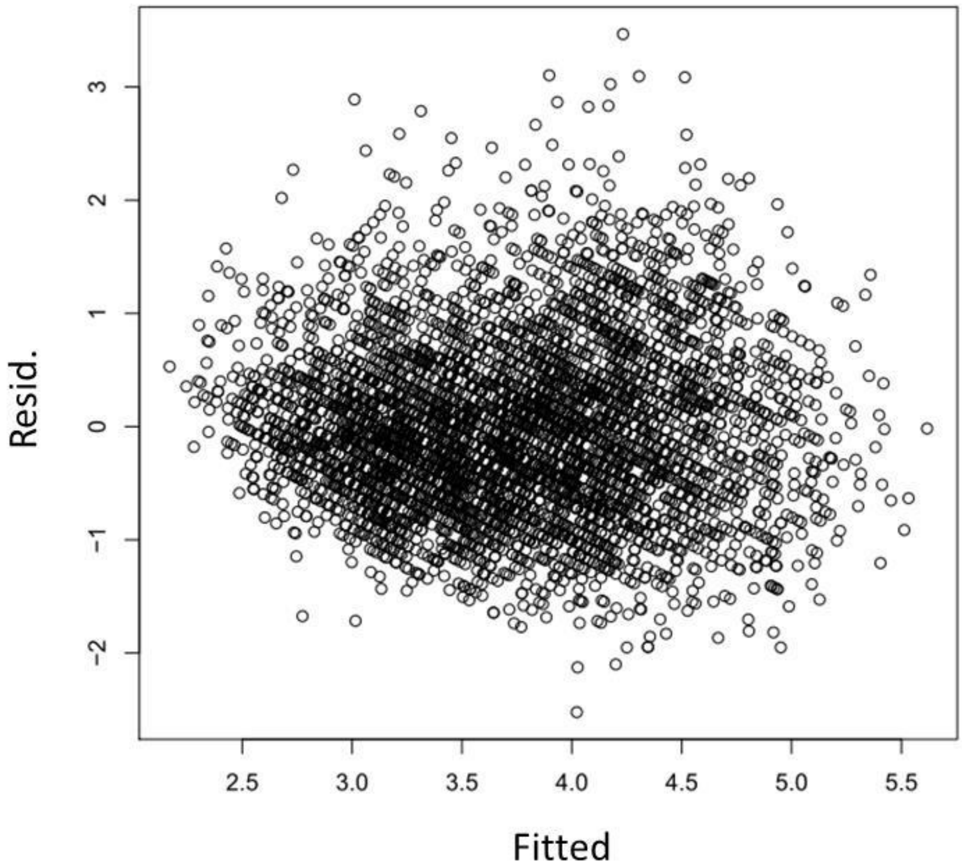

Figure 1 Residual plot of the best model in BT11 in JARPA period (BT11jarpa 17)

APPENDIX 1

EMWP 7

An investigation of proposals made in SC/63/O16

Hans J. Skaug

SC/62/O16 questioned the conclusion in Konishi et al. (2008, Polar Biol. 31:1509-20) about decline in blubber thickness of Antarctic minke whales, and suggested that mixed regression should be fitted to account for various forms of heterogeneity. The present working paper fits a selection of models that arose in the discussion of O16.

Models considered

The models are are displayed in standard R notation, where "DateNum" is date within year, and "YearNum" is year number. The parameter of interest is the slope associated with "YearNum". The following 6 models were fitted:

m1 = lm(BT11 ~ DateNum + Diatom + Sex + LongDegE + YearNum + Latitude + BLm, data=blubber,)

Note1: The original model from Konishi et al. (2008).

m2 = lm(BT11 ~ DateNum + Diatom + Sex + LongDegE + LongCat + YearNum + Latitude + BLm, data=blubber)

Note2: Categorical variable "LongCat", coding for 6 areas, added.

m3 = lmer(BT11 ~ (DateNum-1|Year) + Diatom + LongDegE + YearNum + Latitude + BLm + Sex, data=blubber,REML=reml)

Note3: The slope associated with "DateNum" variable between years (treated as random effect). Note that "Year" is a categorical version of "YearNum".

m3b = lmer(BT11 ~ (DateNum-1|Year) + Diatom + LongDegE:LongCat + YearNum + Latitude:LongCat + BLm + Sex, data=blubber,REML=reml)

Note 3b: Same as model 3, but with area specific slopes for "Longitude" and "Lattitude".

m4 = lmer(BT11 ~ (DateNum|Year) + (DateNum|LongCat) + Diatom + LongDegE + YearNum + Latitude + BLm + Sex, data=blubber,REML=reml)

Note 4: As model 3, with the addition of 1) a random intercept associated with "Year", and a random intercept and slope (of "DateNum") associated with "LongCat".

m5 = lmer(BT11 ~ (DateNum|Year:LongCat) + Diatom + LongDegE + YearNum + Latitude + BLm + Sex, data=blubber,REML=reml)

Note 5: As model 4, but with an interaction between the random effects associated with "Year" and "LongCat".

Summary of results for «year effect» (YearNum)

	AIC	MLE			REML		
		Estimate	Std. Error	t value	Estimate	Std. Error	t value
m1	10766.096	-0.0203966	0.0022408	-9.102	-0.0203966	0.0022408	-9.102
m2	10719.26	-0.0232417	0.0023087	-10.067	-0.0232417	0.0023087	-10.067
m3	10629.824	-0.007234	0.005917	-1.223	-0.0072328	0.0059212	-1.222
m3b	10610.875	-0.0167368	0.0067975	-2.462	-0.0167367	0.0068098	-2.458
m4	10574.961	-0.0189226	0.0068127	-2.778	-0.0192157	0.0070532	-2.724
m5	10603.012	-0.0257900	0.0060251	-4.280	-0.025708	0.006279	-4.094

Conclusion: m4 gives the best fit according to AIC

Detailed output from R for best model (m4)

```
Linear mixed model fit by REML
Formula: BT11 ~ (DateNum | Year) + (DateNum | LongCat) + Diatom + LongDegE +
YearNum + Latitude + BLm + Sex
   Data: blubber
   AIC   BIC logLik deviance REMLdev
 10627 10717  -5299    10547   10599
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Year     (Intercept) 5.3613e-02 0.2315456
          DateNum     1.5418e-05 0.0039266 -0.808
 LongCat  (Intercept) 1.8817e+00 1.3717510
          DateNum     2.1119e-04 0.0145322 -0.999
 Residual             5.4348e-01 0.7372078
Number of obs: 4689, groups: Year, 18; LongCat, 6

Fixed effects:
              Estimate Std. Error t value
(Intercept)  1.6763703  0.3826375   4.381
Diatom       0.2265899  0.0092392  24.525
LongDegE     0.0030021  0.0009474   3.169
YearNum     -0.0192157  0.0070532  -2.724
Latitude     0.0130544  0.0043277   3.016
BLm          0.1143693  0.0273181   4.187
Sex2         0.3410411  0.0299599  11.383

Correlation of Fixed Effects:
         (Intr) Diatom LngDgE YearNm Latitd BLm
Diatom    0.010
LongDegE -0.112  0.028
YearNum  -0.131 -0.005 -0.032
Latitude -0.694 -0.107 -0.284 -0.032
BLm      -0.646  0.027  0.017 -0.019  0.059
Sex2      0.533  0.147  0.054  0.009 -0.364 -0.511
```

APPENDIX 2

EM WP 4

DECREASE IN MINKE WHALE FAT STORES DURING 17 JARPA YEARS

Hiroko Kato Solvang and Lars Walløe

In the regression analyses reported in Konishi et al 2008 the development with time of three variables were studied and reported: mid lateral blubber thickness directly below the dorsal fin, girth at the level of the umbilicus, and total fat weight. The criticism raised by de la Mare in the SC meeting in 2011 concerned the reported decline of blubber thickness over the 18 JARPA years. One of his arguments is that neighbouring sample points in space and time could be correlated, and thus that the SD of the regression coefficient with time (year) could be too low.

In this WP we have investigated the development of the variable 'Total fat weight' with time over the JARPA years. Every day during the JARPA cruises the first whale caught was subject to special investigations: the subcutaneous fat (the blubber) was dissected off from the carcass, and the intestinal fat in the omentum was also dissected out. The sum was weighed and the variable is called the 'Total fat'. These two deposits of fat represent the main fat storages in a mammalian body. The 'Total fat weight' is of course part of the 'Total body weight', so in the analyses we have established a new variable, called 'Lean body weight'.
'Lean body weight' = 'Total body weight' – 'Total fat'

The advantage in the use of 'Total fat' for the analysis is that there is at the maximum only one data point per day. The points are therefore presumably far from each other in time (at least one day) and space, and de la Mare's correlation argument should be less relevant. The disadvantage is fewer data points than for 'Blubber thickness' and 'Girth'. The whales were not weighed during the first JARPA year, so the datafile covers only 17 years.

As a first step in the analysis an ordinary linear regression was carried out, with a subsequent jack-knife analysis:

Total number of samples without missing values is 647.
Number of explanatory variables is 9.

The regression model used all variables :

Fat_in_ton ~ Date + Lean Body Weight + Diatom + Body Length + Longitude + Sex + Year + Age + Latitude

Table1. Estimated coefficients, standard errors and p-values

	Estimate	Std error	p-value
Intercept	-3.4688	0.4146	< 2e-16
Date	0.0041	0.0005	1.83e-15
Lean Body Weight	0.2443	0.0285	< 2e-16
Diatom	0.0733	0.0113	1.90e-10
Body Length	0.5068	0.0488	< 2e-16
Longitude	0.0003	0.0003	0.2827
Sex	0.2786	0.0364	7.81e-14
Year	**-0.01856**	**0.002806**	**7.87e-11**
Age	0.0055	0.0013	4.35e-05
Latitude	0.0105	0.0043	0.0164

AIC and BIC selected the following model:
Fat in Ton ~ Date + LBW + Diatom + BL + Sex + Year + Age + Latitude

Re-sampling data analysis by the Jackknife method:
The samples were excluded one year at a time, the same model as in Table 1 was applied.

Table 2. Estimated coefficients and the sd for 'year' according to re-sampled data

Excluded year	Coef. of 'year'	Sd of estimated coef
2	-0.0182319	0.0029651
3	-0.0197697	0.0030091
4	-0.0170386	0.0029964
5	-0.0163207	0.0029081
6	-0.0191240	0.0029478
7	-0.0195325	0.0028842
8	-0.0192628	0.0028321
9	-0.0180074	0.0028021
10	-0.0188081	0.0028658
11	-0.0180545	0.0027951
12	-0.0192344	0.0028136
13	-0.0185284	0.0028341
14	-0.0187901	0.0028925
15	-0.0161558	0.0028584
16	-0.0198579	0.0029460
17	-0.0201943	0.0029906
18	-0.0184392	0.0030901

Mean of the estimated 17 coefficients is -0.01855

The jack-knife SD for slope on year is 0.004544,
which should be compared to 0.002806 for the simple regression (Table 1).

The results indicate that the decline in 'Total fat' during the JARPA years is statistically significant at the 5% level.

As a second step we considered the same linear model but with different random terms:

The models that we considered were:

V1: Fat_in_Ton ~ (Date | year) + LBW + Diatom + BL + Longit + sex + year + age + latit
V2: Fat_in_Ton ~ (Date | year) + LBW + Diatom + BL + (Longit | year) + sex + year + age + latit
V3: Fat_in_Ton ~ (Date | year) + LBW + Diatom + BL + Longit + sex + year + age + (latit | year)
V4: Fat_in_Ton ~ (Date | year) + LBW + Diatom + BL + (Longit | year) + sex + year + age + (latit | year)

Summary of results for year effect:

model	AIC	BIC	estimates	sd	t-value
V1	479.8	538.0	-0.01218	0.004370	-2.789
V2	468.7	535.8	-0.01229	0.004056	-3.030
V3	477.0	544.1	-0.01542	0.004029	-3.829
V4	468.7	544.7	-0.01219	0.004032	-3.024

As a third step we analysed the same four random effect models with the longitudinal area divided in six half-Management Areas treated as categorical variables (set as 'cat_longit'):

Adding categorical 'longitude':

V5: Fat_in_Ton ~ (Date | year) + LBW + Diatom + BL + Longit + sex + year + age + latit + cat_longit

V6: Fat_in_Ton ~ (Date | year) + LBW + Diatom + BL + (Longit | year) + sex + year + age + latit + cat_longit

V7: Fat_in_Ton ~ (Date | year) + LBW + Diatom + BL + Longit + sex + year + age + (latit | year) + cat_longit

V8: Fat_in_Ton ~ (Date | year) + LBW + Diatom + BL + (Longit | year) + sex + year + age + (latit | year) + cat_longit

Summary of results for year effect

model	AIC	BIC	estimates	std	t-value
V5	494.4	570.5	-0.014701	0.004764	-3.086
V6	488.0	573.0	-0.014019	0.004287	-3.270
V7	490.8	575.8	-0.018091	0.004291	-4.216
V8	485.6	579.5	-0.016652	0.004166	-3.997

Conclusion: All analyses show that the 'Total fat' in minke whales has declined over the JARPA period with significance probabilities far below 5%. It is difficult to imagine that any remaining spatial or temporal correlation can change the main conclusion that fat storage in Antarctic minke whales has declined substantially over the JARPA period. The preferred model according to both AIC and BIC is the random effect model V2.

APPENDIX 3.

Model: BT11jarpa17

```
Residuals:
    Min      1Q  Median      3Q     Max
-2.5225 -0.5120 -0.0536  0.4419  3.4671
Coefficients:
                      Estimate  Std. Error  t value  Pr(>|t|)
(Intercept)          2.651e+00   1.253e-01   21.160  < 2e-16 ***
YearNum             -2.027e-02   2.367e-03   -8.564  < 2e-16 ***
I(BLm^3)             5.390e-04   1.339e-04    4.025 5.80e-05 ***
DateNum              8.737e-03   1.435e-03    6.088 1.24e-09 ***
Diatom               2.339e-01   9.328e-03   25.073  < 2e-16 ***
LongCat11[T.2]       3.072e-02   9.247e-02    0.332  0.73978
LongCat11[T.3]      -6.727e-02   8.668e-02   -0.776  0.43780
LongCat11[T.4]      -2.165e-01   8.490e-02   -2.550  0.01081 *
LongCat11[T.5]      -2.616e-01   8.553e-02   -3.058  0.00224 **
LongCat11[T.6]      -2.223e-01   8.659e-02   -2.568  0.01027 *
LongCat11[T.7]      -1.351e-01   8.914e-02   -1.515  0.12979
LongCat11[T.8]       2.843e-02   9.096e-02    0.313  0.75466
LongCat11[T.9]      -1.543e-01   9.265e-02   -1.665  0.09600 .
LongCat11[T.10]     -1.527e-01   9.852e-02   -1.550  0.12123
LongCat11[T.11]     -6.713e-03   9.792e-02   -0.069  0.94535
Sex[T.M]            -3.455e-01   2.806e-02  -12.311  < 2e-16 ***
DateNum:LongNum      5.088e-05   1.011e-05    5.034 4.98e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.7539 on 4579 degrees of freedom
  (22 observations deleted due to missingness)
Multiple R-squared:  0.4007,  Adjusted R-squared:  0.3986
F-statistic: 191.3 on 16 and 4579 DF,  p-value: < 2.2e-16
```

APPENDIX 4

Model: BT11jarpa18

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
YearCat	(Intercept)	5.274e-02	0.229661	
	DateNum	1.661e-05	0.004075	-0.83
Residual		5.421e-01	0.736268	

Number of obs: 4596, groups: YearCat, 18

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	1.710e+00	3.765e-01	4.542
YearNum	**-1.885e-02**	**6.608e-03**	**-2.853**
I(BLm^3)	5.680e-04	1.314e-04	4.323
DateNum	1.016e-02	2.692e-03	3.774
Diatom	2.298e-01	9.290e-03	24.737
LatNum	1.297e-02	4.749e-03	2.731
LongNum	2.723e-03	2.714e-03	1.003
LongCat11[T.2]	-7.730e-02	1.045e-01	-0.740
LongCat11[T.3]	-2.512e-01	1.292e-01	-1.943
LongCat11[T.4]	-4.295e-01	1.587e-01	-2.707
LongCat11[T.5]	-5.414e-01	1.971e-01	-2.747
LongCat11[T.6]	-5.238e-01	2.327e-01	-2.251
LongCat11[T.7]	-4.832e-01	2.727e-01	-1.772
LongCat11[T.8]	-3.361e-01	3.035e-01	-1.107
LongCat11[T.9]	-6.055e-01	3.476e-01	-1.742
LongCat11[T.10]	-6.193e-01	3.815e-01	-1.624
LongCat11[T.11]	-5.428e-01	4.260e-01	-1.274
Sex[T.M]	-3.306e-01	3.035e-02	-10.895
DateNum:LongNum	3.905e-05	1.924e-05	2.030

Correlation of Fixed Effects:

	(Intr)	YearNm	I(BL^3	DateNm	Diatom	LatNum	LongNm	LC11[T.2	LC11[T.3	LC11[T.4	LC11[T.5	LC11[T.6	LC11[T.7	LC11[T.8	LC11[T.9	LC11[T.10	LC11[T.11	S[T.M]
YearNum	-0.136																	
I(BLm^3)	-0.289	-0.023																
DateNum	-0.322	-0.052	-0.020															
Diatom	0.056	-0.012	0.023	-0.024														
LatNum	-0.827	-0.026	0.051	0.085	-0.109													
LongNum	-0.351	-0.039	0.020	0.291	0.034	-0.020												
LngC11[T.2]	0.041	0.024	-0.017	-0.154	-0.027	-0.015	-0.461											
LngC11[T.3]	0.103	0.087	-0.019	-0.265	-0.038	0.018	-0.695	0.760										
LngC11[T.4]	0.105	0.066	-0.022	-0.180	-0.045	0.082	-0.804	0.721	0.921									
LngC11[T.5]	0.136	0.068	-0.021	-0.121	-0.045	0.080	-0.859	0.681	0.882	0.944								
LngC11[T.6]	0.158	0.046	-0.031	-0.101	-0.035	0.083	-0.888	0.649	0.857	0.935	0.962							
LngC11[T.7]	0.171	0.036	-0.029	-0.106	-0.047	0.079	-0.898	0.617	0.824	0.909	0.943	0.964						
LngC11[T.8]	0.179	0.032	-0.022	-0.078	-0.048	0.075	-0.909	0.601	0.810	0.903	0.943	0.966	0.981					
LngC11[T.9]	0.233	0.026	-0.020	-0.044	-0.040	0.016	-0.915	0.581	0.789	0.889	0.938	0.963	0.976	0.984				
LnC11[T.10]	0.245	0.020	-0.021	-0.033	-0.039	0.008	-0.918	0.568	0.776	0.880	0.932	0.958	0.971	0.982	0.992			
LnC11[T.11]	0.234	0.007	-0.013	-0.062	-0.037	0.037	-0.929	0.557	0.766	0.873	0.924	0.950	0.960	0.972	0.982	0.984		
Sex[T.M]	-0.465	-0.007	0.514	0.005	-0.144	0.372	0.016	-0.027	-0.017	-0.011	-0.009	-0.010	-0.011	-0.012	-0.025	-0.029	-0.019	
DatNm:LngNm	0.373	0.066	0.012	-0.909	0.015	-0.189	-0.304	0.150	0.237	0.147	0.089	0.071	0.078	0.052	0.023	0.014	0.051	-0.021