# Work plan for further analyses of prey consumption rate by Antarctic minke whales based on JARPA and JARPAII data

SC/65b/R1 Rev

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## ABSTRACT

This paper is a revised version of SC/F14/R1 presented to the JARPAII Review Workshop. The purpose of this paper is to present details of a work plan for further prey consumption estimate by Antarctic minke whales that takes into account the uncertainty in the estimate. This paper was prepared to respond some recommendations from the JARPAII Review Workshop

**KEYWORDS**: FEEDING; ENERGETICS; FOOD/PREY; MODELLING; SCIENTIFIC PERMITS; ANTARCTIC; ANTARCTIC MINKE WHALE

## INTRODUCTION

In February 2014 the IWC/SC conducted an Expert Workshop to review the ongoing JARPAII research programme (the 2014 JARPAII Review Workshop) (IWC, 2014). Results on prey consumption by Antarctic minke whales were presented in documents SC/F14/J15 and SC/F14/R1, which were discussed in the section 'Feeding ecology, consumption rates and inputs to ecosystem modelling' of the JARPAII Review Workshop.

SC/F14/J15 presented results of the feeding habits of Antarctic minke whales based on samples obtained during the surveys of the JARPA and JARPAII for the period 1987/88-2010/11. Some of the analyses had considered recommendations offered during the 2006 JARPA final review meeting e.g. those related to the duration of the feeding period, digestion rate and examination at smaller scales. SC/F14/R1 proposed the use of a Monte Carlo approach to address uncertainty in the estimates.

The JARPAII Review Workshop welcomed the considerable amount of field and laboratory work undertaken on this subject and analysed in SC/F14/J15. However, it agreed that a major shortcoming of the work originally presented in SC/F14/J15 was that the results presented did not quantify uncertainties in the various estimates of consumption. This shortcoming was identified in SC/F14/O03; in SC/F14/R1.

The Panel recommends that the work proposed in SC/F14/R1 be further developed and allocated high priority. Ideally a new paper should be submitted to the 65b IWC/SC. As a minimum, this should advance the outlined work plan by including in the Monte Carlo simulations, uncertainty in:

(1) $r$ (the ratio of low/high feeding intake) and the length of the feeding season for Method 1; and

(2) The extent of night feeding for Method 2.

The purpose of this paper is to present details of a work plan for further prey consumption estimate by Antarctic minke whales that takes into account the uncertainty in the estimate.

The work will start after discussions on this plan take place at the 65b IWC/SC meeting. The authors will give high priority to this work and they hope to complete it in a 1-2-year period.

## ESTIMATE METHODS, PARAMETERS AND WORK PLAN

### Analytical procedure, parameters and their uncertainties of the daily prey consumption

The amount of krill consumed by Antarctic minke whales are estimated using two independent methods, which were from theoretical energy requirement calculations (method-1) and from diurnal changes of stomach contents (Total of forestomach (1st. stomach) and fundus (2nd. stomach)) (method-2). We identified the uncertainties of both methods, and planed the analyses including in the Monte Carlo simulations. Some example of evaluation and outputs are shown in the reference cases of Methods 1 and 2 are shown in Appendix 1.

*Method-1 Estimation of daily consumption of krill from the standard metabolism*

The daily prey consumption ($D_{kg}$) in each sexual maturity class was estimated from the standard metabolic rate ($SMR_{kJ}$) and energy deposit according to the following equations:

Male or Immature female : $D_{kg} = (SMR_{kJ} + ED_{kJ}) / (E_{KJ} * AE)$ (1)

Mature female : $D_{kg} = (SMR_{kJ} + ED_{kJ} + R_{kJ}) / (E_{KJ} * AE)$ (2)

Where $D_{kg}$ is daily prey consumption (kg day$^{-1}$), $SMR_{kJ}$ is the standard metabolic rate (kJ day$^{-1}$), $ED_{KJ}$ is Energy deposition (kJ day$^{-1}$), $R_{kJ}$ is Reproduction cost (kJ day$^{-1}$), $E_{kJ}$ is the caloric value of prey species (kJ kg$^{-1}$), and $AE$ is Assimilation efficiency (%). The details of these items are described as follows:

1) $SMR_{kJ}$ (Standard metabolic rate, Allometric relationships)

The uncertainty in several components involved in estimating the amounts and types of prey consumed by whales was assisted by a recent review by Leaper and Lavigne (2007) and Tamura *et al*. (2009). They considered that the appropriate consumption estimates is between the high end of Equation 1 and the low end of Equation 2. The estimate of consumption by Equation 3 was considered by the authors at the upper range of these reasonable values. I also estimated daily prey consumption using Equation 4. Equation 4 which was used by Hunt *et al*. (2000) in the PICES region was applied to the Antarctic Peninsula marine ecosystem model and simulation by Hoover *et al*. (2012).

Equation 1: $BMR = 0.42\ W^{0.67}$ (Innes *et al*., 1986) (3)

Equation 2: $SMR = 2{,}529.2\ W^{0.524}$ (Boyd, 2002) (4)

Equation 3: $SMR = 862.95W^{0.783}$ (Sigurjónsson and Víkingsson, 1997) (5)

Equation 3-1: $SMR = 690.36W^{0.783}$ (Sigurjónsson and Víkingsson, 1997) (6)

Equation 4: $SMR = 803.328W^{0.75}$ (Perez *et al*, 1990) (7)

$BMR$ is the daily prey consumption (expressed in kg day$^{-1}$). $SMR$ is the daily prey consumption (expressed in kJ day$^{-1}$) and $W$ is body weight in kg. It should be noted here that the estimates from Equation 1 depend only on the body weight data (expressed in kg). The estimates from Equations 2, 3 and 4 require body weight data (expressed in kg) and energy content of prey (expressed in kJ kg$^{-1}$). Equation 3.1 excluded an $AE$ value of 80% from Equation 3. We use three equations (Equations 2, 3.1 and 4) randomly in the sensitivity analysis. The distribution assumed a triangular distribution with minimum, maximum and mode values.

2) $ED_{kJ}$ (Energy deposited during feeding season in Antarctic)

The energy deposition (expressed in kJ day$^{-1}$) during feeding season in Antarctic was calculated by measuring the energy density (expressed in kJ kg$^{-1}$) of samples of muscle and blubber of some whales sampled in the early and late seasons during austral summer by bomb calorimeter. The length of energy deposition in the feeding season was randomly in the sensitivity analysis.

3) $R_{KJ}$ (Reproduction cost)

The $R_{KJ}$ for a female Antarctic minke whale was calculated by Lockyer (1981) to be $1.89\times10^{6}$kJ, assuming that the length at birth is 273cm (Best, 1982). We assumed that almost all mature females were pregnant, and that all reproduction costs were during feeding season. The $R_{KJ}$ for a female Antarctic minke whale was calculated to be $15.8\times10^{4}$kJ day$^{-1}$.

4) $E_{KJ}$ (Energy value of *Euphausia superba*)

Minimum, maximum and average energy contents of *Euphausia superba* (N=9) were calculated (categorized by size of krill and season) by Bomb calorimeter. The energy content of prey was randomly in the sensitivity analysis.

Minimum contents: 2,092 kJkg-1

Maximum contents: 4,477 kJkg-1

Average contents: 3,510 kJkg-1

The distribution assumed a triangular distribution with minimum, maximum and mode values. We have a plan to analyses additional samples of *E. superba* and *Thysanoessa macrura*. Unfortunately, we could not take a sub sample of ice krill, *E. crystallorophias*.

5) *AE* (Assimilation efficiency)

Although an assimilation efficiency of 0.8 (80%) is commonly assumed, this will clearly vary with prey condition, size and species. The range of assimilation efficiency was assumed between 0.75 (75%) and 0.85 (85%) and used randomly in the sensitivity analysis. The distribution assumed a uniform distribution between 0.75 and 0.85.

6) *r* (the ratio of low/high feeding intake)

Baleen whales are generally known to migrate between feeding grounds in high latitudinal waters in summer and the breeding grounds in low latitudinal waters in winter.

The ratio of high to low feeding seasons and the proportion of the energy intake per year during the high feeding season are assumed without actual data. This could bring some uncertainty to the estimations. For example Lockyer (1981) indicated that around 83% of the annual energy intake in Southern Hemisphere balaenopterid species is ingested during the summer season (*P*). If the number of days of high feeding season (*HD*) is 120 days and the rest of the days (245) is low feeding season (*LD*), the ratio of low feeding/high feeding intake (*r*) is 0.10. Leaper and Lavigne (2007) estimated the *r* to be from 0.34 (Antarctic minke whales) to 0.62 (North Atlantic minke whales) based on other sources.

The *r* was calculated as following:

$$r = ((365(1-P)) / (365-HD))/ (365P/HD) \quad (8)$$

where *P* is the proportion of the annual energy intake ingested in the feeding season.

Minimum days: 0.10

Maximum days: 0.34

The distribution of *r* is assumed a uniform distribution between 0.10 and 0.34.

7) Feeding period (residence days in the feeding ground)

Minimum and maximum feeding season in the Southern Ocean (= our research area) were assumed by literature values (Lockyer, 1981; Kasamatsu *et al*., 1995; Bell, 2014, Gale *et al*., 2014). The length of feeding season was randomly in the sensitivity analysis.

Minimum days: 90 days

Maximum days: 150 days

Average days: 120 days

The distribution is assumed a uniform distribution between 90 and 150.

*Method-2 Estimation of daily consumption of krill from diurnal change in stomach contents mass*

Miura (1969) proposed a method for estimating daily prey consumption from diurnal changes in stomach contents mass (*VI*) with the passage of time based on a known digestion rate in the stomach. If the proportion of prey digested during an interval is *d*, and the proportion of undigested prey (*S*) is *1-d*, the amount of prey consumed (*Cu*) is given by the following equations:

$$t_1: C_1=V_1 \quad (9\text{-}1)$$

$$t_2: C_2=V_2-SV_1 \quad (9\text{-}2)$$

$$t_3: C_3=V_3-SV_2-S^2V_1 \quad (9\text{-}3)$$

$$t_i: C_i=V_i-SV_{i-1}-S^2V_{i-2}\ldots S^{i-1}V_1 \quad (9\text{-}4)$$

Therefore, the daily prey consumption ( $\sum_{i=1}^{k} C_i$ ) is given by:

$$\sum_{i=1}^{k} C_i = V_1 \frac{(1-2S+S^k)}{1-S} + V_2 \frac{(1-2S+S^{k-1})}{1-S} + \cdot\cdot + V_{k-1}(1-S) + \cdot\cdot + V_k \quad (9\text{-}5)$$

In this study, we calculated the mean stomach contents (forestomach and fundus stomach) mass as % of body mass (*VI*) at 1 hour intervals based on the stomach contents mass (kg) and body mass (kg). Nordy *et al*. (1993) showed that krill were digested by bacterial fermentation, and that this digestion process was very rapid. Assuming that it takes 4 hours for prey to be digested in the stomach of Antarctic minke whales (Bushuev, 1986) and that *d* is exponential (Elliott and Persson, 1978), we estimated *S* to be 0.82, if the proportion of undigested prey in the stomach after 4 hours is 45% (Tamura and Konishi, 2014). We estimated the daily prey consumption of krill from diurnal change in stomach contents' mass in research areas excluding the Ross Sea of JARPA and JARPAII periods. We eliminated the data with less than 10 samples in each hourly interval. The improving of the value of *S* is important. We recognized that digestion rate have some uncertainty, but we think that there is little uncertainty in the digestion rate of Antarctic minke whales.

We estimated that the proportion of undigested prey in the stomach after 4 hours was 45% (*S*=0.82) based on digestion experiment of krill *in vitro*. The digestion rate was randomly in the sensitivity analysis.

High value: 80 % (*S*=0.93)
Low value: 30 % (*S*=0.74)
Average value: 45 % (*S*=0.82)

The distribution assumed a uniform distribution between 30% and 80%.

Data have not been obtained due to logistical difficulties during night. We assumed that Antarctic minke whales did not feed at night because *E. superba* disperses at night in the late summer (Ichii, 1987). However, the Antarctic minke whale might feed on prey from 21:00 to 02:00. If they feed on prey that time, the prey consumption rate is higher than our estimation.

We will assume both options feeding at night and no feeding at night (see recommendation from the JARPAII Review Workshop).

**Analytical procedure and their uncertainties of the seasonal prey consumption for all Antarctic minke whales in the research area**

In Areas III east and IV in the 2007/2008 season, the abundance was estimated to be 9,406 and 14,739, respectively. In Area V and VI west in the 2008/2009 season, the abundance was estimated to be 108,097 and 26,364, respectively Hakamada and Matsuoka (2014). We will estimate the seasonal prey consumption of all Antarctic minke whales in the research area with 10,000 Monte Carlo simulations using the electronic software package in the next step.

In this step, we will reconsider some uncertainties such as the *r* (the ratio of low/high feeding intake) and feeding period (residence days in the feeding ground) (see recommendation from the JARPAII Review Workshop).

## ACKNOWLEDGMENTS

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## Appendix 1. Examples of analyses outputs

### Method-1. Estimation of daily consumption of krill from the standard metabolism

Body weight 6,900kg (Mature male)

We estimated the daily prey consumption of Antarctic minke whales based on Method 1 with 10,000 Monte Carlo simulations using the electronic software package.

a) $SMR_{kJ}$ (Standard metabolic rate)
: 522,530KJ (From 259,741KJ (Eq-2) to 699,672KJ (Eq-3))

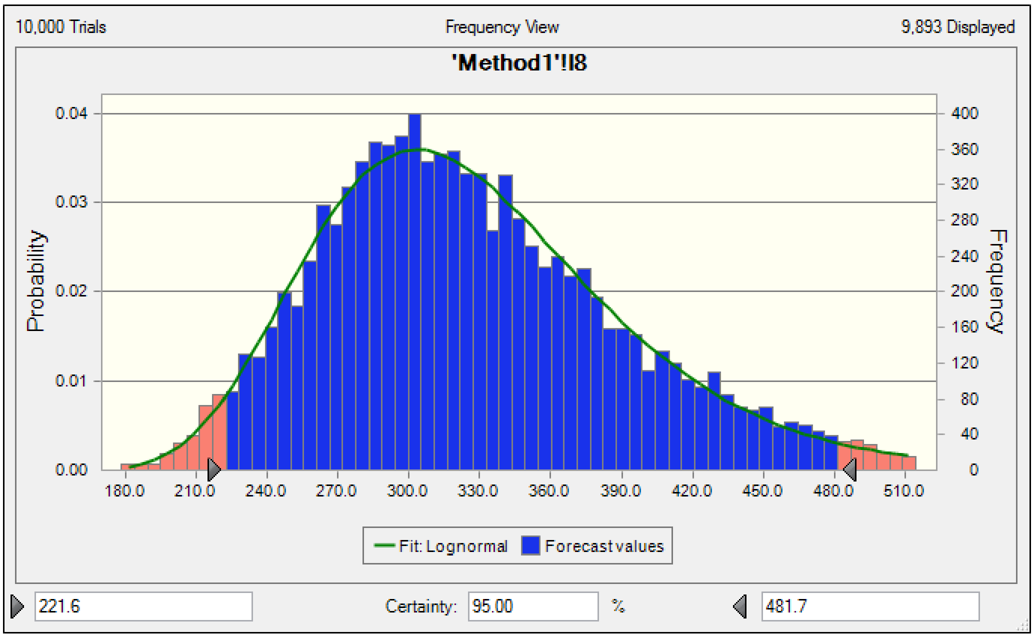
b) $ED_{kJ}$ (Energy deposited during feeding season in Antarctic)
: 364,613KJ (S.D =±36,461KJ)

c) Energy content of prey
: 3,510KJ/kg (From 2,092 $kJkg^{-1}$ to 4,477 $kJkg^{-1}$)

d) Assimilation efficiency
: 0.8 (From 0.75 to 0.85)

Equation: $D_{kg} = (SMR_{kJ} + ED_{kJ}) / E_{KJ}$ (1)

$(SMR_{kJ} + ED_{kJ})$ / (Energy content of prey * $AE$)




| | |
|---|---|
| Average | 327.4 kg (4.74 % of body weight) |
| S.D | 65.3 kg |
| Min. | 159.3 kg (2.31 % of body weight) |
| Max. | 608.4 kg (8.82 % of body weight) |
| 95%CI | 221.9 kg (3.22 % of body weight) |
| | 479.6 kg (6.95 % of body weight) |

**Method-2. Estimation of daily consumption from diurnal change in stomach contents mass**

a) Digestion rate

We estimated that the proportion of undigested prey in the stomach after 4 hours was 45% based on digestion experiment of krill *in vitro*. The digestion rate was randomly in the sensitivity analysis.

| | |
|---|---|
| High value: | 80 % (*S*=0.93) |
| Low value: | 30 % (*S*=0.74) |
| Average value: | 45 % (*S*=0.82) |

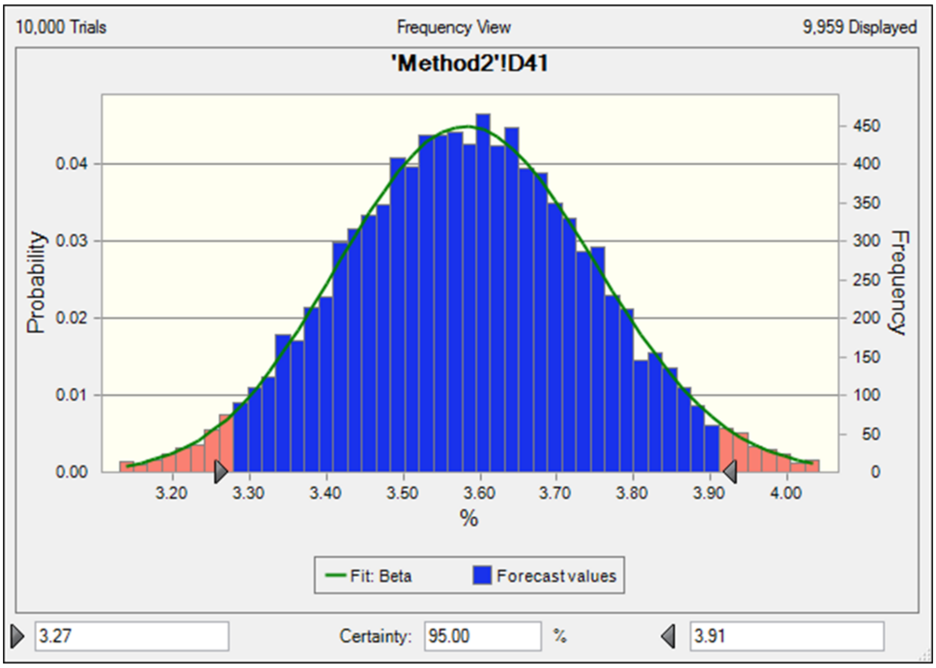
The distribution assumed a uniform distribution between 30% and 80%.

b) Extent of feeding at night

We will assume that feeding at night do and/or do not in the future analyses.

- Body weight 6,900kg (Mature male), Feeding time: 3:00-21:00

We estimated the daily prey consumption of Antarctic minke whales based on Method 2 with 10,000 Monte Carlo simulations using the electronic software package. At first, we assumed that they do not feed at night.

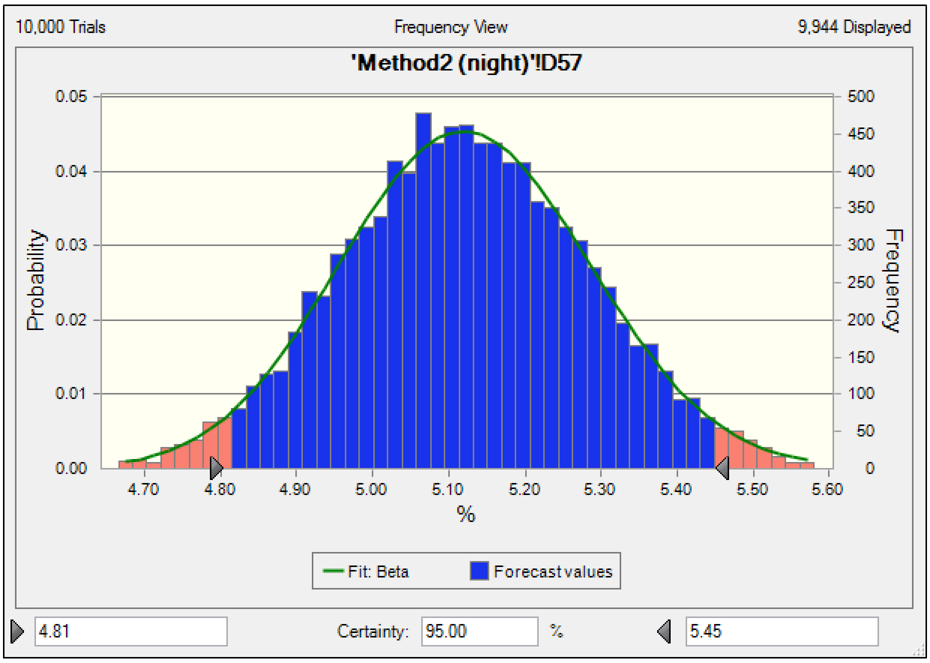



| | |
|---|---|
| Average | 247.7 kg (3.59 % of body weight) |
| S.D | 11.0 kg (0.16 % of body weight) |
| Min. | 206.31 kg (2.99 % of body weight) |
| Max. | 287.04 kg (4.95 % of body weight) |
| 95%CI | 225.63 kg (3.27 % of body weight) |
| | 269.79 kg (3.91 % of body weight) |

- Body weight 6,900kg (Mature male), Feeding time: 0:00-24:00 (Antarctic minke whales also feed on prey at night)

  We estimated the daily prey consumption of Antarctic minke whales based on Method 2 with 10,000 Monte Carlo simulations using the electronic software package.

  In this case, Antarctic minke whales also feed on prey at night. Between 21:00 and 2:00, the average stomach contents estimated based on actual data.




| | |
|---|---|
| Average | 353.28 kg (5.12 % of body weight) |
| S.D | 11.04 kg (0.16 % of body weight) |
| Min. | 311.19 kg (4.51 % of body weight) |
| Max. | 396.06 kg (5.74 % of body weight) |
| 95%CI | 331.89 kg (4.81 % of body weight) |
| | 376.05 kg (5.45 % of body weight) |