Title	**REFERENCE OBSERVATIONS FOR VALIDATING AND TUNING OPERATING MODELS FOR KRILL FISHERY MANAGEMENT IN AREA 48**

Author(s)	Simeon Hill[1], Jefferson Hinke[2], Eva Plagányi[3] and George Watters[4]
Affiliation(s)	[1] British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge, CB3 0ET, UK.
	[2] Scripps Institution of Oceanography, UCSD, 9500 Gilman Drive, La Jolla CA, 92093, USA.
	[3] Department of Mathematics and Applied Mathematics, University of Cape Town, Private Bag, Rondebosch 7701, South Africa.
	[4] Southwest Fisheries Science Center, NOAA Fisheries, Protected Resources Division, 1352 Lighthouse Avenue, Pacific Grove, CA 93950, USA.

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ABSTRACT

In 2007 WG-SAM defined a set of reference observations for validating and tuning proposed models to evaluate krill catch allocation options for Area 48 (the SAM calendar). The observations, which were endorsed by WG-EMM, were largely qualitative and relative. We used available data to translate these observations into numerical terms (the numerical calendar). We provide spatially-resolved reference points for the density of krill, and the abundance of "generic" seals, penguins and whales in 1970, 2007 and at least one intermediate year. Recent work on baleen whales indicates a higher growth rate than that suggested by WG-SAM, so the numerical calendar for this taxon deviates from the SAM calendar. The numerical calendar is a partly subjective interpretation of limited data and should not be considered a definitive description of the relevant dynamics. This exercise resulted in population sizes for several taxa that are adjusted for asynchronous observations and are potentially more suitable for initialising models than those published in Hill et al (2007).

SUMMARY OF FINDINGS AS RELATED TO NOMINATED AGENDA ITEMS

Agenda Item   Findings

WG-SAM 5.2 *WG-SAM 6.3,* *WG-EMM 2,* *WG-EMM 6.3*	*(1) This paper provides a numerical interpretation of* WG-SAM 2007 *para 5.24, which can be used for tuning models such as FOOSA, SMOM and EPOC.* *(2) It also revises the abundance parameters given in Hill et al. (2007) for three of the four generic predator groups.*

Reference observations for validating and tuning operating models for krill fishery management in area 48.

Simeon Hill[1], Jefferson Hinke[2], Eva Plagányi[3] and George Watters[4]

[1] British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge, CB3 0ET, UK.

[2] Scripps Institution of Oceanography, UCSD, 9500 Gilman Drive, La Jolla CA, 92093, USA.

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ABSTRACT

In 2007 WG-SAM defined a set of reference observations for validating and tuning proposed models to evaluate krill catch allocation options for Area 48 (the SAM calendar). The observations, which were endorsed by WG-EMM, were largely qualitative and relative. We used available data to translate these observations into numerical terms (the numerical calendar). We provide spatially-resolved reference points for the density of krill, and the abundance of "generic" seals, penguins and whales in 1970, 2007 and at least one intermediate year. Recent work on baleen whales indicates a higher growth rate than that suggested by WG-SAM, so the numerical calendar for this taxon deviates from the SAM calendar. The numerical calendar is a partly subjective interpretation of limited data and should not be considered a definitive description of the relevant dynamics. This exercise resulted in population sizes for several taxa that are adjusted for asynchronous observations and are potentially more suitable for initialising models than those published in Hill et al (2007).

INTRODUCTION

The work of WG-EMM includes providing advice on the allocation of area 48 krill catch limits to small-scale management units. The work of WG-SAM includes evaluating the operating models developed to help provide this advice. This evaluation process aims to ensure that the models provide an appropriate representation of the observed behaviour of the real system. There are three key stages which affect the ability of ecosystem models to represent real systems. The first is the design stage, in which the model's structure should be based on plausible hypotheses about the structure and operation of the system. The second is setting the values of fixed model parameters based on observations from the system or close analogues. The third is conditioning the model on data representing the behaviour of the system. For ecosystem dynamics models, the data are generally timeseries representing the

dynamics of one or more elements of the system, and the conditioning process involves estimating model parameters which provide the best fit between model dynamics and the data. As ecosystem models generally have large numbers of parameters and there are only limited tuning data available, it is usually appropriate to estimate only a limited number of model parameters in this way.

Published accounts suggest that the dynamics of the Scotia Sea area have been particularly dramatic over recent decades, with an explosion of the fur seal population at South Georgia (Payne 1977, Boyd 1993), collapses in demersal fish stocks (Kock 1992, Myers & Worm 2003), declines in krill (Atkinson et al 2004), and albatross (Arnold et al. 2006) populations and both increases and decreases in different penguin populations (Fraser et al. 1992, Trathan et al. 1996, Forcada et al 2006, Hinke et al. 2007). Authors have arrived at some of these conclusions through analysing data on seal and bird abundance within study colonies which are now compiled under the CCAMLR ecosystem monitoring program. However, there are no coherent timeseries which give a direct indication of the dynamics of krill and its predators at the scales represented in operating models. For this reason, WG-SAM has elected to define a largely qualitative account of recent dynamics based on colony-scale observations, individual surveys and expert opinion. Specifically, the process for evaluating operating models (WG-SAM 2007 para 5.23, 5.24, 5.37, 5.38) includes comparison of model outputs with a set of reference points representing "known or suspected changes to the ecosystem" over recent decades. WG-SAM proposed a calendar of reference points for area 48, which were endorsed by WG-EMM (2007 para 6.45), and which we will subsequently refer to as "the SAM calendar", as follows (WG-SAM 2007 para 5.24):

(i) Subareas 48.1 and 48.2 –
(a) krill
• near step change in total biomass and interannual variability in biomass in about 1986 (biomass was greater and less variable prior to the change point);
• interannual variability in biomass is concordant with that in Subarea 48.3;
(b) penguins
• increase in abundance of about 5–10% per year during 1970 to about 1977;
• overall decline in abundance of 60–70% during the period from about 1977 to 2000 (this decline should not be explained by changes in breeding success that are related to changes in food availability during the breeding season);
• *continued, possibly steeper, decline after 2000 (this decline may be explained by changes in breeding success that are related to predation on chicks and fledglings);
(c) seals
• increase in abundance of about 10–15% per year during 1970 to about 1995;
• no significant trend in abundance after about 1995;
(d) whales
• increase in abundance of about 4–5% per year since about 1980;

(ii) Subarea 48.3 –
(a) krill
• biomass was greater and less variable prior to about 1980 than after about 2000;
• *smoother (than in Subareas 48.1 and 48.2) change in biomass and interannual variability during the period from about 1980 to 2000;

• *interannual variability in biomass is concordant with that in Subareas 48.1 and 48.2;*
(b) penguins
• **possibly no significant trend in abundance from 1970 to about 1980;*
• *overall decline in abundance of 40–50% during the period from about 1980 to the present;*
(c) seals
• *increase in abundance of about 10–15% per year during the period from 1970 to about 1988;*
• **possibly slower rate of increase in abundance after about 1988;*
(d) whales
• *increase in abundance of about 4–5% per year since about 1980.*

* Reference observations considered to be less certain and, therefore, likely to be of secondary importance in model validation and tuning.

We have developed a numerical representation of the SAM calendar to aid comparison with model outputs. We will subsequently refer to this numerical representation as "the numerical calendar". Our approach was to identify years for which population size or density estimates are available in the literature and to project these values back to 1970 (the earliest year mentioned in the SAM calendar) and forwards to 2007 using:

    a) rates of change derived from the literature where available.
    b) rates of change suggested by the SAM calendar.
    c) inflexion points (years in which rates changed) suggested by the SAM calendar.

We then extracted predator population size estimates from our projections, corresponding to the years 1970 and 2007, and any inflexion points mentioned in the SAM calendar. The 1970 estimates may be used for initialising models while those for subsequent years, alongside the empirical data, provide a set of reference points for model tuning and validation. Our expectation is that models will mostly use krill time series to drive the dynamics of the other species. We therefore provide complete krill density time series for 1970 to 2007.

DETAILS

The numerical calendar is based on the following definitions:

    a) <u>Units</u>

The numerical calendar for krill (Table 1) is expressed in arbitrary biomass units. Predator abundance (Tables 2 to 5) is expressed as the number of generic animals, where a generic animal represents the average characteristics (averaged across species in the case of baleen whales and penguins, and across sexes and breeding status in seals, and weighted by relative krill demand) of the members of a given taxon in an SSMU (see Hill et al. 2007 for further details).

b) Population growth

We assume a simple exponential population growth model:
$$N_{t+1} = N_t(1 + r_t)$$
conversely:
$$N_{t-1} = \frac{N_t}{1 + r_{t-1}}$$

Where N_t is the population size (or density) and r_t is the annual population growth rate at time t.

c) Time periods

Most observations of Antarctic marine populations occur during the summer season which spans two calendar years. The minimum requirements for models used to evaluate krill catch allocation options include the ability to resolve seasonal differences (SC-CAMLR-XXIV, paragraph 3.20). This has been addressed in some models and parameter sets with six-month time steps representing October – March and April – September (Hill et al. 2007).

We assumed that a year runs from October to September and is labeled (in both the SAM and numerical calendars) with the calendar year in which it ends. Thus the model/data year labeled 1970 begins in October 1969 and ends in September 1970.

The SAM calendar uses a variety of phrases to describe the timing of events. Our exact interpretation of each phrase is given in the appropriate section below.

KRILL

Although the SAM calendar describes changes in both biomass and interannual variability, our focus is on biomass (as indicated by density). We obtained SSMU-specific krill density estimates for 2000 from Hewitt et al (2004a). The SAM calendar indicates that densities were higher in the 1970s to mid 1980s, but does not advise on the magnitude of the change. There are no consistent empirical data series that allow a direct comparison of krill abundance or biomass before and after the mid-1980s. However, application of the same model to acoustic data collected during the 1981 FIBEX survey (Trathan & Everson 1994) and the 2000 CCAMLR synoptic survey (Hewitt et al 2004a,b) suggests regional scale krill density in 1981 was approximately double that in 2000. We therefore assumed that densities in 1970 were double those in 2000.

The SAM calendar is inconsistent in that it suggests that interannual variability in biomass is consistent in all three subareas, yet describes a different scenario of biomass change in subarea 48.3 compared to subareas 48.1 and 48.2. As the synchrony between subareas was considered less certain than other aspects of the SAM calendar, we projected krill density as specified elsewhere in the SAM calendar.

For subareas 48.1 and 48.2, we interpreted "near step change in total biomass …in about 1986" as meaning that the density in the period 1970 to 1985 was higher than that in the period 1986 to 2007. We assumed that SSMU specific density was constant at $2d_{i,2000}$ in the early period and $d_{i,2000}$ in the later period, where $d_{i,2000}$ is the krill density in SSMU i in 2000 (Hewitt et al. 2004a).

For subarea 48.3 we assumed a constant density of $2d_{i,2000}$ in the period 1970 to 1980, followed by a linear decline from 1981 to 2000 (that is $d_{i,1979}= d_{i,1980}> d_{i,1981}> d_{i,1982}…> d_{i,2000}$) and that density in 2000 to 2007 was constant at $d_{i,2000}$.

PENGUINS

We obtained SSMU-specific estimates of generic penguin abundance from Hill et al (2007), and assigned these to observation years using Woehler (1993). The penguin colonies listed in Woehler (1993) were counted over many different years from 1901 to 1990. We used a fairly crude method to identify a representative observation year for each SSMU. We identified the dominant species by biomass in each SSMU, identified the year in which the largest number of that species were counted in the SSMU, and used that as the observation year.

We did not find any rates of population change in the literature, so we used the midpoints of ranges suggested in the SAM calendar. Specifically:
- In subareas 48.1 and 48.2 we used $r_t=0.075$ for $t<=1976$ and $r_t=-0.045$ for $t>=1977$ where –0.045 is the annual rate that leads to a 65% decline over the 23 years 1977 to 2000.
- In area 48.3 we used $r_t=0$ for $t<=1979$, and $r_t=-0.022$ for $t>=1980$ where –0.022 is the annual rate that leads to a 45% decline over the 27 years 1980 to 2007.

SEALS

We obtained SSMU-specific estimates of generic fur seal abundance from Hill et al (2007). The abundances for subarea 48.3 were based on observations in 1991 (Boyd 1993). Additional information on subarea 48.3 was available in the form of annual growth rates from the mid-1950s through to 1991 (Boyd 1993) and a rough indication that the current fur seal population size is around 4,000,000 (+/- 25%) (A. Martin, pers comm.). Assuming a constant ratio of generic animals to total animals (1.34:1), we used this information to calculate the generic population size in 1970 and approximate growth rates for the periods specified in the SAM calendar. Specifically: $r_t=0.117$ for $t<=1987$ and $r_t=0.061$ for $t>=1988$. These values are within the ranges suggested in the SAM calendar.

For subarea 48.1 we assumed the abundance estimate in Hill et al. (2007) applied to 1991. We also used $r_t=0.117$ for $t<=1994$ and $r_t=0$ for $t>=1995$. The value for the early period was derived from data collected at South Georgia (subarea 48.3) but is consistent with the SAM calendar. Since we did our calculations we have established that the abundance estimates were from 2002, and that $r_t=0.145$ for $t<=1994$ gives a better fit to data. We discuss the implications of these differences in appendix 1, but note that models presented at WG-SAM 2008 will be tuned to the numerical calculations resulting from our original calculations.

WHALES

We obtained SSMU-specific estimates of generic whale abundance from Hill et al (2007). These were based on observations in 2000 (Reilly et al.2004). We obtained species specific growth rates from Taylor et al. (2007) and calculated generic growth rates for the Scotia Sea and Antarctic Peninsula subareas using the weighting method and data in Hill et al. (2007). These rates were 0.057 and 0.056 respectively. We used these rates in our projections even though they are above the range suggested in the SAM calendar (4-5%). This is the only point at which the numerical calendar deviates from the SAM calendar. However, these numbers are defensible and we suggest a revision to the SAM calendar to include this update (see also Branch et al. 2007).

The SAM calendar provides no specific guidance on whale dynamics before 1980. We assumed that the annual growth rate was constant throughout the whole period 1970 to 2007.

RESULTS

The numerical calendar, and the empirical abundance estimates are presented in Tables 1 to 5. Using the per-capita demand estimates from Hill et al. (2007), the numerical calendar suggests that krill demand attributable to whales, seals and penguins in subareas 48.1 and 48.2 reached a peak in 1977 and has since then fallen below 1970 levels (Fig 1). The demand attributable to these taxa in subarea 48.3 has, apparently, risen monotonically since 1970, mainly due to the increasing fur seal population in SSMU 14 (Fig 2).

DISCUSSION

The process defined by WG-SAM for evaluating models requires a qualitative match to the SAM calendar. However, because models work in terms of numbers, it was necessary to convert this representation of the system to numerical terms. Our numerical calendar is emphatically not a definitive account of the dynamics of the relevant species. Nonetheless, this exercise has demonstrated that the SAM calendar is reasonably consistent with the available data, with the minor exception of whale population growth rates.

This work has produced three different types of reference observation. There are the empirical abundance estimates obtained from the literature; the projections of these values using the exponential growth model to key dates in the SAM calendar; and the backward extrapolations to 1970. We make these distinctions because we envisage different uses for the different types of observation.

The backward extrapolations to 1970 are suitable for initialising model runs covering the calendar period. The process of projecting a number of asynchronous observations of population size to a common starting point provides a more plausible representation of relative abundance than the data in Hill et al. (2007) which were not adjusted for changes occurring after data on population size were collected.

The empirical abundance estimates, and the projections of these to key dates in the SAM calendar provide two sets of reference points for model tuning and validation. Although the two are not strictly independent, the parameter values that produce the best fit to one set (and the resulting dynamics of modelled populations) are likely to be different from those producing the best fit to the other set. Nonetheless, both sets of parameter values will be plausible if the fit is reasonable. Therefore fitting to two sets of reference points gives an indication of feasible parameter space.

It would be possible to construct alternative numerical representations of the SAM calendar, by changing any combination of the population growth model, the population growth rate, the empirical estimate of population size and the date this empirical estimate is assigned to. All of these are uncertain to some extent. However, our numerical calendar is a suitable representation of the dynamics specified in the SAM calendar, which is available for CCAMLR's working groups to use. The fact that alternatives could be constructed once again highlights the uncertainties in our understanding of the Scotia Sea ecosystem.

One way to reduce these uncertainties would be to conduct a more complete investigation of the system's dynamics using all of the available data. There have been limited attempts to compare the available data series on krill abundance (e.g. Brierley et al. 1999) but there are a range of additional data on krill dynamics including acoustic data from the FIBEX, SIBEX and CCAMLR synoptic surveys (Hewitt et al 2004b; Trathan et al. 1995), and series of smaller-scale surveys to the northeast and northwest of South Georgia (e.g. Brierley et al. 1999, Trathan et al 2003), the South Shetland Islands (e.g. Brierley et al. 1999, Hewitt et al. 2003) and the Western Antarctic Peninsula (Quetin et al. 2007), net haul data which has already been compiled into an extensive database (Atkinson et al. 2004), and data from the fishing fleet. It would be an extremely valuable exercise to analyse all of these data simultaneously to develop an integrated view of krill dynamics.

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Table 1. Numerical calendar of krill biomass (scaled to mean=1) for the two groupings of SSMUs identified in the SAM calendar.

Year	Subareas 48.1 & 48.2	Subarea 48.3
1970	1.41	1.30
1971	1.41	1.30
1972	1.41	1.30
1973	1.41	1.30
1974	1.41	1.30
1975	1.41	1.30
1976	1.41	1.30
1977	1.41	1.30
1978	1.41	1.30
1979	1.41	1.30
1980	1.41	1.30
1981	1.41	1.27
1982	1.41	1.23
1983	1.41	1.20
1984	1.41	1.17
1985	1.41	1.14
1986	0.70	1.10
1987	0.70	1.07
1988	0.70	1.04
1989	0.70	1.01
1990	0.70	0.97
1991	0.70	0.94
1992	0.70	0.91
1993	0.70	0.88
1994	0.70	0.84
1995	0.70	0.81
1996	0.70	0.78
1997	0.70	0.75
1998	0.70	0.71
1999	0.70	0.68
2000	0.70	0.65
2001	0.70	0.65
2002	0.70	0.65
2003	0.70	0.65
2004	0.70	0.65
2005	0.70	0.65
2006	0.70	0.65
2007	0.70	0.65

Table 2. Numerical calendar for the abundance of generic penguins: abundance in "observation years" identified in the literature and at key points in the SAM calendar.

	SSMU	Observation year	Empirical abundance estimate	1977	1980	2007
1	APPA					
2	APW	1987	253873	400726		101895
3	APDPW	1987	74798	118065		30021
4	APDPE	1990	1084367	1962804		499095
5	APBSW	1971	1160224	1790575		455301
6	APBSE	1985	298817	430517		109470
7	APEI	1977	1413511	1413511		359423
8	APE	1985	823403	1186308		301650
9	SOPA					
10	SOW	1983	2286	3006		764
11	SONE	1983	584507	768650		195450
12	SOSE	1983	2003958	2635284		670091
13	SGPA					
14	SGW	1977	6642811		6642811	3653546
15	SGE	1977	564496		564496	310473

Table 3. Numerical calendar for the abundance of generic seals.

	SSMU	Empirical abundance estimate (1991)	1995	1988	2007
1	APPA				
2	APW				
3	APDPW	12204	18974		18974
4	APDPE	211	328		328
5	APBSW				
6	APBSE				
7	APEI	1002	1558		1558
8	APE				
9	SOPA				
10	SOW				
11	SONE				
12	SOSE				
13	SGPA				
14	SGW	611054		511541	1576913
15	SGE	6090		5098	15716

Table 4. Numerical calendar for the abundance of generic baleen whales. The final three columns sum data for the Antarctic Peninsula and Scotia Sea areas into a single SSMU in each.

	SSMU	Empirical abundance estimate (2000)	1980	2007	2000	1980	2007
1	APPA	9233	3098	13531	13788	4626	20207
2	APW	767	257	1124			
3	APDPW	330	111	484			
4	APDPE	341	114	500			
5	APBSW	460	154	674			
6	APBSE	600	201	879			
7	APEI	773	259	1133			
8	APE	1284	431	1882			
9	SOPA	6808	2244	10039	15694	5173	23143
10	SOW	131	43	193			
11	SONE	86	28	127			
12	SOSE	126	42	186			
13	SGPA	7737	2550	11409			
14	SGW	354	117	522			
15	SGE	452	149	667			

Table 5. Estimates of krill density (kg.km^{-2}) and the abundance of generic penguins, seals and whales in 1970. The final column sums whale data for the Antarctic Peninsula and Scotia Sea areas into a single SSMU in each.

SSMU	krill density	penguins	seals	whales	whales (2 areas)
1 APPA	22.4			1794	2680
2 APW	75.4	241540		149	
3 APDPW	75.4	71164	1203	64	
4 APDPE	75.4	1183090	21	66	
5 APBSW	75.4	1079278		89	
6 APBSE	75.4	259496		117	
7 APEI	75.4	852001	99	150	
8 APE	75.4	715053		250	
9 SOPA	49			1288	2970
10 SOW	300.8	1811.99		25	
11 SONE	300.8	463307		16	
12 SOSE	300.8	1588430		24	
13 SGPA	49			1464	
14 SGW	78.6	6642811	70208	67	
15 SGE	78.6	564496	700	86	

Figure 1. Trends in total krill demand from whales, penguins and fur seals, and krill standing stock in subareas 48.1 and 48.2 according to the numerical calendar. The seal abundance data used to derive demand estimates were based on the calendar in Table A1.
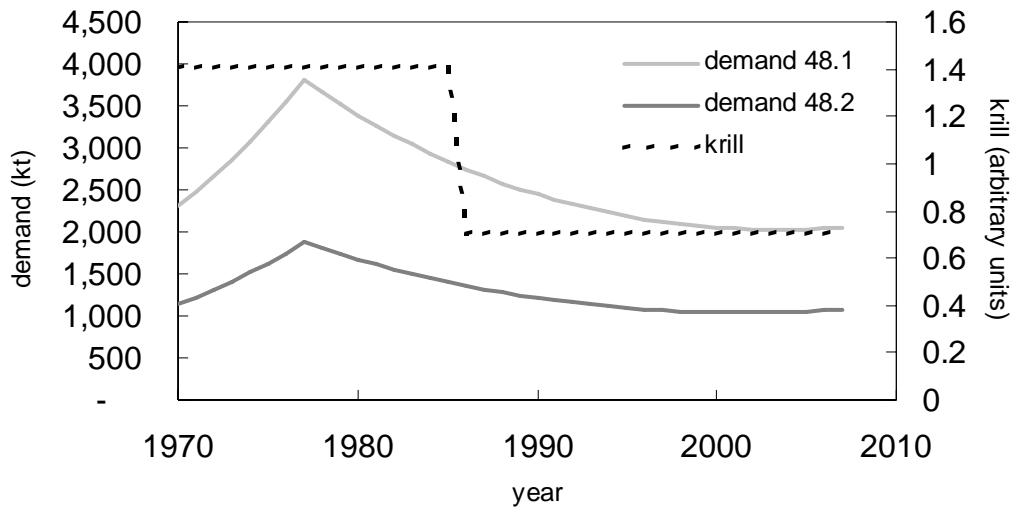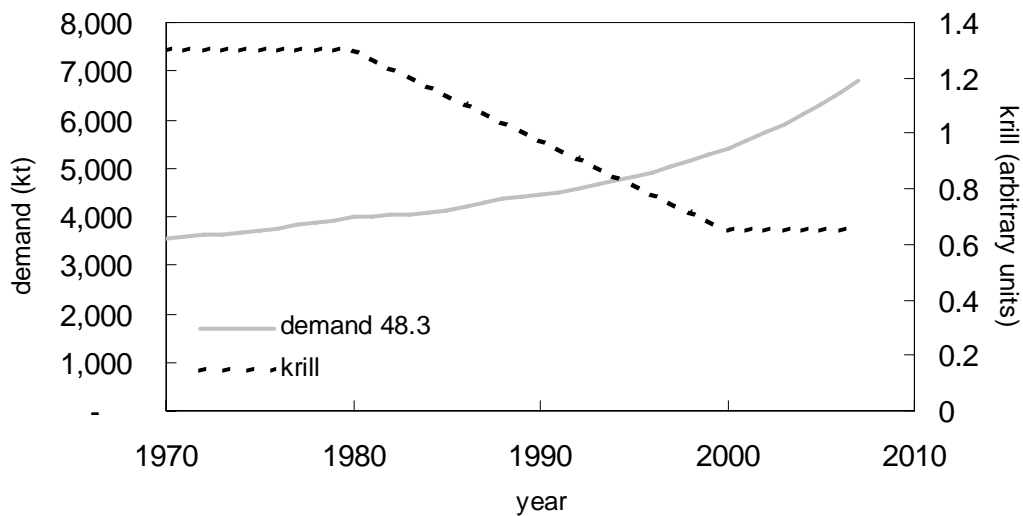

Figure 2. Trends in total krill demand from whales, penguins and fur seals, and krill standing stock in subarea 48.3 according to the numerical calendar.

APPENDIX 1

Revised results for fur seals in subarea 48. 1

The data on fur seal abundance for subarea 48.1 used in the 2002 WG-EMM workshop and therefore as the basis for calculations in Hill et al. (2007) were collected in 2002 and presented in Goebel et al. (2002). This paper also gives data (in terms of pup production) for four earlier years which suggest a sigmoidal population trajectory (Fig A1). These data give a reasonable fit to the SAM calendar, with a 1970 to 1994 growth rate of 14.5% (just below the maximum growth rate specified in the SAM calendar).

We did not have access to Goebel et al. (2002) when we constructed the numerical calendar. Instead we assumed, on the basis of fur seal work at South Georgia, that abundance in subarea 48.1 was observed in 1991 and we used a growth rate of 11.7% for the period 1970 to 1994. The consequences of these assumptions are shown in Fig. A1. The data from Goebel et al. (2002) suggest that abundances in 1970, 1995 and 2007 were 35%, 64% and 64% respectively of the values in the numerical calendar. Model fits to the empirical abundance estimates will also be affected because the population was still growing in 1991. Seal abundances based on Goebel et al. (2002) are given in table A1.

According to Hill et al. (2007), fur seals account for 6.67%, 0.06% and 0.19% of krill demand in SSMUs 3, 4 and 7 respectively and 0.20% in subarea 48.1 as a whole. The difference between the two estimates of fur seal abundance for 2007 (Tables 3 and A1) equates to a 19,818 tonne difference in estimated krill demand, which is 0.11% of the estimated demand in subarea 48.1 and 0.04% of that for subareas 48.1, 28.2 and 48.3 combined. It would have been preferable to tune the models to the values in Table A1. However given the relatively minor difference this makes to krill demand, it is unlikely to have a significant impact on model performance.

Table A1 Revised numerical calendar for the abundance of generic seals, where trends in subareas 48.1 and 48.2 are based on data in Goebel et al. (2002).

	SSMU	1970	1995	1988	2007	Observation year	Empirical abundance estimate
1	APPA						
2	APW						
3	APDPW	416	12,204		12,204	2002	12,204
4	APDPE	7	211		211	2002	211
5	APBSW						
6	APBSE						
7	APEI	34	1,002		1,002	2002	1,002
8	APE						
9	SOPA						
10	SOW						
11	SONE						
12	SOSE						
13	SGPA						
14	SGW	70,208		511,541	1,576,913	1991	611,054
15	SGE	700		5,098	15,716	1991	6,090

Fig A1. Generic fur seal abundance in subarea 48.1 (summed across SSMUs 3, 4 and 7) as represented in the calendar and data (filled triangle) used to tune models, and a revised calendar fitted to data in WG-EMM 02/51. Filled symbols represent the abundance reported in Hill et al. (2007). Generic abundance was calculated as 1.34 * pup production.