ANNEX 4

REPORT OF THE WORKING GROUP ON ECOSYSTEM MONITORING AND MANAGEMENT

(Kochi, India, 10 to 20 August 1998)

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INTRODUCTION

Opening of the Meeting

1.1 The fourth meeting of WG-EMM was held in Kochi, Kerala, India, from 10 to 20 August 1998.

1.2 In his welcoming address, Dr A.E. Muthunayagam, Secretary to the Government of India, Department of Ocean Development, New Delhi, outlined India's Antarctic Research Program and the importance of oceans and their sustained utilisation. The Honourable Minister for Fisheries, Government of Kerala, Sh. T.K. Ramakrishnan, described regional concerns about the exploitation of fishery resources and the environment, and the efforts underway to establish sustainable utilisation and conserve the marine resources. Sh. G. Eden, Honourable Member of Parliament, and Dr S. Paul, Honourable Member of Legislative Assembly of Kerala, extended their welcome to participants.

1.3 His Excellency, Justice (Retd) Sukhdev Singh Kang, Governor of Kerala, officially opened the meeting by welcoming all participants and expressing his hopes for fruitful scientific discussions. On behalf of the Working Group, the Convener, Dr I. Everson, thanked His Excellency, Justice (Retd) Sukhdev Singh Kang, the Government of India and, in particular, the Department of Ocean Development for the good wishes extended in the opening addresses to the meeting and also for hosting the meeting. Dr Everson noted that the CCAMLR management regime was dependent on the provision of sound scientific advice. Accordingly, he was pleased to welcome so many scientists from a large proportion of Member countries, many from the host country, India, to the meeting. Sh. V. Ravindranathan, Director of the Department of Ocean Development, gave a vote of thanks.

Adoption of the Agenda and Organisation of the Meeting

1.4 The Provisional Agenda was introduced and discussed. No changes were proposed and the Agenda was adopted (Appendix A).

1.5 The List of Participants is included in this report as Appendix B and the List of Documents submitted to the meeting as Appendix C.

1.6 The report was prepared by Drs D. Agnew (UK), A. Constable (Australia), R. Hewitt (USA), R. Holt (USA), P. Penhale (USA), D. Ramm (Data Manager) and E. Sabourenkov (Science Officer), J. Watkins (UK) and P. Wilson (New Zealand). It was decided that item 9.5 of the agenda, 'Plans for a Synoptic Krill Survey in Area 48' would first be discussed in a subgroup. Drs Hewitt, Holt and Watkins were asked to set up the subgroup and report back to the Working Group on its findings.

FISHERIES INFORMATION

Catches Status and Trends

2.1 The spatial distribution of catches from the krill fishery during the split-year 1996/97 (July 1996 to June 1997) was presented (WG-EMM-98/7 Rev. 1). The fishery targeted krill near the South Shetland Islands (Subarea 48.1) in all months except August and September 1996. Near South Georgia (Subarea 48.3), traditionally a winter fishery, it operated during July to September 1996 and in June 1997. Near the South Orkney Islands fishing took place in December 1996. The total reported catch of krill taken in 1996/97 was 83 919 tonnes.

2.2 The krill catches reported to the Secretariat by August 1998 indicated that four Members fished for krill during 1997/98, all in Area 48: Japan (63 413 tonnes); Korea (1 621 tonnes); Poland (15 312 tonnes) and the UK (634 tonnes). No fishing was reported from Areas 58 and 88. The total catch of krill reported at the time of the meeting was 80 980 tonnes.

2.3 Dr Ramm had sought information on catches of krill taken in FAO Division 41.3.2 from Members fishing in the northern sector of Subarea 48.1. He had also searched the FAO FISHSTAT database. This search confirmed the reported catches taken in Division 41.3.2 by Poland in 1988/89 (801 tonnes) and 1992/93 (2 506 tonnes) and reported in the *Statistical Bulletin*, and additional catches taken by the former Soviet Union in 1979/80 (161 tonnes) and Russia in 1990/91 (112 tonnes). Further, Poland submitted monthly catch and effort reports for krill fishing in Division 41.3.2 during 1997/98 (total catch 74 tonnes). The Working Group encouraged Members that have fished, or plan to fish, for krill in waters adjacent to the Convention Area to submit catch and effort data to the Secretariat in the CCAMLR formats.

2.4 The Working Group noted that STATLANT data for the past season would soon be submitted to the Secretariat. The Working Group reiterated the importance of fine-scale data and haul-by-haul data in the assessment of the krill fishery and its interactions with the ecosystem. Members were encouraged to submit all available data to the Secretariat.

2.5 In regard to plans to fish for krill during the split-year 1998/99, Mr T. Inoue (Japan) advised that Japan planned to continue fishing at the same level of about 60 000 tonnes of krill taken by four trawlers. Dr S. Kim (Republic of Korea) reported that the Republic of Korea planned to continue fishing at the same level of about 2 000 tonnes. Dr Agnew reported that fishing for krill by UK vessels in 1998/99 was likely to be at a level similar to 1997/98. For the moment, UK fishing for krill has been restricted to summer and winter periods, and is linked to the spring and autumn squid fisheries around the Falkland/Malvinas Islands. Dr Holt advised that a permit to take krill had been issued by the USA to one operator, and fishing may begin in September. Information in WG-EMM-98/13 indicated that Ukraine planned to renew krill fishing in the future. Dr K. Shust (Russia) advised that the present economic situation in Russia prevented Russian trawlers from operating in the krill fishery.

2.6 The Working Group had no further information on the proposed joint Ukraine/Canada fishing venture using two vessels (SC-CAMLR-XVI, paragraph 2.3). The Secretariat was requested to contact both countries, and seek further information on fishing activities which may have taken place during 1997/98 or were intended in 1998/99. The Secretariat was also asked to contact Uruguay, Panama and China to determine their intentions to fish for krill in CCAMLR waters.

Harvesting Strategies

2.7 Mr Inoue explained that krill harvested by Japanese trawlers in CCAMLR waters is used mostly as feed in the aquaculture industry and bait in recreational fisheries; a small proportion of the catches is also processed as food for human consumption. The demand for krill has dropped recently due to the severe downturn in the regional economy.

2.8 The quality of krill for use as feed, bait or food for human consumption is judged by three attributes: greenness of the hepatopancreas, body colour and body size. Large white krill with little green in their hepatopancreas are the most valuable, and are targeted by the fishing industry. Over recent years, Japanese trawlers have extended their fishing season to autumn and winter so as to avoid catching early season green krill, increase their catch of white krill, and avoid unduly large stocks of krill products in freezer stores onshore.

2.9 The Working Group discussed the need for information on past and current market prices for krill. This information would provide further insight into the fishery, for instance in an appreciation of the economic factors affecting this fishery.

2.10 The results of biochemical analyses of krill harvested during the First Indian Antarctic Krill Expedition were presented (WG-EMM-98/39 and 98/42). These results not only indicated the biochemical composition of krill, but also showed the effects of processing on the moisture content, fluoride content, and autolytic properties of krill taken during fishing operations.

2.11 Krill, processed aboard, were also subject to trials in post-harvest processing. A variety of frozen, dried, canned and marinated products had been evaluated (WG-EMM-98/40). Fluoride in the processed products was reduced to 1–15 ppm. Tests on the use of krill as an additive to food products for human consumption yielded variable results (WG-EMM-98/41), some of which reduced the acceptability of such products (e.g. as a consequence of a characteristic or bitter taste).

2.12 The Working Group noted that these results were important since they provide the first descriptions of krill biochemistry, product type and product scope for a number of years. Furthermore, some of the information presented in the above papers (WG-EMM-98/39 and 98/42) may have important application in the production and updating of energetic models for krill-dependent predators. The Working Group therefore encouraged publication of the Indian data as well as a comparison of these data with earlier work on krill biochemistry and energetics (e.g. Grantham, 1977; Clarke and Morris, 1983; Budzinski et al., 1985).

Observer Scheme

2.13 The Working Group noted that there had been no international observer coverage of the krill fleet in 1996/97 and 1997/98. Consequently, observer data, including time-budget data, for this period were not available. The Working Group reiterated the need for observer data and encouraged Members to collect such data and submit these to the Secretariat. Observer-type data have been collected from the Japanese fleet as part of the Japanese research program, and reported in WG-EMM-98/33.

MEETINGS DURING THE INTERSESSIONAL PERIOD

Report of the Workshop on Area 48

3.1 The Convener of the workshop, Dr Hewitt, introduced the Report of the Workshop on Area 48 to the meeting (WG-EMM-98/16). The workshop was held at the Southwest Fisheries Science Center in La Jolla, USA, from 15 to 26 June 1998. The terms of reference were:

(i) identify the extent of between-season and within-season variation in key indices of the environment, harvested species, and dependent species over past decades;

(ii) identify coherence in the indices between sites and clarify understanding of the linkages between Subareas 48.1, 48.2 and 48.3;

(iii) develop working hypotheses; and

(iv) provide a summary report for consideration of the 1998 meeting of WG-EMM.

3.2 The workshop was organised around the hypothesis H_0 and an alternative, H_1 as described below:

(i) H_0: Subareas 48.1, 48.2 and 48.3 are discrete ecosystems and events observed in any one subarea do not reflect what is happening in other subareas; and

(ii) H_1: area is a homogenous ecosystem and events observed in any one subarea reflect the entire area.

3.3 It was recognised that neither of these hypotheses was likely to be correct. However, they represent the end points of the spectrum of possibilities and may thus serve a useful purpose for organising the workshop (SC-CAMLR-XVI, Annex 4, paragraphs 8.112 and 8.113).

3.4 As findings and recommendations contained in the report relate to a number of topics discussed by WG-EMM, it was decided that the report would be considered in detail by section during discussions under subsequent agenda items.

3.5 The Working Group congratulated Dr Hewitt on a very successful workshop during which a large number of datasets were processed and a number of complex analyses undertaken. It was noted that Dr Hewitt was involved not only in the conduct of the workshop, but he had taken an active role in all stages of its organisation beginning with initial correspondence with potential contributors of data and the conduct of initial analyses.

3.6 The Working Group recommended that, as with previous scientific workshops, the report should be appended to the Working Group report and published in the bound volume of the report of the 1998 meeting of the Scientific Committee.

3.7 During discussions of this issue it was also noted that the Report of the Workshop on Area 48 (Appendix D) did not contain a number of background data and indices which were used by the workshop. It had been decided at the workshop that this information would only be made available by the Secretariat in accordance with CCAMLR's normal rules of data access (see Appendix D, paragraph 2.11).

HARVESTED SPECIES

Distribution and Standing Stock

4.1 Under this agenda item the following papers were considered to contain relevant information: WG-EMM-98/18, 98/30, 98/36, 98/13, 98/32, 98/51, 98/33, WS-Area48-98/11, WG-EMM-98/12 and 98/50, and these will be discussed in the following paragraphs.

4.2 WG-EMM-98/18 discussed the occurrence of Antarctic krill concentrations in the vicinity of the South Shetland Islands during a cruise in the austral summer of 1990/91. From early to mid-summer krill density increased and showed distinct offshore–inshore differences in abundance. In mid-summer acoustically determined krill density was low in the oceanic zone (8 g/m^2), higher in the slope frontal zone (36 g/m^2) and highest along the shelf break in the inshore zone (131 g/m^2).

4.3 Working in the same area as the previous paper, WG-EMM-98/30 presented a recalculation of krill biomass using the Polish FIBEX acoustic data so that it would be comparable with the recalculation of other FIBEX datasets presented by Trathan et al. (1992). The new results indicated that the acoustic krill density for stratum 1 (an area of the Drake Passage northwest of the South Shetland Islands) was 3.0 g/m^2 (CV 44.1%), while the acoustic density for stratum 2 (within the Bransfield Strait) was 76.6 g/m^2 (CV 33.2%).

4.4 WG-EMM-98/36 presented an acoustic krill density estimate (0.6 g/m^2) for the infrequently surveyed area between 60°–61°S and 34°–40°E (Area 58) collected by the Indian Antarctic expedition in January 1996. Comparisons within the paper with other survey results indicated that the krill density in that area was low.

4.5 WG-EMM-98/13 presented estimates of larval density of krill for Subarea 48.2. North and east of the South Orkney Islands the average density was ~30 000 individuals/m^2. In comparison with data from other years the abundance of larvae in 1997 was extremely high.

4.6 WG-EMM-98/32 presented estimates of three large surveys to estimate distribution and abundance of krill between the Antarctic Peninsula and South Georgia in 1983/84, 1984/85 and 1987/88. The mean biomass estimated from Isaacs-Kidd Midwater Trawls (IKMT) for the whole region was relatively constant on the three cruises (76.5 g/1 000 m^3 in January–March 1984, 101.7 g/1 000 m^3 in October–December 1984 and 101.4 g/1 000 m^3 in January–March 1988). In marked contrast there were significant changes in the quantity of krill observed in individual subareas. This was most obvious in Subarea 48.3 where krill densities of less than 1.5 g/1 000 m^3 were observed around South Georgia in 1984 while this had increased dramatically to 147.5 g/1 000 m^3 in 1988. In contrast, densities in Subareas 48.1 and 48.2 were smaller in 1988 than in 1984, this was particularly marked for Subarea 48.1 where the density in 1988 was approximately one-third of the density seen at the end of 1984.

4.7 WG-EMM-98/51 presented acoustic estimates of krill density obtained at South Georgia (Subarea 48.3) for 11 austral summers between 1981 and 1998. Krill abundance fluctuated widely from year to year over this time period, ranging from ~2 to ~150 g/m^2. In 1981/82, 1990/91 and 1993/94 there were particularly low abundances of krill. For five of the summers between 1990 and 1998 separate density estimates for the northeastern and northwestern ends of South Georgia were calculated. In four of these years the density was higher at the eastern end of the island.

4.8 WS-Area48-98/11 presented a comparison of acoustic krill densities around South Georgia (Subarea 48.3) and Elephant Island (Subarea 48.1) for seven summers between 1981 and 1997. The magnitude of abundance and the between-year gradients of change of abundance were similar at each site; e.g. very low densities of krill were found at both sites in 1991 and 1994. There was no apparent lag in changes in abundance at each site suggesting that densities of krill at both locations were linked and may be impacted by the same gross physical and biological factors acting over the same temporal and spatial scales.

4.9 WG-EMM-98/12 presented a summary of the results obtained by YugNIRO during the period from 1977 to 1990 for an area between 60° and 80°E in the Indian Ocean (Sodruzhestva Sea, Area 58). Results from monitoring the krill biomass revealed two main periods of differing krill abundance. During the period from 1977 to 1984 the krill density was high (15–20 g/m^2), while from 1985 until 1988 the density was lower (1–5 g/m^2), in the last two years (1989–1990) the density increased but the values were lower than those seen at the beginning of the data series.

4.10 WG-EMM-98/50 presented updated krill density estimates obtained from standardised scientific net hauls for the Elephant Island region (Subarea 48.1) for the period from 1977 to 1998. The density estimate for 1997/98 was 59 krill/1 000 m^3. This was substantially less than the values that had been obtained in 1995/96 and 1996/97 (120 and 213 krill/1 000 m^3 respectively) and was seen as a possible return to the lower values found in the period from 1990 to 1994.

4.11 In Subarea 48.1, both net and acoustic density data were available for the period 1981 to 1997 (Appendix D, paragraph 4.7). Changes in density from year to year occurred in the same direction for both datasets. Note, however, that the absolute relationship between the two density estimates was not constant, and that major changes were observed around 1985/86 and 1992/93.

Population Structure, Recruitment, Growth and Production

4.12 Dr Hewitt presented a summary of the analyses on krill population structure and recruitment indices which were carried out at the Workshop on Area 48 (Appendix D, paragraphs 4.8 to 4.18).

(i) Proportional recruitment indices at Elephant Island were low in 1988/89, 1989/90, 1991/92, 1993/94, 1995/96 and 1996/97. They were high in 1979/80, 1980/81, 1981/82, 1987/88, 1990/91 and 1994/95.

(ii) Proportional recruitment indices at South Georgia were low in the same years they were low at Elephant Island. Proportional recruitment was high in South Georgia in 1994/95. Note, however, that no estimates of recruitment were available for 1979/80, 1980/81, 1981/82, 1987/88 and 1990/91.

(iii) Absolute recruitment at Elephant Island was highest in 1979/80, 1980/81 and 1981/82. It was relatively low in 1987/88, 1990/91 and 1994/95.

(iv) Krill length frequencies at Elephant Island and South Georgia were most similar in 1989/90, 1992/93 and 1996/97. They were more different in 1993/94 and 1997/98.

(v) Krill predators at South Georgia shifted their diet from large- to medium-size krill as the summer progressed in 1990/91 and 1993/94 but not during intervening years.

4.13 In addition Dr Hewitt presented a summary of the krill fishery data analysed as part of the Workshop on Area 48 (Appendix D, paragraphs 4.20 to 4.27).

(i) CPUE was calculated for fishing areas near Elephant Island, Livingston Island, South Orkneys, western end of South Georgia and eastern end of South Georgia.

(ii) CPUE at Livingston Island and Elephant Island were similar from 1982/83 through until 1992/93. The CPUE in the Livingston Island area has been low since 1992/93.

(iii) Low CPUE for the winter fishery at South Georgia occurred at the eastern end of the island in 1991 and 1993 while it was low at the western end of the island in 1991 and 1994.

4.14 The Working Group reiterated the conclusion of the Workshop on Area 48, that there was considerable concordance between proportional recruitment indices in Subareas 48.1 and 48.3, implying that large-scale phenomena were likely to be influencing population dynamics in both regions.

4.15 Under this section of the agenda the Working Group considered the following papers: WG-EMM-98/13, 98/18, 98/33, 98/37, 98/50, WS-Area48-98/15 and Appendix D. Important points of relevance to the Working Group are summarised as follows.

4.16 WG-EMM-98/18 presented data on the krill population structure on the western side of the Antarctic Peninsula in 1990/91. The characteristic general pattern of increasing size and maturity with distance offshore was observed. Mature krill in spawning condition (44–55 mm) were found only offshore and in the frontal zone while small krill (24–33 mm) were restricted to the inshore zone.

4.17 WG-EMM-98/13 presented data on the general population structure in Subarea 48.2 in March 1997. In this year up to half the population were in the size range of 39 to 47 mm

(3+ year class), no juveniles (1+ year class) were observed and only 5 to 10% of the population were in the 2+ year class. In contrast, near Elephant Island (Subarea 48.1), 5% of the krill were juvenile, 30% were in year class 2+ and 30% were in year class 3+.

4.18 WG-EMM-98/37 presented data on the population structure of krill sampled during the January and February 1996 in Area 58 (57°–61°S and 30°–40°E). The observed length frequency distribution was bimodal with a mode at 19–20 mm and at 53–54 mm. Very few krill were found in between these two size groups implying that in this area at least two year classes were missing.

4.19 WG-EMM-98/33 presented a large and comprehensive dataset on proportional recruitment indices derived from Japanese fisheries data in Area 48 between 1980 and 1997. The results for the R2 values derived from the fishery data in Subarea 48.1 showed significant correlations with the R1 and R2 proportional recruitment indices derived from scientific surveys (Siegel et al., 1998). In contrast R1 values derived from the fishery did not show significant correlations with the scientific data; this could have been due to net selectivity and/or incomplete coverage of the areas where 1+ year class krill tend to occur. R1 and R2 recruitment indices from the fishery data were not significantly correlated. In Subarea 48.1 recruitment peaks were observed in 1980/81, 1981/82, 1987/88 and 1994/95. In Subarea 48.2 recruitment peaks were seen in 1980/81, 1981/82, 1990/91 and 1994/95. While in Subarea 48.3 recruitment peaks were observed in 1988/89, 1989/90, 1993/94 and 1994/95.

4.20 It was emphasised that some caution was required when using recruitment indices from fishery data because of net selectivity and the area covered by the commercial fishery. Nevertheless, the Working Group recognised this as an extremely valuable contribution and was very pleased to see such a comprehensive review of data collected from the commercial fishery.

4.21 WS-Area48-98/15 presented data on krill population structure derived from krill eaten by three predator species at South Georgia (Subarea 48.3) for the summers from 1991 to 1997. A comparison of krill sampled by nets and predators revealed similar length-frequency distributions when comparing nets with samples from Antarctic fur seals and macaroni penguins combined. The length-frequency distribution of krill within a season was most variable in 1990/91 and 1993/94, both years of low krill biomass at South Georgia. In both these years large krill dominated in the diet of fur seals and macaroni penguins during December but were completely replaced by small krill by February. The mean length of krill in March showed a regular increase from 1991 to 1993, fell to a minimum in 1994 and thereafter increased steadily until 1997. It is suggested that years of high mean krill length reflect the failure of small krill to recruit to the South Georgia population, producing a period of low krill biomass the following year.

4.22 The Working Group recognised that while individual predators may show some selectivity (e.g. in some years fur seals showed clear selectivity for large krill), this was less apparent when the three predator species were combined. It was difficult to weight the contributions of the different predators. The results of the changes of recruitment indices through the season had potential implications for the timing of surveys to assess recruitment. It was also recognised that the predators may not be sampling the same krill populations as the surveys.

4.23 WG-EMM-98/50 presented the updated time series of recruitment indices for the Elephant Island region (Subarea 48.1) derived from scientific net sampling. This paper confirmed that after the high proportional and absolute recruitment shown by the 1994/95 year class, the values for the 1995/96 and 1996/97 year classes were showing a downwards trend.

4.24 It was noted that the small krill observed in the Indian Ocean sector (WG-EMM-98/37) implied success of the 1994/95 year class, which is the same year class that was successful in Area 48. However, the Working Group felt that it was premature to accept that such an observation implied concordance in recruitment between these two areas.

Detailed Consideration of Recruitment Indices

4.25 The Workshop on Area 48 used two indices of recruitment in its work, proportional and absolute recruitment. Estimates of proportional recruitment (R1) are derived from mixture analyses (i.e. the proportion of individuals in a given year that fall within the year 1 age class) and are used to determine absolute recruitment in that year (see paragraph 4.29).

4.26 The Workshop on Area 48 used this estimate of proportional recruitment backdated to the previous year as an index of the reproductive performance of krill in respective subareas. This was done in an attempt to understand whether variation in reproductive performance in krill coincided with variation observed in key environmental or predator parameters. The Working Group noted that the terminology needed to be refined so that notions of reproductive performance would not be confused with methods for calculating absolute recruitment in a given year. To this end, the Working Group agreed that 'Per Capita Recruitment' (PCR) encapsulates the meaning desired in discussions about affects of the environment on krill reproductive output and larval survival.

4.27 The Working Group examined methods for determining PCR. It noted that the proportion of R1 in the stock at a specific time does not provide an indicator of reproductive success because it does not refer to the reproductive stock in the previous year. For this reason, an index of reproductive success needs to include a measure of recruits from one year and a measure of the spawning stock from the previous year. A potential method for estimating PCR was discussed under item 9 in paragraphs 9.6 to 9.12.

4.28 Last year, the Working Group noted progress on assessing krill recruitment and indicated that a priority task was to develop a reliable predictor of krill recruitment and to determine its statistical properties so that it can be used in assessments (SC-CAMLR-XVI, Annex 4, paragraph 3.27). Also, the Working Group noted the need to understand whether small-scale estimates of recruitment based on restricted surveys reflected more global trends (SC-CAMLR-XVI, Annex 4, paragraph 3.28).

4.29 These questions were raised again following the assessments undertaken by the Workshop on Area 48. In particular, the Working Group noted that the estimates of recruitment (based on proportions of R1 combined with the estimates of krill density), when considered in combination with the estimate of M = 0.8 (Siegel, 1991; but note that estimates of M may vary from year to year and that Butterworth et al. (1994) integrated over a range of M = 0.4–1.0 in the calculations of a precautionary yield for krill), did not seem to be sufficient to sustain the populations of krill despite the apparent abundance of krill to predators in many years. The Working Group undertook some preliminary analyses using the results from Subarea 48.1 in an attempt to reconcile the recruitment estimates and M.

4.30 For clarification, the proportion of one-year-olds, R1, in any year, y, is

$$R1_y = \frac{N_{1,y}}{\sum_{a=1}^{n} N_{a,y}}$$

where $N_{a,y}$ is the number at age a in year y, and there are n ages. In addition, some analyses are based on recruits at age 2 rather than age 1. In this case, the formula of the proportion of two-year-olds, R2, in any year, y, is

$$R2_y = \frac{N_{2,y}}{\sum_{a=2}^{n} N_{a,y}}$$

These formulae apply to the year of capture, y. In the Workshop on Area 48, these values were related to the year class, which is y-1 and y-2 for R1 and R2 respectively.

4.31 The problem identified above can be examined, in the first instance, using a model of a closed krill population considered to be in equilibrium. In this case, the number of krill in one year, N_{t+1}, should be equal to the number of krill in the previous year, N_t. In this case, losses to mortality should equal recruitment, R. Thus,

$$R1 = \frac{R}{N} = 1 - e^{-M}$$

The current estimate of M is 0.8. Thus, the average replacement recruitment required for a sustainable population would require R1 = 0.55. However, R1 has been observed to be consistently below this value at about 0.1 during the late 1980s and early 1990s (see Figure 1). Under a scenario of equilibrium, M would need to be approximately 0.11, which is considerably different from the current estimate.

4.32 The Working Group recognised that this calculation does not account for variable recruitment or sampling variability. Two analyses were undertaken using measures of absolute recruitment to solve for a constant M, where absolute recruitment was considered to be

$$R_y = D_y R1_y$$

and D_y is the density of krill in the current year, y (see Siegel et al. 1998 for discussion). Values of D_y and R1 are taken from WG-EMM-98/50 and the values of D_y are the bootstrap estimates of density from net surveys.

4.33 The first was an age-structured population projection with six age classes using the absolute recruitments and solving for M by minimising the sums of squared differences between the expected and observed numbers in each year. In this model, the missing values in estimates of R1 and the absolute densities were interpolated. The estimate of M was 0.584. A projection of the stock based on this estimate of M is shown together with the estimates of absolute density in Figure 1.

4.34 The second method used only the available data to estimate M and accounts for uncertainty in both the estimates of R1 and absolute density. It minimised the error in M from a series of equations of differences between the expected density from the previous year projected to the current year and the estimate of adult animals from the current year

$$D_y.(1 - R1) - D_{y-1}.e^{-M} = 0$$

The series of equations included only those years for which data were available. The estimate of M in this case was 0.603. The estimates of total density for each year are overlaid on Figure 1 where the density in a year was the projected density of adults from the previous year plus the density of recruits estimated for that year from R1 and the total recorded density.

4.35 The results of both these methods estimated M to be less than the current estimate of 0.8. Figure 1 shows that the values of M derived from these methods provide projection results that are close to the estimates of density in the years prior to 1992 but, following that year, the difference between observed and estimated densities becomes greater, particularly in the most recent years from 1996. This result suggests that the observed recovery of the density of krill in Subarea 48.1 following 1994 could not be attributed to recruitment alone.

4.36 The Working Group considered that the discrepancies between estimates of M and between observed and expected estimates of density using these analyses could have arisen, *inter alia*, from:

(i) the current estimates of recruitment are correct and the model for M needs revision, e.g. the estimate of a constant M over all post-recruit year classes may need to be revised or the model may need to account for interannual variability in M;

(ii) the estimate of the proportion of recruitment is representative of the whole population but the estimates of density vary in their representativeness of the population, (e.g. arising from interannual variability in advection); and

(iii) the estimates of proportional recruitment (R1) may be incorrect, arising from spatial variability in the distribution of different age classes and/or different residence times of those age classes in the survey area, or as a result of interannual variability in growth rate which may affect the interpretation of the length-density data.

4.37 The Working Group noted that work needs to be undertaken to determine the reasons for the discrepancies. It also noted that the Workshop on Area 48 had made considerable progress in allowing these questions to surface and to provide some direction for pursuing them. The Working Group agreed that the results of the Workshop on Area 48 need to be carried forward intersessionally with the aim to determine how to utilise length-density data from restricted areas in estimating large-scale trends in absolute recruitment. In particular, the following questions were highlighted for further developmental work:

(i) What model/s of recruitment can be applied to local stocks in different subareas?

(a) Are local stocks independent?

(b) How important are immigration and emigration to the dynamics of local stocks?

(c) Does the local stock have a single origin or multiple origins? If so, is the demography of krill the same in each of these stocks? What are the relative inputs of the different source stocks?

(d) Does the pattern of immigration or emigration vary between cohorts or between locations or times?

(ii) How does intra-annual variability in krill distribution affect estimates of recruitment?

(a) Does sampling have to occur throughout a season or is a single time appropriate?

(iii) How should sampling be stratified in space to ensure a representative sample from the local stock is obtained?

(a) What methods can be applied to ensure that small-scale surveys can be used to understand trends over large-scale areas?

(iv) How sensitive is the method for estimating R1 to variation in growth, mortality and recruitment rates?

DEPENDENT SPECIES

CEMP Indices

5.1 Dr Ramm presented a summary of the anomalies and trends in CEMP indices (WG-EMM-98/4 Rev. 2). New data for indicator species in the 1997/98 season were included where available; sea-ice data were available to December 1997 and sea-surface temperatures (SST) were available to March 1998. Information on missing values were also presented, as requested at last year's meeting. The Working Group recognised that missing values may occur as a result of technical or logistical constraints, however, some missing values arise as a result of an absence of the properties to be measured. The Working Group noted that a methodology needs to be developed that can incorporate these latter missing values in assessments of anomalies.

Studies on Distribution and Population Dynamics

General

5.2 Analyses of land-based predator indices from the Workshop on Area 48 (Appendix D, paragraph 9.4) show that:

(i) most land-based predator indices showed greater coherence between species within sites than across sites (Appendix D, paragraphs 7.9 to 7.16);

(ii) land-based predator indices in summer were generally coherent across Subareas 48.1, 48.2 and 48.3 (Appendix D, paragraphs 7.18 to 7.29):

'good' years: 1984/85, 1987/88, 1988/89, 1994/95 to 1996/97;
'bad' years: 1990/91 and 1993/94, particularly 1990/91.

(iii) coherence in land-based predator indices for summer across subareas was generally more evident in good than in bad years (Appendix D, paragraphs 7.28 and 7.32);

(iv) winter land-based predator indices show less coherence across subareas than summer indices. When there was coherence:

'good' years: 1977, 1988 and 1989;
'bad' years: 1990 and 1994

it was more consistently area-wide than in summer (Appendix D, paragraphs 7.33 to 7.48); and

(v) there was no consistent sequence in land-based predator indices between bad winters and bad summers; that is, either can precede the other (Appendix D, paragraph 7.45).

Antarctic Fur Seals

5.3 The Working Group thanked SCAR for the report on status and trends in Antarctic seals (WG-EMM-98/8 and 98/27) but noted that some of the data are now well out of date. The utility of such data being solicited from SCAR is discussed further in paragraph 5.5.

5.4 WG-EMM-98/17 reported a population decline of Antarctic fur seals at Cape Shirreff during 1997. This followed six years of annual increases in the number of seals at this site, although pup growth rates in 1997 were within the historical norm (WS-Area48-98/18). The Working Group suggested that these results could be attributed to a number of possible causes, including density-dependent factors and/or environmental linkages. However, it agreed that a single annual decline in population numbers may not necessarily indicate the beginning of a population decline of Antarctic fur seals at Cape Shirreff and that more research is required.

Birds

5.5 The status and trends of Antarctic and sub-Antarctic seabirds (SC-CAMLR-XV/BG/29) were discussed by the Working Group. The document, through necessity, contains data of questionable reliability and is dated. The Working Group recognised that SC-CAMLR-XV/BG/29 had been produced in response to a request for information from SCAR-BBS. Given that data on bird population status and trends are annually submitted to the CEMP database, the question of the potential utility of data from SCAR at five-yearly intervals should be referred to SC-CAMLR for consideration.

5.6 Foraging trip duration in male and female macaroni penguins at Bouvet Island (WG-EMM-98/23) indicated that female, not male penguins may provide superior data on foraging. This needs to be reviewed intersessionally in relation to information from South Georgia. The Working Group expressed interest in the future of this study as it was monitoring a species known to feed on krill but present in an area for which there is little information. Diet composition studies would also be of interest in addressing the issue of prey switching – also it is known that fish are eaten in the early part of the season; krill are eaten later on. In addition, knowledge of meal size in relation to foraging trip duration would give some indication of feeding efficiency.

5.7 Diet and foraging effort of Adélie penguins in relation to pack-ice conditions in the southern Ross Sea (WG-EMM-98/15) reconfirmed the importance of *Pleuragramma antarcticum* and *Euphausiacrystallorophias* in the diet delivered to chicks by provisioning parents on Ross Island and showed that successful foraging during the chick-rearing phase appears to depend on the proximity of pack-ice to nesting colonies. The Working Group expressed interest in this paper for modelling purposes.

Whales

5.8 According to the whale data provided by the IWC (WS-Area48-98/21) for which the Working Group expressed thanks to Dr S. Reilly (Observer, IWC), sighting surveys of minke whales appeared to offer the best technique for censusing whales for analyses in CCAMLR.

Other Information

5.9 WG-EMM-98/49 describes the US AMLR 1997/98 field season, and of note is that this season was the first at Cape Shirreff after shifting base from Seal Island. The Working Group welcomed the news from Dr Holt that the Admiralty Bay dataset would soon be available to CCAMLR.

5.10 The Working Group reviewed SC-CAMLR-XVII/BG/2 and considered that it was no longer necessary to present this information in a paper. Instead, it was suggested that for Table 1 (summary of Members' CEMP activities on monitoring approved predator parameters) the Secretariat directly pursue the submission of relevant historic data. The Working Group suggested Table 2 (directed research programs required to evaluate the utility of potential predator parameters) should go onto the CCAMLR website and also recommended that the Scientific Committee ensure a standard approach, if possible, for this sort of data across both WG-EMM and WG-FSA.

ENVIRONMENT

6.1 Participants at the Workshop on Area 48 emphasised the following results (Appendix D, paragraph 9.2):

(i) global ocean/atmosphere signals were evident in indices of the physical environment (SSTs, air temperatures, difference in sea-level pressure across Drake Passage (DPOI, Drake Passage Oscillation Index), sea-ice extent derived for Area 48) (Appendix D, paragraphs 3.16 to 3.22);

(ii) approximately four-year periodicity was evident in SST and with the Antarctic Circumpolar Wave (ACW) described by White and Petersen (1994) (Appendix D, paragraphs 3.23 to 3.28);

(iii) precession of SST anomalies across Scotia Sea was consistent with the FRAM advective transport model, suggesting transport times of four to eight months between the Antarctic Peninsula and South Georgia (Appendix D, paragraphs 3.29 to 3.37);

(iv) global ocean/atmospheric signals showed strongest coherence with South Georgia, weaker coherence with the Antarctic Peninsula and the South Orkneys implying different local influences (such as Weddell Sea) (Appendix D, paragraphs 3.31, 3.32 and 3.36); and

(v) a warming trend over the last seven years was apparent in the surface temperature data only at the Antarctic Peninsula and the South Orkneys (Appendix D, paragraphs 3.26 and 3.28).

6.2 Table 4 of WG-EMM-98/4 presents sea-ice indices updated to include 1998 data. The Working Group expressed appreciation to the Secretariat for providing the new information but also questioned whether the data were being utilised in analyses. However, it was recognised that several key participants, who might utilise the information, were not in attendance at the meeting and it was decided to defer the issue until the next meeting of the Working Group.

6.3 WG-EMM-98/12 presented an overview of 30 years of oceanographic monitoring by YugNIRO in the Indian Sector of the Antarctic waters, especially in the waters of the Kerguelen Archipelago, Ob and Lena Banks, and the Sodruzhestva and Cosmonauts Seas. Major investigations included the distribution of water masses, position of fronts, current flows, gyre formation and thermocline locations.

6.4 The large amount of data collected in this area over a long time period was noted. It was recognised that much of the data might be useful in furthering the work of the Working Group and participants were encouraged to define specific data needs to address specific problems. The authors could then be encouraged to provide appropriate data.

6.5 WG-EMM-98/14 reported a program to provide fisheries users with information pertaining to current and monthly environmental conditions. Information in the form of maps is derived using SST satellite data. Although current maps are not prepared for Antarctic waters, the authors suggest similar data could be obtained and provided for areas of interest to the

Working Group. It was suggested that it would be important to know how fishers utilised these data. It was also recognised that data of this type might be used to investigate how predators respond to certain environmental factors both within and among years.

6.6 WG-EMM-98/15 investigated pack-ice at three sites in the Ross Sea from 1994/95 to 1996/97. Sea-ice was extensive and persistent in 1994/95 compared to the other two years; it was least extensive in 1996/97.

6.7 WG-EMM-98/31 used satellite microwave observations to report on daily transition of polynyas in the Ross Sea from 1978 to 1994. A typical polynya existed in the inner area of the Ross Sea in November of each year. The shape of the polynyas changed remarkably in several days. They usually opened to the northern oceanic water in late December.

6.8 It was suggested that it would be of interest to standardise methods used to investigate polynya dynamics which would allow comparisons to other variables across years, etc. It also would be useful to develop some spatial index to determine variability in the characteristics of polynyas.

6.9 WS-Area48-98/10 reported that high levels of autocorrelation were evident in the SST anomalies around South Georgia (Subarea 48.3) with periodicity evident at a lag period of four years. To the north of the island significant autocorrelation was also evident at a lag period of one year. Cross-correlation analyses with indices describing the El Niño areas of the Pacific indicated that temperature fluctuations at South Georgia reflected temperature fluctuations in the Pacific. This link was separated temporally with the Pacific preceding South Georgia by almost three years. High levels of intra-annual variability at South Georgia were observed and the Principal Component Analysis (PCA) indicated that seasonal differences between winter and summer were important.

6.10 The authors noted that based upon the anticipated three-year lag, the greatest impact of the 1997/98 El Niño event will be unlikely to reach South Georgia until 2000/0l (WG-Area48-98/10). The Working Group noted that some models of the physical environment are reaching sufficient maturity to provide testable predictions as to their effects on the Antarctic ecosystem. It encouraged participants to test the predictive capacity of these models by generating predictions, determining the types of data that would indicate the effects on the ecosystem and undertaking the necessary field monitoring to acquire these data. To that end, the Working Group suggested that efforts be made to formulate and test predictions arising from the anticipated influence of the 1997/98 El Niño.

ECOSYSTEM ANALYSIS

Analytical Procedures

Combination of Indices

7.1 For a number of years, the CEMP indices have been presented as standardised normal variates. At the 1997 meeting of the Subgroup on Statistics a method for the combination of these standardised indices into a Composite Standardised Index (CSI) was proposed by de la Mare (WG-EMM-STATS-97/7). At the Workshop on Area 48 a computer program provided by Drs I. Boyd and A. Murray (UK) was used to calculate CSIs. In their paper describing the operation of the program (WS-Area48-98/6) the authors commented that they had not been able to reproduce de la Mare’s results exactly, because the original paper had not been explicit in describing the calculation of the covariance matrix. WG-EMM-98/45 provided a worked example of the de la Mare method which clarified this operation. It was recognised that the difference between the methods described in WG-EMM-98/45 and WS-Area48-98/6 was that the former (de la Mare method) calculated covariances by pairwise correlation over the time series where all indices in the CSI were represented (i.e. a complete dataset, where there were no missing values, and where the covariance matrix is identical to the correlation matrix). The latter calculated covariances between indices of all available cases in each pairing.

7.2 The Working Group requested Drs Constable and Boyd to correspond in order to establish the most appropriate statistical approach to the calculation of covariance matrices for CSIs.

7.3 WG-EMM-98/45 examined the sensitivity of the CSI method to missing values in the indices making up the CSI. The most robust CSIs were those where parameters included in the index were positively correlated with all other parameters, preferably with correlations greater than 0.3. Indices including parameters that were negatively correlated with other parameters were particularly sensitive to missing values.

7.4 It was agreed that the choice of parameters to include in a CSI should be made with care, including consideration of the correlation between indices, the time and space scales integrated by them, and the weighting factors that might be applicable.

Multivariate Approaches

7.5 Examples of several possible multivariate approaches to interpreting indices were available to the Working Group. These included multiple regression (WS-Area48-98/16; Appendix D, Table 14), PCA (WS-Area48-98/10; Appendix D, Attachment E) and spectral analysis (WS-Area48-98/11). PCA and spectral analysis are primarily descriptive, rather than predictive approaches, which are of assistance in identifying components of the system which might be of most use when developing predictive models. Multiple regression and associated models have predictive capability. The various merits of these approaches are discussed in detail in Appendix D.

7.6 It was recognised that there are two primary objectives for ecosystem analysis, both of which can be approached using multivariate techniques:

(i) understanding the autecological properties of species, and the interactions between ecosystem components; and

(ii) identifying predictive/operational models from which management advice can be derived.

7.7 It was also recognised that the interpretation of the results of multivariate analyses is contingent on the correct formulation of the CSIs. There is unlikely to be only one CSI that is most appropriate for describing any parameter set, since the parameters and weighting factors included in a CSI are likely to be influenced by the purpose to which the CSI will be put. CSIs of use in understanding the relationships between ecosystem components might contain different parameter sets from those of use in making management decisions.

7.8 Further development of multivariate approaches, including especially exploration of the sensitivity of such analyses to the CSIs used, is encouraged. The significance of the contribution made to the multivariate model of each parameter or index should be clearly identified in the results of such studies, as should the covariance matrix of the CSI. Consideration can then be given to whether inclusion of an index, or a parameter within a CSI, is appropriate.

General Yield Model

7.9 Drs Ramm and Constable reported on progress with validation of the General Yield Model (GYM), which has been accepted by the Working Group as a replacement for the existing krill yield model (SC-CAMLR-XVI, Annex 4, paragraph 7.3). Validation will be initiated in 1998, and should be completed in 1999, before the proposed Area 48 synoptic survey.

7.10 The Working Group requested that details of the validation methods, and the worksheets and programs used in the validation procedure, be available to members of the CCAMLR scientific community as soon as possible, to encourage a peer-review process similar to that used to validate the original krill yield model. This is particularly important given the potentially high use that may be made of this model in deriving management advice for a number of harvested species. However, given the complexity of the model, it was suggested that scientists wishing to examine the validation procedures do so in close consultation with Dr Constable and the Secretariat.

7.11 The existing krill yield model will be kept at the Secretariat in its current form for cross-checking purposes. The Secretariat was requested to develop a comprehensive set of documentation for this model prior to it being archived, so that it might easily be used in the future if necessary.

Krill-centred Interactions

Krill–Environment Interactions

7.12 Considerable information was available on the interaction of krill and their environment in the report of the Workshop on Area 48 and a number of papers. The results of the workshop relevant to this agenda item are given in (Appendix D, paragraphs 8.11 to 8.43).

7.13 Introducing the relevant section of the report, Dr Hewitt identified the following main conclusions with regard to interactions:

(i) environmental indices for SST, sea-ice and DPOI in Area 48 showed strong coherence, all being in phase with the same periods, and are an expression of the ACW (Murphy et al., 1995; White and Petersen, 1996). The phase period between the east and the west Scotia Sea is four to eight months (Appendix D, paragraph 9.2). Although data from the Antarctic Peninsula and the South Orkneys have similar signals, they are less strong and indicate that either local effects, or influences from other areas (such as the Weddell Sea) may also be important;

(ii) proportional krill recruitment above an index value of approximately 0.3 was correlated with sea-ice extent in the Antarctic Peninsula (Appendix D, paragraph 8.17);

(iii) krill density at South Georgia was associated with regional sea-ice and summer SOI, in particular the low krill density, low sea-ice years of 1990/91 and 1993/94 (Appendix D, paragraphs 8.21 and 8.35). In contrast krill density at the Antarctic Peninsula was not associated with indices of physical variability (Appendix D, paragraphs 8.20 and 8.34); and

(iv) land-based and pelagic predator indices in Subarea 48.3 were correlated with summer krill densities but were also influenced independently by physical variables (Appendix D, paragraphs 8.21, 8.24, 8.27 and 8.34). In contrast, land-based predator indices in Subarea 48.1 were not correlated with krill or physical indices (Appendix D, paragraphs 8.20 and 8.34).

7.14 WG-EMM-98/18 examined oceanic waters, the shelf slope frontal zone and inshore waters around the South Shetland Islands and found that the topographic features associated with the shelf and islands were responsible for two distinct current patterns in the area. The larvae resulting from spawning in the slope frontal zone would be carried onshore to be entrained in the Bransfield Strait by the slower currents and eddy systems along the shelf break (paragraph 4.2). In contrast adults and larvae in the offshore region would be likely to be carried through the Drake Passage away from Subarea 48.1 by the faster, more linear current flowing offshore.

7.15 WS-Area48-98/11 noted that the magnitudes and between-year gradients of change in acoustic abundance were similar at both Elephant Island and South Georgia. This indicated that densities of krill at both locations are linked and may be impacted by the same gross physical and biological factors and are in agreement with paragraph 7.13(i) above. WS-Area48-98/8 suggested that the transport of krill to South Georgia may be different in warm and cold years, possibly mediated by sea-ice extent and the relative influences of the Weddell–Scotia Confluence (WSC) and the Antarctic Circumpolar Current (ACC) in warm (reduced sea-ice) and cold (increased sea-ice) years. WG-EMM-98/32 presented direct evidence of links between krill around the Antarctic Peninsula, South Orkneys and Scotia Sea and transport to South Georgia, by mapping both current structures and krill density over the Scotia Sea in 1983/84, 1984/85 and 1987/88.

7.16 Both WS-Area48-98/8 and WG-EMM-98/32, however, found inconsistencies in simple environmental explanations of krill occurrence at South Georgia. For instance, in 1984/85, although there was a clear current between the Antarctic Peninsula and the eastern side of South Georgia, high densities of krill around South Georgia were not apparent at the time of the Russian survey. The occurrence of krill at South Georgia is therefore not simply explained by physical transport mechanisms from the Antarctic Peninsula through Subarea 48.2, but is likely to involve interactions between various biological and physical processes. A conceptual model presented in WS-Area48-98/8 captured this through the inclusion of environmental influences on egg production and overwinter survival in addition to regional transport. It was noted that both WG-EMM-98/32 and WS-Area48-98/8 presented evidence that the pattern of currents between the Peninsula and South Georgia may be quite variable, and include the abovementioned Weddell Sea input and the possibility of transport to the west of South Georgia rather than the east of the island in some years.

7.17 WG-EMM-98/32 also presents information which runs counter to the evidence for concordance within Area 48. Although these surveys did observe a decline in krill abundance in Subareas 48.1 and 48.2 in 1987/88, this was not accompanied by declines in Subarea 48.3. The abundance over the whole area (Subareas 48.1, 48.2 and 48.3) remained relatively stable in each of the surveys (1983/84, 1984/85 and 1987/88). This suggested that the multiannual trends in krill abundance seen in Subarea 48.1 did not necessarily reflect trends in krill abundance over the entire Area 48.

7.18 WG-EMM-98/12 reported that studies in the Indian Ocean Sector (Prydz Bay) had revealed that a period of high krill density from 1977 to 1984 was followed by a period of low krill density from 1985 to 1988. The Working Group noted that this coincided with the drop in krill densities seen around the Antarctic Peninsula from 1985 onwards. Although it is unlikely that there are direct links between the two areas, it is possible that both are influenced by the ACW, which has an eight-year transit cycle of two peaks, with peaks occurring at opposite sides of the Antarctic Continent simultaneously (White and Petersen, 1996). Any one side, therefore, experiences a four-year period between peaks. However, considerations of convergence between various areas in the Antarctic should be made with caution, as this periodicity appears to be a rather recent phenomenon and the wave does not necessarily progress at the same speed in all areas.

7.19 WG-EMM-98/12 reported on analyses developed by Ukrainian scientists in which krill density was linked to atmospheric pressure measurements to produce krill 'forecasts'. The Working Group reflected that this might be a similar index to the DPOI (the difference in sea-level pressure between Rio Gallegos and Esperanza) used by the Workshop on Area 48, and encouraged presentation of further details of these analyses.

7.20 The Working Group recognised that, with the large number of connections between krill abundance and environmental variables now being suggested, it might soon be possible to suggest forecasts for likely future krill recruitment and/or abundance. For instance, in 1997 observed late spawning and high salp abundance around the Antarctic Peninsula suggested that recruitment of the 1996/97 year class would be low, as indeed has been observed in 1998 (WG-EMM-98/50). WG-EMM-98/52 pointed to a number of environmental variables that could be used to make these forecasts. Using them may not be simple: the Workshop on Area 48, for instance, demonstrated a positive relationship between sea-ice and the proportion of one-year-old krill in the population only in Subarea 48.1 and only for proportions of one-year-olds greater than 0.3 (Appendix D, Figure 39). Nevertheless, the Working Group agreed that it should work towards a predictive model of krill recruitment which would improve the ability to make such forecasts.

7.21 The Working Group noted that some of the relationships established by bivariate analyses during the Workshop are probably non-linear (Appendix D, paragraph 8.43). Therefore, the Working Group agreed that it was important to carry out further analyses with regard to predicting krill recruitment.

Krill–Plankton Interactions

7.22 Results from the First Indian Antarctic Krill Expedition were presented. Sampling was conducted in Area 58 (around 61°S 34°E) during January to February 1996. Krill were sampled using a 2.5-m IKMT, a 42-m commercial trawl net, and a 49.5-m experimental midwater trawl (WG-EMM-98/38). Krill only made up 45.6% by weight of trawl catches, 54% being salps. The expedition also recorded high abundances of copepods (WG-EMM-98/34, 98/35, 98/37). These samples were taken in an oceanic area from which there are very few data on krill biology and abundance. Further information which might suggest the origin of krill in this area would be useful (see paragraphs 4.18 and 4.24). The Working Group welcomed the results of the expedition as these contributed to the knowledge of Area 58. This area has received little attention over the past 20 years. India has submitted data on by-catch to the ad hoc working group on finfish by-catch in krill fisheries.

7.23 WG-EMM-98/13 presented distribution plots which suggested separation between salps and krill in water masses north of the South Orkneys in 1997. However, examination of the full dataset would be necessary before drawing conclusions from these observations.

7.24 In the Peninsula area, poor recruitment is indicated for the 1995/96 and 1996/97 year classes (WG-EMM-98/50). Dr Hewitt recalled that the failure of the 1996/97 year class had been predicted last year (paragraph 7.20 above). This prediction was based in part on links with high salp abundance in the latter half of the 1996/97 season. WG-EMM-98/50 reported (i) that salps had been dominant in the zooplankton in 1998 and 1993, (ii) that copepods had been dominant in 1995 and 1996, and (iii) identified 1994 and 1997 as transition years between the salp dominated and copepod dominated years. The transitions happened over a matter of weeks suggesting advective rather than population processes. The Working Group suggested a number of multivariate analyses including multidimensional scaling using software such as that developed by Plymouth Marine Laboratories (UK) that might be used to characterise the years using all the species recorded. As to the question of whether salps and krill compete for phytoplankton, it was noted that WS-Area48-98/4 had found different relationships between salps and krill depending on sampling location.

7.25 The presence of the salp *Ihlearacovitzai* had been identified for the first time in US AMLR surveys (WG-EMM-98/50), although this species has been recorded from the Antarctic Peninsula region before by other national surveys. This species is generally described as being present at higher latitudes than *Salpa thompsoni*. A further unusual feature of the 1998 survey was the occurrence of unusually small krill at some southern survey stations. Several alternative hypotheses might explain these phenomena, including significant incursions of Weddell Sea waters, delayed spawning of krill in 1997 and transport of *Ihlea* from further south on the Antarctic Peninsula.

7.26 The Working Group previously noted that the Japanese fishery generally encountered green krill in the early summer, with an increasing proportion of white krill throughout the summer and autumn. Green krill are taken to reflect high levels of feeding on phytoplankton. WG-EMM-98/29 reported the proportion of green krill sampled around the South Shetland Islands, was related to the amount of phytoplankton of >2 μm in size rather than very small phytoplankton of <2 μm (WG-EMM-98/29). These larger phytoplankton declined in the autumn, explaining the transition from green to white krill.

Krill–Fishery Interactions

7.27 WG-EMM-98/5 reported on the Secretariat's application of the Schroeder index of spatial resource overlap to the Agnew–Phegan model of overlap between penguin foraging demands and the krill fishery in Subarea 48.1. The new results indicate that while the Agnew–Phegan index of Foraging–Fishery Overlap has been declining over the last decade, the Schroeder index has been increasing. Concern was expressed that the Schroeder index measured only the relative overlap of two 'predators', without considering the magnitude of the overlap. Thus, even if the catch was very low, if it coincided exactly with foraging areas the index would equal 1. In the current formulation of the Schroeder index this is partly a consequence of only considering catches within the critical period (December to March) rather than the whole period over which the fishery operates.

7.28 It was recognised that indices reflecting the relative degrees of overlap (such as the Schroeder index) and indices reflecting the absolute catch of krill relative to predator foraging demands (such as the Agnew–Phegan index or the catch in the critical period-distance) are required to judge the impact that the fishery might be having on predators. Both should therefore be retained for the time being, and consideration should be given to producing various graphical outputs which would aid interpretation of the indices (for instance, maps of predator consumption density). Investigation of the performance of these two indices to changes in fishing distribution and size, and to variants of model formulation, should be undertaken by the Secretariat in the intersessional period in addition to the bullet points identified as further work in WG-EMM-98/5.

7.29 One of the objectives of an ecosystem assessment should be to identify areas which, should the krill fishery increase rapidly, may require some management measures. However, estimates of predator numbers and consumption appear to be quite variable and are often, for logistic reasons, quite separated in time between various areas. A B_0 survey for predators, similar to that for krill proposed for 2000, might therefore be needed. Any quantitative assessment of the impact of the krill fishery on predators in local areas should also require the development of a functional relationship between predators, krill and the fishery.

Krill–Predator Interactions

7.30 WS-Area48-98/17 examined the differences in predator foraging characteristics in years of high and low krill abundance. A ten-fold decrease in krill abundance between 1986 and

1994 was accompanied by reduction of krill in predator diets, an increase in prey diversity and reduced diet overlap between species. Breeding success was markedly reduced in all species except macaroni penguin, which switched from krill to amphipods. The results showed a coherent pattern of responses to the reduction in krill availability, which confirm assumptions of the links between predators and krill made by the ecosystem monitoring program.

7.31 WG-EMM-98/15 showed that the amount of food brought to Adélie penguin chicks on Ross Island increased as trip duration increased up to periods of two days, and then decreased as trip duration increased further up to four days, as a result of more of the food being used for adult maintenance. A complex relationship between the consumption of *E. crystallorophias*, *P. antarcticum* and the amount of pack-ice was revealed. These observations contribute to the understanding of the significance of changes in foraging duration in Adélies.

Fish- and Squid-based Interactions

7.32 The Working Group noted the work on the correlation of *Champsocephalus gunnari* condition index with krill density from South Georgia and Subarea 48.1 (Appendix D, paragraph 8.27). Further work on this relationship should result in an index of the condition of *C. gunnari* as a krill-dependent species.

7.33 A considerable number of datasets of the by-catch of fish in krill fishing operations has now been acquired by the Secretariat (WG-EMM-98/23). The Working Group looked forward to the detailed analysis of these data to be discussed by WG-FSA.

ECOSYSTEM ASSESSMENT

Precautionary Catch Limits

8.1 The Working Group agreed that the information available to the meeting did not warrant a reassessment of precautionary catch limits for krill (SC-CAMLR-XVI, Annex 4, paragraphs 7.4 to 7.9). However, it noted that continued progress in developing a general model of krill dynamics in Area 48 arising from the Workshop on Area 48 would, in the near future, contribute to an evaluation of a subdivision of the precautionary catch limit in this area.

Assessment of the Status of the Ecosystem

8.2 Prior to assessing the ecosystem, the Working Group recalled the definition of ecosystem assessment in its report from 1995 (SC-CAMLR-XIV, Annex 4, paragraphs 2.12 to 2.21). Also, the Working Group acknowledged the considerable progress made in synthesising indices at the Workshop on Area 48 which are in line with the recommendations of the Subgroup on Statistics last year for making assessments of the status of the ecosystem (paragraphs 7.1 to 7.8; SC-CAMLR-XVI, Annex 4, Appendix D). As these methods are not yet in a form suitable for undertaking assessments, the Working Group summarised the temporal trajectories in krill catch, environmental variables (sea-ice extent and SST) and populations of krill and dependent species (population size (Method A3) and reproductive output (Method A6)) monitored at or, in the case of krill, near to CEMP study sites up to the present. These were used to undertake the following assessment which aimed to identify ecologically important values (EIVs) and/or trends in the data (see SC-CAMLR-XVI, Annex 4, paragraph 7.11). Other sources of information were used to explain observed EIVs and/or trends where appropriate.

8.3 A method of presentation was developed that provided the summaries of these data in a format similar to that developed at last year's meeting (SC-CAMLR-XVI, Annex 4, paragraphs 7.29 and 7.30; SC-CAMLR-XVI, Annex 4, Appendix D) and, at the same time, one that will be useful in displaying the results of the multivariate indices (e.g. CSI) in future years. This revised tabular format displays each of the parameters noted above for each area or subarea. Each parameter is represented as a graph showing standardised normal deviates such that wide deviations from the long-term mean can be easily discerned. Some parameters show a running five-year average alongside the graph to indicate general trends in the dataset. Also included is the coefficient of variation (CV), which scales the deviates. Percentage change in an index from time 1 to time 2 can be calculated using the following formula:

$$\delta\% = \frac{(x_2 - x_1).\mathrm{CV}}{1 + x_1.\mathrm{CV}}.100$$

where $\delta\%$ is the percentage change, x_1 and x_2 are the standardised normal deviates from time 1 and time 2 respectively. A negative $\delta\%$ indicates a decline, while a positive indicates an increase, expressed as a percentage of the index value at time 1.

8.4 Currently, data from fisheries are reviewed as trends in total catches from each subarea or area. Such data provide a useful guide as to what catches are likely in future years. However, this data does not reflect directly the availability of krill to the fishery because it does not account for economic constraints on the fishery. As a consequence, the current analyses do not allow a comparison of the performance of the fishery with environmental, prey or other parameters. As a result, an examination of the interaction between the fishery and other parameters could not be undertaken. The Working Group agreed that, in future, fishery-dependent indices related to krill availability, such as CPUE, should be incorporated into the assessments.

8.5 The Working Group noted that results from Marion Island for abundances of macaroni and gentoo penguins in the CEMP database are not representative of the patterns observed in the literature for the population as a whole (paragraphs 8.13 and 8.14). This drew attention to the general use of Method A3. The Working Group agreed that the current description of the method was ambiguous such that data arising from this method may not provide a good indicator of trends in the overall population of a dependent species at the scale at which comparisons can be made with other parameters such as sea-ice extent, SST, krill catch and krill population parameters. To this end, the Working Group identified a number of questions to be addressed intersessionally to help with future assessments of ecologically important events or trends in each dependent species:

(i) What size of area within a statistical area or subarea or within an Integrated Study Region (ISR) is considered to be sufficient for comparing trends in abundance of the resident species with trends in environmental or prey parameters?

(ii) In what manner can subsampling in space and time be undertaken to give reliable estimates of the overall abundance and trends in abundance of the resident species?

(iii) How representative are the existing datasets of the overall abundance of the resident species and how may we judge this from available data? What errors might be involved in scaling up small-scale results to the larger-scale area?

(iv) What terminology can be used in an unambiguous way to reflect the spatial and temporal scales of sampling desired in the standard methods?

8.6 The Working Group agreed that the Secretariat be asked to contact the researchers submitting data for input to the CEMP database to examine these questions for input to the next meeting. Despite the need to clarify these issues, the Working Group agreed that common trends or events between dependent species provide sufficient grounds for making an assessment this year.

Subarea 48.1

8.7 Table 1 provides a summary for Subarea 48.1. Declines in dependent species were generally correlated with krill density. Such a relationship is not easily interpreted at this stage because CSIs based on predator performance showed little correlation with krill density found by the Workshop on Area 48 (Appendix D). However, the Working Group recognised the need for more work on clarifying how to use and interpret CSIs (paragraphs 7.1 to 7.8).

8.8 The Working Group noted that Adélie breeding success did not show similar trends to the decline in abundance of Adélie penguins. This implies that the reduction in population size may be due to increases in post-fledging mortality rather than decreases in reproductive success.

Subarea 48.2

8.9 Table 2 provides a summary for Subarea 48.2. Gentoo penguins gradually increased in abundance between 1990/91 and 1996/97. Chinstrap penguins underwent a 28% decrease from a relatively stable larger population (over three years) to a relatively stable smaller population (over three years) between the years 1993/94 and 1994/95. As with Subarea 48.1, breeding success in penguins was unrelated to trends in the population.

Subarea 48.3

8.10 Table 3 provides a summary for Subarea 48.3. Macaroni penguins and black-browed albatrosses show consistent declines over the last decade. The Working Group noted that the decline in albatrosses is likely to result from incidental mortality in longline fishing. However, the reasons for the decline in macaroni penguins are not clear. As with Subarea 48.1, breeding success in penguins was unrelated to trends in the population. However, breeding success was extremely poor in this species in 1983/84, which has been identified as a very poor krill year (Appendix D).

8.11 The 83% increase in gentoo penguins in 1988/89 followed by a reduction to the previous level in 1990/91 is difficult to explain. One hypothesis is that the high density of krill observed to be present in the area in 1987/88 (WG-EMM-98/32) resulted in gentoo penguins immigrating to the monitored areas followed by them emigrating two years later.

Area 58

8.12 Adélie penguins have been increasing in recent years at Béchervaise Island and Syowa Station (Table 4).

8.13 The Working Group was informed by Dr D. Miller (Chairman, Scientific Committee) of trends in penguin abundances at Marion Island, which have been published in Adams and Wilson (1987). Although populations of macaroni and gentoo penguins have shown long-term stability, the breeding population of gentoo penguins has decreased steadily over the last three years. Macaroni penguins had poor breeding success in 1994/95. Gentoo penguins had poor breeding success in 1994/95 and especially in 1997/98; the seasons in which breeding commenced early and late respectively.

8.14 The Working Group noted that these gross population estimates for penguins at Marion Island contained in the literature differed from those contained in the CEMP database. This was attributed to the data in the CEMP database coming from a single small colony. In the case of gentoo penguins on Marion Island, the CEMP data did not reflect a steady decline in the number of breeding pairs over the past three years (compared with the population trends reported above). The Working Group also noted discrepancies in breeding success for gentoos with only one poor year (1997/98) being reflected in the CEMP database compared with two (1994/95 and 1997/98) in data available to its meeting (paragraph 8.13).

8.15 The Working Group agreed that the Secretariat should seek clarity from Dr R. Crawford (South Africa), responsible for the submission of CEMP data from the Prince Edward Islands.

Area 88

8.16 The population of Adélie penguins at Ross Island has been observed to undergo cyclical fluctuations in abundance. Dr Wilson reported to the Working Group that a recent and, as yet, unpublished study, has found that the magnitude and frequency of the cycle is most likely explained by changes in mortality of adults/sub-adults and not changes in breeding success.

Development of Assessment Methods

8.17 Considerable progress has been made in recent years on developing assessment methods. The Working Group highlighted a number of areas of research required to further this work in developing a framework for evaluation of ecosystem status (part 1 of an ecosystem assessment described by the Working Group in SC-CAMLR-XIV, Annex 4, paragraphs 2.13 and 2.21). In particular, the Working Group requested further work to be undertaken on:

(i) methods for selecting parameters to derive indices for use in assessments, including identifying parameters that:

  (a) integrate over the temporal and spatial scales for which comparisons need to be made;

  (b) have a clear relationship to measured parameters of the prey or environment;

  (c) are robust to violations of underlying assumptions;

(ii) how indices, such as CSIs, can be interpreted in relation to the demography and abundance of the indexed species; and

(iii) defining EIVs and the methods for identifying when trends in the data are ecologically significant.

8.18 In regard to developing management advice (part 2 of an ecosystem assessment described by the Working Group in SC-CAMLR-XIV, Annex 4, paragraph 2.13), the following work should be undertaken:

(i) developing models to help predict what might happen in the future given current trends, e.g. the recent development of a conceptual model for predicting recruitment in Subarea 48.1 (paragraph 7.20); and

(ii) methods to assist with providing quantitative advice on the implications to the ecosystem of alternative management actions.

8.19 The Working Group noted that work is being undertaken elsewhere to develop methods for assessing the status of ecosystems relative to historical levels, notably the mass balance methods using Ecopath and Ecosim simulation software (Christensen and Pauly, 1992). It considered that an evaluation of these methods as to their applicability to the work of WG-EMM would be desirable.

Consideration of Possible Management Measures

8.20 The Working Group noted that the long time series of data now available from the CEMP and other monitoring programs provide a unique and valuable dataset for undertaking ecosystem assessments. It also noted that the graphical presentation of the temporal sequence of indices facilitated greatly the review and assessment of the status of the ecosystem. However, the causes of the trends and events discussed in paragraphs 8.7 to 8.16 above could not be explained at this stage.

8.21 No new management measures were proposed.

METHODS AND PROGRAMS INVOLVING STUDIES ON HARVESTED AND DEPENDENT SPECIES AND THE ENVIRONMENT

Methods for Estimating Distribution, Standing Stock, Recruitment and Production of Harvested Species

9.1 WG-EMM-98/19, 98/20 and 98/21 noted the difficulties associated with scaling measurements of volume backscattering strength to densities of krill. In general practice this is accomplished by using the mean target strength (TS), or the distribution of TS, for ensonified animals. The distribution of TS may be obtained from *in situ* measurements or from a theoretical model relating TS to a suite of morphometric, physiological and behavioural parameters. For krill, SC-CAMLR-X (1991) recommended the use of a simple linear relationship between body length and TS which represented a reasonable fit to several datasets available in the literature at that time. The working papers (WG-EMM-98/19, 98/20 and 98/21) made the following points:

(i) length-frequency distributions obtained from trawl samples and those inferred from *in situ* TS measurements differed significantly; for the comparisons reported, mean length from trawls was 20 to 25% greater than that inferred from *in situ* measurements in 11 out of 13 cases resulting in as much as a 200% difference in numerical density when scaling volume backscattering strength to numerical density;

(ii) length-frequency distributions derived from a simple sum over a series of trawl samples compared with those derived after weighting each trawl by its catch and also those weighted by both catch and catchability were different resulting in as much as a 48% difference in numerical density; and

(iii) scaling volume backscattering strength to biomass density, rather than numerical density, substantially reduces these discrepancies and that TS per kilogram of krill is reasonably stable over a wide range of body lengths.

9.2 The Working Group noted that the third point had been acknowledged by several investigators and was one of the reasons why the results of acoustic surveys for krill are often reported in units of biomass density rather than numerical density. Furthermore, the conclusion is a consequence of using the simple model of krill target strength adopted by SC-CAMLR-X (1991) and may be less valid if a more complex model were to be used.

9.3 WG-EMM-98/24 summarised decisions and recommendations by the Scientific Committee and its working groups with regard to krill surveys over the last several years. The Working Group appreciated the collection of such material in one place and recognised its potential utility when preparing plans for the near-synoptic survey of krill in Area 48.

9.4 WG-EMM-98/47 contained a detailed specification for the collection of acoustic data in support of the near-synoptic survey of krill in Area 48, including transceivers, transducers, data logging and viewing software, calibration procedures, instrument settings, and operational protocols. The Working Group noted that such a specification, if acceptable to all participants, would ensure that data would be collected in a comprehensive and uniform manner across all ships involved in the survey. It was agreed that adopting a specification at the level of detail proposed in the paper would greatly facilitate analysis of the data and increase the probability of a successful survey.

9.5 Information contained in WG-EMM-98/14, 98/29 and 98/35 stimulated the suggestion that remote sensing of SST and/or phytoplankton pigments may be useful for locating concentrations of krill. The Working Group noted the existence of several studies that may be relevant in pursuing this idea, but cautioned that the relationship between sea-surface signatures of water temperature and/or phytoplankton biomass and krill may be complex and therefore difficult to interpret.

9.6 In response to the comments made in paragraphs 4.25 to 4.27 regarding the index of proportional recruitment for krill (R1), Dr Hewitt proposed an index of PCR:

$$PCR_{y-1} = \frac{R1_y}{(1 - R1_y)e^{M_{y-1}}}$$

where M is the post-recruit mortality rate and y is an index of year.

9.7 Use of such a formulation to index krill reproductive success, which includes reproductive output as well as survival through the egg and larval phases, is based on two assumptions that:

(i) a representative sample of the population is available in the form of a length density distribution and that the proportion of one-year-old animals (R1) can be unambiguously determined; and

(ii) post-recruit mortality (M) is constant over all age classes.

9.8 This formulation can be extended over a series of years by assuming that the variability of M over those years is negligible compared to the variability of reproductive output and pre-recruit mortality.

9.9 It is not necessary to assume that the same proportion of the population is sampled each year, only that the sample is representative of the total population.

9.10 Such a formulation has the following advantages:

(i) proportional indices, such as R1, demonstrate statistical problems associated with their being constrained between zero and one; the possible range of PCR values extends from zero to infinity.

(ii) it has a logical definition (that is, the ratio of one-year-olds to the rest of the recruited population with one year of mortality removed); and

(iii) it is a simple transformation of the existing R1 index.

9.11 It was suggested that the statistical properties of the PCR index and its robustness to relaxation of the assumptions and sampling requirements be investigated during the intersessional period.

9.12 The intended use for a series of PCR values is to provide a measure of krill PCR that could be compared against factors postulated to affect reproductive output and survival through pre-recruit stages (e.g. sea-ice extent, salp density, seasonal timing of spawning).

Consideration of CEMP Sites

9.13 The Working Group noted that no new CEMP sites were proposed for consideration by the Working Group. It was also noted that no Protected Area Management plans had been forwarded by SCAR for consideration by the Working Group.

9.14 At the 1997 meeting of WG-EMM, a paper entitled 'The Application of CCAMLR Ecosystem Monitoring Program (CEMP) Standard Methods in the Antarctic Site Inventory Project' (WG-EMM-97/38) was considered. It was noted that the results of the study might be of interest to CCAMLR.

9.15 The Scientific Committee had invited the author, Mr R. Naveen (USA), to provide a list of its sites and to submit a paper to CCAMLR with results of studies when about five years of consecutive data are available from most sites (SC-CAMLR-XVI, paragraph 4.13).

9.16 In response, Mr Naveen submitted three recent publications to the Secretariat. The paper containing the list of sites in the Antarctic Site Inventory Project (WG-EMM-98/9) was distributed to the Working Group. In response, the Working Group thanked Mr Naveen for this information and looked forward to seeing the results of the study in the future.

Methods for Monitoring the Performance of Dependent Species

9.17 The Working Group noted that the completed revised *CEMP Standard Methods* had been circulated in September 1997.

Existing Methods

A3 – Breeding Population Size

9.18 The Working Group recalled uncertainties (see paragraph 8.5) associated with the results from the use of Method A3, and that the instructions for the use of this method are potentially confusing (particularly subparagraph 1). The Working Group recommended that the Subgroup on Methods should address these issues and revise Method A3 intersessionally.

A5 – Duration of Foraging Trips

9.19 The concerns raised last year regarding this method have been addressed by Australian scientists who have offered to conduct analyses on their extensive data and produce a discussion paper for WG-EMM in 1999. The Working Group welcomed this offer.

9.20 Last year Dr F. Mehlum (Norway) outlined the problem Norwegian scientists experienced on Bouvet Island with data using Method A5 for macaroni penguins. The method of only using males in the study reduces the chance of acquiring data since males stay at the nest for 10 days or more before they commence foraging trips after chicks hatch. Following last year's request, Norway submitted a paper (WG-EMM-98/28) which quantifies the differences between male and female foraging trips and suggests that female not male penguins, may be better for gathering data on foraging, and questioned why the standard method recommends using data only from males.

9.21 The Working Group agreed this issue should be addressed intersessionally by the Subgroup on Methods and in particular in relation to information on macaroni penguins at South Georgia. Mr T. Ichii (Japan) also noted that the recent paper by Jansen et al. (1998) on foraging modes of chinstrap penguins, which contrast daytime and overnight foraging trips, should be considered when reviewing Method A5.

A6 – Penguin Breeding Success

9.22 WG-EMM-98/10 proposed changes to the assessment technique described in Method A6. The Working Group recommended that this paper be referred intersessionally to the Subgroup on Methods for consideration.

9.23 It was noted that Method A6 specifies use of the same colonies as Method A3, although whether the concerns about A3 (paragraph 9.18) will affect the application of results from Method A6 is unknown. The Working Group requested that the Subgroup on Methods look at Method A6 when considering the problems with A3.

B3 – Black-browed Albatross Demography

9.24 The Working Group noted that Dr J. Croxall (UK) had, in July 1998, submitted the demographic data from Bird Island, for the period 1976 to 1998 (WG-EMM-98/23).

New Methods

A3B – Breeding Population Size

9.25 Dr Wilson introduced WG-EMM-98/46, a revised version of a draft standard method, for using aerial photography as an alternative method to ground counts for nests in entire colonies. The Working Group suggested that the rationale for recommending an altitude of 2 500 feet above ground level for helicopter flights be included in the method. This altitude is the minimum to avoid disturbance to the incubating adults. Additionally, reference to the footprint of the photo size should be deleted, since all photos taken by a hand-held camera are high-angle obliques, and for the purposes of counting incubating adult penguins, it is not necessary to have a measure of scale or area covered by the photograph so long as full coverage is achieved.

9.26 With these changes, the Working Group recommended adoption of this method for Adélie penguins and noted it may be applicable to, and could be tested on, other species.

B4 – Petrel Diet

9.27 The Working Group noted that the diet data for Cape petrels at Bouvet Island and Antarctic petrels at Svarthamaren requested last year from Dr S.-H. Lorentsen (Norway) (SC-CAMLR-XVI, Annex 4, paragraph 8.58) have not yet been received (WG-EMM-98/23).

B5 – Antarctic Petrel Population Size, Breeding Success

9.28 The Working Group noted that the data requested last year from Norway (for the period 1992–1998) have now been submitted. Intersessional requests for similar data to Dutch and US scientists (e.g. Drs J. van Franeker and P. Hodum) working with Australia, has not yet resulted in receipt of the data (WG-EMM-98/23).

C3 – Antarctic Fur Seal Adult Female Survival Rate and Pregnancy Rate, C4 – Antarctic Fur Seal Diet

9.29 The Working Group noted that the revision of these two methods discussed last year (SC-CAMLR-XVI, Annex 4, paragraphs 8.65, 8.66 and 8.67) has been deferred and also noted that the new method for tagging seals (SC-CAMLR-XVI, Annex 4, paragraph 8.85) to be prepared by Dr Boyd has also been deferred in both cases until WG-EMM in 1999 (WG-EMM-98/23).

New Method for Non Krill-dependent Species

9.30 A new method for non krill-dependent species, which proposes monitoring changes in coastal fish populations by the analysis of pellets of the Antarctic shag (WG-EMM-98/11) was considered by the Working Group. It was agreed that the method be approved for a five-year trial period initially. Formatting and minor alterations need to be addressed, and the originators should liaise with Dr Sabourenkov to this end. When finalised the new method will be published and circulated to all Members.

Otolith Size and Mass as Predictors of Fish Length and Mass

9.31 WG-EMM-98/43 describes measurements of otolith chord and mass from the mackerel icefish. Both chord length and mass were good predictors of fish length but mass was slightly superior. The same measures did not predict fish total mass as well because fish condition and hence mass varies with season and other environmental variables.

9.32 The Working Group acknowledged this paper improved the accuracy of assessing size and age of fish consumed by predators.

9.33 Mr Ichii, however, was concerned that the erosion of the otoliths in the gut of Antarctic fur seals would reduce the viability of the technique. The Working Group suggested overcoming that problem would be a task for dependent species researchers.

Seabirds At-sea Methodology

9.34 WG-EMM-98/22 briefly describes the methods that have been used in seabird at-sea studies in the Southern Ocean with a view to recommending methods for future studies in the region, particularly quantifying data on seabird densities. The synoptic survey of Area 48, for example, will require standardised at-sea bird methods.

9.35 The Working Group recommended that Dr Sabourenkov contact scientists with experience in recording at-sea bird behaviour for guidance on how best to formulate a new standard method for at-sea bird studies.

Crabeater Seal Monitoring

9.36 The Working Group expressed thanks to SCAR-GSS, for the report of the 1996 APIS Survey Meeting (WG-EMM-98/26) and the report on the meeting of SCAR-GSS (WG-EMM-98/27), following WG-EMM's request for this information last year.

9.37 Specifically, CCAMLR is interested in formulating a viable technique for monitoring crabeater seal abundance within CEMP. However, as WG-EMM-98/27 points out, it is unlikely the APIS program will produce a standard method for routine monitoring of crabeater seals before the APIS program is finished in the year 2000.

9.38 The Working Group expressed its continuing interest in the development of a suitable technique to be completed as soon as possible.

CEMP Indices for Environmental Variables

9.39 As part of the CCAMLR Ecosystem Monitoring Program, the Secretariat currently produces four environmental indices (F2a–c and F5) which are considered to be relevant to the assessment of dependent species indices (A1–8, B1a–b, C1–2). The dependent species indices are mainly site related and the current environmental indices reflect that situation. The existing indices are (SC-CAMLR-XVI, Annex 4, paragraph 8.92):

- F2a Sea-ice percentage cover in a subarea in September;
- F2b Sea-ice retreat past a CEMP site: number of ice-free days;
- F2c Sea-ice distance to a CEMP site: weeks sea-ice is within 100 km of site; and
- F5 Summer SST adjacent to a CEMP site.

9.40 Further standard methodologies have been drafted. These indices are also site related:

- F1 Sea-ice cover viewed from a CEMP site;
- F3 Local weather at a CEMP site; and
- F4 Snow cover at a CEMP site.

9.41 In 1997, the Working Group reviewed each of the environmental indices. It noted that some Members already collect information to describe the amount of sea-ice cover in the vicinity of predator colonies (Index F1) and some Members prepare their own indices using remotely-sensed sea-ice data (Index F2). Therefore, Dr Ramm was asked to review the methodologies used by Members prior to developing or updating draft method descriptions (SC-CAMLR-XVI, Annex 4, paragraphs 8.95 and 8.96). In addition, Dr Ramm was asked to review the availability of meteorological data from CEMP sites and from research stations so that consideration of appropriate weather indices (Index F3) may be developed (SC-CAMLR-XVI, Annex 4, paragraph 8.97).

9.42 Before an index to describe the local snow cover at a CEMP site (Index F4) could be developed, the Working Group felt it would be useful for Dr Ramm to determine if snow cover records were collected at CEMP sites and to review methodologies used by Members (SC-CAMLR-XVI, Annex 4, paragraph 8.98).

9.43 Finally, the Working Group also requested the Secretariat to document the methodology used to describe the SST adjacent to a CEMP site (Index F5) and produce a method description (SC-CAMLR-XVI, Annex 4, paragraph 8.99).

9.44 WG-EMM-98/6 presents a revised draft of Index F2. It notes that sea-ice concentration is derived from satellite data (US National Snow and Ice Data Center) and provides a consistent time series of daily sea-ice concentrations. However, there is a lead time of about six months before the digital images are available.

9.45 A revised draft of Index F5 was also presented in WG-EMM-98/6. It noted that SST data are available from the US Environmental Modeling Center which analyses *in situ* and satellite data and produces weekly and monthly SST datasets. These data are freely available with no restrictions on use. The Secretariat downloads these data and has developed software to extract monthly mean SST data for 1° x 1° grids adjacent CEMP sites and calculate Index F5.

9.46 Participants reviewed the drafts of Indices F2 and F5 (WG-EMM-98/6) and accepted the revised methods.

9.47 To determine information used to calculate Indices F1, F3 and F4, the Secretariat sent a circular to Members of the Scientific Committee and WG-EMM. In addition, information on data and shore-based protocols for recording weather was sought from the US Long Term Ecological Research (LTER) and the Australian Antarctic Division.

9.48 Responses to the circular (WG-EMM-95/6) were only received from South Africa, Russia and New Zealand. Responses were also received from the LTER and the Australian Antarctic Division. The Working Group welcomed these responses and requested others to provide similar information so that the Secretariat could provide draft methods at the next meeting.

Plans for a Synoptic Krill Survey in Area 48

9.49 At previous meetings of the Working Group and the Scientific Committee a number of documents and recommendations specifically directed at planning for a synoptic survey in Area 48 had been produced. All of these discussions and recommendations were summarised in WG-EMM-98/24.

9.50 In addition, members of the synoptic survey steering committee and task groups who were present at the Workshop on Area 48 (La Jolla, USA, June 1998) met briefly to discuss progress of plans for the survey. A report of these deliberations and tasks carried out immediately following that meeting is presented in WG-EMM-98/25.

9.51 The primary objective of the synoptic survey is to improve estimates of B_0 (pre-exploitation biomass) used in the krill yield model to estimate sustainable yield for Area 48 (SC-CAMLR-XII, paragraphs 2.39 and 2.41 to 2.47).

9.52 The Working Group considered the implications of interpreting the results from a single large-scale synoptic survey for estimating a long-term annual yield. The Working Group agreed that the krill yield model was robust with respect to interannual variability in krill biomass and will be able to use the B_0 estimate directly in its calculations.

9.53 The Working Group noted that the smaller-scale regional surveys could be used to monitor for long-term trends in krill biomass. However, the relationship between these surveys and the biomass throughout Area 48 needs to be determined. In this respect it would be advantageous to ensure that the regular regional surveys (such as the US AMLR survey (USA) and the BAS Core Program (UK)) could be linked to the large-scale synoptic survey in time and space so that the temporal variations observed in the regional surveys may be interpreted in respect of the larger area.

Survey Design

9.54 A number of documents specifically addressing the subject of survey design have been submitted to WG-Krill and WG-EMM over a number of years (summarised in WG-EMM-98/24) and a number of general survey designs had been proposed.

9.55 At the Workshop on Area 48, survey design was discussed in general terms and it was agreed that a randomised design coupled to a design-based analysis would produce the most statistically defensible result (WG-EMM-98/25, Appendix 1; see also conclusions from WG-Krill-94/20 which is presented as Appendix 10 in WG-EMM-98/24).

9.56 The Working Group considered the set of four draft survey plans (WG-EMM-98/44 and 98/53) which were drawn up at the request of the Area 48 synoptic survey planning meeting. All plans considered alternative ways of interleaving the tracklines of three ships that each had 30 days of time available to carry out the entire survey (including associated logistic costs).

(i) Plan 1 comprised a stratified random design with four strata. Three separate strata were placed around the South Shetland Islands, South Orkney Islands and South Georgia. The fourth strata covered the remaining oceanic regions of Area 48.

(ii) Plan 2 was an adaptive survey design utilising the same large-scale grid as plan 1 but directing additional survey effort into a series of survey cells (2° latitude x 2° longitude) that were shown to have above-average levels of biomass from the first pass through the area.

(iii) Plan 3 comprised a random transect design where all the effort for the three ships was put into conducting a series of large-scale transects across the area.

(iv) Plan 4 was an adaptive survey design where a series of small-scale surveys were carried out each time a ship passed through an area where there was a high biomass of krill.

9.57 The Working Group first considered the relative merits of an adaptive survey design against a pre-planned survey design (plans 2 and 4 versus plans 1 and 3). It was agreed that an adaptive survey design could offer increased understanding of the structure of the system, through a more detailed description of the distribution of krill within high density areas. However, the Working Group felt that the advantages of an adaptive approach, particularly as outlined in plan 4, in terms of improving the CV of the biomass estimate were less obvious. Indeed such techniques appeared to introduce increased complexity in terms of the design, execution and subsequent analysis of the survey.

9.58 The Working Group agreed that a model simulation of the relative merits of the adaptive and pre-planned surveys would be required to quantify the advantages of the two approaches. However, considerable concern was expressed both over the time-scale of such a simulation and the conclusiveness of the outcome.

9.59 The Working Group was also in agreement that a decision on the overall survey design had to be taken at this meeting. The Working Group agreed therefore that, given the concerns expressed above, the more conservative approach of utilising a pre-planned survey should be the preferred approach. This approach had been widely used in the past (for instance FIBEX) and was statistically robust and defensible.

9.60 The Working Group then considered the relative merits of a stratified versus unstratified design (plan 1 versus plan 3). It was pointed out that if krill were distributed in similar quantities both in the open ocean and in the shelf areas then a design which gives a uniform density of sampling across the whole area should be used (plan 3). However, if krill are concentrated in particular predictable areas, then a stratified sample design which takes account of this is likely to produce a lower overall CV. Note, however, that such a design will not change the expected estimate of mean biomass.

9.61 The Working Group was unable to agree on the relative importance of krill occurring on the shelves around the coast of the Antarctic Peninsula and the islands in Area 48. A variety of datasets and published papers (cf. WG-EMM-98/18 and 98/32) illustrate the complexity of the system.

9.62 The Working Group finally agreed that a modification of plan 3 would be adopted. Such a modification seeks to maximise the coverage provided by a series of large-scale transects carried out across the Scotia Sea by the three ships undertaking the survey. However, in order to reduce the CV of the biomass estimate, within three regions (north coast of South Georgia, north coast of the South Orkneys and offshore from the South Shetlands) there will be an additional transect between each of the large-scale transects (see Figure 2), in effect doubling the transect density in the three regions described above relative to the rest of the survey area. For analytical purposes, this allocation of survey effort would provide data from two distinct strata (one being more densely sampled than the other).

9.63 To supplement the core survey as described above the Working Group also agreed that:

(i) if a fourth or fifth ship was able to contribute time within the period January 2000 then a series of extra transects would be interleaved within the existing large-scale transects;

(ii) the length of the transects would be tuned to the latitudinal boundaries of the krill distribution; and

(iii) participants would be encouraged to carry out their standard regional surveys either prior to or after the main synoptic survey. This was extremely important because it is necessary to link the temporal sequence of regional surveys with the wide spatial coverage of the synoptic survey.

Methods

Acoustics

9.64 The general philosophy for the acoustic methodology and equipment had been discussed previously. All participants were using Simrad EK500 systems and it was therefore possible to ensure a high level of standardisation. A preliminary proposal suggesting standard sampling protocols had been submitted (WG-EMM-98/47). The Working Group agreed with the general philosophy of the paper; that is whenever possible exact equipment, software and settings should be dictated. When exact matches were not possible, pertinent comparative information should be specified.

9.65 These protocols which cover (i) instrument settings, (ii) data logging, (iii) system calibration including multifrequency TS calibrations, intership calibrations and characterisation of system noise, (iv) survey operations and (v) additional recommendations should be agreed by the acousticians of the participating nations.

9.66 Multifrequency acoustics (38, 120, 200 kHz frequencies) would be available on the three ships carrying out the core transects. However, if additional ships were able to contribute to the survey effort (see paragraph 9.63) then such data would be a valuable addition to the dataset even if only 38 and 120 kHz data could be provided.

Net Sampling

9.67 The Working Group agreed that the main priority for the net sampling program was the determination of krill population structure demography. The requirements for estimates of net density and target identification were of secondary importance given that much information on krill identification would come from multifrequency acoustics.

9.68 There was considerable discussion of the sampling strategy used in the draft plans submitted in papers WG-EMM-98/44 and 98/53. In this case, a single night-time period was allocated for both net sampling and oceanographic sampling.

9.69 Given that the priority was to obtain a good coverage of samples for estimating the population structure, the Working Group agreed that a net sample should be taken around midnight and midday on each day of the survey. The timing of the midnight sample was constrained by the period of darkness. However, the timing of the midday sample was more flexible and the Working Group agreed that consideration should be given to allowing the time of this sample to shift as necessary to maintain a more regular pattern of sampling stations.

9.70 The Working Group considered that given the theoretical variation in catchability and selectivity of nets (see WG-EMM-98/20) it was highly desirable to standardise on the type of net used for krill sampling. At present the following nets were available:

Country	Net	Mesh Size (mm)	Mouth Area (m^2)
Japan	KYMT	3.4	9.0
Korea, Republic of	IKMT	0.5	4.5
Russia	IKMT	6.0	6.0
UK	RMT8	4.0	8.0
USA	IKMT	0.5	2.5

9.71 The Working Group felt that the most appropriate net in terms of catchability was the RMT8. However, they recognised also the financial implications of standardising on a single design and size of net.

9.72 Therefore the Working Group made two recommendations to achieve the best possible compromise with regard to net standardisation:

(i) to investigate the possibility of obtaining RMT8 systems from other CCAMLR Members which were not able to contribute ship time to the survey, or from any other sources; and

(ii) if the above was not possible then to allow the use of any of the above nets which had a mouth area of between 8 and 10 m^2 and a mesh size of between 3.0 and 4.0 mm.

9.73 The Working Group agreed that representative samples of krill would be measured on board ship and results would be entered onto computer prior to the end of each cruise. Detailed protocols must be established as soon as possible.

Environmental Sampling

9.74 The Working Group considered that each ship should undertake a CTD to a depth of 1 000 m at each midnight and midday station. A detailed protocol including the use of water-bottle samples for CTD calibration must be produced as soon as possible and the time implications assessed.

Other Sampling

9.75 The Working Group agreed that the acoustic transects, net sampling for population structure and CTD conducted at the midnight and midday stations would form the core of the sampling program and must be undertaken to standard protocols by all ships participating in the survey.

9.76 There were likely to be a number of other variables that participating countries would normally collect (for instance phytoplankton fluorescence, macro-zooplankton species composition, underway data such as obtained by pumped seawater supply or undulator). Such measurements were encouraged by the Working Group. It was emphasised, however, that such measurements must not compromise the collection of the core datasets.

9.77 The Working Group felt that it was appropriate that protocols and arrangements could be discussed between countries intending to collect similar data through the respective cruise leaders.

9.78 Appendix 8 of WG-EMM-98/25 presented a proposal from the IWC to send whale observers to participate on synoptic survey ships. Plans for such participation would be discussed at an IWC workshop at St Andrews, Scotland in March 1999. The Working Group felt that such a proposal was a valuable contribution to the synoptic survey. However, considerable concern was expressed about the number of observers traditionally used on such sighting surveys (six to eight persons per ship).

9.79 Although it was not possible to detail exactly how many spaces would be available on each participating ship it was thought that Japan and Russia would most likely only have room for one observer on each ship, UK was also tightly constrained but might be able to offer two berths while the USA thought it likely that they would be able to accommodate four to six observers.

9.80 The UK felt that independent estimates of whale numbers and incidental bird numbers would make a valuable comparison with the continuous bird and at-sea mammal observations that it conducts on its standard core program cruises and which are likely to be a component part of the synoptic survey.

Data Analysis and Storage

9.81 The Working Group agreed that the core datasets (i.e. acoustic data, krill length-frequency data and CTD data) should be analysed in the first instance within a CCAMLR workshop by all survey participants. Such a workshop should be timed to take place as soon after the cruise as practical and in any event prior to the 2000 meeting of WG-EMM.

9.82 Further the Working Group agreed that the initial dissemination and publication of these core data results should take place as a joint undertaking.

9.83 A copy of all core data and appropriate meta-data must be deposited with the CCAMLR data centre. The Working Group agreed that the appropriate data storage formats would need to be addressed prior to the cruise.

Coordination of Planning after Meeting of WG-EMM-98

9.84 The Working Group agreed that there was an urgent requirement to appoint a survey coordinator who would undertake the following tasks:

(i) serve as a focal point between CCAMLR and cruise participants, and among cruise participants, for all matters relating to the survey planning, conduct and analysis;

(ii) organise a planning workshop. This would include defining all tasks to be accomplished at the workshop, coordinating the preparation of cruise protocols and ensuring such cruise methodologies are uniformly applied;

(iii) coordinate cruise plans and preparations amongst participants prior to the beginning of the survey. This would include coordinating the participation and interchange of key experts;

(iv) serve as the at-sea coordinator;

(v) ensure that data are supplied to CCAMLR and participants;

(vi) organise data analysis workshop for survey participants; and

(vii) coordinate report generation.

9.85 The Working Group agreed that the planning workshop should take place in mid- to late March 1999.

9.86 The Working Group also agreed that each participating country should provide a summary of any additional activities relevant to the synoptic survey that they would be undertaking during the 1999/2000 season.

9.87 Such summaries, all protocols and preliminary cruise plans must be completed and circulated to participants one month prior to this planning meeting.

9.88 The Working Group asked Dr Watkins to act as coordinator. In addition Drs Hewitt, M. Naganobu (Japan) and Watkins were appointed principal contacts for participating nations.

9.89 Any other countries wishing to participate should give a firm commitment prior to the planning meeting and supply the coordinator with a principal point of contact as soon as possible, but in any event no later than 15 March 1999.

9.90 Finally, the Working Group agreed that to facilitate planning it was important to nominate a definite start date as soon as possible. As a matter of priority all participants should confirm their ability to arrive at South Georgia in the first week of January 2000 to start the first calibration.

OTHER ACTIVITIES IN SUPPORT OF ECOSYSTEM MONITORING AND MANAGEMENT

9.91 Attention of the Working Group was drawn to a number of international meetings which were of relevance to WG-EMM.

9.92 Dr Kim advised of research activities which will be carried out by the Southern Ocean GLOBEC (SO-GLOBEC) program from 1999 onwards. The SO-GLOBEC activities will focus on winter processes in Antarctic waters, which include:

(i) over-wintering strategy of krill;
(ii) predator–prey interactions; and
(iii) interactions between the biological populations and their environment, especially sea-ice.

9.93 The SO-GLOBEC Steering Committee has drafted a Science Plan for this program which is in the process of being finalised. It is anticipated that this plan will be available for consideration at the forthcoming meeting of the Scientific Committee or soon thereafter.

9.94 SO-GLOBEC will focus on two primary field sites: Antarctic Peninsula area and 70°E region. In the Peninsula area, several research vessels from Germany, UK and USA will conduct research during the 2000/01 season. The 70°E program will provide seasonal coverage starting from the 1999/2000 season.

9.95 SO-GLOBEC looks for cooperation with IWC and CCAMLR, especially because a number of CCAMLR Members have conducted regular surveys in the Peninsula area during summer and CCAMLR plans to conduct the multinational synoptic survey in Area 48 in summer 1999/2000. The cooperation could, therefore, be beneficial for both organisations.

9.96 It was noted that Dr Kim, as a liaison officer between SO-GLOBEC and the CCAMLR Scientific Committee, should liaise with the coordinator of the Area 48 survey and convey details of the CCAMLR survey plan to the current Chair of the SO-GLOBEC Steering Committee (Dr E. Hofmann (USA)) (paragraph 9.92(i)).

9.97 Another meeting of interest to the Working Group will be convened in Kochi, India from 25 to 27 November 1998. Its subject is 'Large Marine Ecosystems: Exploration and Exploitation for Sustainable Development and Conservation of Fish Stocks'. The Working Group noted that the subject matter of the symposium is of relevance to the ecosystem monitoring and management and that it would be looking forward to the publication of the proceedings of the symposium.

9.98 The Convener also informed the meeting that an international workshop on interannual variability in the Southern Ocean would be held in August 1999 at the British Antarctic Survey, Cambridge, UK. Topics to be discussed at the workshop are of relevance to CCAMLR.

9.99 The Working Group noted that the subject matter of the workshop is of interest to the Working Group. At the same time it was noted that the timing of the workshop coincides with the timing of the Symposium on Krill Biology sponsored by CCAMLR. The workshop organisers pointed out that, to some extent, it would be a follow-up to CCAMLR's Workshop on Area 48. The Chairman of the Scientific Committee advised that the Committee would consider at its forthcoming meeting the CCAMLR representation at the workshop.

9.100 A Symposium of ICES/SCOR on 'Ecosystems Effects of Fishing' will be held in Montpellier, France, from 16 to 19 March 1999. The subject matter of the symposium was considered to be highly relevant to the CCAMLR objectives on ecosystem monitoring and management. Dr Constable had been invited by the organising committee to coordinate the development of a keynote paper, in conjunction with colleagues from the Scientific Committee.

It was recommended that past and current conveners involved in the development of the ecosystem approach and still involved in CCAMLR, together with the Chairman of the Scientific Committee and the former and current Data Managers, Drs Agnew and Ramm, would assist with this task.

International Coordination Plans

9.101 Dr Kim reported that the Subgroup on International Coordination plans to conduct its third activity in the Peninsula area during summer 1999/2000. Data collection activities will include acoustic surveys, net sampling and oceanographic studies. Activities will be conducted by Japan, the Republic of Korea and USA around the South Shetland Islands from December 1999 to February 2000. Efforts will be made to use the same methodologies as used by participants in the synoptic survey. It is expected these results will complement the synoptic survey objectives and activities included under SO-GLOBEC.

THE ECOSYSTEM APPROACH AS APPLIED IN OTHER PARTS OF THE WORLD

10.1 This agenda item was included with the intention to consider information outside CCAMLR on the subject of ecosystem monitoring and management. Such considerations would concentrate on the following issues:

(i) collection of information on new scientific approaches and practical aspects of ecosystem monitoring and management in other parts of the world which might be incorporated into CCAMLR's management plan; and

(ii) promotion of CCAMLR as a leading international organisation in the development and implementation of an ecosystem approach to fisheries management.

10.2 Dr Miller advised the Working Group of the Southern African BENEFIT Program which focuses on the Benguela Current ecosystem. The BENEFIT Science Plan will be provided to the Secretariat in the near future.

ADVICE TO THE SCIENTIFIC COMMITTEE

Management Advice

11.1 Precautionary catch limits for krill were not re-assessed. Continued progress in developing a general model of krill dynamics in Area 48 is being made (paragraph 8.1).

11.2 No new management measures were proposed (paragraph 8.21).

11.3 No proposals for new CEMP sites and for the protection of CEMP sites had been received by WG-EMM (paragraph 9.13).

11.4 Methods for preparing advice on ecosystem assessment are being developed. No specific management advice on the status of the ecosystem was provided. Analyses of the status of the ecosystem undertaken at the meeting are set out in paragraphs 8.1 to 8.21.

General Advice with Budgetary/Organisational Implications

11.5 The attention of the Scientific Committee is drawn to the following Working Group recommendations and tasks which have budgetary implications:

(i) the report of the Workshop on Area 48 should be appended in full to the report of WG-EMM (paragraph 3.6);

(ii) a number of new and revised standard methods should be published in the *CEMP Standard Methods* (paragraphs 9.26, 9.30 and 9.46); and

(iii) a workshop to analyse the core datasets resulting from the synoptic krill survey in Area 48 should be convened prior to WG-EMM in 2000 (paragraph 9.81).

Future Work for WG-EMM

11.6 The Working Group has identified a number of tasks to be undertaken intersessionally by participants and the Secretariat. These tasks are summarised in the following section of the report under 'Future Work' (paragraphs 12.1 to 12.7).

Recommendations from WG-EMM to the Scientific Committee for Coordination between Groups

11.7 The Working Group found the reports on the status of birds and seals prepared by SCAR to be useful. However, since some of the data are now quite old, the Working Group recommended that the Scientific Committee consider the potential utility of data from SCAR on bird and seal population status and trends provided to CCAMLR at five-year intervals (paragraph 5.5).

11.8 The Working Group also recommended that:

(i) a theme coordinator should be nominated for the 1999 meeting of WG-EMM (paragraphs 13.5 and 13.6); and

(ii) application of a standard approach should be considered for placing on the CCAMLR website summary information on Members' activities in relation to WG-EMM and WG-FSA (paragraph 5.10).

FUTURE WORK

12.1 The Working Group identified a number of tasks to be carried out by WG-EMM participants and the Secretariat during the 1998/99 intersessional period. The tasks are summarised below. References are given to paragraphs in the report which contain these tasks.

12.2 The following tasks were identified in the work on **harvested and dependent species and the environment:**

Secretariat tasks:

(i) Request submission of data for krill fisheries conducted in waters adjacent to the Convention Area (paragraph 2.3).

(ii) Encourage submission of haul-by-haul data where possible (paragraph 2.4).

(iii) Request information from Panama and China in order to determine their intentions to fish for krill in the Convention Area (paragraph 2.6).

(iv) Seek further information from Canada, Ukraine and Uruguay on their krill fishing activities in 1997/98 and 1998/99 (paragraph 2.6).

(v) Reiterate the need for observer data and encourage Members to collect such data on board krill fishing vessels (paragraph 2.13).

(vi) Directly pursue acquisition of historical CEMP data listed in Table 1 of SC-CAMLR-XVII/BG/2 (paragraph 5.10).

(vii) Encourage submission of data described by Ukrainian scientists in WG-EMM-98/12 (paragraph 6.4).

(viii) Encourage presentation of further details of analyses of DPOI index (paragraph 7.19).

Working Group activities:

(ix) Encourage Indian scientists to publish results of its 1995 krill expedition in Area 58 (paragraph 2.12).

(x) Develop krill population models to help reconcile current problems with relating estimates of M and absolute recruitment to observed densities of krill (paragraph 4.38).

12.3 The following tasks were identified in the work on **ecosystem analysis and assessments**:

Secretariat tasks:

(i) Develop the mechanisms for automating the production of ecosystem assessment summaries and for producing CSIs based on the existing database structures (paragraphs 7.1 to 7.4 and 8.6).

(ii) Arrange for details of the validation methods and procedures used for the validation of the General Yield Model (GYM) to be available to CCAMLR scientists for peer review (paragraph 7.10).

(iii) Develop and archive a comprehensive set of documentation for the existing krill yield model (paragraph 7.11).

(iv) Request further details of analyses linking krill density to atmospheric pressure measurements to produce krill ‘forecasts’ – an approach outlined by Ukrainian scientists (paragraph 7.19).

(v) In collaboration with certain Working Group participants, investigate the performance of the Agnew–Phegan and Schroeder indices of krill fishery–foraging overlap in relation to fishing distribution and size (paragraph 7.28).

(vi) Incorporate fishery-dependent indices into the ecosystem assessment (paragraph 8.4).

(vii) Clarify discrepancies in population estimates for penguins at Marion Island contained in the CEMP database and estimates contained in the published literature (paragraphs 8.14 and 8.15).

Working Group activities:

(viii) Work on the identification of subsets of data which are required to investigate the effect of El Niño in the waters of South Georgia (paragraph 6.10).

(ix) Establish the most appropriate statistical approach to the calculation of covariance matrices for the CSI (paragraph 7.2).

(x) Encourage collection of information which might suggest the origin of krill in Area 58 (paragraph 7.22).

(xi) Encourage development of a functional relationship between predators, krill and the fishery (paragraph 7.29).

(xii) Further work on the correlation of *C. gunnari* condition index with krill density in Subareas 48.1 and 48.3 (paragraph 7.32).

(xiii) Address questions on future assessments of ecologically important events or trends in dependent species (paragraphs 8.5 and 8.6).

(xiv) Consider reasons for the decline of macaroni and gentoo penguins, and black-browed albatrosses in Subarea 48.3 (paragraphs 8.10 and 8.11).

(xv) Investigate intersessionally properties of the index of PCR of krill (paragraph 9.11).

12.4 The following tasks were identified in the work on existing and new **standard methods:**

Secretariat tasks:

(i) Consult experts in seabird studies for guidance on the formulation of a new standard method for at-sea bird studies (paragraph 9.35); and

(ii) Request information used to calculate Indices F1, F3 and F4 and prepare draft standard methods for these indices (paragraph 9.48).

Working Group activities:

(iii) Review foraging trip duration in male and female macaroni penguins at Bouvet Island in relation to information from South Georgia (paragraph 5.6).

(iv) The Subgroup on Methods has been asked to address intersessionally the following tasks:

(a) review Methods A3 and A6 (paragraph 9.23);

(b) investigate the applicability of monitoring foraging trips of female macaroni penguins in accordance with Method A5 (paragraph 9.21); and

(c) consider changes proposed to the assessment technique described in Method A6 (paragraph 9.22).

12.5 The planning work for the synoptic survey of krill in Area 48 will be undertaken by the coordinating committee. The tasks for this committee are detailed in paragraphs 9.84 to 9.88.

12.6 The Working Group encouraged the Secretariat to continue its work on the CCAMLR website (paragraphs 13.10 to 13.17).

12.7 In addition to intersessional tasks the Working Group also identified the following general requirements for its current and future work:

(i) standardise methods used to investigate polynya dynamics (paragraph 6.8).

(ii) develop and test predictive models and investigate the effect of environmental parameters on recruitment (paragraph 7.20).

OTHER BUSINESS

13.1 The following subitems were proposed for consideration under this item:

(i) organisation of future Working Group meetings based on a thematic approach, i.e. focusing each meeting on a specific topic;

(ii) review of membership of the WG-EMM intersessional subgroups; and

(iii) CCAMLR website.

Themes for Future Meetings

13.2 A thematic approach to the organisation of future meetings was discussed. It was felt that it would be appropriate if, in addition to standard and key agenda items, such as ecosystem assessments, each meeting of the Working Group could be focused on a specific topic.

13.3 It was decided that each Working Group meeting would identify a specific topic and detail the information required and the organisation of discussions. This advance notification of the topic would allow Members to nominate participants who have appropriate expertise. A theme coordinator would normally be nominated at the Working Group meeting. It would allow the nominee to be involved in the intersessional work on the preparation of the topic for discussion. The number of topics for each meeting would be limited to one and a maximum of two days at each meeting might be set aside for discussion.

13.4 It was also decided that agendas of Working Group meetings should be kept under constant review with a view to streamlining some routine parts, concentrating on key points, and giving an adequate description of the thematic topic for each meeting.

13.5 Arising from the issues identified in paragraphs 8.5 and 8.17, the Working Group agreed that a 'Sampling Approaches' theme should be included in its agenda for 1999. The theme would attempt to explore the principles underlying the sampling of prey, predators and environment in the provision of data necessary for ecosystem analysis and assessment.

13.6 To facilitate preparation, the Working Group agreed that the theme coordinator should be appointed as soon as possible to liaise with the Convener on the development of the theme topic for the 1999 meeting. In addressing this task the following general considerations would apply:

(i) Due consideration should be given to sampling type and intensity (both spatial and temporal) in the provision of data for ecosystem analysis. Parameters to be sampled should be referenced to specific working hypotheses on ecosystem function/interactions and to consideration of, *inter alia*, the relationship between sample and population estimates of key variables, the variability over time and space of the variables and possible errors/biases likely to arise from sampling as opposed to biological variability.

(ii) In addressing (i), focus should be given to the following guiding questions:

(a) What variable is being sampled?

(b) Why is this specific variable being sampled?

(c) What sampling regime is most practical?

(d) What statistical assumptions underline the chosen sample regime?

(e) What statistical procedures and general analyses should be applied to the sample data?

(f) What and how are sample results to be used in ecosystem analysis, assessment and the provision of management advice?

13.7 It was recognised that the points outlined in paragraph 13.6 require adequate appreciation of both ecological (including seasonal timings and geographical limitation) and logistic constraints (e.g. practical feasibility and frequency of sampling) on the chosen sampling regime.

Membership of Intersessional Subgroups

13.8 The Working Group considered membership of the following two subgroups which had been established for intersessional work by the former WG-CEMP:

(i) subgroup on the designation and protection of CEMP sites; and
(ii) subgroup on the practical aspects of standard monitoring methods.

13.9 It was agreed that these subgroups undertake very important work during intersessional periods which facilitate discussion at Working Group meetings. It was decided to confirm the present membership of the subgroup on the designation and protection of CEMP sites (Drs Penhale, K. Kerry (Australia) and D. Torres (Chile)) and also to add one additional member (Dr Wilson). New membership of the subgroup on practical aspects of standard monitoring methods would include Drs Boyd and W. Trivelpiece (USA) (dependent species), Dr V. Siegel (Germany) (prey species), Dr E. Murphy (UK) (environment) and Dr Constable (statistics).

CCAMLR Website

13.10 Dr Ramm reported on the development of the CCAMLR website (WG-EMM-98/23). As agreed by the Scientific Committee, the primary objective of the website is to provide a framework for organising, presenting and delivering CCAMLR information, in the four languages of the Commission, to Members of the Commission, Scientific Committee and working groups, technical coordinators, scientific observers, scientists, related organisations and the general public.

13.11 Web pages containing general information and publications would be made available to the public. However, the access to pages containing information on meeting and related papers and data would be restricted to participants at those meetings. For example, participants at meetings of WG-EMM would be issued with a single and unique user name and password. Passwords could be changed from time to time, or when the membership of each group was reviewed. The Working Group referred the membership of groups, and the way in which passwords are issued, to the Scientific Committee.

13.12 The English version of the WG-EMM web pages was released to Working Group participants on 31 July 1998 for a one-month trial. With the exception of the introductory web page, the pages were protected by password and contained information for the 1998 meeting. Selected papers were made available, with the permission of authors, for a trial electronic distribution. Information and reports from previous meetings were also available. A demonstration of the web pages was given during the meeting.

13.13 A number of the participants who had accessed the website prior to the meeting had found that the WG-EMM pages had been well structured and presented, and had provided valuable information prior to the meeting. The Working Group agreed that the website had the potential to grow into a very useful tool which would facilitate the exchange of information and expedite decision-making.

13.14 The Working Group agreed that the development of the website should continue, and include the addition of:

(i) scanned versions of all meeting papers in advance of meetings;
(ii) the CCAMLR bibliography;
(iii) maps of CEMP sites showing the location of colonies; and
(iv) STATLANT data published in the *Statistical Bulletin*.

13.15 As a further development, meeting papers could be copied from the website to CD-ROM and made available to participants during the meetings. This format may eventually provide a suitable alternative to hard copies of meeting papers.

13.16 The Working Group requested that the Secretariat specify the formats used on the website so that Members who may wish to contribute information, such as maps, may submit this in a website-ready format.

13.17 The Working Group thanked Dr Ramm and all the Secretariat staff involved in the development of the website. The Working Group agreed that this was an important activity which reflected its work in the broadest context of CCAMLR's overall activities. Dr Ramm and associated Secretariat staff were therefore encouraged to continue development of the website.

ADOPTION OF THE REPORT

14.1 During the adoption of the report, the Working Group met with Mr P.K. Brahma, Joint Secretary and Financial Adviser, Department of Ocean Development, and Dr P.C. Pandey, Director, Antarctic Study Centre, Goa, India. Both Mr Brahma and Dr Pandey welcomed the Working Group's approach to ecosystem management, and reiterated the global importance of the Antarctic and the Southern Ocean.

14.2 The report of the fourth meeting of WG-EMM was adopted.

CLOSE OF MEETING

15.1 In closing the meeting, the Convener, Dr Everson, thanked Sh. Ravindranathan and all those involved in the local organising committee for the very effective way in which the meeting was organised, and for their enthusiasm and very kind hospitality. He also thanked the staff of the Casino Hotel who had also played a large role in the successful running of the meeting. Dr Everson expressed appreciation for the hard work of the Secretariat in support of the meeting. He thanked the rapporteurs for carefully summarising papers, thus providing a sound basis for discussion, and all participants for developing the agenda in a spirit of excellent cooperation.

15.2 Dr Miller, on behalf of the Working Group, thanked Dr Everson for the large amount of work in convening the meeting, and for steering the meeting to a successful outcome. He also thanked the Government of India, the local organising committee and the staff of the Casino Hotel for organising a very successful and memorable meeting.

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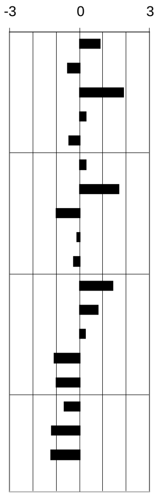
Table 1: Ecosystem assessment for Subarea 48.1.
Five-year running means and plots of standardised normal deviates for krill catch, krill density (net), proportional recruitment (krill R1), sea-surface temperature (summer SST, adjacent to Elephant Island), winter sea-ice extent and population parameters for CEMP species. SST and sea-ice indices, and A6A data from Admiralty Bay, are from the Workshop on Area 48 (Appendix D). CEMP data are from Admiralty Bay and Anvers Island. A3 – number of pairs, A6A – breeding success A (potential chicks), A6C – breeding success C (potential chicks).

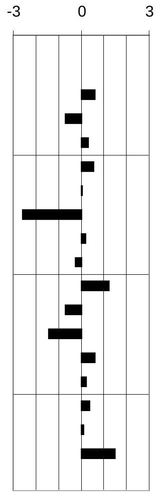
Split-Year	Krill Catch (CV = 0.50) Mean (tonnes)	Krill Density (CV = 0.96) Mean (no./m^3)	Krill R1 (CV = 1.00)	SST (CV = 0.42) Mean (°C)	Calendar Year	Sea-ice (CV = 0.21) Mean (10^6km^2.mo)
1979/80					1979	
1980/81					1980	
1981/82	48796		0.36		1981	5.13
1982/83	41227	218	0.29		1982	4.96
1983/84	31077	232	0.17	0.88	1983	4.51
1984/85	31382	201	0.09	0.68	1984	4.88
1985/86	47059	118	0.25	0.81	1985	5.02
1986/87	61744	64	0.26	0.79	1986	4.99
1987/88	67921	41	0.24	0.81	1987	4.61
1988/89	72426	32	0.27	0.72	1988	4.65
1989/90	73994	30	0.24	0.85	1989	4.36
1990/91	65753	30	0.12	0.80	1990	4.06
1991/92	53660	21	0.12	0.81	1991	4.08
1992/93	52170	32	0.22	0.77	1992	4.54
1993/94	51718	55	0.19	0.85	1993	4.67
1994/95	46299	94	0.21	0.97	1994	4.41
1995/96		93			1995	4.47
1996/97					1996	
1997/98					1997	

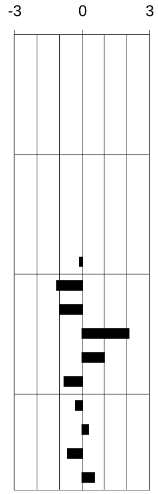
Split-Year	A3 Adélie Penguin Admiralty Bay (CV = 0.22) Mean (no. pairs)	A6A Adélie Penguin Admiralty Bay (CV = 0.12) Mean (%)	A3 Chinstrap Penguin Admiralty Bay (CV = 0.18) Mean (no. pairs)	A6A Chinstrap Penguin Admiralty Bay (CV = 0.15) Mean (%)	A3 Gentoo Penguin Admiralty Bay (CV = 0.18) Mean (no. pairs)	A6A Gentoo Penguin Admiralty Bay (CV = 0.22) Mean (%)	A3 Adélie Penguin Anvers Island (CV = 0.16) Mean (no. pairs)	A6C Adélie Penguin Anvers Island (CV = 0.14) Mean (%)
1979/80								
1980/81								
1981/82								
1982/83								
1983/84								
1984/85								
1985/86								
1986/87								
1987/88								
1988/89								
1989/90								
1990/91								
1991/92								
1992/93								
1993/94								
1994/95								
1995/96								
1996/97								
1997/98								

Table 2: Ecosystem assessment for Subarea 48.2.
Five-year running means and plots of standardised normal deviates for krill catch, sea-surface temperature (summer SST), winter sea-ice extent and population parameters for CEMP species. SST and sea-ice indices are from the Workshop on Area 48 (Appendix D). CEMP data are from Signy Island. A3 – number of pairs, A6A breeding success A (potential chicks).

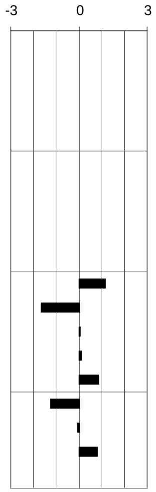
Split-Year	Krill Catch (CV = 0.81) Mean (tonnes)	SST (CV = 0.17) Mean (°C)	Calendar Year	Sea-ice (CV = 0.52) Mean ($10^6 km^2$.mo)
1979/80			1979	
1980/81			1980	
1981/82	136343		1981	
1982/83	126356		1982	
1983/84	162583	2.39	1983	
1984/85	115024	2.14	1984	
1985/86	108835	2.21	1985	
1986/87	112494	2.17	1986	
1987/88	131832	2.22	1987	
1988/89	116948	2.16	1988	
1989/90	137605	2.25	1989	
1990/91	121207	2.29	1990	0.61
1991/92	108578	2.32	1991	0.57
1992/93	74241	2.26	1992	0.61
1993/94	41336	2.32	1993	0.69
1994/95	16718	2.55	1994	0.53
1995/96			1995	0.50
1996/97			1996	
1997/98			1997	

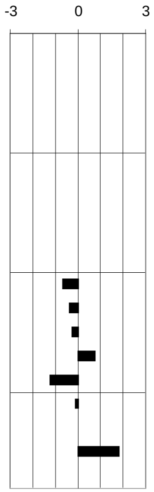
Krill Catch (CV = 0.81)


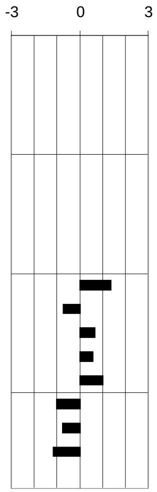
SST (CV = 0.17)


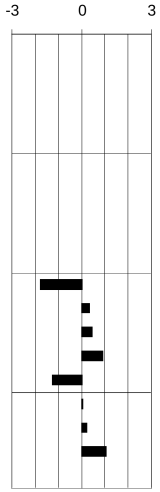
Sea-ice (CV = 0.52)


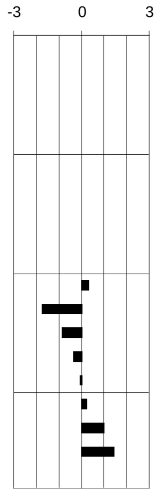
Split-Year	A3 Adélie Penguin (CV = 0.13) Mean (no. pairs)	A6A Adélie Penguin (CV = 0.43) Mean (%)	A3 Chinstrap Penguin (CV = 0.16) Mean (no. pairs)	A6A Chinstrap Penguin (CV = 0.38) Mean (%)	A3 Gentoo Penguin (CV = 0.19) Mean (no. pairs)	A6A Gentoo Penguin (CV = 0.42) Mean (%)
1979/80						
1980/81						
1981/82						
1982/83						
1983/84						
1984/85						
1985/86						
1986/87						
1987/88						
1988/89						
1989/90						
1990/91						
1991/92						
1992/93						
1993/94						
1994/95						
1995/96						
1996/97						
1997/98						

A3 Adélie Penguin (CV = 0.13)


A6A Adélie Penguin (CV = 0.43)


A3 Chinstrap Penguin (CV = 0.16)


A6A Chinstrap Penguin (CV = 0.38)


A3 Gentoo Penguin (CV = 0.19)


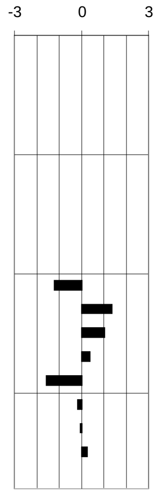
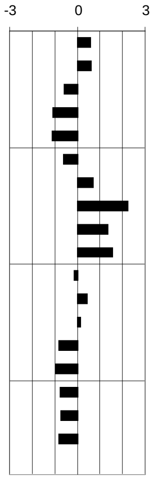
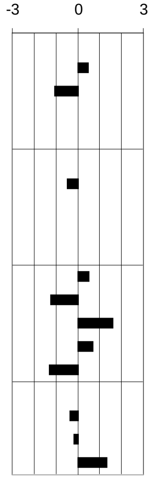
A6A Gentoo Penguin (CV = 0.42)


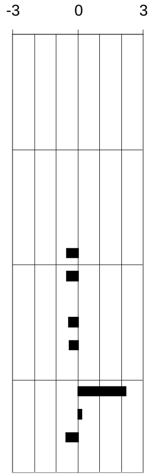
Table 3: Ecosystem assessment for Subarea 48.3.

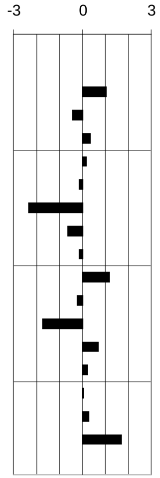
Five-year running means and plots of standardised normal deviates for krill catch, krill density (acoustic), proportional recruitment (krill R1), sea-surface temperature (summer SST), winter sea-ice extent and population parameters for CEMP species. SST and sea-ice indices are from the Workshop on Area 48 (Appendix D). CEMP data are from Bird Island. A3 – number of pairs, A6A – breeding success A (potential chicks), B1A – black-browed albatross population, B1B – black-browed albatross breeding success.

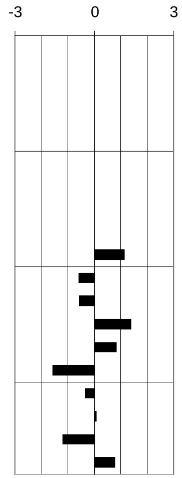
Split-Year	Krill Catch (CV = 0.82) Mean (tonnes)	Krill Density (CV = 0.69) Mean (g/m^2)	Krill R1 (CV = 1.83)	SST (CV = 0.12) Mean (°C)	Calendar Year	Sea-ice (CV = 0.15) Mean (10^6km^2.mo)
1979/80					1979	
1980/81					1980	
1981/82	67163				1981	
1982/83	49485				1982	
1983/84	50851			3.59	1983	
1984/85	92719			3.32	1984	
1985/86	128521			3.30	1985	
1986/87	168104			3.27	1986	
1987/88	175301			3.35	1987	
1988/89	171597			3.34	1988	
1989/90	140617			3.39	1989	
1990/91	108527			3.50	1990	2.40
1991/92	70986	46	0.03	3.53	1991	2.22
1992/93	61430	43	0.25	3.44	1992	2.23
1993/94	44035	50	0.24	3.48	1993	2.28
1994/95	29998	36	0.23	3.75	1994	2.10
1995/96		41			1995	2.10
1996/97					1996	
1997/98					1997	



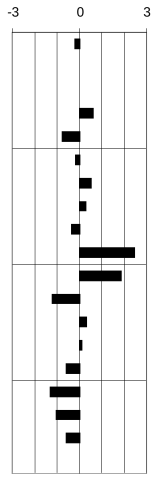


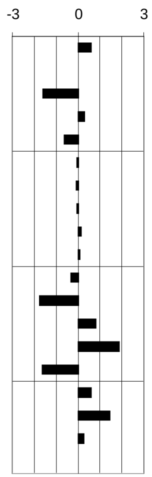


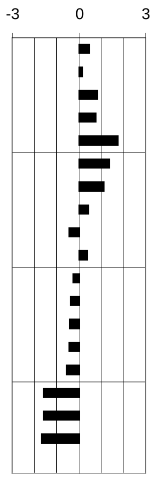


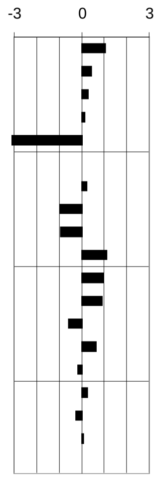


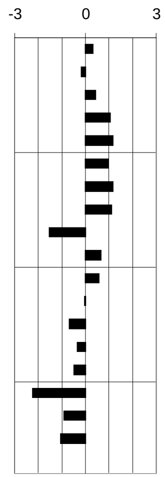
Split-Year	A3 Gentoo Penguin (CV = 0.27) Mean (no. pairs)	A6A Gentoo Penguin (CV = 0.56) Mean (%)	A3 Macaroni Penguin (CV = 0.25) Mean (no. pairs)	A6A Macaroni Penguin (CV = 0.25) Mean (%)	B1A Black-browed Albatross (CV = 0.39) Mean (no. pairs)	B1B Black-browed Albatross (CV = 0.83) Mean (%)
1979/80						
1980/81						
1981/82						
1982/83						
1983/84						
1984/85						
1985/86						
1986/87						
1987/88						
1988/89						
1989/90						
1990/91						
1991/92						
1992/93						
1993/94						
1994/95						
1995/96						
1996/97						
1997/98						











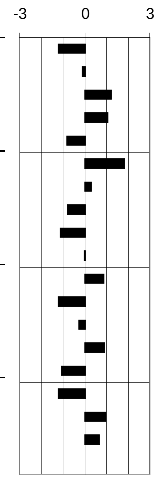
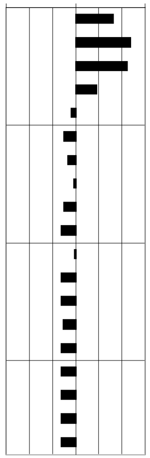


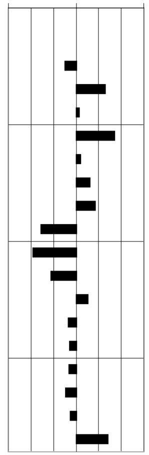
Table 4: Ecosystem assessment for Area 58.
Five-year running means and plots of standardised normal deviates for krill catch, sea-surface temperature (SST, F5 adjacent to SYO), sea-ice extent (F2A for Prydz Bay) and population parameters for CEMP species. CEMP data are from Béchervaise Island, Marion Island and Syowa Station (SYO). A3 – number of pairs, A6A – % breeding success A (potential chicks).

Split-Year	Krill Catch (CV = 1.59) Mean (tonnes)	SST F5 SYO (CV = 0.39) Mean (°C)	Sea-ice F2A (CV = 0.06) Mean (%)
1979/80			
1980/81			
1981/82	104483		90
1982/83	82296		93
1983/84	54472	-0.68	93
1984/85	30788	-0.60	92
1985/86	16157	-0.63	92
1986/87	11621	-0.75	91
1987/88	16385	-0.99	92
1988/89	13469	-1.08	92
1989/90	7558	-1.09	91
1990/91	7412	-1.17	89
1991/92	7549	-1.08	88
1992/93	1851	-0.97	85
1993/94	1587	-0.93	85
1994/95	1587	-0.98	85
1995/96	434	-0.86	86
1996/97			
1997/98			

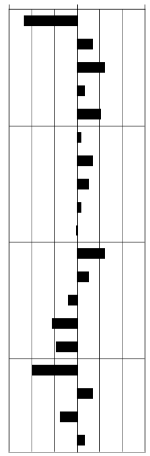
Krill Catch (CV = 1.59)



SST F5 SYO (CV = 0.39)

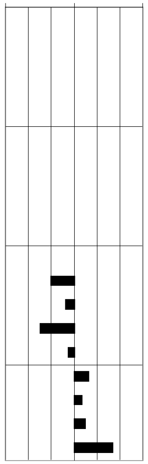


Sea-ice F2A (CV = 0.06)

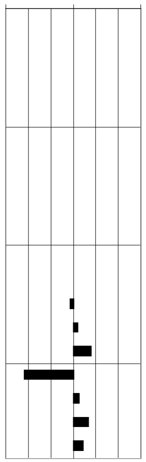


Split-Year	A3 Adélie Penguin Béchervaise Is (CV = 0.10) Mean (no. pairs)	A6A Adélie Penguin Béchervaise Is (CV = 0.42) Mean (%)	A3 Adélie Penguin Syowa Station (CV = 0.22) Mean (no. pairs)	A3 Macaroni Penguin Syowa Station (CV = 0.20) Mean (%)	A3 Gentoo Penguin Marion Is (CV = 0.16) Mean (no. pairs)	A6A Gentoo Penguin Marion Is (CV = 0.65) Mean (%)
1979/80						
1980/81						
1981/82						
1982/83						
1983/84						
1984/85						
1985/86						
1986/87						
1987/88						
1988/89						
1989/90						
1990/91						
1991/92						
1992/93						
1993/94						
1994/95						
1995/96						
1996/97						
1997/98						

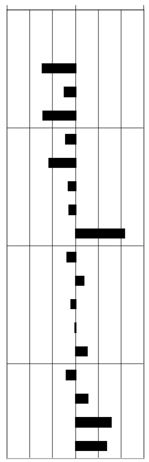
A3 Adélie Penguin Béchervaise Is (CV = 0.10)



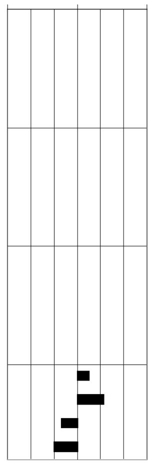
A6A Adélie Penguin Béchervaise Is (CV = 0.42)



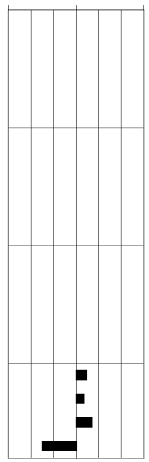
A3 Adélie Penguin Syowa Station (CV = 0.22)



A3 Macaroni Penguin Syowa Station (CV = 0.20)



A3 Gentoo Penguin Marion Is (CV = 0.16)



A6A Gentoo Penguin Marion Is (CV = 0.65)

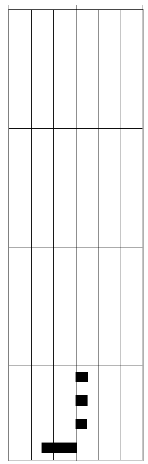
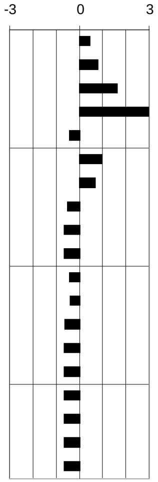


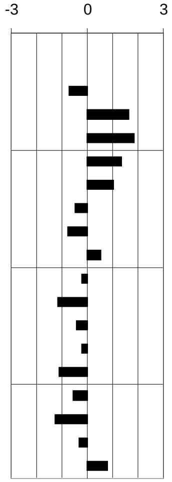
Table 5: Ecosystem assessment for Area 88.
Five-year running means and plots of standardised normal deviates for krill catch, sea-surface temperature (SST, adjacent to Edmonson Point) and population parameters for CEMP species. CEMP data are from Edmonson Point (EDP) and Ross Island. A3 – number of pairs, A6A – % breeding success A (potential chicks).

Split-Year	Krill Catch (CV = 1.57) Mean (tonnes)	SST F5 EDP (CV = 0.14) Mean (°C)
1979/80		
1980/81		
1981/82	5066	
1982/83	5374	
1983/84	5306	-1.23
1984/85	4057	-1.22
1985/86	1930	-1.32
1986/87	1801	-1.37
1987/88	989	-1.43
1988/89	360	-1.52
1989/90	291	-1.52
1990/91	291	-1.50
1991/92	291	-1.56
1992/93	160	-1.58
1993/94	10	-1.58
1994/95	0	-1.58
1995/96	0	-1.54
1996/97		
1997/98		

Krill Catch (CV = 1.57)

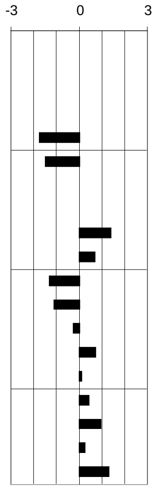


SST F5 EDP (CV = 0.14)

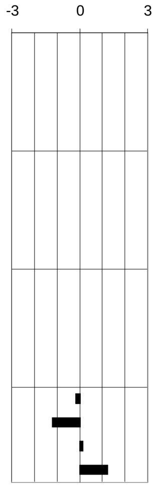


Split-Year	A3 Adélie Penguin Ross Island (CV = 0.16) Mean (no. pairs)	A3 Adélie Penguin Edmonson Point (CV = 0.04) Mean (no. pairs)	A6A Adélie Penguin Edmonson Point (CV = 0.22) Mean (%)
1979/80			
1980/81			
1981/82			
1982/83			
1983/84			
1984/85			
1985/86			
1986/87			
1987/88			
1988/89			
1989/90			
1990/91			
1991/92			
1992/93			
1993/94			
1994/95			
1995/96			
1996/97			
1997/98			

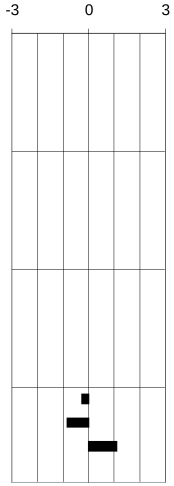
A3 Adélie Penguin Ross Island (CV = 0.16)



A3 Adélie Penguin Edmonson Point (CV = 0.04)



A6A Adélie Penguin Edmonson Point (CV = 0.22)



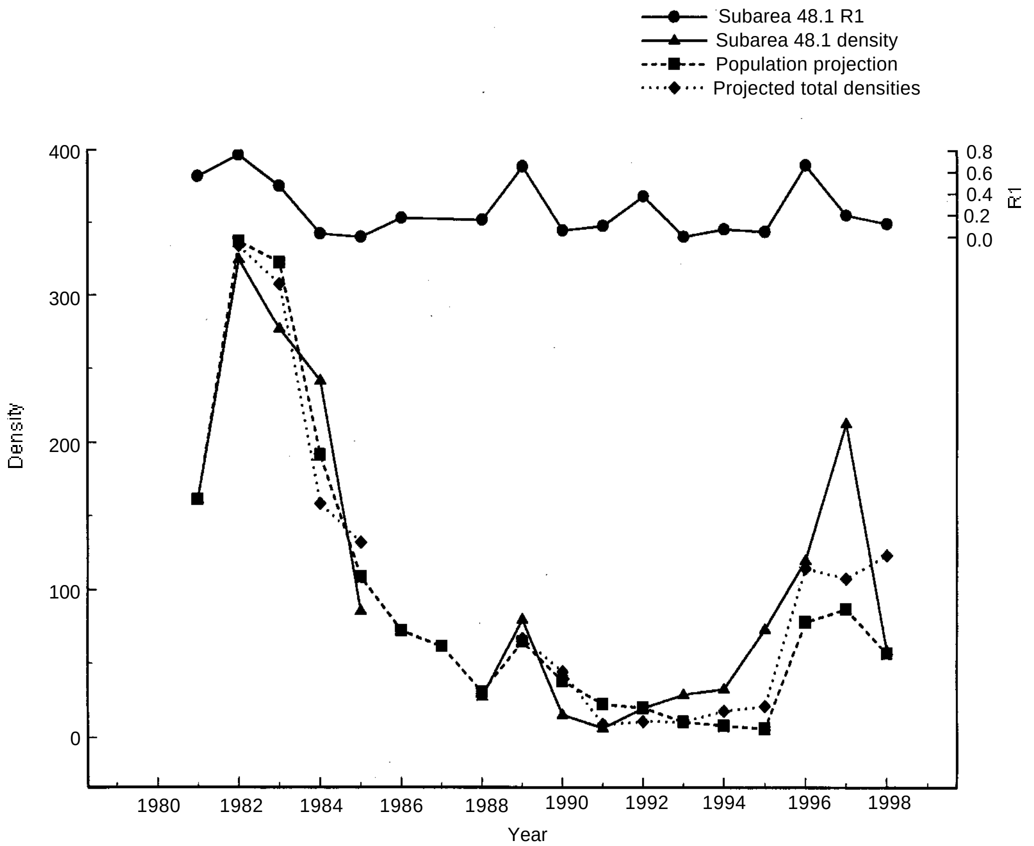


Figure 1: Comparative plot showing the **krill density** and proportional recruitment at age 1 (**R**1) estimated for Subarea 48.1 from 1980/81 to 1997/98 combined with the results of a **population projection** based on estimates of absolute recruitment and M = 0.548 and **projected total densities** where the density in a year was the projected density of adults from the previous year plus the density of recruits estimated for that year from R1 and the total recorded density.

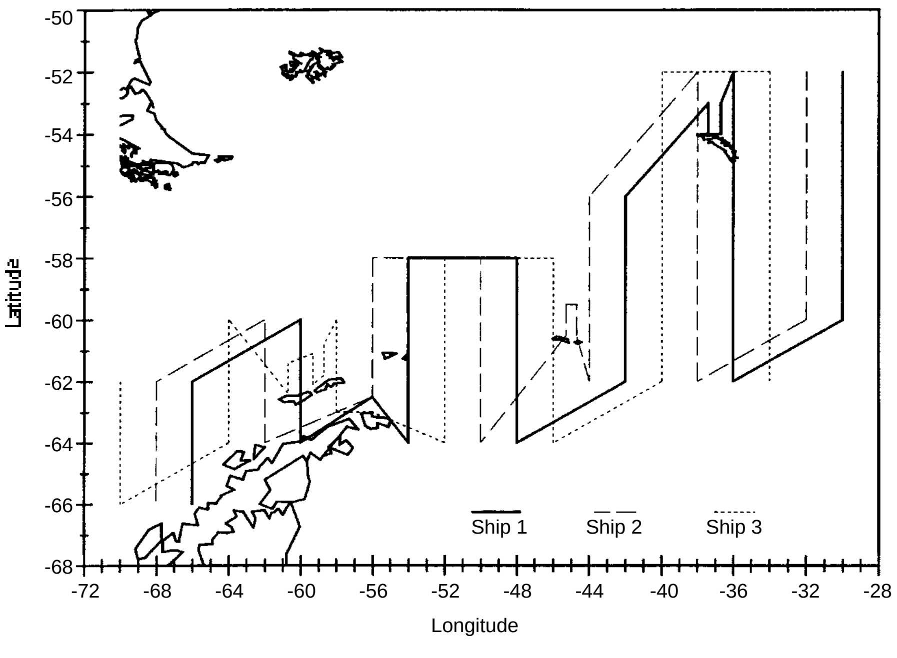


Figure 2: Proposed transects for three ships undertaking the synoptic survey in Area 48.

APPENDIX A

AGENDA

Working Group on Ecosystem Monitoring and Management
(Kochi, India, 10 to 20 August 1998)

1. Introduction

   1.1 Opening of the Meeting
   1.2 Organisation of the Meeting and Adoption of the Agenda

2. Fisheries Information

   2.1 Catches Status and Trends
   2.2 Harvesting Strategies
   2.3 Observer Scheme
   2.4 Other Information

3. Meetings During the Intersessional Period

   3.1 Report of the Workshop on Area 48
   3.2 Other Major Meetings

4. Harvested Species

   4.1 Distribution and Standing Stock
   4.2 Population Structure, Recruitment, Growth and Production
   4.3 Indices of Abundance, Distribution and Recruitment
   4.4 Future Work

5. Dependent Species

   5.1 CEMP Indices
   5.2 Studies on Distribution and Population Dynamics
   5.3 Future Work

6. Environment

   6.1 Consideration of Studies on Key Environmental Variables
   6.2 Indices of Key Environmental Variables
   6.3 Future Work

7. Ecosystem Analysis

   7.1 Analytical Procedures and Combination of Indices
      (i) Multivariate Analysis of CEMP Indices
      (ii) Use of GYM for Krill Stock Assessments
      (iii) Other Approaches
   7.2 Krill-centred Interactions
   7.3 Fish and Squid-centred Interactions

8. Ecosystem Assessment

   8.1 Estimates of Potential Yield
   8.2 Assessment of the Status of the Ecosystem
      (i) Current Trends by Areas and Species
      (ii) Presentation of Assessments in Summary Form
   8.3 Consideration of Possible Management Measures

9. Methods and Programs Involving Studies on Harvested and Dependent Species and the Environment

   9.1 Methods for Estimating Distribution, Standing Stock, Recruitment and Production of Harvested Species
   9.2 Consideration of CEMP Sites
   9.3 Methods for Monitoring the Performance of Dependent Species
      (i) Consideration of Comments on Existing Methods
      (ii) Consideration of New Draft Methods
   9.4 Methods for Monitoring Environmental Variables of Direct Importance in Ecosystem Assessment
   9.5 Plans for a Synoptic Krill Survey in Area 48
   9.6 Other Activities in Support of Ecosystem Monitoring and Management

10. The Ecosystem Approach as Applied in Other Parts of the World

11. Advice to the Scientific Committee

12. Future Work

13. Other Business

14. Adoption of the Report

15. Close of the Meeting.

APPENDIX B

LIST OF PARTICIPANTS

Working Group on Ecosystem Monitoring and Management
(Kochi, India, 10 to 20 August 1998)

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APPENDIX C

LIST OF DOCUMENTS

Working Group on Ecosystem Monitoring and Management
(Kochi, India, 10 to 20 August 1998)

WG-EMM-98/1	Provisional and Annotated Provisional Agenda for the 1998 Meeting of the Working Group on Ecosystem Monitoring and Management (WG-EMM)
WG-EMM-98/2	List of participants
WG-EMM-98/3	List of documents
WG-EMM-98/4 Rev. 2	CEMP indices 1998: summary of anomalies and trends Secretariat
WG-EMM-98/5	Revision of the fishery–foraging overlap model Secretariat
WG-EMM-98/6	Development of standard methods for environmental data Secretariat
WG-EMM-98/7 Rev. 1	Report on fine-scale krill data for the 1996/97 season Secretariat
WG-EMM-98/8	Status and trends of Antarctic seals Report of SCAR
WG-EMM-98/9	Human activity and disturbance: building an Antarctic site inventory R. Naveen, Oceanites (USA)
WG-EMM-98/10	Comments of the Antarctic site inventory project on the application of the Standard Method A6 ‘penguins breeding success’ Secretariat
WG-EMM-98/11	Monitoring changes in coastal fish populations by the analysis of pellets of the Antarctic shag *Phalacrocorax bransfieldensis*: a new proposed standard method R. Casaux and E. Barrera-Oro (Argentina)
WG-EMM-98/12	The principal results of YugNIRO complex studies in the Indian sector of the Antarctic V.I. Bondarenko, V.A. Bibik, V.V. Gerasimchook, E.P. Goubanov, A.V. Romanov and B.G. Trotsenko (Ukraine)
WG-EMM-98/13	Preliminary results of biological studies in the 1st Ukrainian Antarctic expedition in Subarea 48.2 in March 1997 V.A. Bibik (Ukraine)

WG-EMM-98/14	VNIRO program on remote monitoring of oceanographic conditions in fishing areas of the World Ocean (the southwestern Atlantic and the southeastern Pacific) G.P. Vanyushin, T.B. Barkanova and A.A. Troshkov (Russia)
WG-EMM-98/15	Diet and foraging effort of Adélie penguins in relation to pack-ice conditions in the southern Ross Sea D.G. Ainley (USA), P.R. Wilson, K.J. Barton (New Zealand), G. Ballard, N. Nur (USA) and B. Karl (New Zealand)
WG-EMM-98/16	Report of the Workshop on Area 48 (La Jolla, USA, 15 to 26 June 1998)
WG-EMM-98/17	Decline of Antarctic fur seal (*Arctocephalus gazella*) population at SSSI No. 32, South Shetlands, Antarctica, during 1997/98: a discussion of possible causes R. Hucke-Gaete, D. Torres, A. Aguayo and V. Vallejos (Chile)
WG-EMM-98/18	Occurrence of Antarctic krill (*Euphausia superba*) concentrations in the vicinity of the South Shetland Islands: relationship to environmental parameters T. Ichii, K. Kayatama, N. Obitsu, H. Ishii and M. Naganobu (Japan)
WG-EMM-98/19	On the possibility of practical utilisation of krill target strength TS in situ obtained on the basis of EK-500 measurements S.M. Kasatkina (Russia)
WG-EMM-98/20	Catchability of midwater trawls in relation to krill fishery S.M. Kasatkina (Russia)
WG-EMM-98/21	Some comments on the procedure of krill target strength assessment in echosurveys S.M. Kasatkina (Russia)
WG-EMM-98/22	SCAR Bird Biology Subcommittee Ad Hoc Working Group on Seabirds at Sea Methodology SCAR
WG-EMM-98/23	Secretariat work in support of WG-EMM Secretariat
WG-EMM-98/24	Hydroacoustic and net krill sampling methods Area 48 survey (decisions and recommendations of the Scientific Committee and its working groups) Secretariat
WG-EMM-98/25	Report from the Steering Committee for the synoptic survey of Area 48 Steering Committee
WG-EMM-98/26	Report of the 1996 APIS Survey Design and Implementation Workshop
WG-EMM-98/27	Report of the Meeting of the SCAR Group of Specialists on Seals Submitted by SCAR

WG-EMM-98/28	Foraging trip duration in male and female macaroni penguins at Bouvetøya F. Mehlum, K. Isaksen and V. Bakken (Norway)
WG-EMM-98/29	Green krill, the indicator of micro- and nano-size phytoplankton availability to krill S. Kawaguchi, T. Ichii and M. Naganobu (Japan)
WG-EMM-98/30	Status of the Polish FIBEX acoustic data from the west Atlantic P.N. Trathan (UK), J. Kalinowski (Italy) and I. Everson (UK)
WG-EMM-98/31	Pursuit and polynyas in the Ross Sea, Antarctica M. Naganobu, T. Tanaka, Y. Okada, N. Kimura and S. Matsumura (Japan)
WG-EMM-98/32	Krill distribution in the western Atlantic sector of the Southern Ocean during 1983/84, 1984/85 and 1987/88 on the basis of the Soviet mesoscale surveys with Isaacs Kidd midwater trawl V.A. Sushin and K.E. Shulgovsky (Russia)
WG-EMM-98/33	Proportional recruitment indices of Antarctic krill from Japanese fisheries data in Subareas 48.1, 48.2 and 48.3 during 1980 through 1997 S. Kawaguchi, T. Ichii and M. Naganobu (Japan)
WG-EMM-98/34	Phytoplankton standing stocks in relation to krill in Antarctic waters X.N. Verlecar, R. Vijayakumar, F. Saldhana and L. Martins (India)
WG-EMM-98/35	Studies on zooplankton with special reference to krill from the Indian Ocean sector of the Southern Ocean K.L. Bhat, R. Vijayakumar and V. Jaya Sree (India)
WG-EMM-98/36	Hydroacoustic assessment of krill in Area 58 of the Indian Ocean sector of the Antarctic region Z. Klusek and A. Anrose (India)
WG-EMM-98/37	Biology, distribution and abundance of Antarctic krill (*Euphausia superba*) and by-catch A. Anrose, Z. Klusek, M.K.R. Nair and M. R. Bhoopendranath (India)
WG-EMM-98/38	Investigations on midwater trawling for krill (*Euphausiasuperba*) in the Southern Ocean M.R. Bhoopendranath, M.K.R. Nair, A. Anrose and V.C. George (India)
WG-EMM-98/39	Studies on Antarctic krill (*Euphausia superba*) biochemical and processing aspects C.N. Ravishankar and K. Ashok Kumar (India)
WG-EMM-98/40	Product development from Antarctic krill and test marketing M.K.R. Nair, S. Girija, K.K. Muhammad Basheer and M.K. Venu (India)

WG-EMM-98/41	Products for human consumption from krill (*Euphausia superba*) J. Joseph, V. Muraleedharan, R. Thankamma and C.N. Ravishankar (India)
WG-EMM-98/42	Biochemical investigations on Antarctic krill (*Euphausia superba*) M.R. Raghunath, T.V. Shankar, A.G. Radhakrishnan, S. Mathew, K. Ammu, C.N. Ravishankar, K. Jayan and L. Jose (India)
WG-EMM-98/43	Otolith size in the mackerel icefish I. Everson and B. Bendall (UK)
WG-EMM-98/44	The Area 48 synoptic survey: an adaptive survey design J. Watkins, A. Murray and I. Everson (UK)
WG-EMM-98/45	Evaluation of de la Mare's composite standardised index for generating a simple time-series summary of many long-term datasets on Antarctic predators: consequences of missing values and criteria for inclusion of predator parameters A. Constable (Australia)
WG-EMM-98/46	CCAMLR Standard Method A3b P. Wilson (New Zealand)
WG-EMM-98/47	Some suggestions for acoustic protocols for the synoptic survey of FAO Area 48 D.A. Demer (USA)
WG-EMM-98/48	A model at the level of the foraging trip for the indirect effects of krill (*Euphausiasuperba*) fisheries on krill predators (*Ecological Modelling* (1998), 105: 235–256) M. Mangel and P.V. Switzer (USA)
WG-EMM-98/49	AMLR 1997/98 Field Season Report: Objectives, accomplishments and tentative conclusions US Delegation
WG-EMM-98/50	Interannual variability of krill, salp and other zooplankton populations in the South Shetland Island area during Austral summer 1993–1998 V. Loeb, W. Armstrong, R. Hewitt (USA) and V. Siegel (Germany)
WG-EMM-98/51	Acoustic estimates of krill density at South Georgia during 11 austral summers between 1981 and 1998 A.S. Brierley, J.L. Watkins, C. Goss, M.T. Wilkinson and I. Everson (UK)
WG-EMM-98/52	Natural fluctuations in the abundance of krill with due regard to global climate changes in the southern hemisphere: forecasting possibilities K. Shust (Russia)
WG-EMM-98/53	The Area 48 synoptic survey: three possible approaches J. Watkins, A. Murray and I. Everson (UK)

Other Documents

WS-Area48-98/4 Rev. 1	Do krill and salp compete? Contrary evidence from the krill fisheries (*CCAMLR Science*, in press) S. Kawaguchi (Japan), W.K. de la Mare (Australia), T. Ichii and M. Naganobu (Japan)
WS-Area48-98/6	A method for providing a statistical summary of CEMP indices I.L. Boyd and A.W.A. Murray (UK)
WS-Area48-98/8	Interannual variability of the South Georgia marine ecosystem: biological and physical sources of variation in the abundance of krill E.J. Murphy, J.L. Watkins, K. Reid, P.N. Trathan, I. Everson, J.P. Croxall, J. Priddle, M.A. Brandon, A.S. Brierley (UK) and E. Hofman (USA)
WS-Area48-98/10	Sea-surface temperature anomalies near South Georgia: relationships with the South Atlantic and the Pacific El Niño regions P. Trathan and E.J. Murphy (UK)
WS-Area48-98/11	Concordance of interannual fluctuations in densities of krill around South Georgia and Elephant Islands: biological evidence of same-year teleconnections across the Scotia Sea A.S. Brierley (UK), D.A. Demer, R.P. Hewitt (USA) and J.L. Watkins (UK)
WS-Area48-98/15	Krill population dynamics at South Georgia 1991–1997, based on data from predators and nets K. Reid, J. Watkins, J. Croxall and E. Murphy (UK)
WS-Area48-98/16	Environmental variability and the behavioural dynamics of Antarctic fur seals in the South Atlantic I.L. Boyd (UK)
WS-Area48-98/17	Diet, provisioning and productivity responses of predators to differences in availability of Antarctic krill J.P. Croxall, K. Reid and P.A. Prince (UK)
WS-Area48-98/18 Rev. 1	Antarctic fur seal (*Arctocephalus gazella*) pup growth rates at Cape Shirreff, Livingston Island, South Shetlands: 1994/95 to 1997/98 R. Hucke-Gaete, V. Vallejos and D. Torres (Chile)
WS-Area48-98/21 Rev. 1	IWC whale data indices for CCAMLR Area 48 Workshop S. Reilly, C. Allison, H. Kata and D. Borchers
SC-CAMLR-XVII/BG/2	Draft CEMP Tables 1 to 3 Secretariat
SC-CAMLR-XVII/BG/3	Towards a closer cooperation between CCAMLR and the IWC CCAMLR Observer (K.-H. Kock, Germany)
SC-CAMLR-XV/BG/29	The status and trends of Antarctic and sub-Antarctic seabirds Submitted by the SCAR Subcommittee on Bird Biology

APPENDIX D

REPORT OF THE WORKSHOP ON AREA 48
(La Jolla, USA, 15 to 26 June 1998)

REPORT OF THE WORKSHOP ON AREA 48
(La Jolla, USA, 15 to 26 June 1998)

INTRODUCTION

1.1 The Workshop on Area 48 was held from 15 to 26 June 1998. The meeting was convened by Dr R. Hewitt (USA) and held at the Southwest Fisheries Science Center in La Jolla, USA.

1.2 The workshop was opened by Dr P. Smith, Acting Director, Southwest Fisheries Science Center.

1.3 A provisional agenda had been circulated and was discussed. It was agreed that two additional items be added to the agenda:

1a. Presentation of background material with a particular emphasis on Area 48; and

2a. Presentation and discussion of methods for combining and integrating indices, and solutions for handling missing values in datasets.

The agenda (Attachment A) was adopted without further modification.

1.4 The list of participants is included as Attachment B, and the list of documents submitted to the meeting is included as Attachment C.

1.5 The report was prepared as a collaborative effort among participants.

BACKGROUND, AIMS AND OBJECTIVES

2.1 Ecosystem variability in Area 48 (South Atlantic sector of the Southern Ocean, see Figure 1) has been documented using retrospective analyses of time series data collected at several sites and areas and presented to WG-EMM. For example, annual variability of proportional recruitment of krill (*Euphausia superba*) has been described from surveys conducted in the Antarctic Peninsula area (Subarea 48.1), variability in the reproductive success of land-breeding krill predators has been described from monitoring studies conducted near South Georgia (Subarea 48.3), and variability in sea-ice has been described from records collected in the South Orkney Islands (Subarea 48.2).

2.2 On several occasions during the meetings of WG-EMM, participants have commented on the apparent coherence between occasional observations from different sites and more complete time series collected elsewhere within Area 48. Participants have noted the need for a more formal comparison of datasets, both biological and physical, over a range of spatial scales. The objective of such an exercise would be to describe the nature, extent and scale of coherence among processes occurring in Area 48.

2.3 At its 1996 meeting, the Scientific Committee agreed to the request of WG-EMM to hold a workshop to explore the coherence among processes occurring throughout Area 48 (SC-CAMLR-XV, paragraph 5.25), and reiterated in 1997 the need for the workshop (SC-CAMLR-XVI, paragraph 6.50).

2.4 The terms of reference for the workshop were:

(i) identify the extent of between-season and within-season variation in key indices of environment, harvested species and dependent species over past decades;

(ii) identify coherence in the indices between sites and clarify understanding of the linkages between Subareas 48.1 (Antarctic Peninsula), 48.2 (South Orkney Islands) and 48.3 (South Georgia);

(iii) develop working hypotheses; and

(iv) provide a summary report for consideration of the 1998 meeting of WG-EMM.

2.5 The particular hypotheses (SC-CAMLR-XVI, paragraph 6.51) being addressed were that:

(i) H_0: Subareas 48.1, 48.2 and 48.3 are discrete ecosystems and events observed in any one subarea do not reflect what is happening in other subareas; or, conversely,

(ii) H_1: that Area 48 is a homogeneous ecosystem and events observed in any one subarea reflect the entire area.

2.6 It was recognised that neither of these hypotheses was likely to be correct. However, they represent the end points of the spectrum of possibilities and were believed to assist in focusing the objectives of the workshop.

2.7 To provide a structured basis for the workshop, it was agreed that:

(i) indices derived from datasets (not necessarily using standard methods) should be submitted prior to the meeting;

(ii) these indices would be loaded on a central server that could be accessed by a network of computers available to workshop participants;

(iii) working papers could be submitted that elucidated the details of sampling and data processing leading to the formulation of an index; and

(iv) additional working papers could be submitted which drew attention to apparent relationships between indices.

2.8 To prepare for the workshop, participants were requested to submit indices. They were also encouraged to undertake analyses of their own data (e.g. investigating properties of indices, multivariate analysis, etc.) in advance of the workshop and to report their results to it.

2.9 To assist in data coordination and submission, relevant ecosystem processes were divided into four categories and coordinators were assigned. Processes to be indexed and their coordinators were:

(i) Physical Environment – Mr A. Amos (USA), Dr P. Trathan (UK) and Dr M. Naganobu (Japan):
(a) sea-ice;
(b) circulation;
(c) hydrography;
(d) meteorology; and
(e) sea-surface temperature (SST).

(ii) Biotic Environment – Dr V. Loeb (USA):
 (a) phytoplankton; and
 (b) zooplankton.

(iii) Dependent Species – Dr J. Croxall (UK) and Dr W. Trivelpiece (USA):
 (a) CEMP indices;
 (b) other indices; and
 (c) cetacean catches and sightings.

(iv) Krill – Dr J. Watkins (UK) and Dr V. Siegel (Germany):
 (a) demographics;
 (b) recruitment;
 (c) abundance and distribution of post-larval forms (as determined from net samples and acoustic surveys);
 (d) abundance and distribution of larvae; and
 (e) fishery-dependent data.

2.10 All coordinators circulated requests for data widely amongst the community of Antarctic scientists working in relevant research fields.

2.11 In all circulars it was stressed that data contributed and workshop results would only be used by the Scientific Committee and its scientific subsidiary bodies. The basic rights of data originators/providers are regulated by CCAMLR under 'Access to and use of data within CCAMLR' (as set out in SC-CAMLR-XIII, Annex 10). Therefore, the data and results, both during and after the workshop, will not enter the public domain without the express permission of the data originators.

2.12 In order to disseminate information regarding terms of reference, background material and logistic arrangements for the workshop, Dr Hewitt created a website with open access to all potential participants. Indices were also posted on the website and cross-referenced by type (physical environment, biotic environment, krill and krill predators) and by geographic area (Subarea 48.1 – Antarctic Peninsula, Subarea 48.2 – South Orkney Islands and Subarea 48.3 – South Georgia).

2.13 The datasets available to the workshop on this website are listed in Attachment D.

2.14 To carry out a range of initial tasks involving evaluation and analysis of data and indices, five subgroups were formed:

(i) physical environment (coordinator Dr Trathan), see Section 3;
(ii) biotic environment (coordinator Dr Loeb), see Section 5;
(iii) krill (coordinator Dr Watkins), see Section 4;
(iv) land-based krill predators (coordinator Dr I. Boyd (UK)), see Section 7; and
(v) marine predators of krill (icefish and whales) (coordinator Dr I. Everson (UK)), see Section 6.

2.15 Discussions on interactions between the environment, prey and predators were coordinated by Dr E. Murphy (UK); see Section 8.

2.16 The workshop considered data from summer and winter periods. The winter period, generally from May to October, spans the changeover date for CCAMLR split-years which run from 1 July to 30 June. The following convention was adopted throughout the text of the report:

(i) winter as the calendar year of the observations; e.g. data from May or August 1991 would be designated 1991; and

(ii) summer as the split-year; viz 1990/91 for the CCAMLR year 1991.

2.17 The formatting software for the figures did not allow the full implementation of these conventions and consequently seasons are specified by the calendar year in which the season ended. In this form winter seasons are the same as in the text and summer seasons as the conventional CCAMLR split-year.

PHYSICAL ENVIRONMENT

Introduction

3.1 The environmental data available to the subgroup were relatively limited and it was not possible to fully investigate all of the questions important to the aims of the workshop. The subgroup noted that there is a considerable body of literature on the physical environment in the Southern Ocean, including the Scotia Sea, and that the Southern Ocean and its linkages within the southern hemisphere is currently the focus of extensive research. The following comments are presented in this context.

3.2 In considering the physical environment as part of ecosystem interactions, the subgroup emphasised that caution should be used in interpreting relationships between physics and biology in Area 48. It was acknowledged that simplistic views of the physical environment are unlikely to be realistic.

3.3 The attention of the subgroup was drawn to a number of papers which highlight the complexity of the physical environment and its effects upon the ecosystem.

Environmental Data Available to the Subgroup

3.4 The environmental data available to the subgroup included:

(i) sea-ice extent from 1987 to 1997 – from passive microwave sensor data for the Antarctic Peninsula, South Orkneys, South Georgia and for the Scotia Sea;

(ii) SSTs from 1981 to 1998 – from the National Center for Atmospheric Research (NCAR);

(iii) temperature profiles from 1990 to 1998 – from the US AMLR CTD grid near Elephant Island;

(iv) Palmer Station air temperatures from 1947 to 1996;

(v) Drake Passage Oscillation Index (DPOI) from 1982 to 1994 – the difference in sea-level pressure between Rio Gallegos and Esperanza;

(vi) Southern Oscillation Index (SOI) from 1951 to 1998 – the difference in sea-level pressure between Darwin and Tahiti; and

(vii) El Niño (EN) SST indices from 1950 to 1998 – with EN1+2 from the Eastern Pacific, EN3 from the Central Pacific and EN4 from the Western Pacific.

3.5 Dr Hewitt described monthly estimates of sea-ice extent based on subsets of ice concentration images generated from passive microwave sensor data with a nominal pixel resolution of 25 x 25 km. Subsets were defined for the South Shetland Islands, the South Orkney Islands, South Georgia and the entire Scotia Sea.

3.6 Dr Trathan described the NCAR SST data around South Georgia (WS-Area48-98/10). The data were extracted from the NCAR global database which has a spatial resolution of 1° latitude by 1° longitude with a temporal resolution of one month. The data are based on an optimal interpolation of Advanced Very High Resolution Radiometry (AVHRR) data with *in situ* data from buoys and ships (see Reynolds and Smith 1994). NCAR data at a weekly resolution were also available.

3.7 Mr Amos outlined the CTD data from the US AMLR Program. Since 1990 the Program has measured the physical oceanographic properties of the water column annually in the Elephant Island region of Subarea 48.1. Each year, two 30-day cruises have been undertaken with a standardised grid of CTD profiles to depths of 750 m (or to the bottom where depths were less than 750 m). Each year the first cruise takes place in January/February, and the second in February/March. The CTD stations' positions from the AMLR CTD grid that were used during the workshop are shown in Figure 2.

3.8 Dr Naganobu presented data on sea-level pressure (SLP) differences across the Drake Passage, reporting that these data provided an alias for fluctuations in westerly winds which may be regarded as geostrophic winds. The data were calculated as the pressure difference at sea level between Rio Gallegos (51°32'S, 69°17'W) and Esperanza (63°24'S, 56°59'W). Data were extracted from the World Surface Meteorological database supplied by the Japanese Meteorological Agency. Dr Naganobu reported that high SLP differences were associated with strong westerly winds and that low SLP differences were associated with weak westerly winds; the strength of the westerly winds governed the magnitude of Ekman transport (Defant, 1961).

Selected Subjects of Interest to the Subgroup

3.9 During the 1991 meeting of WG-Krill (SC-CAMLR-X, Annex 5), the topic of krill transport through Area 48 by the general oceanic circulation was discussed. Three hypotheses were proposed to account for the krill populations in Subareas 48.1, 48.2, and 48.3: (i) that each subarea has a self-contained stock; (ii) that all of Area 48 has a single stock; or (iii) that the Antarctic Peninsula is the major source of krill that is transported through each subarea by the circulation. A schematic diagram was developed showing the general circulation and a simple conceptual model proposed. Favouring hypothesis (iii), WG-Krill recommended that the Scientific Committee pay attention to fluxes in Area 48 and the interaction of physical and biological processes.

3.10 At the 1994 meeting of WG-Krill, the Working Group considered the topic of krill biomass and fluxes (SC-CAMLR-XIII, Annex 5, Appendix D). In evaluating krill flux factors, WG-Krill considered the report from the Workshop on Evaluating Krill Flux Factors which ran the Fine Resolution Antarctic Model (FRAM) and compared results with the geostrophic flow calculated from some of the existing hydrographic data from Area 48 (the AMLR data were not used in this exercise). FRAM predicted velocities much higher than those calculated from direct observation, did not show the counter flow of the Antarctic Coastal Current, and did not resolve seasonal variability in the flow. WG-Krill noted the distinction between theoretical and applied considerations, the utility of smaller-scale repeat surveys, and the necessity for synoptic surveys to resolve the flux problem. The idea that krill is a passive 'tracer', transported from subarea to subarea, remained as a viable hypothesis in the opinion of WG-Krill in 1994.

3.11 Based on the historical CCAMLR perspective, the subgroup considered all the data available to the workshop and formulated a series of questions that it considered to be important to the aims of the workshop. In determining these questions, notice was also taken of recent papers indicating the importance of large-scale processes in the physical environment. The main questions addressed during the workshop were:

(i) Is the NCAR SST dataset a reasonable proxy for ocean temperatures?
(ii) Are global atmospheric (e.g. SOI) signals present in Area 48?
(iii) Are these atmospheric signals evident in the surface layers of the ocean?
(iv) Is there evidence of multi-year signals in the environment?
(v) Is there coherence among the subareas in Area 48?

3.12 In considering these questions a series of lagged cross-correlation analyses were undertaken using GENSTAT 5.3 (Payne et al., 1993). These were based on the methodology described in WS-Area48-98/10. Other comparisons were undertaken by plotting and graphing.

Comparison of NCAR SST and CTD SST

3.13 A comparison of NCAR SST data with data from the AMLR CTD grid was carried out to determine whether the NCAR data provided a good proxy for temperature data measured in the field. In order to accomplish this, 4-m CTD data were extracted from those CTD casts that occurred within each of three NCAR SST grid cells. The cells were located north of Elephant Island – Drake Passage (EI1) (60°30'S, 56°30'W), southwest of Elephant Island – Frontal (EI2) (61°30'S, 56°30'W) and southeast of Elephant Island – Bransfield (EI3) (61°30'S, 54°30'W). The CTD data are accurate to better than 0.01°C.

3.14 A plot of weekly NCAR SST data, monthly NCAR SST data and AMLR 4-m CTD data are shown in Figure 3. This indicated that the NCAR data were a reasonable proxy for data collected in the field, with the best approximation being in Elephant Island EI3.

Conclusions

3.15 It was concluded that no statistical analysis was possible with the present data, however it was recognised that a formal analysis was appropriate and should be pursued intersessionally. As the graphical comparison between the NCAR SST and the AMLR 4-m CTD temperatures suggested broad similarities, it was concluded that for the purposes of the workshop, the large-scale NCAR dataset should be used for comparisons within Area 48.

Global Atmospheric Signals in Area 48

3.16 Lagged cross-correlation analysis of SOI anomalies and DPOI anomalies (1982 to 1992) indicated that positive correlations existed between the two indices with the SOI leading the DPOI by three to four months and by 69 months. Negative correlations were also evident, with maximum correlation at a temporal lag of 43 to 44 months. Based on the significance of levels identified by $\pm 2/\sqrt{n}$ (where n is the number of values in the data series), the correlations were determined as significant, though only just so.

3.17 Lagged cross-correlation analysis of SOI anomalies and Palmer Station air temperature anomalies (1951 to 1996) indicated that strong correlations existed with the SOI leading the Palmer air temperatures. The most significant positive correlation occurred at a lag of 0 month, and the most significant negative correlation at approximately a lag of 20 months.

Conclusions

3.18 The analysis of SOI, DPOI and Palmer Station air temperature suggests that global atmospheric signals were evident in Area 48. The available data for the DPOI covered a relatively short time period (10 years), suggesting that care should be exercised in interpreting this correlation. The subgroup suggested that the analysis of DPOI should be continued with the addition of recent data. The time series for the Palmer Station air temperatures was considerably longer (45 years), suggesting that this atmospheric correlation was more robust.

Evidence of Atmospheric Signals in the Ocean

3.19 Lagged cross-correlation analysis between the SOI anomalies and EN4 anomalies indicated very strong correlations, with the strongest relationship being evident as a negative relationship at a lag of zero months.

3.20 Lagged cross-correlation analysis of SOI anomalies and sea-ice extent at the Antarctic Peninsula (1987 to 1997) indicated that correlations existed with the SOI leading the sea-ice.

3.21 A lagged cross-correlation analysis between SOI anomalies and South Georgia (54°30'S, 34°30'W) anomalies showed strong negative correlations at a lag of 34 months and strong positive correlations at four months. In contrast, lagged cross-correlation analyses between EN4 anomalies and South Georgia NCAR SST anomalies showed strong positive correlations at a lag of 34 months and strong negative correlations at 11 months. These inverse results are consistent with the anticipated negative relationship between SOI and EN4. However, for all lag periods, the correlations between EN4 and South Georgia were stronger than the correlations between SOI and South Georgia. A similar analysis for the Southeast Pacific (61°30'S, 75°30'W) showed a similar result with the strongest correlations between the Southeast Pacific and EN4 at a lag of 28 months.

Conclusions

3.22 As anticipated, the comparison between SOI and EN4 indicated that SST is negatively correlated with SOI. The analyses also confirm conclusions made by earlier investigators that large-scale signals are evident in the sea-ice extent data (for example, Carlton and Carpenter, 1989; Murphy et al., 1995; White and Peterson, 1996) and SST data (White and Peterson, 1996). The comparison between SOI and South Georgia, and EN4 and South Georgia suggested that the most obvious correlations were evident from EN indices rather than from the SOI index. The strong correlation between surface seawater temperatures at South Georgia and those recorded in the Western Pacific is highlighted (WS-Area48-98/10), and is consistent with the general circulation pattern of the Pacific.

Evidence of Multi-year Signals in the Environment

3.23 Lagged auto-correlation analyses for the separate EN anomaly indices indicated that very strong serial correlations exist in the Pacific, with the strongest relationship evident at a lag of 50 months (WS-Area48-98/10).

3.24 Lagged auto-correlation analysis for SST anomalies at a reference point in the Southeast Pacific (61°30'S, 75°30'W) indicated that very strong serial correlations exist, with the strongest relationship evident at a lag of 50 months. Similarly, an auto-correlation analysis for SST anomalies at South Georgia (54°30'S, 34°30'W) indicated strong correlations at a lag period of 49 months (WS-Area48-98/10).

3.25 Spatial and temporal coherence was evident in the sea-ice, including evidence of a four-year cycle, confirming earlier results from other investigators (e.g. Murphy et al., 1995; White and Peterson, 1996).

3.26 The NCAR SST series for the Elephant Island area and the South Orkneys showed a multi-year warming over the latter part of the series. Figure 4 shows SST anomalies from South Georgia, South Orkneys and Elephant Island EI1 and EI2. From 1992 the temperatures at the South Orkneys, Elephant Island EI1 and EI2 show a multi-year trend.

Conclusions

3.27 Strong periodicity was evident in some of the global signals (EN) as well as in variables that described the local physical environment in Area 48 (sea-ice and NCAR SST). The period of these signals was approximately four years, equivalent to the periodicity described by White and Peterson (1996).

3.28 Other multi-year signals are also present in the NCAR SST data, with (short-term) warming trends apparent in some areas.

Coherence Among Subareas within Area 48

3.29 Lagged cross-correlation analysis between EN4 anomalies and SST anomalies for the reference point in the Southeast Pacific indicated that very strong correlations existed between the two indices, with the strongest relationships evident as positive correlations at a lag of 26 months. Similarly, an analysis between EN4 and South Georgia (54°30'S, 34°30'W) indicated strong cross-correlations at a lag of 34 months.

3.30 The difference in temporal lag for the maximum correlations between EN4 and the Southeast Pacific and the maximum correlation between EN4 and South Georgia is consistent with the circumpolar anomaly precession as reported by Murphy et al. (1995) and White and Peterson (1996). Thus the time lag between the Southeast Pacific and South Georgia was approximately eight months. White and Peterson (1996) reported that a single phase of the Antarctic Circumpolar Wave (ACW) takes approximately eight to nine years (see also Murphy et al., 1995) to propagate around the globe and that two phases are generally present. This would suggest that for the ACW to travel from the Southeast Pacific to South Georgia (41° of longitude) should take just over six months, a value comparable with the estimate derived here.

3.31 Lagged cross-correlation analysis between EN4 and Elephant Island EI1 indicated correlations exist between the two indices. However, the correlations were not as strong as those determined for the Southeast Pacific or South Georgia. Furthermore, the correlations did not follow the same simple pattern consistent with the ACW. For example, positive correlations existed at a slightly later date than those for the Southeast Pacific, however the maximum correlation peak was noisy. A similar analysis for EN4 and the South Orkneys (60°30'S, 47°30'W) showed a similar picture with noise around the maximum correlation peak.

3.32 The ACW reported by White and Peterson (1996) was described for the Antarctic Circumpolar Current (ACC); thus it may be anticipated that correlations may be weaker for areas adjacent to the Antarctic Peninsula. In these areas other factors are likely to be important, for example, continental waters or outflow from the Weddell Sea may influence local oceanographic signals.

3.33 The calculated estimate for the precession of SST anomalies is consistent with the analysis of simulation data that indicate that water transport across the Scotia Sea from the Antarctic Peninsula region occurs with a mean of about six to eight months (WS-Area48-98/8).

3.34 However, drifter data indicate that realised rates of transport may be much greater. Values of three to four months are typical for the large-scale transport from the Antarctic Peninsula to South Georgia. Transport in about two months has also been recorded.

3.35 The subgroup noted that transport across the Scotia Sea depends on the precise nature of the flow field. The ACC comprises a series of broad slow-moving zones, separated by fast-moving frontal regions. The frontal systems are important in the transport of material across the Scotia Sea. The positions of these are known to vary but there are no recent time series which allow this to be clarified for the present exercise. Furthermore, the NCAR SST data are not of sufficient resolution to show changes in the position of fronts.

Conclusions

3.36 NCAR SST data for the Drake Passage and South Georgia are consistent with the multi-year cycle described by White and Peterson (1996). Although data from positions close to the Antarctic Peninsula and the South Orkneys have similar signals, they are less strong and indicate that either local effects, or influences from other areas (such as the Weddell Sea), may also be important.

3.37 Estimates of coherence across the Scotia Sea are compatible with the mean flow field. However, the subgroup emphasised that transport may also occur at much shorter time scales.

Indices for Analyses

3.38 In order to combine variables describing the physical environment with those describing krill and krill-dependent predator populations, a series of physical indices was calculated. To maintain compatibility with the krill and predator indices, environmental indices were based on summer and winter values. Summer was defined as the months from November to March (inclusive) and winter as the months from June to October (inclusive). Summer and winter indices were determined for NCAR SST, EN1+2, EN3, EN4, SOI, DPOI, Palmer Station air temperature and sea-ice extent (Figures 5 to 8). For the NCAR SST dataset, indices were determined by averaging summer and winter months for all included SST data.

3.39 The NCAR dataset provides global coverage of SST, with areas covered by sea-ice represented by a single fixed value (-1.79°C). As the areas selected for the NCAR SST indices may occasionally include sea-ice, especially in winter, the NCAR indices should be considered as a type of ice–ocean index.

3.40 For the South Georgia region, NCAR SST data were selected to cover the summer foraging range of predators from Bird Island. The selected areas also include a proportion of the winter foraging range of many krill-dependent species. The NCAR data were selected to avoid high levels of correlation expected from adjacent positions in the global grid.

3.41 For the Antarctic Peninsula region, NCAR SST data were selected to cover the summer and winter foraging ranges of predators foraging from Anvers Island, Admiralty Bay and Signy Island.

3.42 For the Scotia Sea region, NCAR SST data were selected to include the areas already selected for South Georgia and the Antarctic Peninsula, together with additional areas of the Scotia Sea.

3.43 For the Elephant Island area, indices were also calculated from the CTD grid of the AMLR Program. The indices were based on CTD casts within each of three NCAR SST grid cells. The cells were located north of Elephant Island (EI1), southwest of Elephant Island (EI2) and southeast of Elephant Island (EI3). CTD data within each NCAR cell were averaged for each year to produce a single temperature index for each year at the surface (in reality 4 m depth), 100 m and 500 m.

3.44 The deeper levels have oceanographic significance in Area 48. The temperature at the 100-m level approximates the winter water temperature minimum in the Antarctic Surface Water. This layer, detectable in summer, is the residual from the previous winter's upper mixed layer temperature and may be thought of as a 'fossilised' temperature, perhaps giving insight into the temperatures during the previous season's winter. At 500 m, Circumpolar Deep Water (CDW) occurs north of the South Shetlands. This warm, deep layer may encroach onto the shelf and mix with waters originating from the Weddell Sea and Bransfield Strait.

3.45 The areas of the NCAR cells (Elephant Island EI1, EI2 and EI3) within the AMLR region approximately define oceanographic domains of similar temperature and salinity characteristics. However, to further refine the classification, stations were grouped into one of five temperature and salinity zones (Amos and Lavender, 1992) with values for each of the three months (January to March) covering the AMLR surveys. The indices are the mean temperatures at 4 m, 100 m, and 500 m. In Figure 9 the mean temperatures for Drake Passage and Bransfield Strait waters are contrasted. By inspection, temperatures at 100 m are out of phase with the surface waters in the same year.

3.46 Figure 10 compares the temperature index at 100 m in the winter water minimum with the Antarctic Peninsula winter SST. Contrary to expectations, the indices appear in phase.

KRILL

4.1 Krill data on abundance, recruitment and population structure for Subareas 48.1 and 48.3 available for analysis at the workshop are summarised in Table 1.

Krill Abundance

4.2 Estimates of krill abundance derived from acoustic surveys were available from both subareas. The methods used to collect the data in the two subareas were broadly comparable, however, there were differences in technique that are likely to have introduced biases into the absolute values obtained. WS-Area48-98/9 presents the best estimates of krill biomass obtained from surveys undertaken around South Georgia (Subarea 48.3) between 1980/81 and 1997/98. The techniques used to identify krill acoustically have evolved during the data series; the earliest cruises classified all acoustic targets as krill, later cruises used either echo-chart classification or dB difference to partition acoustic biomass estimates into krill, zooplankton and nekton. Results from US AMLR surveys in Subarea 48.1 were summarised from published reports and had been loaded onto the workshop website.

4.3 WS-Area48-98/9 indicated that acoustic densities at the eastern end of South Georgia were generally higher than those estimated for the western end of the island. This difference was particularly apparent in 1997/98. In addition, the subgroup recognised that there is considerable intra-annual variability in krill acoustic density estimates (Hewitt and Demer, 1994). To overcome this problem, acoustic surveys discussed here have been restricted to the period around January each year, the one exception being the 1981/82 survey in Subarea 48.3 which took place in November and December 1981.

4.4 WS-Area48-98/11 compared the acoustic estimates for Subarea 48.3 with those produced for the Elephant Island region of Subarea 48.1. Although there were differences in sampling techniques, in particular for krill identification and diel sampling period, the subgroup agreed that these were unlikely to alter the general patterns observed between years in the two subareas.

4.5 The analysis presented in WS-Area48-98/11 indicated that krill densities at both South Georgia and Elephant Island fluctuated markedly between years. Moreover, in all but one of the years where data were available from both regions, changes in density occurred in the same direction at both sites (Figure 11). The exception was the 1997/98 season where krill biomass at South Georgia increased to one of the highest values seen in the entire data sequence (see also paragraph 4.17).

4.6 For years where acoustic data exist for both subareas, very low krill biomasses were observed concurrently in both Subareas 48.1 and 48.3 in 1993/94. While in Subarea 48.3 a similarly low biomass was observed in 1990/91, the biomass in Subarea 48.1 in 1990/91 was no lower than biomasses observed in 1983/84 and 1984/85.

4.7 For Subarea 48.1 both net and acoustic density data were available. A comparison of the two datasets (Figure 12) revealed that changes in density from year to year occurred in the same direction for both acoustic and net densities. Note, however, that the absolute relationship between the two density estimates was not constant, major changes were observed around 1985/86 and 1992/93. The subgroup was unable to establish the cause of such changes with the information available at the meeting.

Krill Population Structure

4.8 Changes in the population structure of krill in Subareas 48.1 and 48.3 were analysed in two separate ways. Firstly, recruitment indices were used as a way of considering what proportion of the population was present in particular year classes. Secondly, the shape of length-frequency histograms from scientific haul-by-haul data was used to investigate the overall population structure in each area.

4.9 Proportional krill recruitment indices for Subarea 48.3 are presented in WS-Area48-98/20. In this paper the length-frequency distributions have been weighted by the acoustically determined density of krill for the eastern and western ends of South Georgia. Such a technique was developed because relatively few standard station hauls were carried out and so it was necessary to include acoustically targeted net hauls.

4.10 At South Georgia the proportional krill recruitment of the 1+ year class (R1) was low in spawning years 1988/89, 1989/90, 1991/92 and 1993/94 (Figure 13). In contrast, a year of very high recruitment was observed for the 1+ year class spawned in 1994/95, this decreased for krill spawned in the following year and had reached zero recruitment for the krill spawned in 1996/97. Note, however, that for this last year many of the krill were found to be intermediate in size between that normally observed for 1+ and 2+ aged krill. The analysis presented in WS-Area48-98/20 allocated these small krill to the 1+ year class. Inspection of krill from

Subarea 48.1 revealed not only the presence of 2+ aged krill that were smaller than usual but also some 1+ aged krill that were smaller than usual. As a result, the subgroup re-allocated these krill found in Subarea 48.3 to the 2+ year class.

4.11 R1 in the Elephant Island region has been presented at previous meetings of WG-EMM. Comparison of these data with those from South Georgia showed considerable concordance (Figure 13). Thus, in both areas krill spawned in years 1988/89, 1989/90, 1991/92 and 1992/93 all showed very low R1 (<0.1), in addition krill spawned in 1994/95 showed very high recruitment followed by reduced recruitment in both areas. Unfortunately it was not possible to check the concordance between other years of high recruitment (spawning years prior to 1982/83, 1987/88 and 1990/91) because of the lack of data for these years around South Georgia.

4.12 The subgroup also considered the results from the proportional krill recruitment index of the 2+ year class (R2). We might expect that for any spawning year a good R1 would be reflected in a good R2. Thus R2 potentially provides data for spawning success for years not covered by R1. However, a comparison of R1 and R2 from South Georgia shows that, where R1 and R2 were available for the same year, there was little agreement on what constituted good and bad spawning years (Figure 14). Although the relationship between R1 and R2 in Subarea 48.1 showed more concordance than in Subarea 48.3, there were still a number of mismatches.

4.13 The comparison of R2 for Elephant Island and South Georgia showed much less concordance than that observed between R1 values (Figure 15). Such a result was not unexpected given the results detailed in paragraph 4.12. The subgroup recognised that this lack of concordance may be due to methodological problems inherent in the calculation of R2, in particular the difficulty in uniquely separating this year class from larger krill, the longer time period over which environmental influences may operate and the areas sampled in relation to the overall distribution of the krill population.

4.14 Abundance data (from acoustic surveys in Subarea 48.3 and net data in Subarea 48.1) and recruitment data were combined to estimate absolute recruitment of the 1+ year class (Figure 16). The overall trend for Subarea 48.1 was that absolute recruitment was highest from spawning in 1979/80 to 1981/82. Recruitment peaks from spawning in 1987/88 and 1994/95 were relatively low. It was not possible to compare the strength of recruitment peaks in Subarea 48.3 as only one peak was observed in the data. However, it is evident that low absolute recruitment occurred in spawning years 1988/89, 1989/90, 1991/92 and 1992/93 because, irrespective of the total amount of krill, the proportion of 1+ aged krill was extremely low.

4.15 Scientific survey haul-by-haul length-frequency data were available from both Subareas 48.1 and 48.3 over the period 1980/81 to 1997/98 as well as 1983/84 and 1987/88 where data were available from Subarea 48.2. Such data have considerable potential to help understand linkages within the system but it is necessary to reduce these length-frequency distributions to a more easily assimilated index. The subgroup used a cluster analysis technique that was developed for length-frequency distributions around South Georgia (WG-EMM-97/47).

4.16 A cluster analysis based on length-frequency haul-by-haul data, grouped into size classes <30 mm, 30–40 mm, 40–50 mm, and >50 mm, was performed using the furthest neighbour (complete link) hierarchical clustering algorithm in Genstat 5.4.1 (Payne et al., 1993). Grouped data were treated as Euclidean distances and standardised over a range of 0 to 100. The dendrogram of the resulting cluster analysis revealed the presence of four main clusters between 55 and 75 % similarity. The distribution of these clusters was plotted against haul position for each cruise. Following the cluster analysis, the percentage of each cluster type in each subarea in each year was calculated. This gives a measure of the relative proportions of the broad categories of length-frequency distribution in each subarea. These data were then used to calculate a similarity matrix, again assuming that they represent Euclidean distances with a range of 0 to 100. Similarities between Subareas 48.1 and 48.3 for each year where both were sampled were extracted from the matrix. Subarea 48.2, which contained samples from only two years, was considered too poorly represented for inclusion in the similarity index.

4.17 The krill length-frequency similarity index (Figure 17) shows that krill in Subareas 48.1 and 48.3 were very similar in three years (1989/90, 1992/93 and 1996/97). In contrast, some years were very different, for a varying number of reasons. The largest difference between the two subareas was found in 1993/94. In this year large krill were found around the Antarctic Peninsula and around South Georgia. However, at South Georgia some medium to small krill were also found. In 1997/98 medium-sized krill were well represented in both subareas. However, in Subarea 48.3 large krill were found while these were not present in Subarea 48.1. Similarly, in Subarea 48.1 small krill were found which were not present in Subarea 48.3. Although a low similarity value was observed in 1987/88, this result was most likely due to the low number of hauls taken in Subarea 48.3 in this year.

4.18 WS-Area48-98/15 presents length-frequencies of krill taken from predators at South Georgia for the period from 1990/91 to 1996/97. These data indicate considerable variation in the size of krill taken in each season (Figure 18). However, in 1990/91 and 1993/94 large krill (modal size ~58 mm) were taken in December but were completely replaced by small krill (modal size ~40 mm) by February. WS-Area48-98/15 predicted that a similar pattern would be observed in 1997/98 and data presented at the meeting indicated that such a decrease in the size of krill taken by predators had indeed occurred.

4.19 Additional krill length-frequency data from penguin diet samples at Admiralty Bay (Subarea 48.1, see Attachment D) were not critically examined given the short time available at the workshop.

Krill Fishery Data

4.20 Krill fishery data for Subareas 48.1, 48.2 and 48.3 were analysed to provide a combined index for each subarea for each year. The subgroup considered that such data might be useful because the fishery at South Georgia takes place in the winter and so these data could provide information on temporal lags of a different period to those obtained from scientific survey data (which were usually restricted to the summer season).

4.21 Total catch and fishing effort data were extracted from the CCAMLR database (fine-scale catch and effort). For the Japanese krill fishery the effort index was the number of vessel days, where days are the number of days in a reporting period (e.g. ten days). For all other fleets the measure of fishing effort was the number of hours fished. Data were grouped for each fleet and for each fine-scale reporting rectangle.

4.22 Fishing areas were defined as follows:

(i) Elephant Island: the area between 60°–61°30’S and 50°–58°W in Subarea 48.1;
(ii) Livingston Island: the area between 61°30’–63°S and 58°–70°W in Subarea 48.1;
(iii) South Orkneys: all of Subarea 48.2;
(iv) Bird Island: the area between 53°–55°S and 37°–40°W in Subarea 48.3; and
(v) East South Georgia: the area from 53°–55°S and 34°–37°W in Subarea 48.3.

Fishing periods were defined as winter and summer. The winter period was defined as the months of May to October inclusive and summer the months of November to April inclusive.

4.23 Indices of CPUE were calculated and then averaged by fishing season and area.

4.24 The indices were analysed using the Combined Standardised Index (CSI) (see paragraph 7.9) and the results presented in Figure 19 (summer and winter CPUE).

4.25 In Subarea 48.1 the pattern of CPUE from 1982/83 to 1992/93 followed the same pattern in the Elephant Island and Livingston Island areas. Outside that period this pattern was not present.

4.26 In Subarea 48.2 there is some evidence for an increasing trend over the 1980s but otherwise no clear pattern was present.

4.27 At South Georgia (Subarea 48.3 – a winter fishery), the CPUE reached a minimum around Bird Island in 1991 and 1994 and at the eastern end there were minimums in 1991 and 1993. These may reflect krill density, either in advance of, or following, the low density observed from scientific surveys in the 1990/91 and 1993/94 summer seasons.

4.28 The subgroup noted that CPUE indices on these time and space scales were not necessarily the best indicators of local density but that haul-by-haul data would be better. Such data were not used at the workshop and in any case it would have taken a great deal of time to complete any analysis.

4.29 The subgroup considered that length-frequency data from the commercial fishery were likely to be of interest but that considerable work would be required to overcome the net selectivity problems inherent in these datasets.

BIOTIC ENVIRONMENT

Primary Production

5.1 Dr C. Hewes (USA) reported that phytoplankton biomass, measured in terms of chlorophyll concentration, had large inter-, intra-annual and spatial variability. Integrated (0–100 m) chlorophyll concentrations were averaged over the entire US AMLR survey area for each year (surveys made from January to March, Figure 20). Years 1991/92, 1992/93 and 1997/98 were below, and 1989/90 and 1994/95 were above, the average phytoplankton biomass. Comparisons with Subareas 48.2 and 48.3 were not possible since chlorophyll data were not available for these other regions. Years of low chlorophyll concentrations corresponded with those of EN (low summer SOI) (Figure 20).

Zooplankton Assemblages

5.2 Dr Loeb reported that over the past six years net collections made in the Elephant Island area during US AMLR summer surveys have demonstrated a shift from strong numerical dominance by salp (*Salpa thompsoni*) (1993) to copepods (1995 and 1996) and back to salp (1998). These shifts have been associated with abundance changes of one order of magnitude for copepods (primarily *Metridiagerlachei*) and two orders of magnitude for salp. The intervening 'transition' periods (1994 and 1997) were marked by distinct changes in copepod and salp abundance over summer months. These abundance changes occurred over relatively brief time spans (four to six weeks) and could be due to a change in advective regimes (i.e. from poleward to equatorward advection).

5.3 Dr Loeb indicated that summers marked by salp dominance and relatively low copepod abundance ('salp years') have become a recurring phenomenon in this area over the past two decades. Major salp blooms have been noted every four to five years since summer 1983/84.

Dr Loeb also noted that this periodicity conforms to the eastward precession of anomalies described by Murphy et al. (1995) and the ACW wave described by White and Peterson (1996).

5.4 Dr Naganobu reported on WS-Area48-98/4 which dealt with variability of the proportion of salp and green krill (coloured by active phytoplankton feeding) density, using data from Japanese krill trawlers operating near the Antarctic Peninsula. Interannual and seasonal variability of the timing, duration and strength of salp blooms and green krill were analysed. No relationship between salp density and proportion of green krill in the catches was evident, when both salps and krill were found together. In the Livingston Island area, the proportion of green krill was high only when salp density was extremely low. However, no clear relationship was observed in the Elephant Island area.

5.5 The workshop considered these results and concluded they warranted further analysis. However, because they are related to limited areas of Subarea 48.1, and comparable results were not available from other localities, further consideration was referred to WG-EMM.

MARINE PREDATORS OF KRILL

Mackerel Icefish

6.1 The mackerel icefish (*Champsocephalus gunnari*) is found on the shelf of South Georgia, Shag Rocks, the South Orkney and South Shetland Islands in water down to 500 m depth. The species is known to feed preferentially on krill and during ‘good krill years’ its condition index is high (WS-Area48-98/19).

6.2 Studies have been undertaken on diet, feeding status and condition indices. The only dataset which provided a reasonable time series and for which information was available from more than one site was the condition index.

6.3 The condition index is calculated for individual fish from two variables: total mass and estimated total mass. Condition index is the ratio of total mass to estimated total mass. Data from 6 000 fish caught in seven seasons were used to determine an ‘average’ length-to-mass relationship. This relationship was then used to calculate an estimated mass for each of the 24 000 fish over 27 years used in the study.

6.4 Results were initially presented as mean values by month for South Georgia, Shag Rocks, Elephant Islands and South Shetlands (WS-Area48-98/19). To conform with the summer and winter periods recognised for land-based predators of krill, the data were combined into two seasonal indices, summer (November–April) and winter (May–October).

6.5 Periods when the condition index was low were:

(i) South Georgia during the summers of 1977/78, 1982/83, 1990/91 and 1993/94 and winters of 1972, 1985, 1990 and 1997;

(ii) Shag Rocks during the summers of 1972/73, 1986/87 and winter 1997;

(iii) South Shetlands during summer 1984/85; and

(iv) Elephant Island during the summers of 1978/79, 1983/84, 1984/85 and 1987/88.

Whales

6.6 The IWC has four types of whale data that potentially could be of use in addressing the questions posed for this workshop. These include sightings survey results from the International Decade of Cetacean Research (IDCR), from Japanese scouting vessels, commercial catch statistics and biological data taken from a sample of the catch. When divided into Subareas 48.1, 48.2 and 48.3, data of all four types were too sparse to allow meaningful comparisons among areas.

6.7 One source, the Japanese scouting vessels' sightings data, did allow estimation of abundance indices for seven years in Subarea 48.1, and four years in Subarea 48.2 (Figures 21 and 22). Indices were computed for blue, fin, humpback, sei, right and minke whales. Only for minke whales were there sufficient sightings to justify further scrutiny.

6.8 In Subarea 48.1, minke whale abundance was relatively stable during 1973/74, 1974/75, 1975/76, 1979/80 and 1981/82. In 1985/86 the relative abundance increased substantially, approximately sixfold from the previous level. In 1986/87 the index dropped, but only about halfway to the previous level. Assuming these data provide a reasonable index of minke whale abundance, they suggest that the 1985/86 season was notably different. Krill availability to minke whales may have been better that year in Subarea 48.1.

6.9 In Subarea 48.2, as in Subarea 48.1, only data from minke whales were sufficient to justify further scrutiny. Among the four years in which that area was searched, 1980/81 appears to stand out as having about twice the density of minke whales as during 1973/74, 1981/82 and 1985/86. Keeping in mind that these indices are presented without dispersion statistics, and the other relevant caveats, the increase in 1980/81 to just over double the other years' indices may well indicate improved krill availability to minke whales that year.

LAND-BASED MARINE PREDATORS

Data Availability

7.1 In the original subgroup circular, five sites (Bird Island, Signy Island, Seal Island, Admiralty Bay and Anvers Island) were identified for which at least five years of continuous data on dependent species exist.

7.2 For Signy Island, Seal Island and Anvers Island there were no data, additional to those in the CEMP database, available at the workshop. For Bird Island and Admiralty Bay several additional datasets and indices were provided before and/or at the start of the workshop.

7.3 Several shorter (<5 years) time series of data were also available at the workshop, either in the CEMP database (e.g. A1, A2, A3, A6a, A7 for Esperanza 1993/94–1996/97) or in tabled papers (e.g. Antarctic fur seal growth rates at Cape Shirreff 1994/95–1997/98, WS-Area48-98/18).

7.4 It was agreed to concentrate initially on analysis of the larger and longer datasets. If time permitted, the other datasets would be examined to see the extent to which they supported, or contradicted, the conclusions or inferences derived here.

7.5 The datasets available for analysis are summarised in Tables 2 to 4. Additional information on the sources and nature of the data from Bird Island and Signy Island is provided in WS-Area48-98/12 and 98/13.

7.6 Table 3 indicates the relatively restricted nature of the data available for comparisons of species across sites and at scales other than multi-year (population size) and summer.

Data Arrangement and Combination

7.7 In Table 5 the predator indices are set out in logical groupings reflecting relatively discrete biological processes. These have potential for combination into a single index. Other combined indices could also be formed to reflect the temporal scales shown in Table 5.

7.8 It is also possible to create new indices by combining some of the existing ones using simple formulae. Such indices were termed composite indices and examples of predator performance are given in Table 6.

Data Analysis

7.9 Based on the approach developed in WG-EMM-Stats-97/7, WS-Area48-98/6 provides a computer program to calculate a combined index, which we term the Combined Standardised Index (CSI). CSIs were derived from different sections of the database to provide summaries of time series within sites, species and seasons, even though the statistical properties of the index were not completely understood.

7.10 There was insufficient time at the workshop to investigate the combined indices in Table 5, other than those for summer and winter (the latter including population size). There was no time to investigate the use of composite indices.

7.11 Therefore important future tasks to help refine and improve the present analyses would be:

(i) to compare the results of using indices combining all original variables with those combining single indices each representing a group of biologically related variables. (For several species and sites, the combined indices are currently weighted heavily in favour of diet variables.);

(ii) to investigate the use of composite indices to replace the indices included in their calculation. (Note that the use of yield per offspring should eliminate the problems of small numbers of surviving offspring in bad years having weaning/fledging mass greater than the population mean in good years. In addition, provisioning indices would take account of potential trade-offs between meal mass and meal delivery rate.);

(iii) to compare critically the results of using winter indices with and without population size;

(iv) to provide a method of estimating confidence limits around the CSI; and

(v) to examine patterns/scales of variability within the predator indices including investigation of the effects of varying the composition of the indices contributing to each CSI.

7.12 The combined summer and winter indices for each species at each site are illustrated in Figures 23 to 27.

7.13 It should be noted that all analyses, except as otherwise indicated, were performed with the original untransformed values. After Figure 23 was produced, imputed values were substituted for black-browed albatross population size in 1987/88 and population size and hatching (but not rearing) success in 1994/95.

7.14 The initial inspection of the summer indices in Figures 23 to 27 attempted to identify years of notably poor reproductive performance (see Table 7).

7.15 The next stage was to combine species within sites. To ensure that this did not involve combining species with very different patterns of reproductive performance across years, a correlation matrix was created for the combined summer variables separately (Table 8). This table highlights variables with statistically significant correlations. However, correlations between numerous variables must be interpreted cautiously as chance alone may result in a number of significant correlations. Therefore these values were used only as a guide to the level of correlation appropriate for combining or separating species within sites.

7.16 As a consequence, in respect of summer variables, species were separated across sites as follows:

(i) Bird Island, South Georgia (see Figure 28) –
The three diving species (two penguins and Antarctic fur seal) were separated from black-browed albatross. (The lower similarity between black-browed albatross and the other species is principally due to its performance in 1987/88 and 1994/95. These were the two years of greatest abnormality in physical environmental conditions around the time of egg laying, causing numerous changes in reproductive phenology and performance, not all of which will have been addressed through the use of imputed values.)

(ii) Signy Island, South Orkney Islands (see Figure 29a) –
The correlation coefficients suggest that Adélie penguins should be separated from the other two species; this was not, however, implemented at the time that this analysis was undertaken, whereby all three species were combined. In addition to the strong positive relationship between gentoo and chinstrap penguins, Figure 7a indicates possible time-specific differences in responses, particularly for Adélie penguins, whereby performance indices for the 1990s are generally higher than those for the 1980s.

(iii) Admiralty Bay (see Figure 29b) –
There were low correlations for all interspecies comparisons but no indication that any separation was warranted. However, the relationship between Adélie and gentoo penguins indicates strong association across all years in the 1990s but no such relationship for the 1980s. Such a pattern is not evident in the other interspecies comparisons at this site. At neither Signy Island nor Admiralty Bay is there evidence of year-specific similarities in performance of Adélie and chinstrap penguins.

(iv) Seal Island –
There was high correlation between the two species (chinstrap penguin and Antarctic fur seal) which were combined.

7.17 The resulting summer indices are shown in Figure 30 (note that the data for black-browed albatross now include the imputed values for 1987/88 and 1994/95). The resulting identification of years of poor reproductive performance is summarised in Table 9.

7.18 This suggests that there is evidence of coherence in respect of summer indices:

(i) in 1983/84 between Subareas 48.3 and 48.2. Note no data for Subarea 48.1;

(ii) in 1989/90 between Subareas 48.2 and 48.1 (but not chinstrap penguin at Seal Island);

(iii) in 1990/91 across the whole of Area 48, except for Signy Island; and

(iv) in 1993/94 between Subareas 48.3 and 48.2, but not Subarea 48.1 (except Seal Island).

7.19 We also investigated potential inter-relationships between species and sites by constructing a correlation matrix for breeding success – a variable which should reflect overall summer reproductive performance and which is recorded for most long time series at most sites. (The eight year datasets from Seal Island and Anvers Island were excluded from this analysis). To complete the matrix across all sites for the years 1981/82 to 1997/98 (to 1996/97 for Signy Island) values were imputed (by linear interpolation) for Antarctic fur seals at Bird Island in 1982/83 and for all three penguin species at Admiralty Bay in 1983/84.

7.20 The results, shown in Table 10 (to which the same caveats apply as in paragraph 7.15) indicate that there are trivial differences between the datasets with or without the imputed values.

7.21 Taking values >0.4 to represent correlations of biological interest, the three strongest correlations are all within-site (Admiralty Bay gentoo and Adélie penguins, Signy Island gentoo and chinstrap penguins, Bird Island gentoo penguins and Antarctic fur seals). It may be relevant that all these include gentoo penguins, a resident species of restricted foraging range which is typically very sensitive to fluctuations in prey availability. A group of somewhat weaker correlations exist for several comparisons between Bird Island and Signy Island. These involve gentoo penguin and fur seal at Bird Island with some combination of the three penguin species at Signy Island. However, gentoo penguins at Bird Island and Signy Island show no significant correlation – possibly reflecting their highly restricted, site-specific distribution at all times of year.

7.22 Another approach to examining the relationships across indices within and between species is to use Principal Component Analysis (PCA). The advantages and limitations of this technique are indicated in Attachment E. There was insufficient time to apply this technique to the appropriate predator datasets (i.e. especially to species within and between sites). An example, showing the application of the technique to gentoo penguins at Bird Island and Admiralty Bay, is provided in Attachment E.

7.23 Comparison of subareas using site-specific combined summer variables is illustrated in Figure 31. (In interpreting this figure attention has been focused on the bottom-left and upper-right quadrants, which approximate to coherence in bad and good years respectively.)

7.24 For Subarea 48.3 (Bird Island (BIG)), coherences are apparent for:

Subarea[1]	Bad	Good	None
48.2 (SIO)	83/84, 93/94	84/85, 85/86, 87/88, 88/89, 94/95[2], 95/96, 96/97	78/79–82/83, 86/87, 89/90, 90/91
48.1 (SES)	90/91, 93/94	87/88, 88/89, 94/95[2], 95/96[2], 96/97	89/90, 91/92, 92/93
48.1 (ADB)	77/78[2], 90/91	84/85, 88/89, 91/92, 94/95–96/97	81/82, 82/83, 85/86–87/88, 89/90, 92/93, 93/94

1 For explanation of codes, see Table 2.
2 Weak effect

7.25 For Subarea 48.2 (Signy Island (SIO)) the main coherences appear to be:

Subarea[1]	Bad	Good	None
48.1 (SES)	89/90[2], 93/94	87/88, 88/89, 94/95[2], 95/96[2], 96/97	90/91, 91/92, 92/93
48.1 (ADB)	81/82[2], 82/83, 89/90	84/85, 88/89, 91/92, 94/95–96/97	85/86–87/88, 90/91, 92/93, 93/94

[1] For explanation of codes, see Table 2.
[2] Weak effect

7.26 For within Subarea 48.1 the main coherences between Admiralty Bay (ADB) and Seal Island (SES) are:

Subarea[1]	Bad	Good	None
48.1 (SES)	89/90, 90/91, 92/93	84/85, 88/89, 91/92, 94/95–96/97	87/88, 91/92[2], 93/94

[1] For explanation of codes, see Table 2.
[2] Weak effect

7.27 Overall this suggests that there is:

(i) moderate coherence (years fairly equally divided between coherence (good or bad) and incoherence) between Subarea 48.3 and Subareas 48.2 and 48.1, with more coherence in the latter with Seal Island than Admiralty Bay;

(ii) greater coherence between Subareas 48.2 and 48.1, again with stronger relationships with Seal Island than Admiralty Bay;

(iii) good coherence (strong in terms of the aggregate of years but more of these fall close to the main axes) between the two sites in Subarea 48.1; and

(iv) little change in the assessment of responses to notably bad years (i.e. 1990/91 and 1993/94) from that set out in paragraph 7.18.

7.28 To summarise the nature of coherences in bad years from the summer indices (see paragraph 7.18):

(i) 1983/84 – coherence between Subareas 48.3 and 48.2; no data for Subarea 48.1;

(ii) 1989/90 – coherence between Subarea 48.2 and Admiralty Bay in Subarea 48.1. Seal Island is complex with penguins showing longest ever foraging trips and third lowest fledging mass, balanced by largest meal mass. Antarctic fur seals show average foraging trip but low growth rates;

(iii) 1990/91 – coherence throughout Area 48, except Signy Island, where penguin breeding success was normal. However, breeding population sizes in 1991 were 20 to 30% lower than in the previous year, the biggest reductions on record. (This contrasts with 1984 where breeding populations were not reduced but breeding success was very low); and

(iv) 1993/94 – coherence between Subareas 48.3 and 48.2, but in contrast clear evidence of a good year in Subarea 48.1 at Anvers Island and Admiralty Bay. Seal Island apparently transitional (second lowest fledging mass, average foraging trip duration, large meal mass).

7.29 Substantial association across subareas in good years is evident for:

1984/85 – Subareas 48.3, 48.2 and 48.1 (Admiralty Bay but not Seal Island);
1987/88 – Subareas 48.3, 48.2 and 48.1 (Seal Island but not Admiralty Bay);
1988/89 – whole area;
1994/95 – whole area;
1995/96 – whole area; and
1996/97 – whole area.

7.30 Based on the analysis in paragraph 7.24 of the results presented in Figure 31, a scoring system was developed to examine the overall pattern of coherence across years. This involved scoring a year with a -1 if the comparison fell into the 'bad' (bottom left in Figure 31) category; +1 if it fell into the 'good' (upper right in Figure 31) category and 0 if it fell into neither of these. The totalled score for each year was divided by the sample size for each year to give an index between -1 and 1. In cases where the index was -1 this indicated absolute coherence of bad conditions across sites whereas when the index was +1 it showed absolute coherence of good conditions across sites. When the index was 0 then there was no overall coherence across sites.

7.31 Between 1977/78 and 1980/81 only one coherence measure was available but for later years the sample size was three to six except for 1983/84 when only one coherence measure was available. Coherence was either low or suggested that conditions for predators were generally poor during the early 1980s but generally conditions were good during the late 1980s (Figure 32). The index showed low coherence and conditions were generally bad during the early 1990s and in the late part of the time series the index showed a return to high coherence with good conditions.

7.32 This index provides an overall view of the temporal variability in linkages between sites used to monitor predators in Area 48. It suggests that there may be a multi-year pattern of variability with shifts from generally bad conditions for predators with relatively low coherence across monitoring sites to relatively good conditions and high coherence. Each of these phases appears to last approximately five to six years.

7.33 Investigation of the winter indices for species at sites (Figures 23b, 24b, 25b and 27b) is complicated by the fact that population size is usually the main (and often the only) variable. For most species there are strong trends in population size across all or part of the dataset, which make identifying comparable years of poor performance across the whole dataset more difficult.

7.34 Figure 33 indicates that population trends across all or part of the time series exist for:

(i) Bird Island – black-browed albatross (decline throughout); macaroni penguin (decline since 1984); gentoo penguin (small decline overall, more noticeably since 1989);

(ii) Signy Island – Adélie penguin (increase 1979–1989; decline thereafter, especially to 1995); gentoo penguin (increase overall); chinstrap penguin (slight decline overall);

(iii) Admiralty Bay – Adélie penguin (decline, especially since 1989); chinstrap penguin (decline since 1979); gentoo penguin (decline since 1980); and

(iv) Anvers Island – Adélie penguin (decline throughout).

Thus amongst all species and sites, only Antarctic fur seal at Bird Island shows an essentially stable (albeit with substantial fluctuations) population across the complete time series.

7.35 In preparation for combining species within sites, a correlation matrix (Table 11) was prepared. This is more complex to interpret than the similar matrix for summer variables. The following separations/combinations were adopted:

(i) Bird Island, South Georgia (see Figure 34a) –
No consistent pattern, except that black-browed albatross and macaroni penguin are strongly correlated; however, no change was made to the distinction, adopted for the summer variables, between black-browed albatross and the three diving species.

(ii) Signy Island (see Figure 34b) –
Gentoo and Adélie penguins weakly correlated; no other obvious pattern.

(iii) Admiralty Bay (see Figure 34c) –
Gentoo and chinstrap penguins weakly correlated; no other obvious pattern.

For both the last two sites Adélie and chinstrap penguins were separated for analysis of winter variables.

7.36 The resulting combined winter indices for species at sites are shown in Figure 35. The identification of years of poor reproductive performance is shown in Table 12.

7.37 Coherence in bad years across subareas may include:

(i) 1980 (penguins (excluding Adélie) at all sites/subareas, but weakest at Bird Island);

(ii) 1984 (penguins at Bird Island and Signy, but weak at latter);

(iii) 1990 (penguins at all sites/subareas – less evident for Adélie at Admiralty Bay, but population size declined by 25%, the second largest decline in the 20-year database);

(iv) 1994 (penguins at all sites/subareas); and

(v) 1997 (all species at Bird Island; gentoo and Adélie penguins at Admiralty Bay).

7.38 In relation to the main bad years inferred from the summer variables (see paragraph 7.28), the above suggests that the 1990 winter (preceding the 1990/91 summer) was also bad. In contrast, the bad winters of 1984 and 1994 followed the bad summers of 1983/84 and 1993/94.

7.39 To further investigate patterns of population change, a correlation matrix of the difference between populations in successive years was created (Table 13). Missing values for chinstrap and gentoo penguins at Admiralty Bay in 1984 dictated that a time series without imputed values could only commence in 1985 (first difference in 1986). Imputing (by linear interpolation) these 1984 values and also those for Antarctic fur seal and gentoo penguin at Bird Island in 1979 and 1983, and 1981 respectively, allowed the time series to commence in 1979 (first difference 1980).

7.40 In the longer time series the correlations of potential biological significance (>0.4) were chiefly between Bird Island and Signy Island penguins (seven of nine correlations) and between chinstrap penguins at Admiralty Bay and chinstrap and gentoo penguins at Signy. Only three potentially relevant within-site correlations exist: Adélie and chinstrap penguins at Signy, Antarctic fur seal and macaroni penguin at Bird Island, gentoo and chinstrap penguins at Admiralty Bay.

7.41 In the shorter time series there are more, and stronger, correlations. All but one (gentoo and chinstrap penguins at Admiralty Bay) of those from the longer time series are still present. Additional correlations are between chinstrap penguins at Admiralty Bay and all penguins at Bird Island and Signy, Adélie penguins at Admiralty Bay and Signy, Antarctic fur seal and macaroni penguin at Bird Island, gentoo and Adélie penguins at Signy. The differences between the two datasets suggest that greater coherence between sites was a stronger feature of the period after 1986.

7.42 Comparison of subareas using site-specific combined winter variables is illustrated in Figure 36.

7.43 This suggests that there is evidence of coherence between subareas in respect of winter indices as set out below:

For Subarea 48.3 (Bird Island) with:

Subarea/Species[1]	Start	Bad	Good	None
48.2 SIO (PYP, PYN)	77	78, 80, 84, 90, 94	77, 85, 88, 89, 92	79, 81–83, 86, 87, 91, 93, 95–97
48.2 SIO (PYD)	77	78, 80, 84, 90, 94, 95	77, 85, 87–89	79, 81–83, 86, 91–93, 96, 97
48.1 ADB (PYP, PYN)	77	90, 94, 97	77, 79, 81, 87, 88, 92	78, 80, 82–86, 89, 91, 93, 95, 96
48.1 ADB (PYD)	77	90, 93, 94	77, 81, 87, 88, 89	78–80, 82–86, 91, 92, 95–97

[1] For explanation of codes, see Table 2.

For Subarea 48.2 (Signy Island) with:

Subarea/Species[1]	Start	Bad	Good	None
48.1 ADB (PYP, PYN)	77	83, 90, 94	77, 88, 92, 95	78–82, 84–87, 89, 91, 93, 96, 97
48.1 ADB (PYD)	77	79, 90, 94	77, 86-89, 97	78, 80–85, 91–93, 95, 96

[1] For explanation of codes, see Table 2.

7.44 Overall this suggests:

(i) moderate coherence (years fairly equally divided between coherence (good and bad) and incoherence) across subareas; and

(ii) most coherence operates across the whole of Area 48. This is in contrast to the results from the summer variables, presumably reflecting the greater spatial and temporal scales over which the winter variables integrate.

7.45 More specifically, in respect of bad years, there is evidence of coherence for:

(i) 1978, 1980 and 1984 – Bird Island and Signy only;
(ii) 1990 – all sites/subareas; and
(iii) 1994 – all sites/subareas.

7.46 These circumstances probably reflect responses of predators at the population level. However, whereas those in 1990 precede the bad summer of 1990/91, those in 1984 and 1994 follow the bad summers of 1983/84 and 1993/94. In the first case the low populations at the beginning of 1990/91 may reflect predators in poor condition over winter electing not to breed in that summer. In the second case the low populations in the year after bad summer conditions may reflect continuing poor conditions over winter and/or reduced survival and recruitment.

7.47 In respect of good years, coherences are indicated for:

(i) 1977 and 1988 – all sites/subareas; and
(ii) 1989 – Bird Island, Signy Island (all penguin species) and Adélie penguins at Admiralty Bay.

7.48 The results of a similarity analysis, like that for summer variables (see paragraph 7.30), are shown in Figure 32. (Six coherence measures were available for winter variables for each year.) Figure 32 suggests that the pattern of fluctuation of winter indices of population performance generally resembles that of the summer indices. This is particularly true for the strong positive sequence of years from 1985 to 1989. Adjacent periods match somewhat less well, the winter values showing a more complex mixture of positive and negative values. This is likely to reflect some combination of the larger spatial and temporal scales over which winter population processes integrate and the fact that the winter index combines variables with short and long temporal scales.

ENVIRONMENT–PREY–PREDATOR INTERACTIONS

Background

8.1 A synthesis of some aspects of interannual variability of the Southern Ocean ecosystem was presented in WS-Area48-98/8. This highlighted the extensive evidence that there are years when there is a very low abundance of krill in the South Georgia area, and that the variation affects much of the ecosystem with the most obvious impacts on survival and breeding success of some of the major krill predators. The open nature of the South Georgia ecosystem means this variability has large-scale relevance.

8.2 Fluctuations in year class success in parts, or all, of the population across the Scotia Sea, can generate large changes in the available biomass. The ocean transport pathways, maintain the large-scale ecosystem structure by moving krill over large distances to areas where they are available to predator colonies. This large-scale physical system shows strong spatial and temporal coherence in the patterns of the interannual and sub-decadal variability. The physical variability affects both the population dynamics of krill and the transport pathways, emphasising that both the causes and consequences of events at South Georgia are part of much larger-scale processes.

8.3 Model analyses of krill demography and large-scale transport were presented which highlighted how both aspects are important in generating the observed variability. The krill population dynamic processes introduce lags which mean that analyses with environmental variables must be carried out with caution. A conceptual model was presented illustrating how the physical variability can affect krill demography, distribution and abundance.

8.4 Predators are likely to respond to the integrated signal from several environmental variables simultaneously in a way that cannot readily be reflected by bivariate plots amongst environment, prey and predator variables. This theme was developed in WS-Area48-98/16 in which a single predator performance index (16-year time series of fur seal foraging trip duration at Bird Island) was related to several environmental indices, including El Niño Southern Oscillation (ENSO), sea-ice and krill recruitment.

8.5 The results suggested that there was significant cross-correlation between ENSO and fur seal foraging at lags of -9 and +11 months. The negative lag might suggest that fur seals anticipate ENSO. However, this effect is probably the result of harmonics from cyclical processes that are best represented by the positive lag at approximately one year. Overall, these results suggest that Antarctic fur seals at South Georgia are influenced (albeit indirectly) by large-scale physical processes.

8.6 Furthermore, in a multiple regression analysis the combination of sea-ice indices lagged by one year and ENSO also lagged by one year explained a large proportion of the variation in fur seal foraging trip duration. This also suggested that ENSO influenced fur seal foraging trip duration at South Georgia up to one year after the main effect in the Pacific but that variance in foraging trip duration due to physical variables in multiple regression models was greater when ENSO was present in combination with the sea-ice index. Therefore, by combining physical variables in a single analysis it was possible to explain more of the variation in behaviour, suggesting that Antarctic fur seals are responding to environmental factors that depend on both sea-ice and ENSO variability.

8.7 Relationships between population change in Adélie and chinstrap penguins in Subareas 48.1 and 48.2 and ice duration and extent (both in the vicinity of breeding colonies and in areas co-extensive with the penguins winter foraging range) have been investigated by Fraser et al. (1992) and Trathan et al. (1996). Both papers concluded that there was evidence of ice-mediated effects on penguin populations, chiefly in winter, and that these were different for the two species.

8.8 In WG-EMM-95/63 changes in Adélie penguin population size and demography at Admiralty Bay (Subarea 48.1) were linked to reported declines in winter sea-ice extent (Stammerjohn and Smith, 1996) and krill biomass (Siegel and Loeb, 1995) in this same region. Adélie cohort survival dropped from a mean of 22% for the 1982 to 1987 cohorts to 10% for the 1988 to 1995 cohorts. Adélie population size also declined precipitously in 1990 and 1991, two years after the change in cohort survival (consistent with the age of first recruitment at two years in Adélie penguins). These findings suggest that Adélie penguins are responding to observed changes in their physical and biotic environments. However, interpreting the mechanisms and interactions underlining these responses is complicated by multi-year effects known to influence changes in population size and demography.

8.9 WS-Area48-98/17 investigates interspecies differences in the reproductive performance of predators at South Georgia in years of high and low prey availability. The order-of-magnitude difference in krill biomass between 1986 (good year) and 1994 (bad year) was accompanied by: (i) 90% reduction in the mass of krill in predator diets (and some increase in the fish component); (ii) greater prey diversity for most species; (iii) reduced diet overlap between species; and (iv) switching from krill to amphipods in macaroni penguin but no major dietary change in other species. Rates of provisioning offspring decreased by 90% in gentoo penguin and 40 to 50% in the other three species; this was due to reduced meal size in penguins (by 90% in gentoo and 50% in macaroni) and to doubling of foraging trip duration in albatrosses. Breeding success was reduced by 50% in grey-headed albatross (the species least dependent on krill), by 90% in black-browed albatross and gentoo penguin (only 3 to 4% of eggs producing fledged chicks) but only by 10% in macaroni penguin, presumably reflecting its ability to switch to small prey unprofitable for the other species. All species (except black-browed albatross) and particularly macaroni penguin produced fledglings significantly lighter than usual, probably affecting their subsequent survival. These results indicate a coherent, though complex, pattern of within- and between-species similarities and differences, mainly reflecting degree of dependence on krill, the feasibility of taking alternative prey and constraints on trip duration and/or meal size imposed by foraging adaptations (especially relating to travel speeds and diving abilities). Therefore even in a year of very low prey availability there may be important interspecies differences in indices of predator performance – albeit within an overall pattern of poor performance.

8.10 Dr Naganobu reported on the relationship between krill recruitment and DPOI (WS-Area48-98/5). The DPOI showed good correlation with the variability of krill recruitment. The years with high DPOI, meaning strong westerlies, coincided with the high recruitment of krill (1981/82, 1987/88 and 1990/91). The large values of mean R1 occurred in the years of high DPOI (1981/82, 1987/88 and 1990/91). Conversely, the years of extremely small DPOI, meaning weak westerlies, coincided with the extreme poor recruitment of krill (1982/83, 1983/84, 1988/89, 1991/92 and 1992/93). The low values of mean R1 occurred in the years of low DPOI for 1982/83, 1983/84, 1988/89, 1991/92 and 1992/93 respectively. Other years of the low mean R1, e.g. in 1984/85 and 1989/90, approximately coincided with weak values of the DPOI. These coincidences between the DPOI and R1 suggest that the strength of the westerly winds affects krill recruitment through variability of oceanographic conditions mainly caused by Ekman transport. The years of the low DPOI also coincided with EN years in 1983, 1988 and 1992. The result suggests that the DPOI is linked with the SOI.

Workshop Analysis of Interactions

8.11 A combined set of environment, prey and predator indices was generated based on the indices derived by the subgroups. The physical variables consisted of atmospheric indices relating to EN, regional and large-scale SST, and regional and large-scale descriptions of sea-ice. The prey data included indices of recruitment and density of krill. The predator data included information on fish and on land-based predators. The land-based predator data included composite indices based on a number of species and variables and indices based on only one or two species.

8.12 A description of the combined dataset is given in Table 14. This highlights that even with this derived set of data there are many variables for which the data series are incomplete and a number for which there are only a few data points. This restricts the potential of the multivariate analyses to give a complete view of the interactions.

8.13 The analyses were undertaken using three basic approaches with considerable interaction between the different individuals involved in carrying out the analyses. This allowed ideas and information to be exchanged as the analyses progressed. The three approaches were: (i) to develop bivariate plots of some of the relationships; (ii) to undertake a preliminary multivariate analysis; and (iii) to carry out a multiple regression exercise based on the ideas presented in Adams and Wilson (unpublished).

Bivariate Relationships

8.14 There were a number of pre-existing hypotheses relating indices of aspects of krill biology and ecology to environmental variation and others relating predator biology to prey and environmental variability. These were examined using bivariate plots of key variables. As the multivariate analyses developed, these helped in the process of focusing on some of the key relationships. This process was not completed and is best regarded as a first preliminary assessment of the data. It should also be remembered that the data are not independent samples but are time series.

8.15 Attention was given first to relationships between the krill variables from the two subareas. This illustrates (Figure 37) that although there is a general coherence between the acoustic density recorded in Subareas 48.1 and 48.3 this is mainly based on the simultaneous occurrence of years of low krill density in 1991 and 1994. Attention was drawn to the fact that these surveys were based on very different methodologies and may not be fully comparable.

For the relationship between krill recruitment in the two areas there is little resolution in the data as there are so few data points. There is some indication of coherence in 1995 and 1996 when recruitment was high in both subareas.

8.16 An initial examination of the krill density and recruitment values from the two areas in relation to the regional summer SST based on the derived indices does not suggest any simple relationships, although particular years are highlighted (Figure 38).

8.17 The hypothesised relationship of krill recruitment to sea-ice based on data from Subarea 48.1 was examined by plotting the proportional recruitment in Subarea 48.1 against the South Shetland sea-ice index (Figure 39). This suggests that for values of the recruitment index above about 0.3 there is an increase in the proportional recruitment as the ice index increases. Below an index value of 0.3 the data are highly variable and suggest that such values cannot be adequately resolved.

8.18 A plot of log-transformed absolute recruitment against the sea-ice index indicates that higher recruitment occurs at higher values of the index (Figure 40). This is, however, more variable than the relationship for proportional recruitment.

8.19 Plots of the recruitment against the regional sea-ice index in Subarea 48.3 do not reveal simple relationships although there are very few data available (Figures 41 and 42).

8.20 Bivariate plots of the density of krill in Subarea 48.1 and various environmental variables such as regional SST, sea-ice and the larger-scale summer SOI did not reveal any simple relationships, although particular years are identified as outliers in a number of the plots (Figures 43 to 45; see also paragraph 8.35).

8.21 In Subarea 48.3 krill density did not show a relationship with the regional SST index (Figure 46). However, there did appear to be an association between the krill density, the regional sea-ice and the large-scale summer SOI index (Figures 47 and 48; see also paragraph 8.35). These analyses emphasised the difference of the low density years of 1991 and 1994 which occurred in low ice years.

8.22 It was noted in a number of the plots that there is auto-correlation in the time series. In some this is revealed as a cyclical effect. This is illustrated in Figure 49 where the performance of the diving predators at Bird Island and the regional winter SST show a tendency to cycle together. This is not a simple direct response of the performance to the environmental variation and suggests that further examination of the underlying dynamics of some of the relationships will be valuable.

8.23 On the basis of previous hypotheses a number of plots were made of some of the predator performance indices and the krill and environmental values (Figures 50 and 51).

8.24 The performance during summer of the Bird Island diving predators (CSI) shows a relationship with the acoustic density of krill in the area with highest performance values at the highest densities (Figures 51 and 52; see also paragraph 8.32). However, this appears to be an asymptotic relationship, although again attention was drawn to the fact that the krill data were based on different surveys covering different regions.

8.25 The condition index for icefish is assumed to be primarily dependent on krill availability. Consequently, the relationship between icefish condition index and average krill density was investigated.

8.26 Data were available from Subareas 48.1 and 48.3. The mean summer icefish condition index was plotted against average acoustic krill density for the same period. Icefish data from South Shetlands and Elephant Island were used for comparison in Subarea 48.1. In

Subarea 48.3 all the krill acoustic data were from surveys on the South Georgia shelf and these were plotted against icefish data from that region. No comparable data were available for Shag Rocks or the South Orkneys.

8.27 The results are plotted in Figure 53. The correlation between icefish condition and krill density was significant ($r^2 = 0.73$, $N = 10$). The relationship appears to be linear, indicating that icefish condition index is a reasonable proxy, over a wide range of values, for average acoustic krill density.

8.28 Periods when condition index was low, and by implication krill availability low, were:

(i) South Georgia during the summers of 1977/78, 1982/83, 1990/91 and 1993/94, and winters of 1972, 1985, 1990 and 1997;

(ii) Shag Rocks during the summers of 1972/73, 1986/87 and winter 1997;

(iii) South Shetlands during summer 1984/85; and

(iv) Elephant Island during the summers of 1978/79, 1983/84, 1984/85 and 1987/88.

8.29 For South Georgia, the relationship between icefish summer and winter condition indices and the combined summer and winter performance indices (CSI) for penguins and Antarctic fur seals are shown in Figure 55 (BIG 3 PS and BIG 3 PW). Although there is good agreement in some of the bad years (e.g. summers 1990/91 and 1993/94, winters 1990 and 1997) and good years (e.g. summers 1984/85, 1988/89, 1994/95 and 1995/96 and winter 1977), the overall pattern does not show particularly high concordance.

Multivariate Relationships

8.30 The next aspect of the analyses involved the development of multiple regression models. Simple bivariate regression highlighted several potentially significant relationships between indices of the physical environment, harvested species and dependent species, some of which have been discussed above (Table 15). To investigate the relative contributions and interactions of some of the physical and biological variables in relation to both harvested and dependent species, the analysis was extended to include multiple regression models.

8.31 Some of these models explained extraordinarily high levels of variability in the dependent variables (e.g. $r^2 > 0.9$), largely because of the high level of parameterisation in relation to limited sample size. However, in some cases it was possible to show that with even a small number of variables in the model (e.g. three variables), a relatively high degree of variability in the data was explained by the model.

8.32 In particular, the CSI of the three diving predators from Bird Island in summer was influenced by krill acoustic density in Subarea 48.3 but the explained variation was increased when physical variation was included in the model (Table 15, models 1–5). When the Scotia Sea SST was present in the model together with the summer SOI, SOI was found to make the greater contribution to variation in predator performance. When sea-ice was considered in the model containing SOI and krill acoustic density (Table 15, models 38–41), sea-ice tended to reduce the importance of the relative contribution made to the explained variation by SOI.

8.33 Bird Island predator performance was weakly related to krill acoustic density in Subarea 48.1 (Table 15, model 18). Overall, Bird Island winter indices were not as closely related to krill acoustic density in the summer or to summer physical variables as the Bird Island predator indices from the summer season (Table 15, models 1–5, cf. 6–10). However, additional analyses are required to examine the predator winter indices in relation to krill acoustic density in the previous summer period.

8.34 The summer predator indices for Subarea 48.1 (Admiralty Bay) showed little or no relationship with krill acoustic density in Subarea 48.1 (Table 15, models 11 and 16). Addition of physical variables, including local sea-ice indices, did not provide extra significant explanatory power (Table 15, models 12–15 and 17).

8.35 Acoustic density of krill in Subarea 48.3 was strongly related to the South Georgia sea-ice index and to the summer SOI (Table 15, models 42–44) but, when present in combination within models, sea-ice was the dominant physical variable affecting krill acoustic density in Subarea 48.3. There was no equivalent set of relationships when krill acoustic density in Subarea 48.1 was considered.

8.36 Overall, these results suggest that land-based predator performance in Subarea 48.3 is influenced by krill density and, independently, by physical variables which have their greatest effect through sea-ice. In contrast, land-based predator performance in Subarea 48.1 is not closely linked with the current indices of krill density or physical variability. In addition, krill density in Subarea 48.1 appears not to be closely related to local sea-ice or other physical variables.

8.37 In a situation where there are such diverse data types including environmental and biological data, a multivariate statistical approach is often adopted. A simple correlation matrix and PCA was performed on the combined table of indices. The aim was to identify any strong coherence between variables and to help clarify the key factors generating variability in the dataset. In particular, the analysis was used to examine questions of coherence between regions and relationships between krill indices and predator performance.

8.38 PCA was applied to data for sea-ice, physical variables, krill acoustic density, an icefish condition index and predator summer and winter indices in Subarea 48.3 to examine association among variables and ordering of years. This analysis has been carried out mainly for illustration. The scope of the analysis was limited due to incomplete data, since PCA can only be used when data are present for all variables (Attachment E).

8.39 The results are shown graphically in Figure 55. The first principal component, which accounted for 50% of variance in the data, is dominated by physical variables, mainly sea-ice and SST. Interestingly, SOI in summer was different because it was more closely aligned with the second axis.

8.40 The additional proportion of variation explained in the data by the second axis was 25%. Thus, the total variation due to the first two axes was 75%. The second axis was representative of the summer biological indices, SOI and krill acoustic density. However, winter biological variables were aligned more closely with the first axis and therefore were associated with the sea-ice.

8.41 Despite the limited number of years that could be included in this particular analysis the relationships among years were consistent with previous analyses that identified anomalous years in the data time series.

8.42 Additional analyses were undertaken using, for example, krill-related variables individually in order to include a larger sample of years. These and other similar analyses provided results that were broadly consistent with those shown in Figure 54.

8.43 A Canonical Correspondence Analysis (or other multivariate analytical techniques) approach is likely to be useful with such data where many of the relationships involved are not linear. Careful consideration of the development of a detailed multivariate model is required and would take more time than was available to the subgroup. The subgroup felt that there were clear indications from the analyses carried out that such an approach might be useful. The subgroup considered that it was important to develop such an analysis in the future.

Long-term Trends

8.44 From the analyses the subgroup noted that there were some indications of longer-term change in the data. There is evidence of sub-decadal/decadal variability in the SST data from Elephant Island. There were also some indications that such variability was present at the South Orkneys but not at South Georgia. From krill density, estimated from net sampling, in Subarea 48.1 there are indications of sub-decadal/decadal variability with higher values prior to 1985 (Siegel et al., 1998). For land-based marine predators there are indications that reproductive performance in the 1980s was consistently different from the 1990s based on data for penguins (particularly Adélie) at Signy and Adélie and gentoo penguins at Admiralty Bay (paragraph 7.16; see also paragraph 7.41). There was not time at the workshop to examine this further. The subgroup considered that further investigation might be useful.

SUMMARY CONCLUSIONS

9.1 In respect of the workshop's terms of reference (paragraph 2.4) and hypotheses being addressed (paragraph 2.5), the following results were emphasised.

9.2 Environment:

(i) Global ocean/atmosphere signals (SOI, Western Pacific SST) were evident in Area 48 (DPOI, Palmer Station air temperature, sea-ice, SST) (paragraphs 3.18 and 3.22).

(ii) Approximately four-year periodicity was evident (SST, sea-ice, Eastern Pacific SST) which was consistent with previous studies (paragraph 3.27).

(iii) Precession of SST anomalies across Scotia Sea was consistent with the FRAM advective transport model, suggesting transport times of four to eight months between Antarctic Peninsula and South Georgia (paragraph 3.33).

(iv) Global ocean/atmosphere signals (SST) showed strongest coherence with South Georgia and weaker coherence with the Antarctic Peninsula and the South Orkneys, implying different local influences (such as Weddell Sea) (paragraph 3.36).

(v) Warming trend over last seven years was apparent in the NCAR SST data only at the Antarctic Peninsula and the South Orkneys (paragraph 3.26).

9.3 Krill:

(i) Patterns of year-to-year variation in krill density (as measured by acoustic surveys) and population demographics (as defined by R1) were similar in Antarctic Peninsula and South Georgia (paragraphs 4.5 to 4.11):

	Antarctic Peninsula	South Georgia
Low densities	1990/91	1990/91
	1993/94	1993/94
High R1	1982/83	No Data
	1987/88	No Data
	1994/95	1994/95
Low R1	1988/89	1988/89
	1989/90	1989/90
	1991/92	1991/92
	1992/93	1992/93

(ii) Length frequency of krill in the diet of predators at South Georgia for 1991 to 1997 showed a pronounced change between two modal sizes during the course of 1991 and 1994 but not in other years (paragraph 4.18).

9.4 Dependent species:

(i) Although the whale data were extensive in spatial and temporal coverage, the temporal overlap with other available datasets in Area 48 was restricted. Of note, minke whale abundance was highest during 1980/81 in Subarea 48.2 and 1985/86 in Subarea 48.1 (paragraphs 6.7 and 6.8).

(ii) Most land-based predator indices showed greater coherence between species within sites than across sites (paragraph 7.16).

(iii) Land-based predator indices in summer were coherent across subareas in 'good' years (1984/85, 1987/88, 1988/89, 1994/95 to 1996/97), and in 'bad' years (1990/91 and 1993/94), particularly 1990/91 (paragraphs 7.23 to 7.29).

(iv) Coherence in land-based predator indices for summer across subareas was generally more evident in good than in bad years (paragraphs 7.28 and 7.29).

(v) Winter land-based predator indices show less coherence across subareas than summer indices. When there was coherence (1990 and 1994 as 'bad' years, 1977, 1988 and 1989 as 'good' years), it was more consistently area-wide than in summer (paragraphs 7.44 to 7.47).

(vi) There was no consistent sequence in land-based predator indices between bad winters and bad summers; that is, either can precede the other (paragraph 7.45).

9.5 Interactions:

(i) Proportional krill recruitment above an index value of approximately 0.3 was correlated with sea-ice extent in the Antarctic Peninsula (paragraph 8.17).

(ii) Krill density at South Georgia (Subarea 48.3) was associated with regional sea-ice and summer SOI. This particularly emphasised the low krill density and low sea-ice in 1990/91 and 1993/94 (paragraphs 8.21 and 8.35). In contrast, krill density at the Antarctic Peninsula (Subarea 48.1) was not associated with indices of physical variability (paragraphs 8.20 and 8.34).

(iii) Land-based and pelagic predator indices in Subarea 48.3 were correlated with summer krill densities but were also influenced independently by physical variables (paragraphs 8.21, 8.24, 8.27 and 8.34). In contrast, land-based predator indices in Subarea 48.1 were not correlated with krill or physical indices (paragraphs 8.20 and 8.34).

9.6 It was agreed that the summary statements presented above offer a useful basis for the development of working hypotheses on the ecosystem dynamics of Area 48.

CLOSE OF WORKSHOP

10.1 The report of the workshop was adopted. In closing the meeting, Dr Hewitt thanked all workshop participants for their contributions.

10.2 On behalf of the participants and WG-EMM, Dr Everson thanked Dr Hewitt for his tremendous work in organising the workshop, keeping participants informed during the period leading up to the workshop, and for chairing the workshop.

10.3 Dr Miller also thanked Dr Hewitt for his efforts, and the Southwest Fisheries Science Center for hosting the workshop and providing excellent technical and logistic support. He thanked Mrs J. Leland (UK) and Dr D. Ramm (Secretariat) for their valuable support at the workshop. Dr A. Murray (UK) expressed his appreciation to the Center's computing staff.

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Table 1: Krill data available at the workshop. L: length-frequency data; R: recruitment indices; D: density estimates from net sampling; A: density estimates from acoustic surveys.

Year	Subarea		
	48.1	48.2	48.3
1977/78	L D R	L	L
1978/79			
1979/80			
1980/81	L D R A		L A
1981/82	L D R		L A
1982/83	L D R		
1983/84	L D R A	L	L
1984/85	L D R A		
1985/86	R		L
1986/87	R A		L
1987/88	L D R A	L	L
1888/89	L D R A		
1989/90	L D R A		L R A
1990/91	L D R A		L R A
1991/92	L D R A		A
1992/93	L D R		L R A
1993/94	L D R A		L R A
1994/95	L D R A		
1995/96	L D R A		L R A
1996/97	L D R A		L R A
1997/98	L D R A		L R A

Table 2: Predator index reference matrix for Antarctic fur seal (SEA), gentoo penguin (PYP), Adélie penguin (PYD), chinstrap penguin (PYN), macaroni penguin (EUC) and black-browed albatross (DIM). Each series represents presence (1) or absence (0) of data for Bird Island South Georgia (BIG), Signy Island (SIO), Admiralty Bay (ADB), Seal Island (SES) and Anvers Island (AIP), respectively. The time span over which indices integrate is divided into multi-year (MYEAR), year (YEAR), winter (WIN) and summer (SUM).

Index	Units	Code	SEA	PYP	PYD	PYN	EUC	DIM	MYEAR	YEAR	WIN	SUM
Juvenile survival	proportion	1	00000	00100	00100	00000	00000	00000	00100	00000	00000	00000
Breeding population size	absolute number	2	10000	11100	01101	01100	10000	10000	11111	00000	11111	00000
Adult survival	rate	3	00000	00100	00100	00100	00000	10000	00000	10100	00000	00000
Arrival/lay date	d before 31 Dec	4	10000	10000	00000	00000	00000	10000	00000	00000	10000	00000
Arrival mass male	g	5	00000	00000	00100	00100	10000	00000	00000	00000	10000	00000
Arrival mass female	g	6	00000	00000	00100	00100	10000	00000	00000	00000	10100	00000
Birth mass female	g	7	10000	00000	00000	00000	00000	00000	00000	00000	10100	00000
Birth mass difference (m-f)	g	8	10000	00000	00000	00000	00000	00000	00000	00000	10000	00000
'B' egg size	ml	9	00000	00100	00100	00100	00000	00000	00000	00000	00100	00000
Incubation shift duration (m+f)	d	10	00000	00000	00100	00100	00000	00000	00000	00000	00000	00100
Meal mass	g	11	00000	10100	00100	00110	10000	00000	00000	00000	00000	10110
% fish by mass	1-proportion	12	00000	10100	00101	00110	10000	00000	00000	00000	00000	10011
Frequency of occurrence fish	1-proportion	13	10000	10100	00101	00110	10000	00000	00000	00000	00000	10111
% krill by mass	proportion	14	00000	10100	00101	00110	10000	00000	00000	00000	00000	10111
Frequency of occurrence krill	proportion	15	10000	10100	00101	00110	10000	00000	00000	00000	00000	10111
Foraging trip duration	h.-1	16	10110	00000	00001	00010	00000	00000	00000	00000	00000	10011
Offspring growth female	kg.month	17	10010	00000	00000	00000	00000	00000	00000	00000	00000	10010
Offspring growth difference (m-f)	kg.month	18	10010	00000	00000	00000	00000	00000	00000	00000	00000	10010
Offspring combined growth	kg.month	19	00000	00000	00000	00000	00000	00000	00000	00000	00000	00000
Fledge/weaning mass female	g	20	10000	00000	00000	00000	00000	00000	00000	00000	00000	10000
Fledge/weaning mass difference	g	21	10000	00000	00000	00000	00000	00000	00000	00000	00000	10000
Fledge/weaning mass combined	g	22	00000	10000	00101	00110	10000	10000	00000	00000	00000	10011
Hatching success	proportion	23	00000	00100	00100	00000	00000	10000	00000	00000	00000	10100
Fledging success	proportion	24	00000	00100	00100	00000	00000	10000	00000	00000	00000	10100
Breeding success	proportion	25	00000	11100	01101	01110	10010	10000	00000	00000	10100	11111

Table 3: Summarised predator index reference matrix, emphasising number of variables available for analysis by species, site and time scale (M: multiyear; Y: year; W: winter; S: summer). Shaded areas indicate absence of species at specific sites. Species and site abbreviations as in Table 2.

	SEA				PYP				PYD				PYN				EUC				DIM			
	M	Y	W	S	M	Y	W	S	M	Y	W	S	M	Y	W	S	M	Y	W	S	M	Y	W	S
BIG	1		2	8	1		1	7									1		2	9	1	1	1	4
SIO					1			1	1			1	1			1								
ADB					1	1	2	8	2	1	2	9	1	1	2	7								
SES				3												8				1				
AIP									1			7												

Table 4: Summary of predator indices, indicating years for which data are available (x). Species and site abbreviations and variables (var) as in Table 2. Years are designated by that in which the summer ends; i.e. 76 refers to the 1975/76 summer.

Site	Species	Var	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
ADB	PYN	10								x		x	x	x	x										
ADB	PYN	11			x				x	x					x	x		x						x	x
ADB	PYN	13			x				x	x					x	x		x						x	x
ADB	PYN	14			x				x	x					x	x		x						x	x
ADB	PYN	22													x									x	x
ADB	PYN	25																	x	x	x	x	x	x	x
ADB	PYP	11			x				x	x						x	x	x						x	x
ADB	PYP	12			x				x	x						x	x	x						x	x
ADB	PYP	13			x				x	x						x	x	x						x	x
ADB	PYP	14			x				x	x						x	x	x						x	x
ADB	PYP	15			x				x	x						x	x	x						x	x
ADB	PYP	22																							x
ADB	PYP	23			x				x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
ADB	PYP	24			x				x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
ADB	PYP	25			x				x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
ADB	PYD	10							x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
ADB	PYD	11			x				x	x					x	x	x	x						x	x

Table 4 (continued)

Site	Species	Var	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
ADB	PYD	13			x				x	x					x	x	x	x						x	x
ADB	PYD	14			x				x	x					x	x	x	x						x	x
ADB	PYD	22													x	x	x	x	x	x	x	x		x	x
ADB	PYD	23			x				x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
ADB	PYD	24			x				x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
ADB	PYD	25			x				x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
AIP	PYD	2																	x	x	x	x	x	x	
AIP	PYD	11															x	x	x	x	x	x	x	x	
AIP	PYD	13															x	x	x	x	x	x	x	x	
AIP	PYD	14															x	x	x	x	x	x	x	x	
AIP	PYD	16															x	x	x	x	x	x	x		
AIP	PYD	22															x	x	x	x	x	x	x	x	
AIP	PYD	25															x	x	x	x	x	x	x	x	
BIG	DIM	22														x	x	x	x	x	x	x	x	x	x
BIG	DIM	23		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	DIM	24		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	DIM	25	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	EUC	11		x		x	x					x	x			x	x	x	x	x	x	x	x	x	x
BIG	EUC	13															x	x	x	x	x	x	x	x	
BIG	EUC	14														x	x	x	x	x	x	x	x	x	x
BIG	EUC	15															x	x	x	x	x	x	x	x	
BIG	EUC	22														x	x	x	x	x	x	x	x	x	x
BIG	EUC	25		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	PYP	11		x			x					x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	PYP	13															x	x	x	x	x	x	x	x	
BIG	PYP	14														x	x	x	x	x	x	x	x	x	x
BIG	PYP	15															x	x	x	x	x	x	x	x	
BIG	PYP	22														x	x	x	x	x	x	x	x	x	x
BIG	PYP	25		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	SEA	13																x	x	x	x	x	x	x	
BIG	SEA	15																x	x	x	x	x	x	x	x

Table 4 (continued)

Site	Species	Var	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
BIG	SEA	16				x		x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	SEA	17									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	SEA	18									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	SEA	20				x		x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	SEA	21				x		x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	SEA	25				x		x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
SES	PYN	11													x	x	x	x			x				
SES	PYN	12													x	x	x	x			x				
SES	PYN	13													x	x	x	x			x				
SES	PYN	14													x	x	x	x			x				
SES	PYN	15													x	x	x	x			x				
SES	PYN	16													x	x	x	x	x	x	x				
SES	PYN	22													x	x	x	x	x	x	x	x	x	x	
SES	PYN	25													x	x	x	x	x	x	x	x			
SES	SEA	16													x		x	x	x	x	x	x			
SES	SEA	17													x	x	x	x	x	x	x	x			
SES	SEA	18													x	x	x	x	x	x	x	x			
SIO	PYD	25					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
SIO	PYN	25				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
SIO	PYP	25					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
ADB	PYN	2					x	x								x	x		x	x	x	x	x	x	x
ADB	PYN	3			x				x	x			x	x	x	x									
ADB	PYN	5																	x	x	x	x	x	x	x
ADB	PYN	6																	x	x	x	x	x	x	x
ADB	PYN	9																	x	x	x	x	x	x	x
ADB	PYP	2			x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
ADB	PYP	3			x					x			x	x	x	x	x	x	x	x	x	x	x	x	x
ADB	PYP	9										x	x	x	x	x	x	x	x	x	x	x	x	x	x
ADB	PYD	1							x	x	x	x	x	x	x	x	x	x	x	x	x	x			
ADB	PYD	2			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
ADB	PYD	3			x					x			x	x	x	x	x	x	x	x	x	x	x	x	x

Table 4 (continued)

Site	Species	Var	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
ADB	PYD	5																x	x	x	x	x	x	x	x
ADB	PYD	6																x	x	x	x	x	x	x	x
ADB	PYD	9																	x	x	x	x	x	x	x
AIP	PYD	1							x	x	x	x	x	x	x	x	x	x	x	x	x	x			
AIP	PYD	2																	x	x	x	x	x	x	
AIP	PYD	2			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
AIP	PYD	3			x					x			x	x	x	x	x	x	x	x	x	x	x	x	x
AIP	PYD	5																x	x	x	x	x	x	x	x
AIP	PYD	6																x	x	x	x	x	x	x	x
AIP	PYD	9																	x	x	x	x	x	x	x
BIG	DIM	2		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	DIM	3	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
BIG	DIM	4														x	x	x	x	x	x	x	x	x	
BIG	EUC	2		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	EUC	5														x	x	x	x	x	x	x	x	x	x
BIG	EUC	6														x	x	x	x	x	x	x	x	x	x
BIG	PYP	2		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	PYP	4											x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	SEA	2				x		x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	SEA	4									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	SEA	7										x	x	x	x	x	x	x	x	x	x	x	x	x	x
BIG	SEA	8										x	x	x	x	x	x	x	x	x	x	x	x	x	x
SIO	PYD	2				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
SIO	PYN	2				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
SIO	PYN	2				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	

Table 5: Summary of predator indices (code number in parentheses; see Table 2 for definitions), showing potential groupings at the process level and in relationship to temporal scale.

Index	Index Group	Temporal Scale Group
Juvenile survival (1)		Multi-year
Population size (2)		Multi-year (also winter)
Adult survival (3)		Year
Arrival/laying date (4)	Arrival (4–9)	Winter (4–9)
Arrival/laying mass (5–6)		
Birth/egg mass (7–9)		
Incubation shift (10)		Summer (10–25)
Meal mass (11)	Diet (11–15)	
% Fish (12, 13)	Foraging (11–16)	
% Krill (14, 15)	Foraging trip (16)	
Growth rates (17–19)	Growth (17–22)	
Wean/fledge mass (20–22)		
Hatch success (23)	Productivity (23–25)	
Fledge success (24)		
Breeding success (25)		

Table 6: Potential composite indices of predator performance.

I_2 breeding population size;
I_{11} meal mass;
I_{14} % krill by mass;
I_{16} foraging trip duration;
I_{20} weaning mass, female;
I_{21} weaning mass, difference (m-f);
I_{22} fledging mass;
I_{24} fledging success (chicks reared per egg hatched); and
I_{25} breeding success (pup survival).

Composite Index	Formula	
Yield per offspring	B_1 Birds = $I_{24} \cdot I_{22}$	
	B_1 Seals = $I_{25} \cdot \alpha$	where $\alpha = (2 \cdot I_{20} + I_{21})/2$
Total yield	B_2 Birds = B_1 Birds $\cdot I_2$	
	B_2 Seals = B_1 Seals $\cdot I_2$	
Krill availability	$A_k = I_{11} \cdot I_{14}$	
Provisioning index	PBirds = $(-1) \cdot (I_{11}/I_{16})$	
	PSeals = $(-1) \cdot (\alpha/I_{16})$	$= (-1) \cdot (B_1 \text{ Seals}/I_{25})/I_{16}$

Table 7: Years of poor reproductive performance, based on combined summer index, for land-based marine predators in Area 48 (see Figures 23 to 27 for data). Site and species abbreviations as in Table 2. Years are designated by that in which the summer ends; i.e. 76 refers to the 1975/76 summer.

	Start																					
Bird Island (BIG)																						
DIM	76	78*		80				84*			87	88			91			94	95			98
EUC	77	78	79					84			87*	88*			91*			94				
PYP	77	78				82		84*			87*			90*	91			94				98
SEA	79		79					84							91			94				98
Signy Island (SIO)																						
PYD	80									strong positive trend across series												
PYN	79				81			84						90				94				
PYP	80		79*	80	81			84*			87*			90				94				
Admiralty Bay (ADB)																						
PYD	78													90	91		93*	positive trend after ‘93				
PYN	78					82	83*		85	86*				90*							97*	
PYP	78					82	83				87				91			positive trend after ‘91				
Seal Island (SES)																						
PYN	88														91			94				
Anvers Island (AIP)																						
PYD	90													90	91					96*		

* Weak effect

Table 8: Matrices of correlation coefficients and associated probabilities for summer combined index for land-based marine predators for all species at each site for 1975/76 to 1997/98. Site and species abbreviations as in Table 2. Values significant at P < 0.05 are highlighted and in white; values significant at 0.05 > P < 0.10 are also highlighted.

Correlation coefficients

	ADBPYD	ADBPYN	ADBPYP	AIPPYD	BIGDIM	BIGEUC	BIGPYP	BIGSEA	SESPYN	SESSEA	SIOPYD	SIOPYN	SIOPYP
ADBPYD	1.000												
ADBPYN	-0.118	1.000											
ADBPYP	0.267	0.218	1.000										
AIPPYD	0.44	0.609	0.621	1.000									
BIGDIM	0.229	-0.594	0.044	0.063	1.000								
BIGEUC	-0.029	-0.428	0.136	0.167	0.406	1.000							
BIGPYP	0.02	-0.092	0.132	0.372	0.33	0.576	1.000						
BIGSEA	0.099	-0.309	-0.048	0.432	0.383	0.788	0.768	1.000					
SESPYN	0.416	-0.47	0.069	0.277	0.299	0.419	0.897	0.788	1.000				
SEASEA	0.517	-0.143	-0.282	0.689	-0.066	-0.213	0.45	0.299	0.689	1.000			
SIOPYD	-0.127	0.259	0.637	0.042	-0.065	0	0.215	0.213	0.451	0.263	1.000		
SIOPYN	0.276	-0.022	-0.037	0.433	0.357	0.091	0.321	0.365	0.494	0.625	0.267	1.000	
SIOPYP	-0.146	-0.247	-0.209	0.104	0.242	0.264	0.144	0.36	0.14	0.216	0.13	0.788	1.000

Correlation probabilities

	ADBPYD	ADBPYN	ADBPYP	AIPPYD	BIGDIM	BIGEUC	BIGPYP	BIGSEA	SESPYN	SESSEA	SIOPYD	SIOPYN	SIOPYP
ADBPYN	0.652												
ADBPYP	0.301	0.401											
AIPPYD	0.275	0.109	0.1										
BIGDIM	0.378	0.012	0.866	0.883									
BIGEUC	0.913	0.086	0.603	0.693	0.061								
BIGPYP	0.938	0.725	0.614	0.364	0.144	0.006							
BIGSEA	0.726	0.262	0.865	0.286	0.117	0	0						
SESPYN	0.232	0.171	0.851	0.506	0.401	0.228	0	0.007					
SEASEA	0.189	0.735	0.499	0.13	0.877	0.612	0.263	0.473	0.059				
SIOPYD	0.651	0.352	0.011	0.921	0.797	1	0.408	0.429	0.191	0.53			
SIOPYN	0.32	0.938	0.895	0.283	0.133	0.711	0.194	0.15	0.147	0.098	0.283		
SIOPYP	0.604	0.374	0.454	0.806	0.333	0.291	0.58	0.171	0.7	0.607	0.608	0	

Table 9: Years of poor reproductive performance, based on combined summer index across species within sites, for land-based marine predators in Area 48 (see Figure 30 for data). Site and species abbreviations as in Table 2. Years are designated by that in which the summer ends; i.e. 78 refers to the 1977/78 summer.

	Start																				
Bird Island (BIG)																					
DIM	78		80			83*	84			87	88			91	92*		94*	95			98*
Penguins (PYP, EUC)/Seal	78	79					84							91			94				98
Signy Island (SIO)																					
Penguins (PYP, PYD, PYN)			80	81			84						90				94				
Seal Island (SES)																					
Penguin (PYN)/Seal														91			94				
Admiralty Bay (ADB)																					
Penguins (PYP, PYD, PYN)					82	83							90	91	(positive trend after ‘91)						
Anvers Island (AIP)																					
Penguin (PYD)†													90	91					96*		

* Weak effect
† See Figure 27 for data

Table 10: Correlation matrices of breeding success for land-based marine predators, from 1981/82 to 1997/98, without and with imputation of missing values.

Correlation matrix % breeding success for 1981/82, 1985/86–1997/98 (Signy to 1996/97) – no imputation

	ADBPYDb	ADBPYNb	ADBPYPb	BIGDIMb	BIGEUCb	BIGPYPb	BIGSEAb	SIOPYDb	SIOPYNb	SIOPYPb
ADBPYDb	1.00									
ADBPYNb	0.08	1.00								
ADBPYPb	0.54	-0.04	1.00							
BIGDIMb	0.11	-0.35	0.17	1.00						
BIGEUCb	-0.44	-0.11	-0.15	0.13	1.00					
BIGPYPb	-0.08	0.25	0.22	0.33	-0.21	1.00				
BIGSEAb	-0.16	-0.02	0.16	0.37	-0.19	0.71	1.00			
SIOPYDb	-0.12	0.05	0.47	-0.05	-0.03	0.45	0.31	1.00		
SIOPYNb	0.03	-0.19	-0.05	0.09	-0.24	0.40	0.37	-0.08	1.00	
SIOPYPb	-0.38	-0.25	-0.21	0.11	0.20	0.07	0.40	-0.15	0.67	1.00

Correlation matrix % breeding success for 1981/82–1997/98 (Signy to 1996/97) – imputation by long term means

	ADBPYDb	ADBPYNb	ADBPYPb	BIGDIMb	BIGEUCb	BIGPYPb	BIGSEAb	SIOPYDb	SIOPYNb	SIOPYPb
ADBPYDb	1.00									
ADBPYNb	0.18	1.00								
ADBPYPb	0.55	0.04	1.00							
BIGDIMb	0.04	-0.41	0.12	1.00						
BIGEUCb	-0.28	-0.06	-0.09	0.25	1.00					
BIGPYPb	-0.11	0.16	0.20	0.36	-0.05	1.00				
BIGSEAb	-0.14	0.00	0.16	0.39	0.14	0.70	1.00			
SIOPYDb	-0.03	0.26	0.45	-0.08	0.18	0.39	0.37	1.00		
SIOPYNb	0.04	-0.07	-0.04	0.15	0.24	0.41	0.48	0.11	1.00	
SIOPYPb	-0.35	-0.15	-0.20	0.14	0.31	0.10	0.45	-0.03	0.69	1.00

Table 11: Matrices of correlation coefficients and associated probabilities for winter combined index for land-based marine predators for all species at each site from 1976 to 1998. Site and species abbreviations as in Table 2. Values significant at $P < 0.05$ are highlighted and in white; values significant at $0.05 > P < 0.10$ are also highlighted.

Correlation coefficients

	ADBPYD	ADBPYN	ADBPYP	AIPPYD	BIGDIM	BIGEUC	BIGPYP	BIGSEA	SIOPYD	SIOPYN	SIOPYP
ADBPYD	1.000										
ADBPYN	0.268	1.000									
ADBPYP	0.217	0.625	1.000								
AIPPYD	-0.085	0.129	0.749	1.000							
BIGDIM	0.359	0.283	0.154	-0.891	1.000						
BIGEUC	0.315	0.554	0.116	0.885	0.634	1.000					
BIGPYP	0.116	0.286	-0.35	0.028	0.326	0.3	1.000				
BIGSEA	0.278	0.595	0.219	-0.135	0.396	0.423	0.419	1.000			
SIOPYD	0.319	-0.188	-0.05	-0.11	0.078	0.051	0.54	0.69	1.000		
SIOPYN	0.235	0.274	0.127	0.808	0.246	0.687	0.489	0.486	0.263	1.000	
SIOPYP	-0.217	-0.652	-0.227	-0.952	-0.372	-0.629	0.18	0.256	0.406	-0.359	1.000

Correlation probabilities

	ADPYD	ADBPYN	ADBPYP	AIPPYD	BIGDIM	BIGEUC	BIGPYP	BIGSEA	SIOPYD	SIOPYN
ADBPYN	0.426									
ADBPYP	0.359	0.04								
AIPPYD	0.873	0.808	0.087							
BIGDIM	0.11	0.4	0.517	0.017						
BIGEUC	0.164	0.077	0.628	0.019	0.002					
BIGPYP	0.627	0.424	0.142	0.958	0.149	0.187				
BIGSEA	0.265	0.07	0.399	0.798	0.104	0.081	0.095			
SIOPYD	0.184	0.603	0.843	0.836	0.75	0.836	0.021	0.002		
SIOPYN	0.332	0.444	0.617	0.052	0.31	0.001	0.039	0.048	0.276	
SIOPYP	0.373	0.041	0.366	0.003	0.117	0.004	0.474	0.321	0.084	0.131

Table 12: Years of poor predator performance, based on combined winter index across species within sites, for land-based marine predators in Area 48 (see Figure 34 for data). Site and species abbreviations as in Table 2.

	Start											
South Georgia (BIG)												
DIM	75			80					91			97
Penguins (PYP, EUC)/Seal	76	78		80*		84		90		94		97
Signy Island (SIO)												
Penguins (PYP, PYN)	77			80		84*		90		94		
Penguin (PYD)	77	78						90		94		
Admiralty Bay (ADB)												
Penguins (PYP, PYN)	77			80			85	90		94		97
Penguin (PYD)	77		79		82				91	94	96	

* Weak effect

Table 13: Correlation matrices for population change between successive years for land-based marine predators from 1986 to 1998 (without imputed values) and 1980 to 1998 (with imputed values) (see paragraph 7.39). Site and species abbreviations as in Table 2.

Correlation matrix delta population as % of 1986–1998 (Signy to 1997) no imputation

	ADBPYDdp	ADBPYNdp	ADBPYPdp	BIGDIMdp	BIGEUCdp	BIGPYPdp	BIGSEAdp	SIOPYDdp	SIOPYNdp	SIOPYPdp
ADBPYDdp	1.00									
ADBPYNdp	0.36	1.00								
ADBPYPdp	-0.10	0.25	1.00							
BIGDIMdp	0.34	0.00	0.36	1.00						
BIGEUCdp	0.37	0.61	0.06	-0.10	1.00					
BIGPYPdp	0.41	0.67	-0.08	-0.13	0.86	1.00				
BIGSEAdp	0.34	0.46	0.08	0.06	0.42	0.53	1.00			
SIOPYDdp	0.52	0.41	0.16	0.00	0.68	0.69	0.70	1.00		
SIOPYNdp	0.29	0.43	0.24	0.04	0.83	0.81	0.71	0.75	1.00	
SIOPYPdp	0.29	0.57	0.13	0.11	0.19	0.41	0.60	0.42	0.35	1.00

Correlation matrix delta population as % for 1980–1998 (Signy and Bird Island seals to 1997) – imputation of population sizes by linear interpolation

	ADBPYDdp	ADBPYNdp	ADBPYPdp	BIGDIMdp	BIGEUCdp	BIGPYPdp	BIGSEAdp	SIOPYDdp	SIOPYNdp	SIOPYPdp
ADBPYDdp	1.00									
ADBPYNdp	0.39	1.00								
ADBPYPdp	-0.06	0.49	1.00							
BIGDIMdp	0.30	0.02	0.00	1.00						
BIGEUCdp	0.36	0.37	0.09	0.23	1.00					
BIGPYPdp	0.01	-0.08	0.06	-0.29	0.34	1.00				
BIGSEAdp	0.24	0.35	0.04	0.14	0.43	0.24	1.00			
SIOPYDdp	0.35	0.30	0.19	-0.02	0.51	0.61	0.62	1.00		
SIOPYNdp	0.25	0.44	0.28	0.19	0.68	0.53	0.64	0.72	1.00	
SIOPYPdp	0.36	0.54	-0.02	0.08	0.14	-0.08	0.45	0.22	0.14	1.00

Table 14: The set of regression analyses carried out on summary data for Area 48. The abbreviations are referred to in Table 15.

REGRESSION MODEL				r^2	P
Dependent Variable		Independent Variable			
I.	Effects of acoustic density of krill, Scotia Sea SST and SOI				
Predators, Subarea 48.3 (summer)					
1.	BIG3ps	acd483		0.324	0.086
2.	BIG3ps	acd483	ssssts	0.630	0.083
3.	BIG3ps	acd483	ssssts sois soiw	0.970	0.060
4.	BIG3ps	acd483	ssssts sois	0.950	0.004
5.	BIG3ps	acd483	sssstw	0.644	0.075
Predators, Subarea 48.3 (winter)					
6.	BIG3pw	acd483		0.002	0.971
7.	BIG3pw	acd483	ssssts	0.575	0.117
8.	BIG3pw	acd483	ssssts sois soiw	0.822	0.325
9.	BIG3pw	acd483	ssssts sois	0.707	0.103
10.	BIG3pw	acd483	sssstw	0.481	0.194
Predators, Subarea 48.1 (summer)					
11.	ADB3ps	acd483		0.161	0.284
12.	ADB3ps	acd483	ssssts	0.025	0.938
13.	ADB3ps	acd483	ssssts sois soiw	0.216	0.953
14.	ADB3ps	acd483	ssssts sois	0.096	0.930
15.	ADB3ps	acd483	sssstw	0.024	0.940
Predators, Subarea 48.1 (winter)					
16.	ADB3pw	acd483		0.115	0.338
17.	ADB3pw	acd483	ssssts	0.025	0.938
Predators, Subarea 48.3 (summer)					
18.	BIG3ps	acd481		0.278	0.05
19.	BIG3ps	acd481	ssssts	0.362	0.132
20.	BIG3ps	acd481	ssssts sois soiw	0.540	0.306
21.	BIG3ps	acd481	ssssts sois	0.383	0.253
22.	BIG3ps	acd481	sssstw	0.364	0.130
Predators, Subarea 48.3 (winter)					
23.	BIG3pw	acd481		0.002	0.871
24.	BIG3pw	acd481	ssssts	0.082	0.679
25.	BIG3pw	acd481	ssssts sois soiw	0.246	0.744
26.	BIG3pw	acd481	ssssts sois	0.086	0.875
27.	BIG3pw	acd481	sssstw	0.411	0.093
Predators, Subarea 48.3 (summer)					
28.	ADB3ps	acd481	ssssts	0.118	0.613
29.	ADB3ps	acd481	ssssts sois soiw	0.176	0.887
30.	ADB3ps	acd481	ssssts sois	0.174	0.698
31.	ADB3ps	acd481	sssstw	0.255	0.030
Predators, Subarea 48.1 (winter)					
32.	ADB3pw	acd481		0.002	0.890
33.	ADB3pw	acd481	ssssts	0.023	0.897
II.	Effects of sea-ice and SOI				
Predators					
34.	ADB3ps	sshetice		0.001	0.896
35.	ADB3pw	sshetice		0.078	0.247
36.	ADB3ps	icexadb		0.123	0.182

Table 14 (continued)

REGRESSION MODEL			r^2	*P*	
Dependent Variable		Independent Variable			
37.	ADB3ps	ice481	0.060	0.359	
38.	BIG3ps	sgice	0.319	0.089	
39.	BIG3ps	sgice soiw	0.885	0.004	
40.	BIG3ps	acd483 sgice soiw	0.976	0.035	Small sample
41.	BIG3ps	sgice lagged-soiw	0.816	0.034	
Krill, Subarea 48.3					
42.	acd483	sgice	0.675	0.012	
43.	acd483	sgice soiw	0.718	0.150	
44.	acd483	sois	0.589	0.016	
100 m temperature, Subarea 48.1					
45.	t100m	sssstw	0.093	0.424	
46.	t100m	eisstw sssstw soiw	0.681	0.169	Small sample

Table 15: Variables used in analyses of interactions (Table 14 and Figures 37–55).

Category	Code	Description	Number of Years	Earliest Year	Last Year
predator	BIG3ps	summer CSI (SEA, EUC, PYP)	22	77/78	97/98
predator	BIG3pw	winter CSI (SEA, EUC, PYP)	22	77	97
predator	BIGEUCb	breeding success	22	76/77	97/98
predator	BIGEUCdp	% population change from previous year	21	77/78	97/98
predator	BIGPYPb	breeding success	21	76/77	97/98
predator	BIGPYPdp	% population change from previous year	21	77/78	97/98
predator	BIGSEAb	breeding success	18	78/79	97/98
predator	BIGSEAdp	% population change from previous year	19	79/80	97/98
predator	ADB2pw	winter CSI (PYN, PYP)	21	77	97
predator	ADBPYDdw	winter CSI	21	77	97
predator	ADB3ps	summer CSI (PYD, PYN, PYP)	17	77/78	97/98
predator	ADBPYDdp	% population change from previous year	20	78/79	97/98
predator	ADBPYNdp	% population change from previous year	20	78/79	97/98
predator	ADBPYPdp	% population change from previous year	20	78/79	97/98
predator	ADBPYDb	breeding success	17	77/78	97/98
predator	ADBPYNb	breeding success	17	77/78	97/98
predator	ADBPYPb	breeding success	17	77/78	97/98
predator	SIO2pw	winter CSI (PYN, PYP)	21	77	97
predator	SIOPYDw	winter CSI	21	77	97
predator	SIOalls	summer CSI (PYD, PYN, PYP)	19	78/79	96/97
predator	SIOPYNb	breeding success	19	78/79	96/97
predator	SIOPYNdp	% population change from previous year	18	79/80	96/97
predator	SIOPYDb	breeding success	18	79/80	96/97
predator	SIOPYDdp	% population change from previous year	18	79/80	96/97
predator	SIOPYPb	breeding success	18	79/80	96/97
predator	SIOPYPdp	% population change from previous year	18	79/80	96/97
icefish	SGifS	South Georgia icefish condition index for summer	14	75/76	96/97
icefish	SGifW	South Georgia icefish condition index for winter	8	77	97
krill	pr481	proportional recruitment (R1) Subarea 48.1	17	79/80	96/97
krill	ar481	absolute recruitment (R1) Subarea 48.1	16	79/80	96/97

Table 15 (continued)

Category	Code	Description	Number of Years	Earliest Year	Last Year
krill	netdn481	krill density from nets Subarea 48.1	16	80/81	97/98
krill	acden481	krill density from acoustics Subarea 48.1	14	80/81	97/98
krill	acden483	krill density from acoustics Subarea 48.3	10	80/81	97/98
krill	ar483	absolute recruitment (R1) Subarea 48.3	7	88/89	96/97
krill	pr483	proportional recruitment (R1) Subarea 48.3	7	88/89	96/97
physical	sois	Southern Oscillation Index – summer	22	75/76	96/97
physical	soiw	Southern Oscillation Index – winter	21	75	96
physical	csssts	Scotia Sea NCAR SST – summer	16	81/82	96/97
physical	sssstw	Scotia Sea NCAR SST – winter	16	81	96
physical	IcexADB	Stranger Point proportion of year ice free (CEMP F2b)	19	79	97
physical	IcexAIP	Anvers Island proportion of year ice free (CEMP F2b)	19	79	97
physical	IcexSES	Seal Island proportion of year ice free (CEMP F2b)	19	79	97
physical	IcexSIO	Signy Island proportion of year ice free (CEMP F2b)	18	79	96
physical	IcewADB	Stranger Point weeks with sea-ice within 100km (CEMP F2c)	19	79	97
physical	IcewAIP	Anvers Island weeks with sea-ice within 100km (CEMP F2c)	19	79	97
physical	IcewSES	Seal Island weeks with sea-ice within 100km (CEMP F2c)	19	79	97
physical	IcewSIO	Signy Island weeks with sea-ice within 100km (CEMP F2c)	19	79	97
physical	Ice481	Subarea 48.1 September sea-ice cover (%) (CEMP F2a)	19	79	97
physical	Ice482	Subarea 48.2 September sea-ice cover (%) (CEMP F2a)	19	79	97
physical	Ice483	Subarea 48.3 September sea-ice cover (%) (CEMP F2a)	19	79	97
physical	SShetice	normalised South Shetlands sea-ice extent – annual	19	79	97
physical	ScSeaice	normalised Scotia Sea sea-ice extent – annual	10	88	97
physical	SGice	normalised South Georgia sea-ice extent – annual	10	88	97
physical	SOrkice	normalised South Orkney Island sea-ice extent – annual	10	88	97

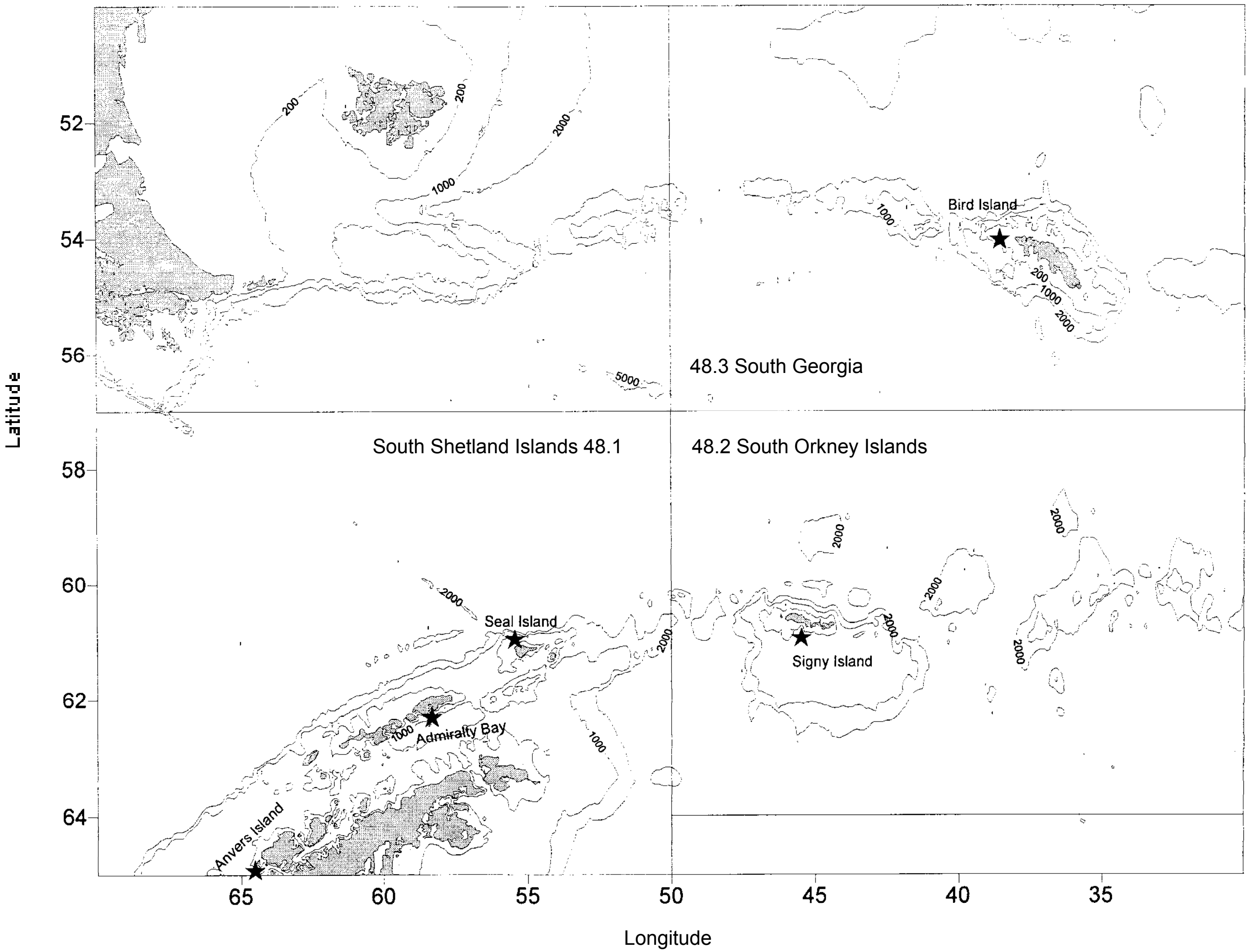

Figure 1: Map of the three statistical areas (Subareas 48.1, 48.2 and 48.3) examined during the workshop. Surveys were generally conducted in waters adjacent to South Georgia and the South Shetland Islands, and most of the data on predators were collected at Admiralty Bay, Anvers Island, Bird Island, Seal Island and Signy Island.

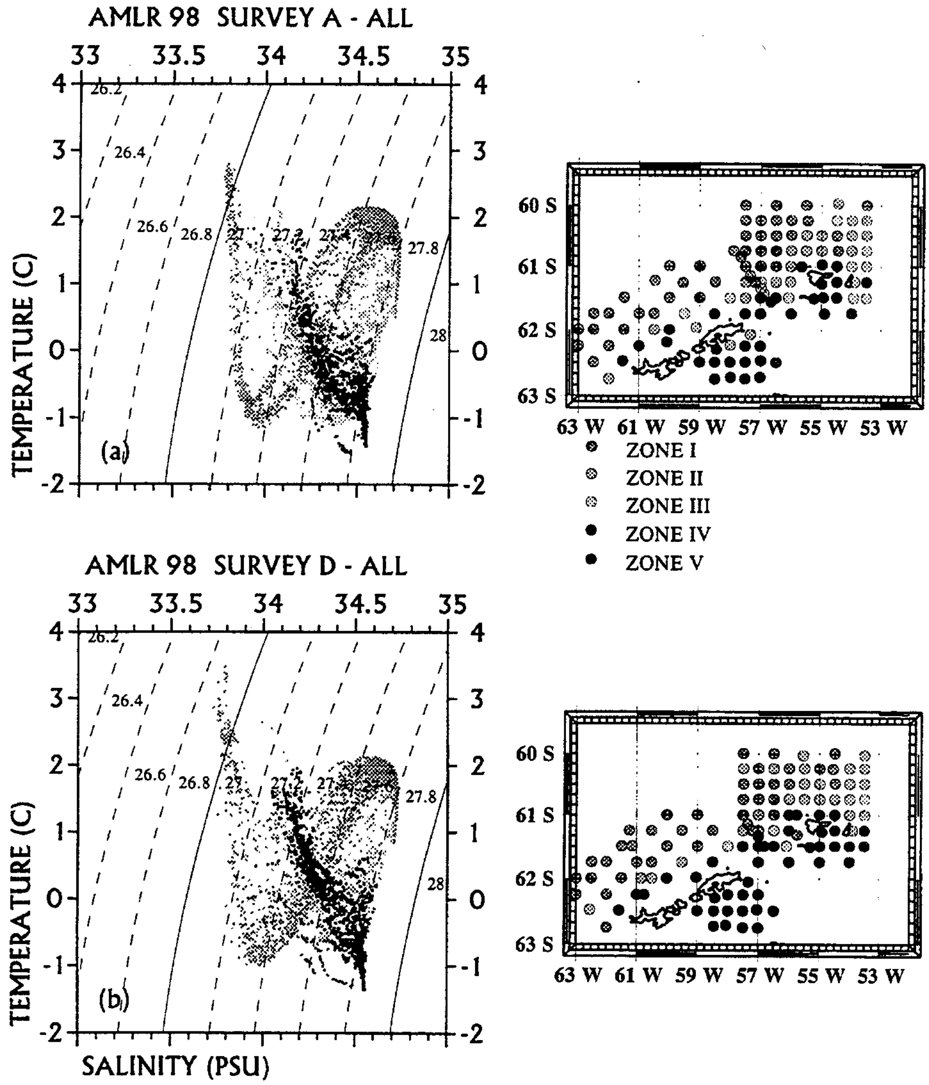

Figure 2: Typical AMLR CTD temperature and salinity diagram and station grid for all stations from the area: (a) Leg I (January/February); (b) Leg II (February/March). Symbols on inset maps show station locations shaded by zones of similar temperature and salinity characteristics.

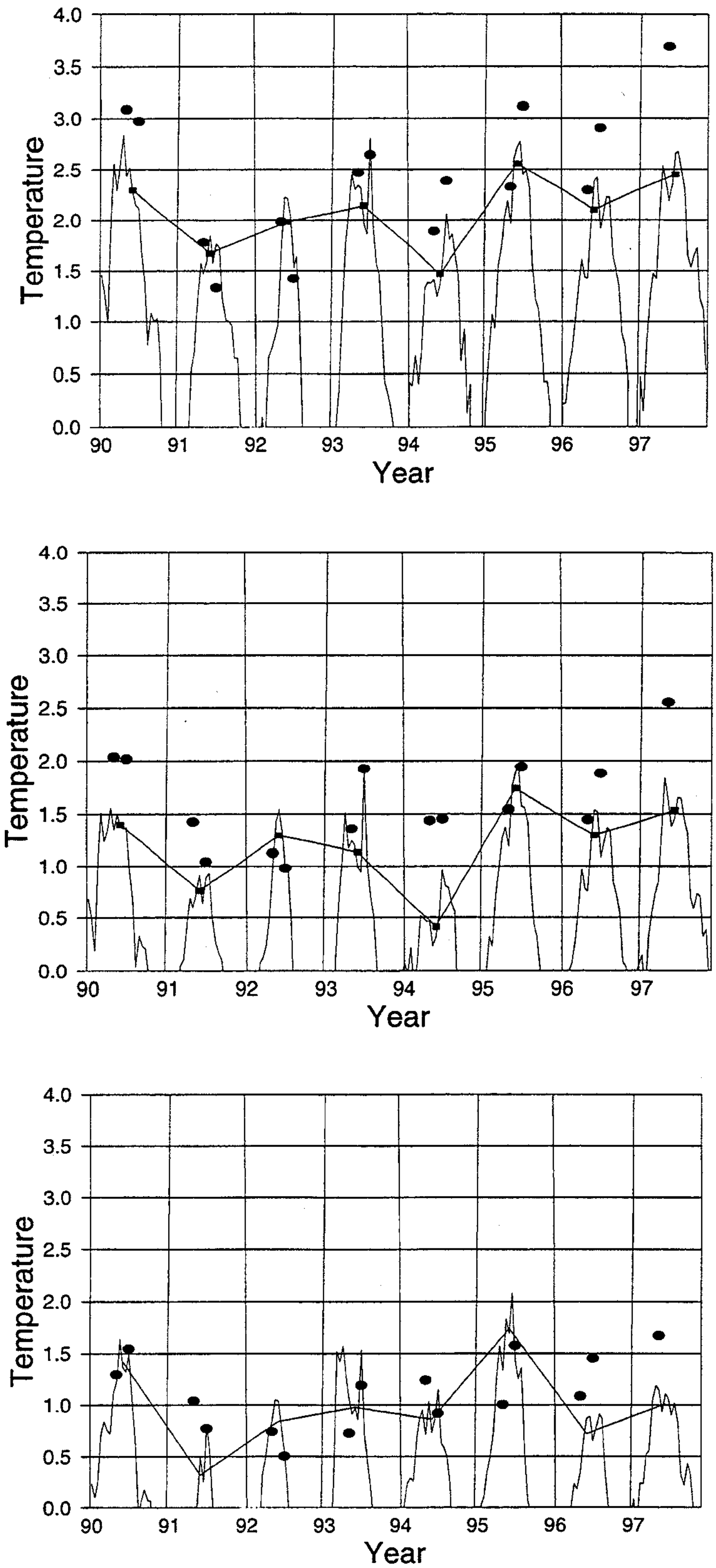

Figure 3: Comparison of AMLR CTD surface (4 m) temperatures with NCAR SST. Weekly NCAR SST data for December through to April and monthly NCAR SST data for February are shown. Average values for both the AMLR cruises carried out each year are shown (one cruise only in 1998). Years are identified by the CCAMR split-year designation. (a) Elephant Island EI1 (60°30′, 56°30′W); (b) Elephant Island EI2 (61°30′S, 56°30′W); (c) Elephant Island EI3 (61°30′S, 54°30′W).

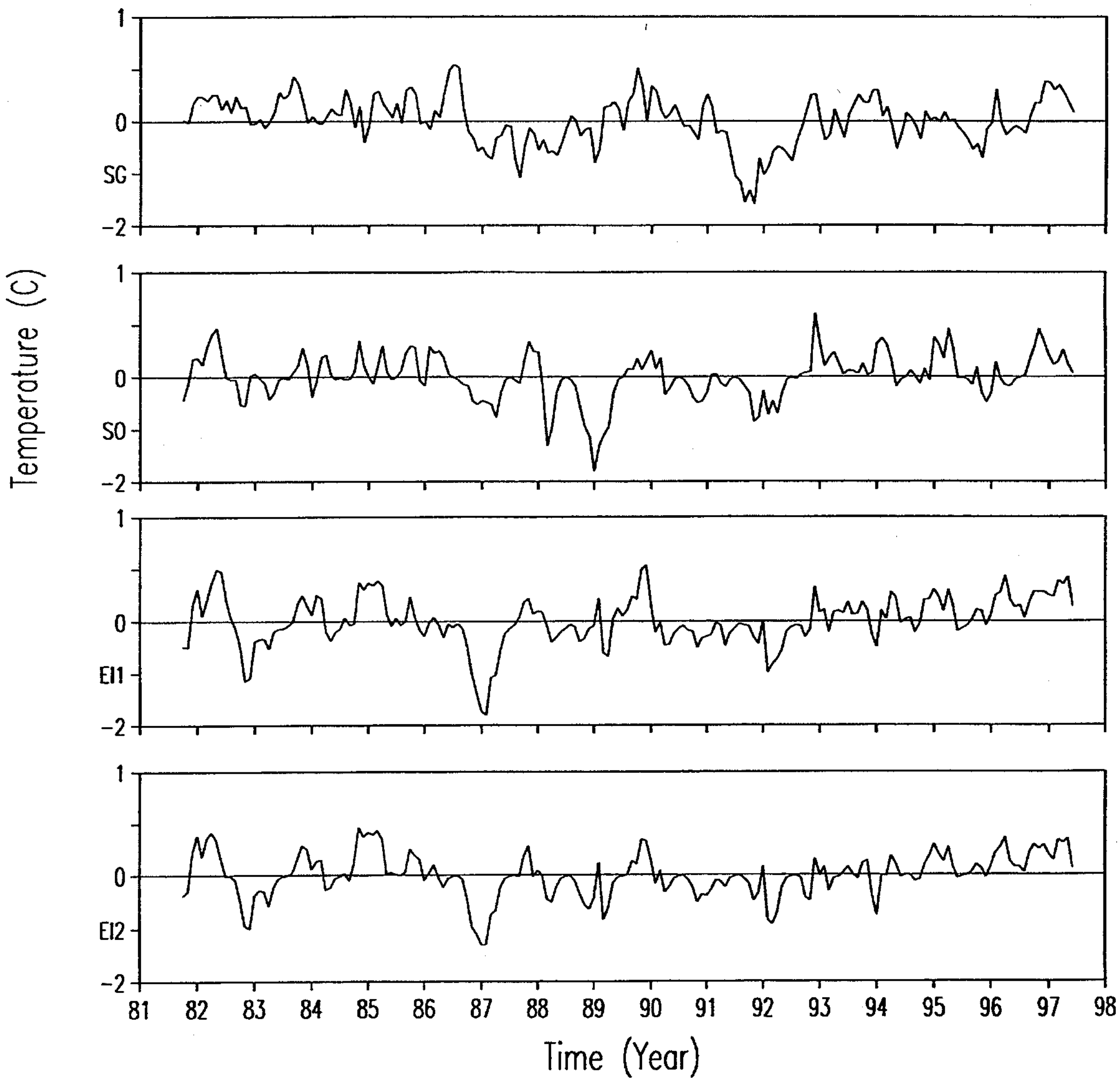

Figure 4: Time series plots for selected NCAR SST monthly time series: (a) South Georgia (54°30′S, 34°30′W); (b) South Orkneys (60°30′S, 47°30′W); (c) Elephant Island EI1 (60°30′S, 56°30′W); (d) Elephant Island EI2 (61°30′S, 56°30′W).

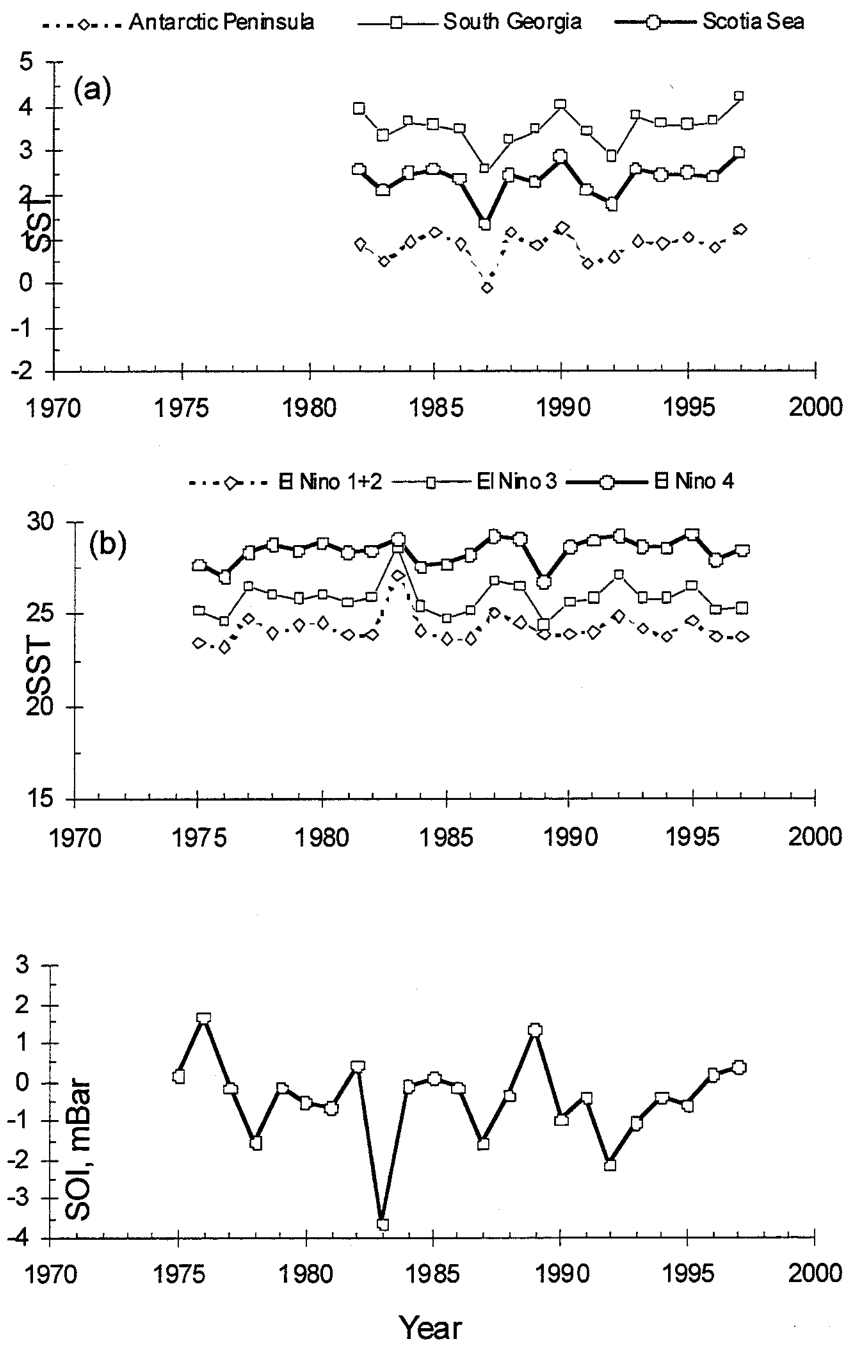

Figure 5: Annual summer index plots: (a) NCAR SST at the Antarctic Peninsula, South Georgia and the Scotia Sea; (b) sea-surface temperature for El Niño 1+2, El Niño 3 and El Niño 4; (c) SOI.

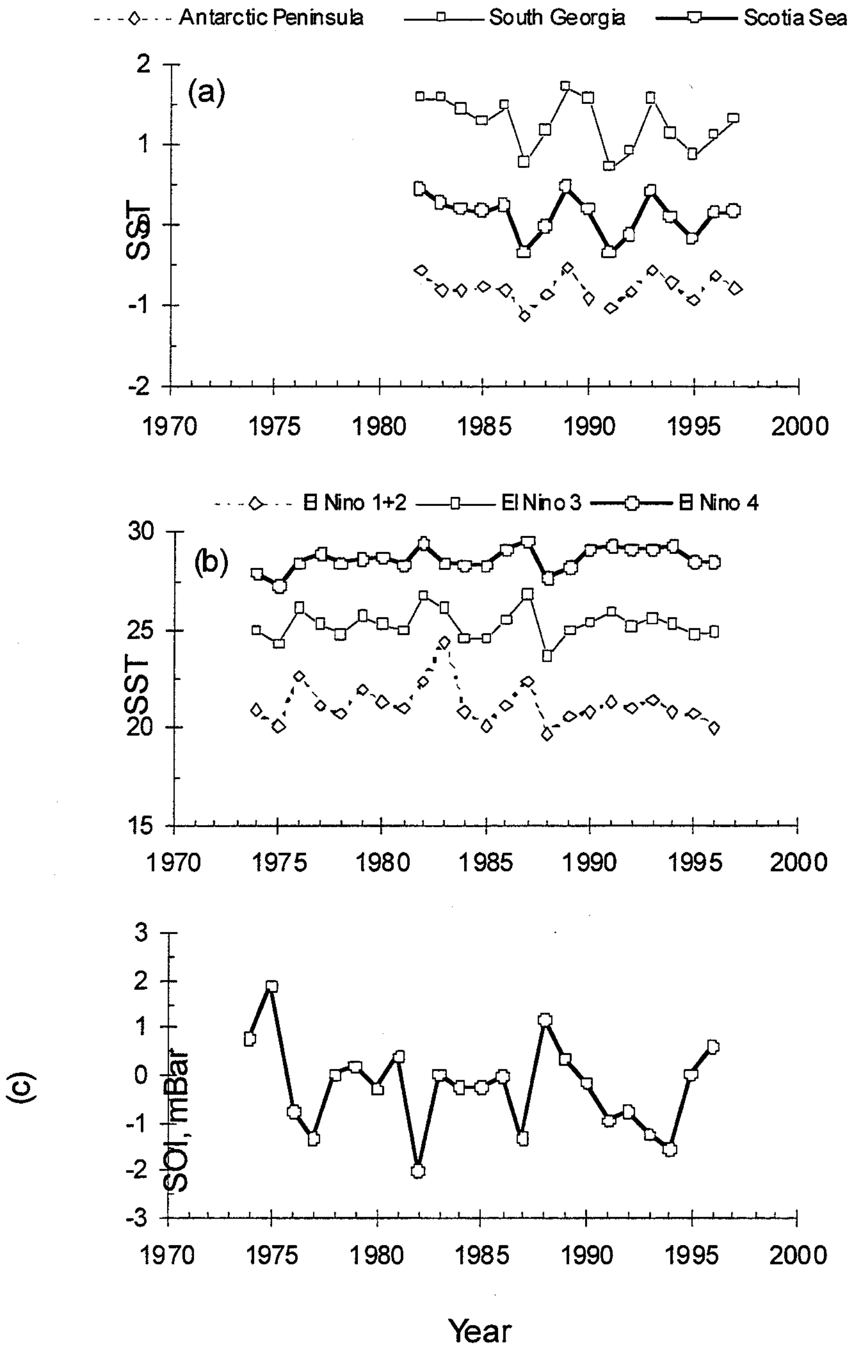

Figure 6: Annual winter index plots: (a) NCAR SST at the Antarctic Peninsula, South Georgia and the Scotia Sea; (b) sea-surface temperature for El Niño 1+2, El Niño 3 and El Niño 4; (c) SOI.

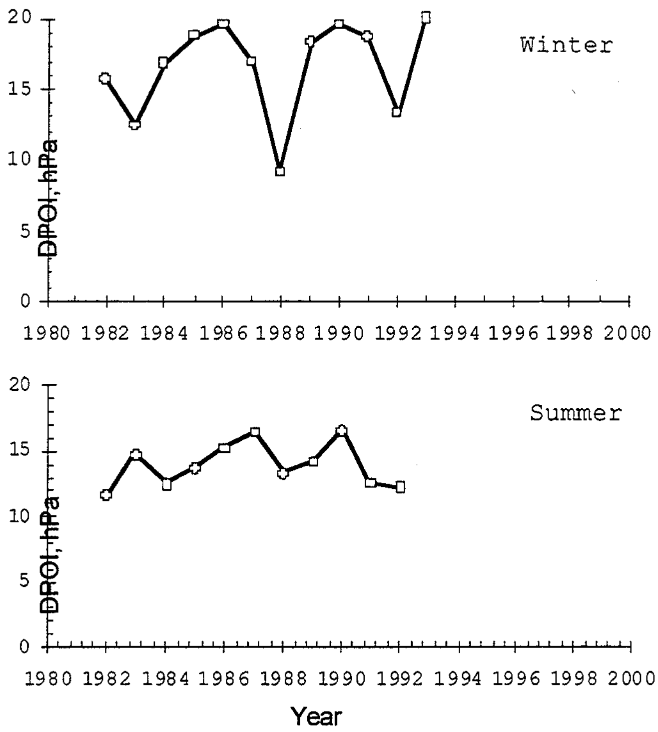

Figure 7: Annual index plots for DPOI: (a) winter; (b) summer.

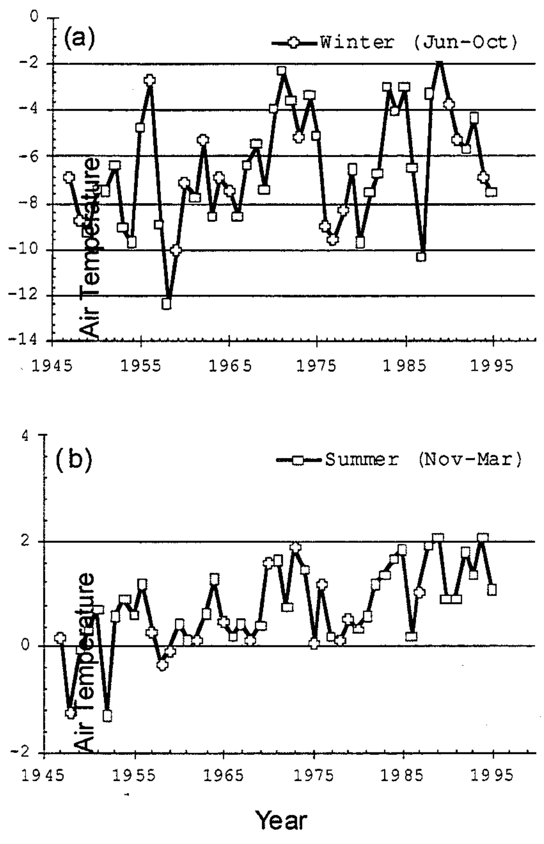

Figure 8: Annual index plots for Palmer Station air temperatures: (a) winter; (b) summer.

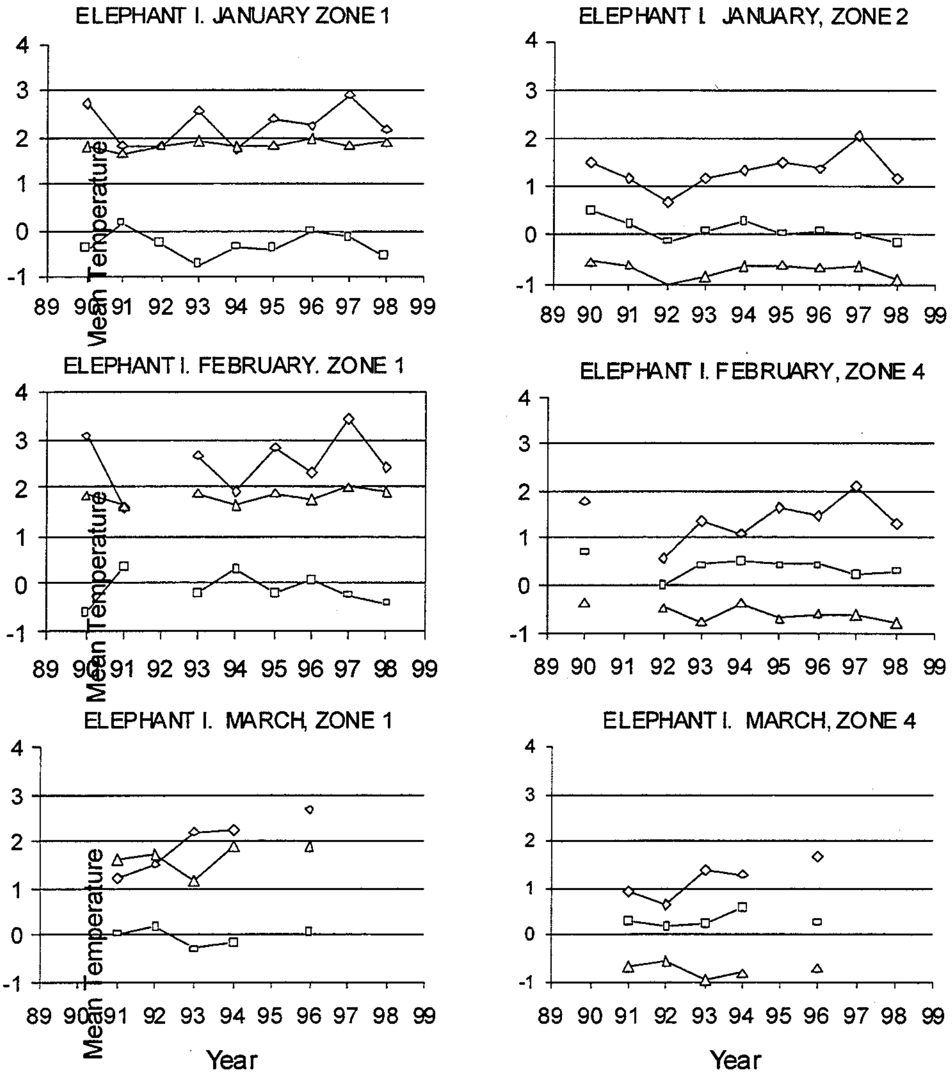

Figure 9: Sea temperature at 4 m (◊), 100 m (□) and 500 m (Δ) in the Elephant Island area from 1990 to 1998. Zones of similar temperature and salinity characteristics (see Figure 2) are compared for January, February and March. Data from AMLR CTD stations in Zone 1 (Drake Passage) and Zone 4 (Bransfield Strait).

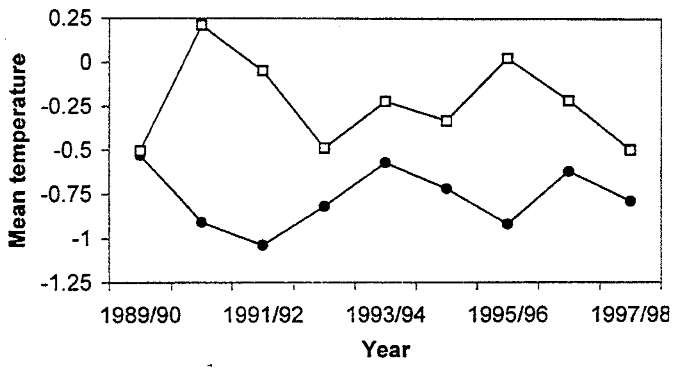

Figure 10: Temperature at 100 m (□) in the Drake Passage winter water from AMLR CTD data compared to NCAR winter SST (●) in the Antarctic Peninsula Area.

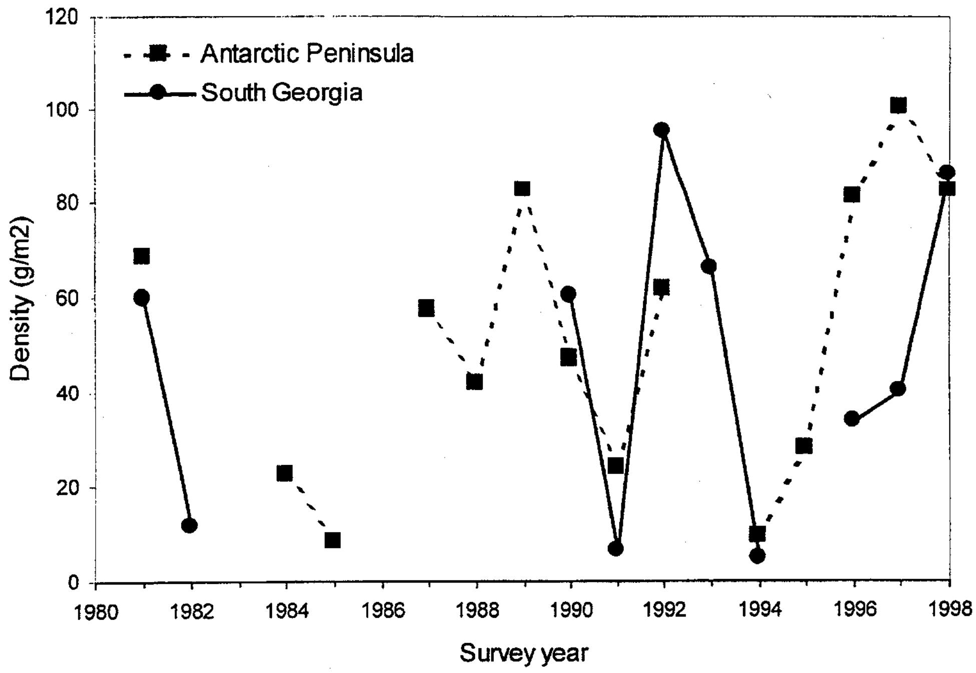

Figure 11: Interannual changes in acoustic krill density estimates for Subareas 48.1 and 48.3.

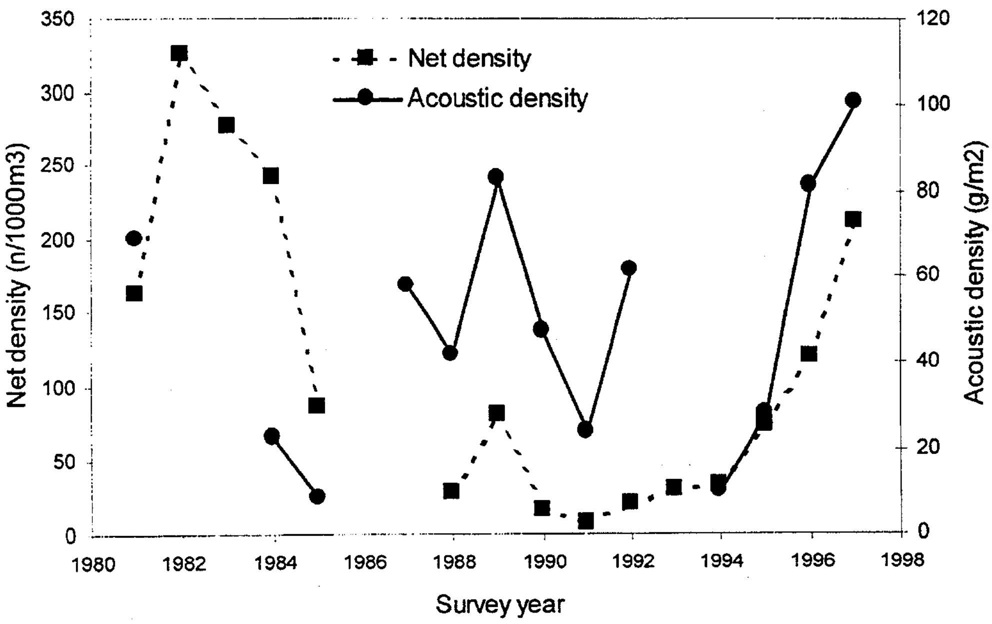

Figure 12: Interannual changes in net and acoustic estimates of krill density in Subarea 48.1.

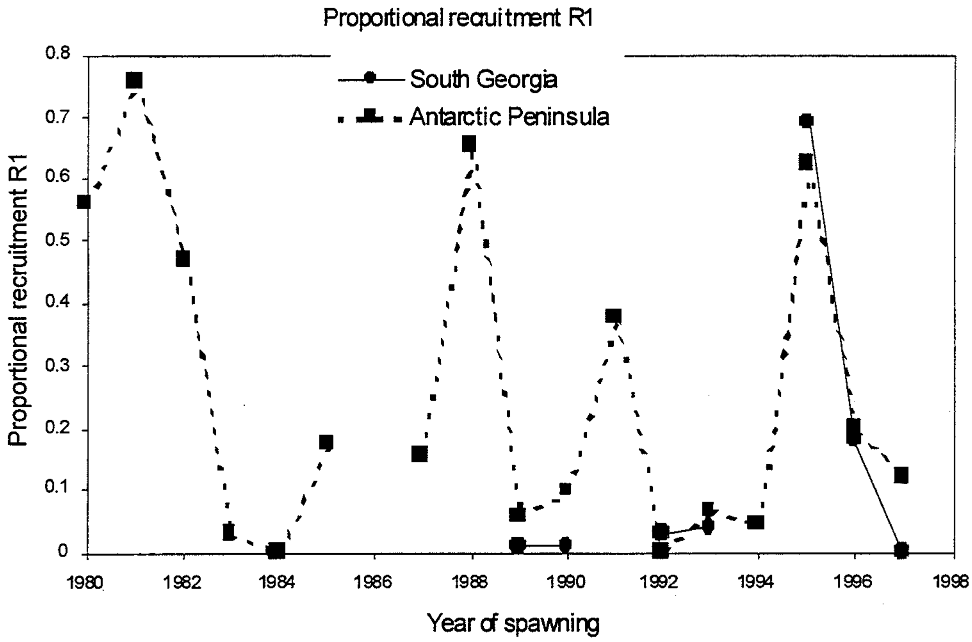

Figure 13: Interannual changes in proportional krill recruitment index (R1) in Subareas 48.1 and 48.3.

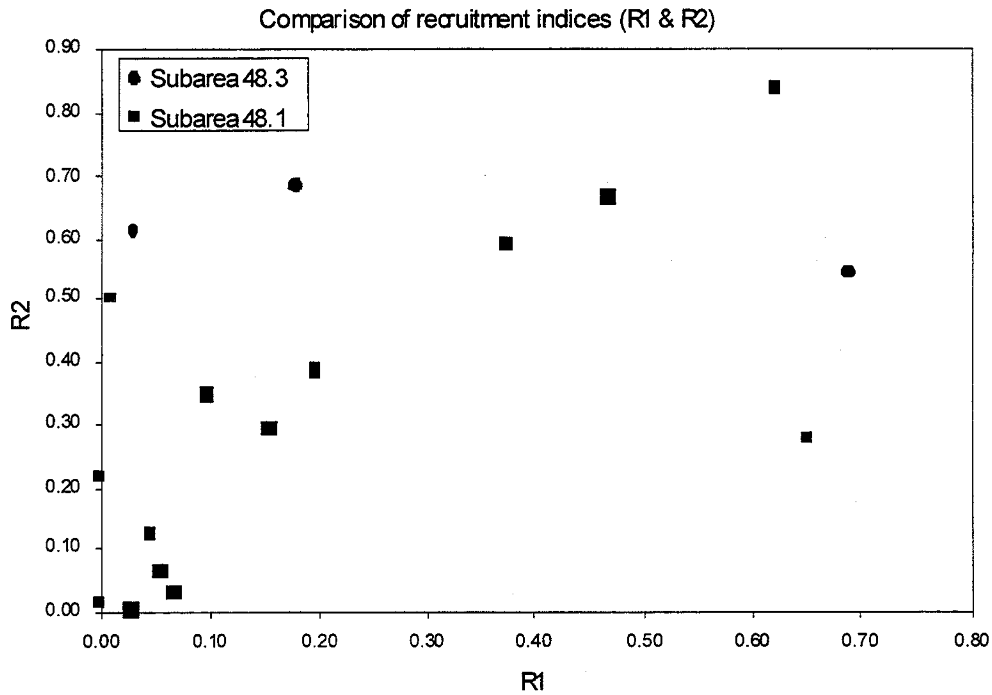

Figure 14: Comparison of R1 and R2 proportional krill recruitment indices.

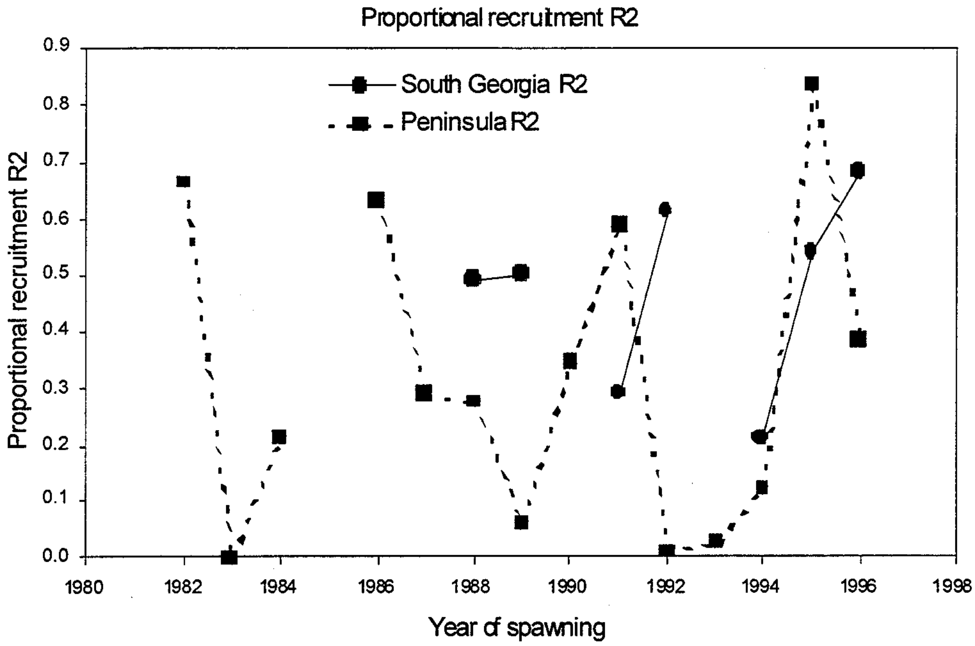

Figure 15: Interannual changes in proportional krill recruitment index (R2) in Subareas 48.1 and 48.3.

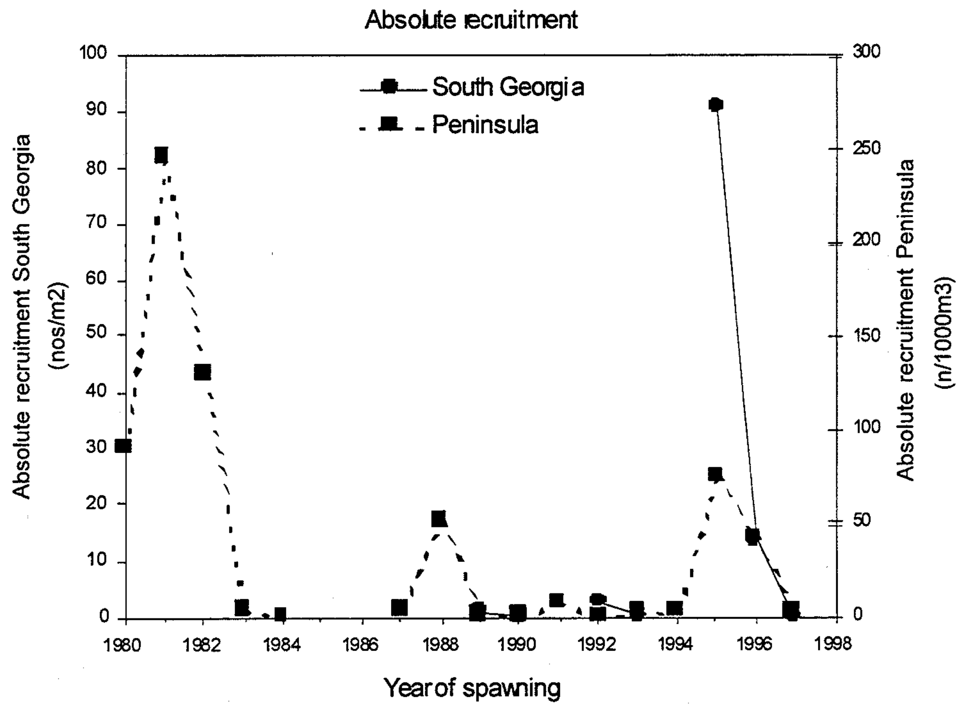

Figure 16: Interannual changes in absolute recruitment of 1+ krill in Subareas 48.1 and 48.3.

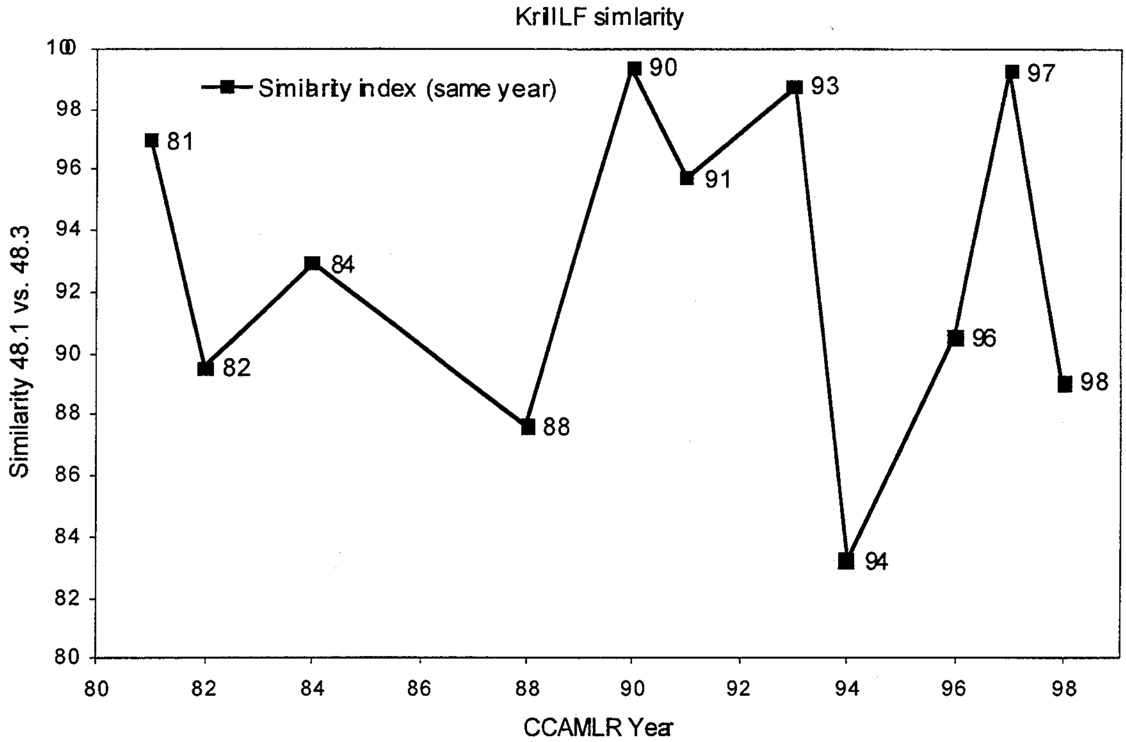

Figure 17: Interannual changes in krill length-frequency similarity index derived from cluster analysis of haul-by-haul length-frequency data in Area 48.

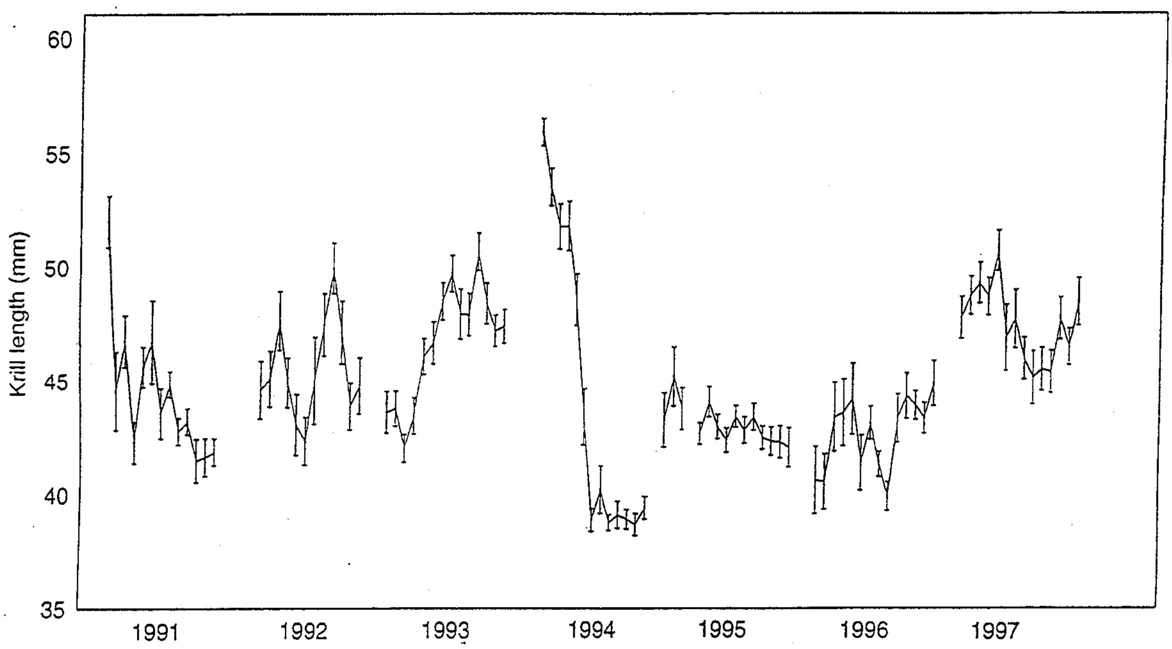

Figure 18: Weekly variation in mean krill length in the diet of Antarctic fur seals during the breeding seasons of 1991 to 1997 (error bars are shown at ±1 standard error). Figure taken from WS-Area48-98/15.

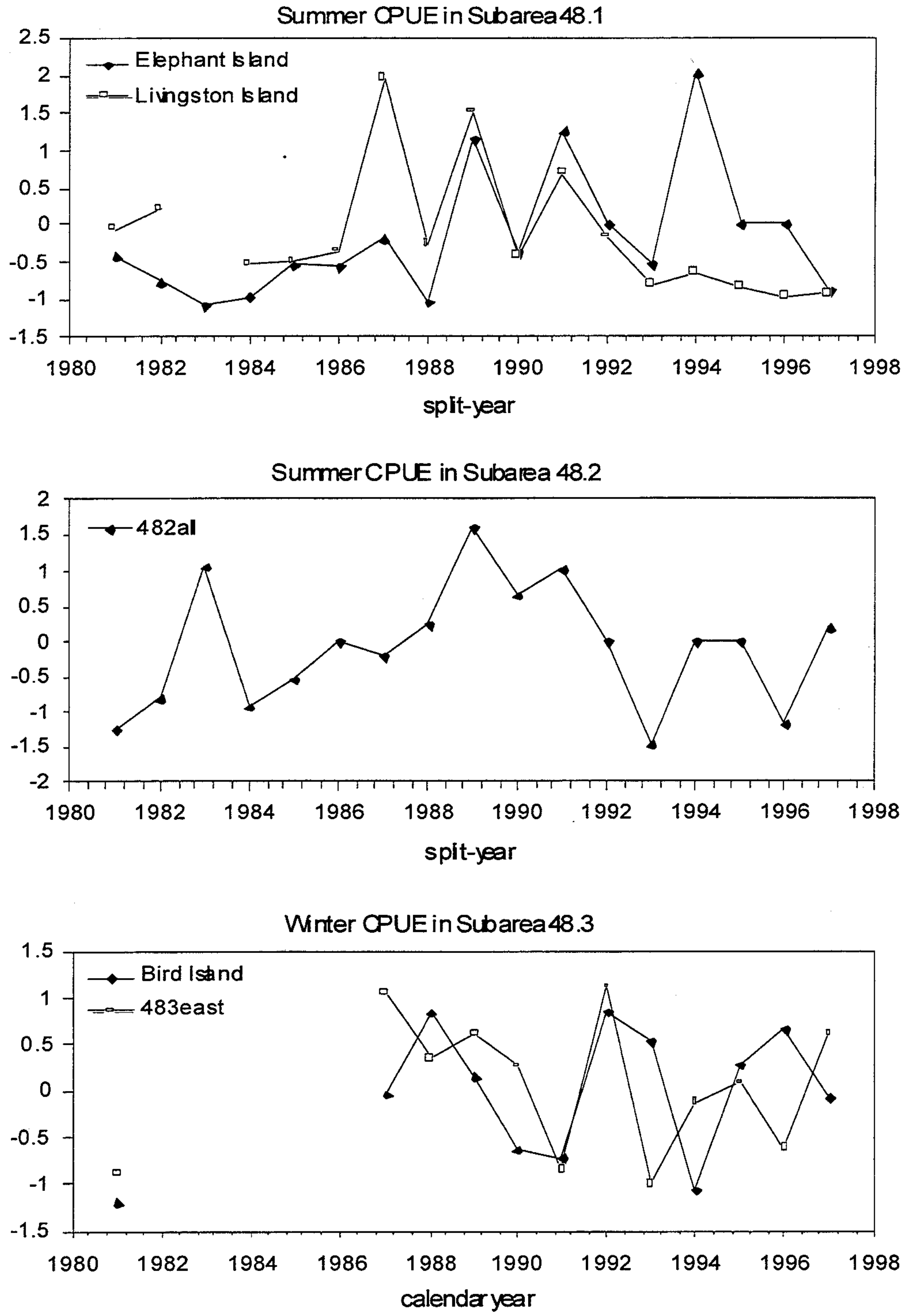

Figure 19: Indices of summer CPUE for krill fishery in Subareas 48.1 and 48.2 and winter CPUE for krill fishery in Subarea 48.3.

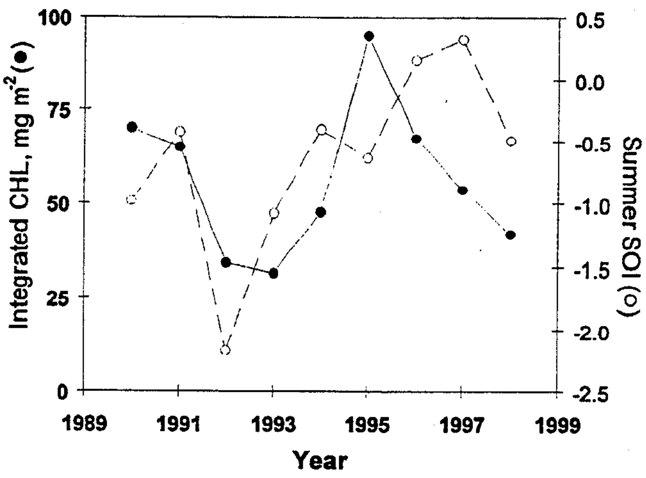

Figure 20: Integrated chlorophyll concentrations (mg·m-2) averaged over US AMLR survey grid (●) and the summer SOI (O) from 1990 onwards.

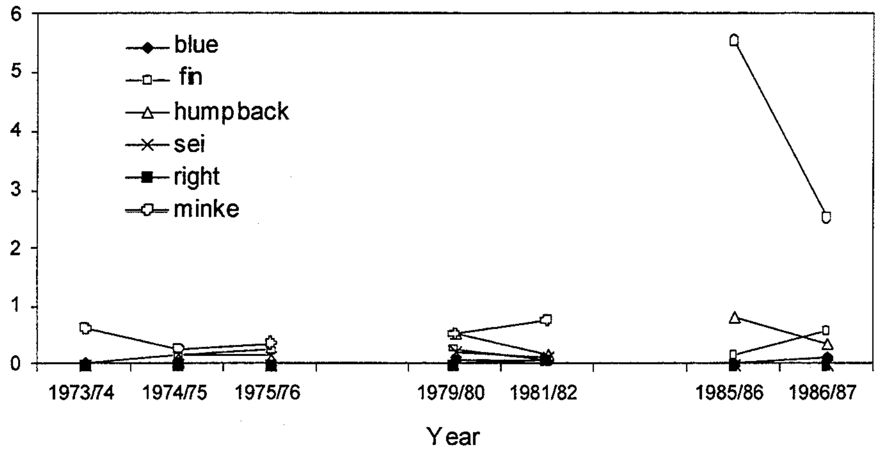

Figure 21: Japanese scouting vessel indices of whale abundance in Subarea 48.1.

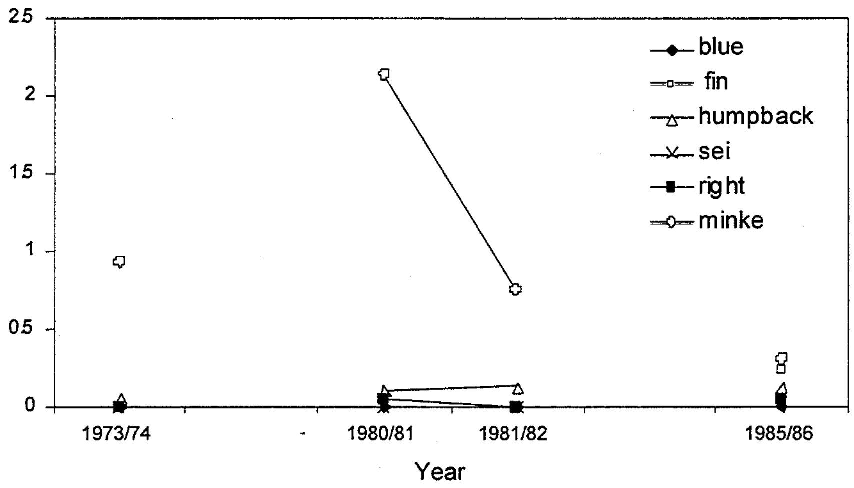

Figure 22: Japanese scouting vessel indices of whale abundance in Subarea 48.2.

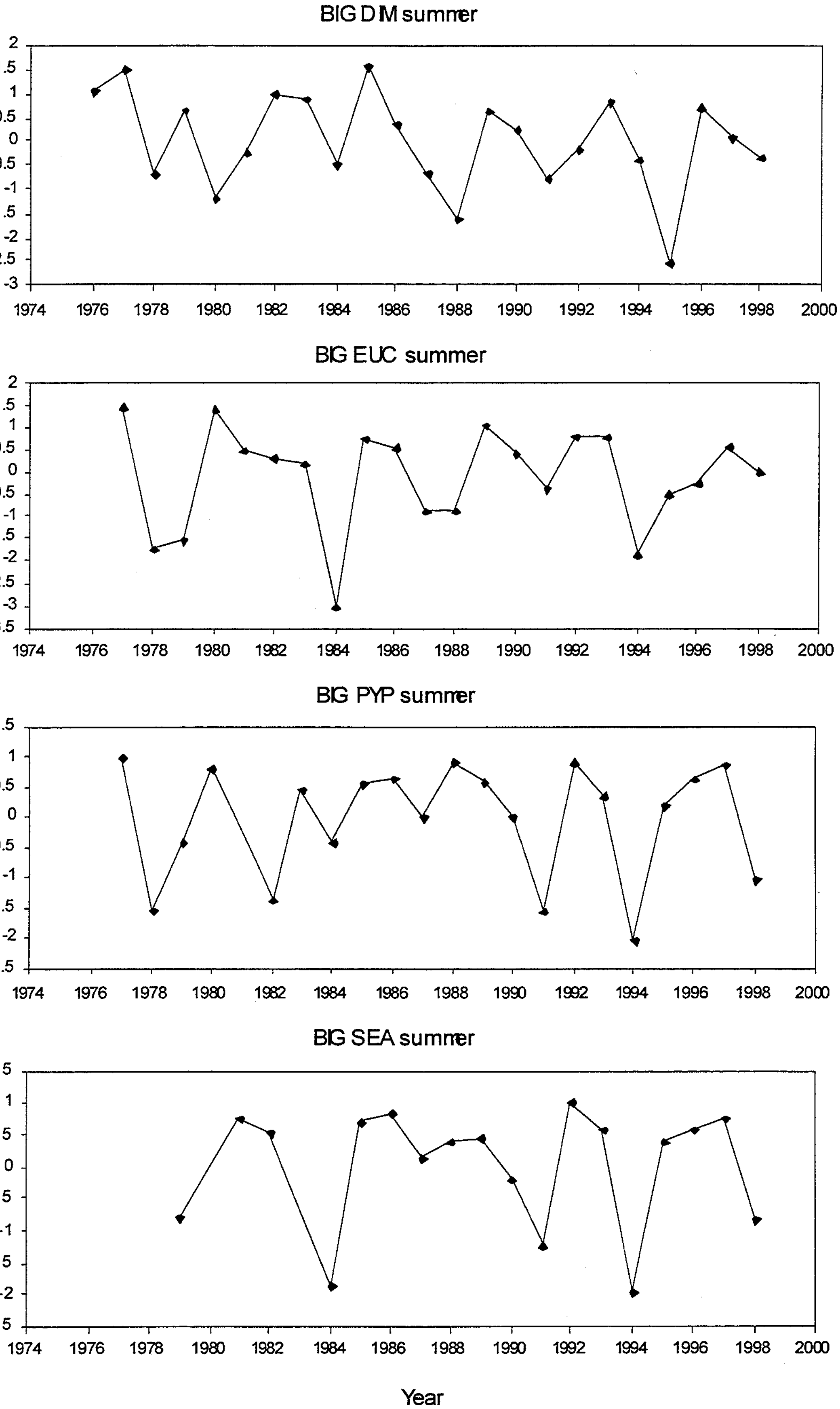

Figure 23a: Bird Island, South Georgia (BIG) CSIs for black-browed albatross (DIM), macaroni penguin (EUC), gentoo penguin (PYP) and Antarctic fur seal (SEA) in summer.

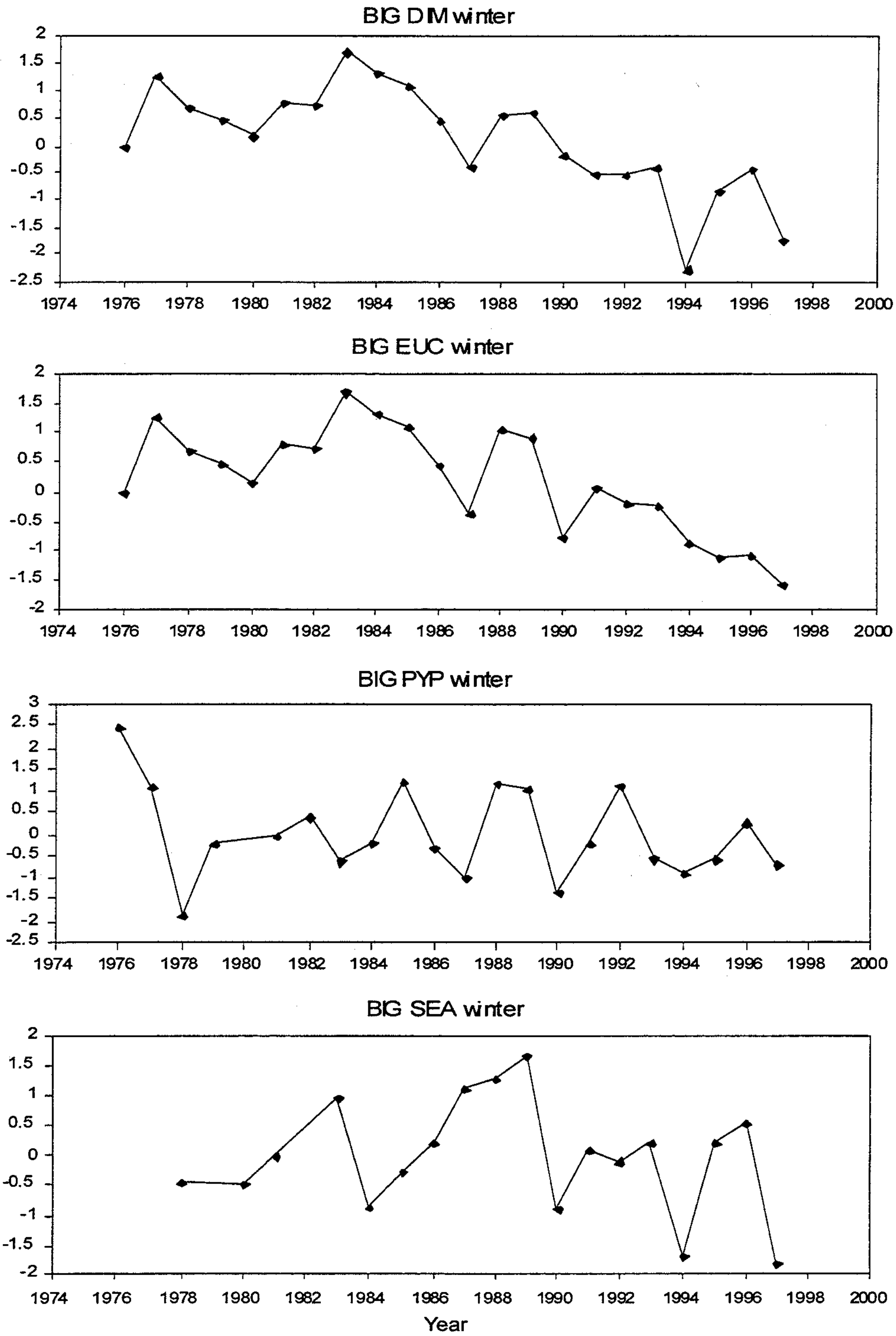

Figure 23b: Bird Island, South Georgia (BIG) CSIs for black-browed albatross (DIM), macaroni penguin (EUC), gentoo penguin (PYP) and Antarctic fur seal (SEA) in winter.

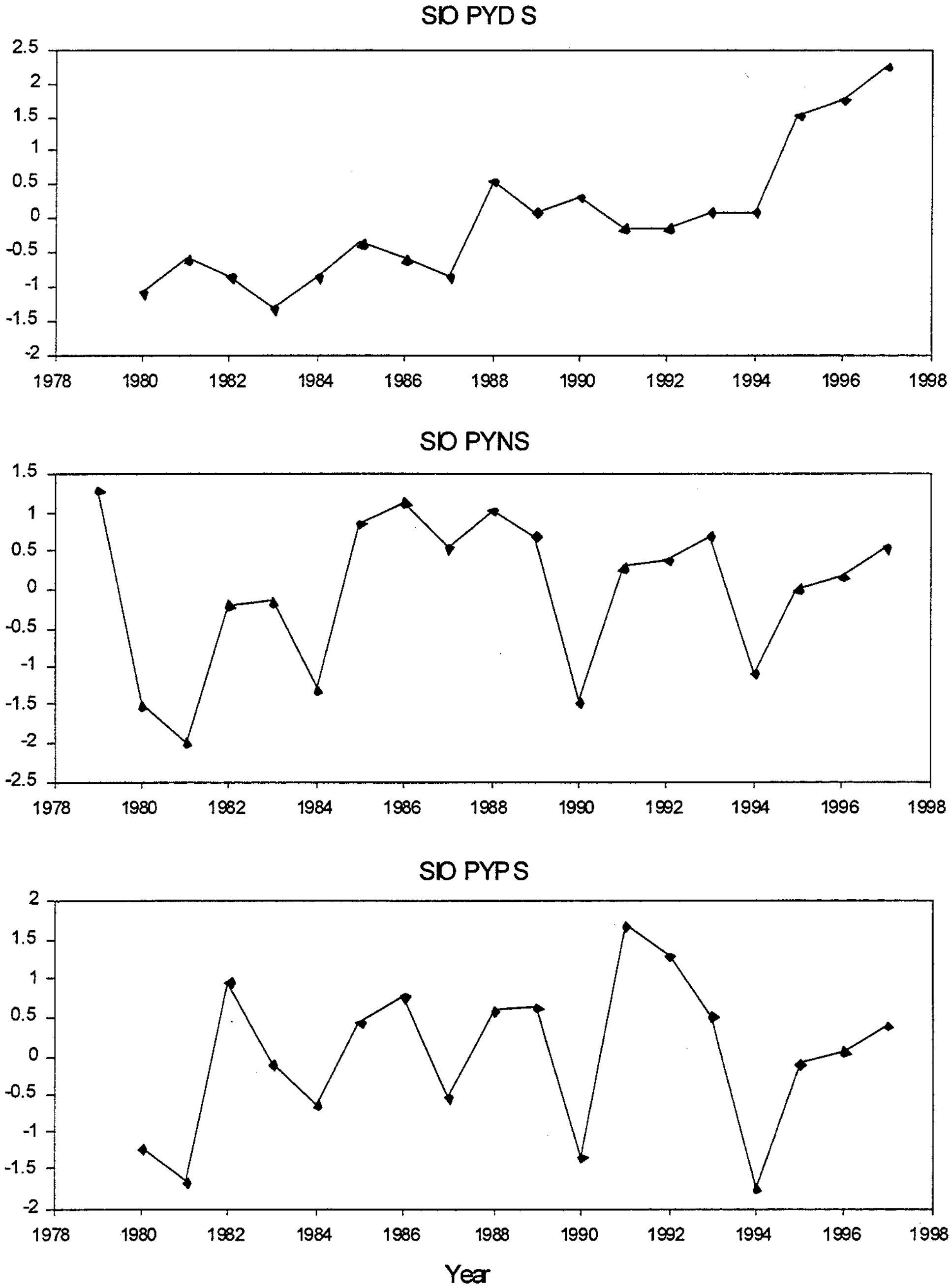

Figure 24a: Signy Island, South Orkney Islands (SIO) CSIs for Adélie (PYD), chinstrap (PYN) and gentoo (PYP) penguins in summer.

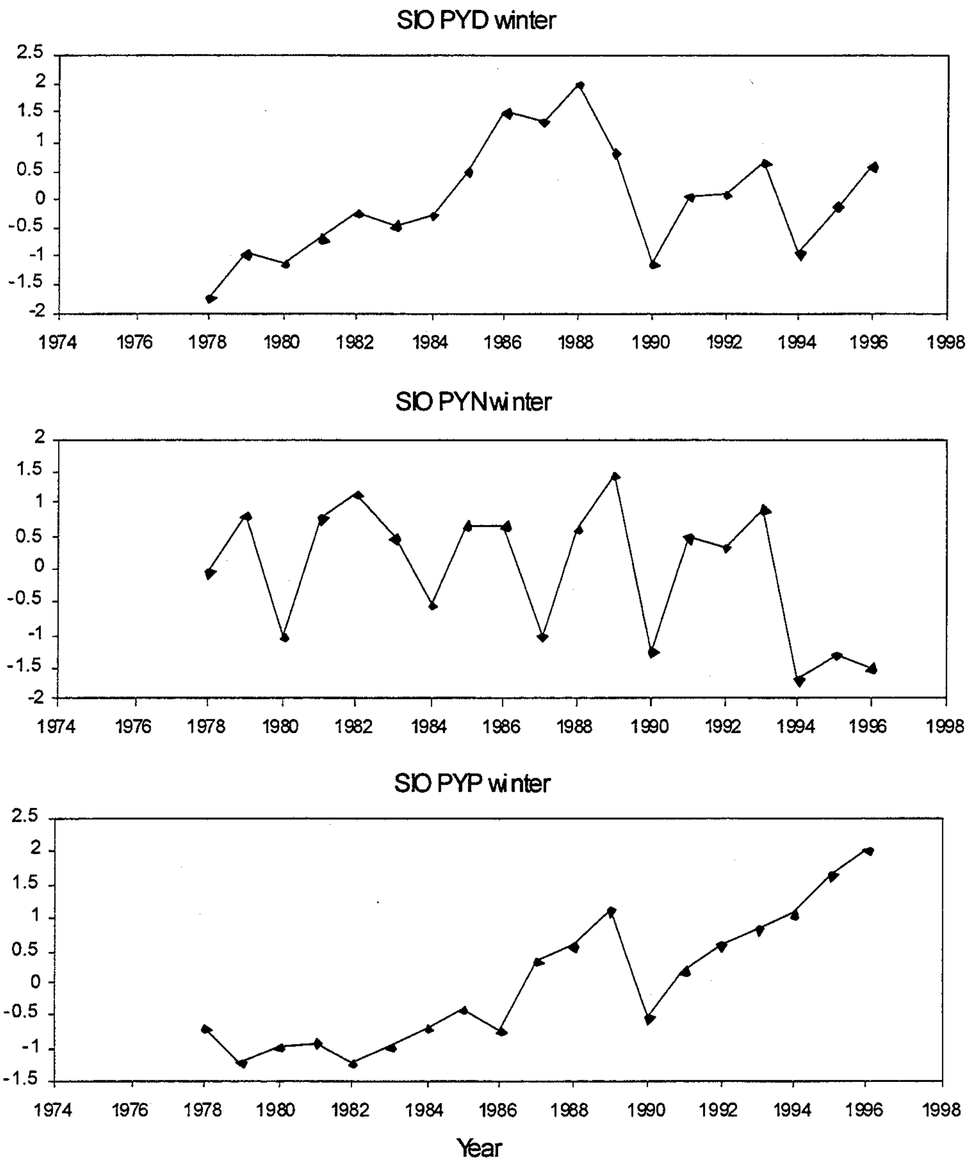

Figure 24b: Signy Island, South Orkney Islands (SIO) CSIs for Adélie (PYD), chinstrap (PYN) and gentoo (PYP) penguins in winter.

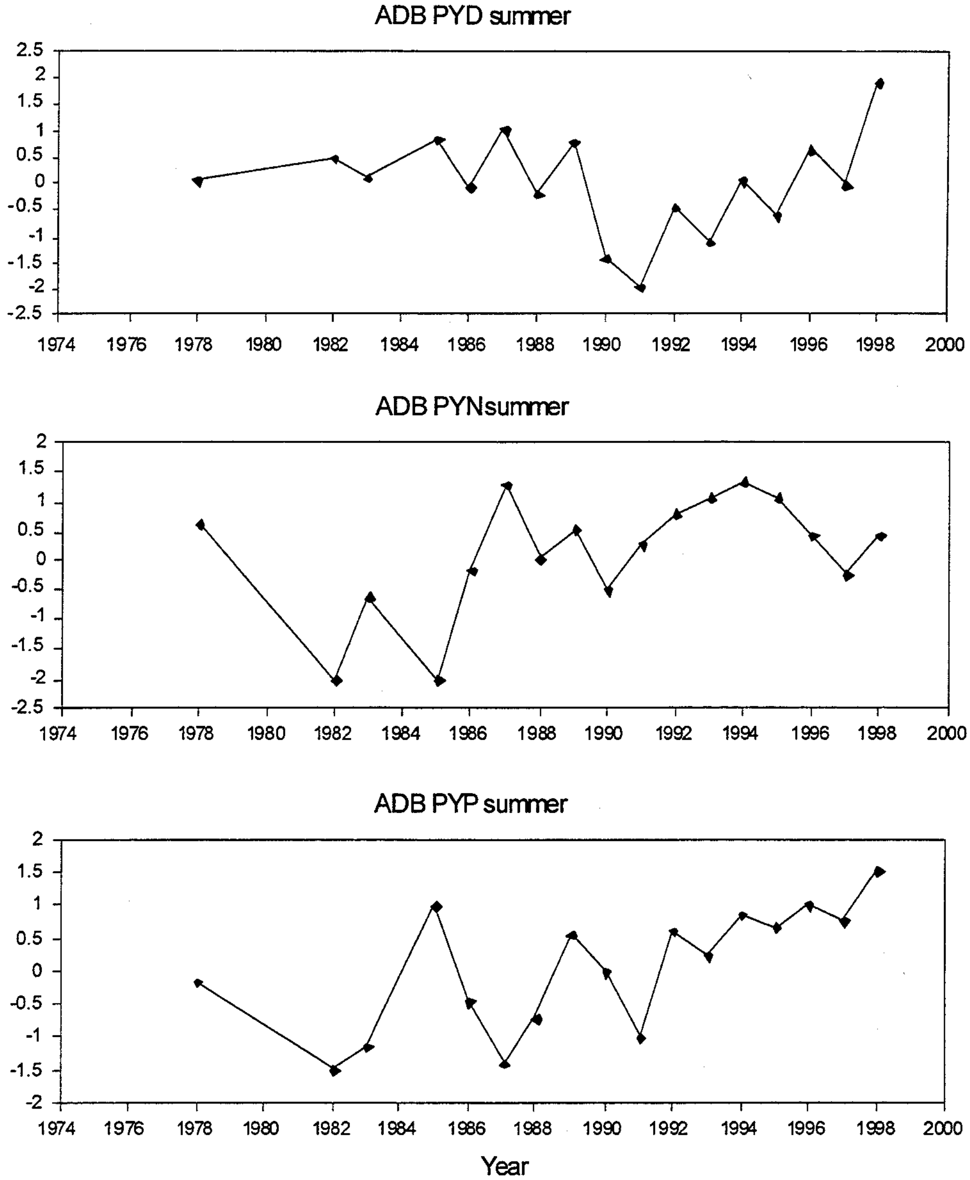

Figure 25a: Admiralty Bay, King George Island, South Shetland Islands (ADB) CSIs for Adélie (PYD), chinstrap (PYN) and gentoo (PYP) penguins in summer.

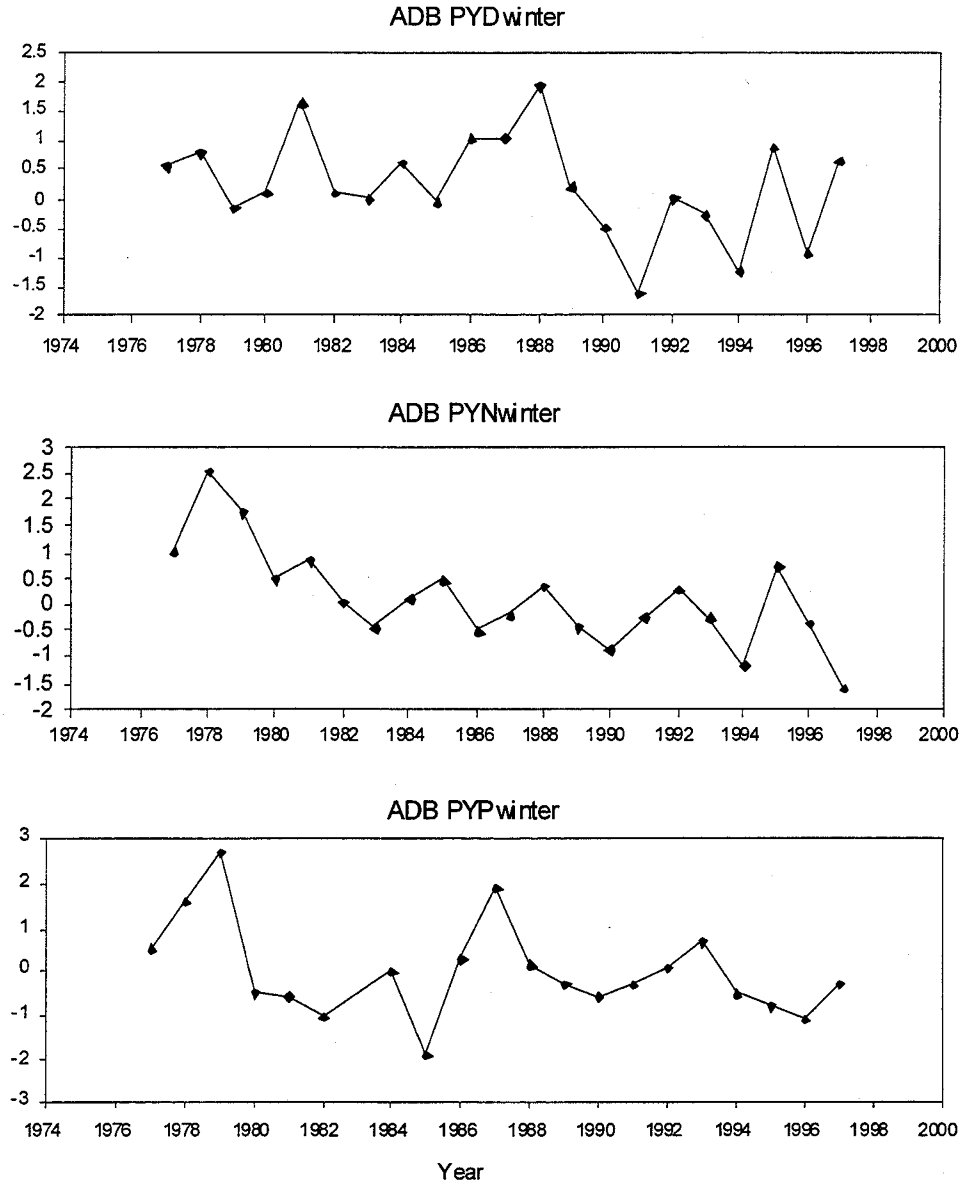

Figure 25b: Admiralty Bay, King George Island, South Shetland Islands (ADB) CSIs for Adélie (PYD), chinstrap (PYN) and gentoo (PYP) penguins in winter.

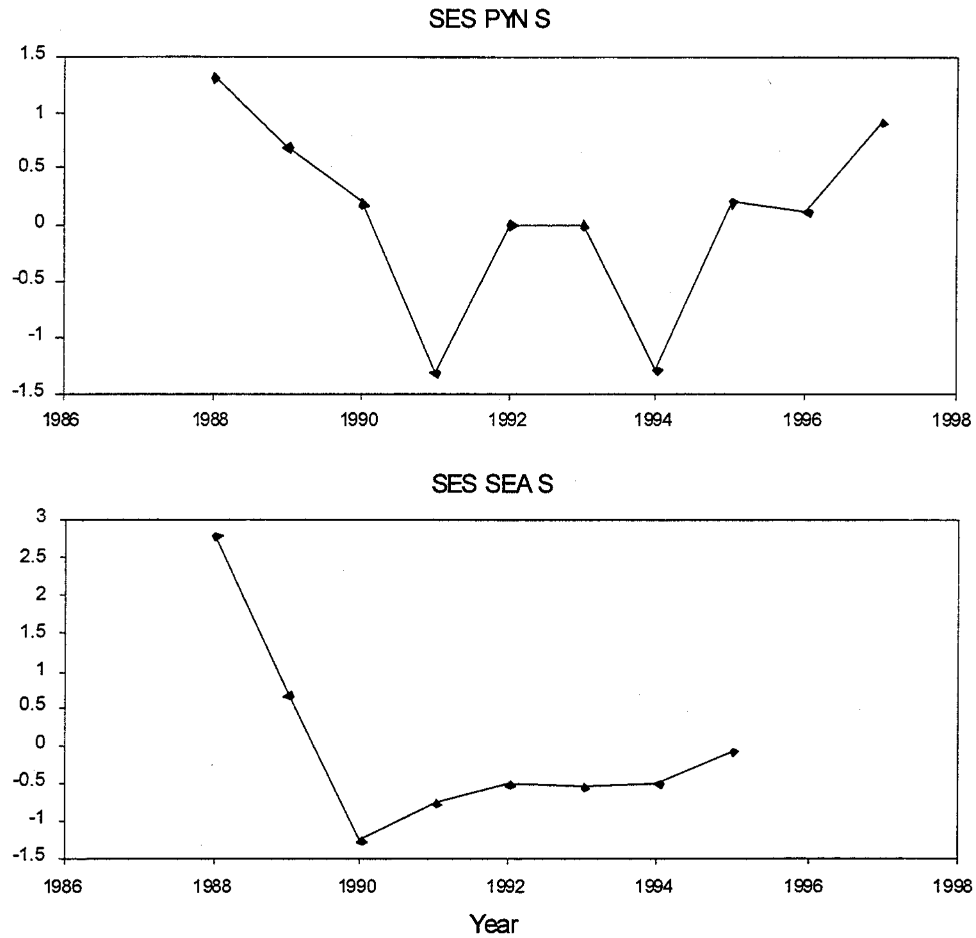

Figure 26: Seal Island, South Shetland Islands group (SES) CSIs for chinstrap penguin (PYN) and Antarctic fur seal (SEA) in summer (S).

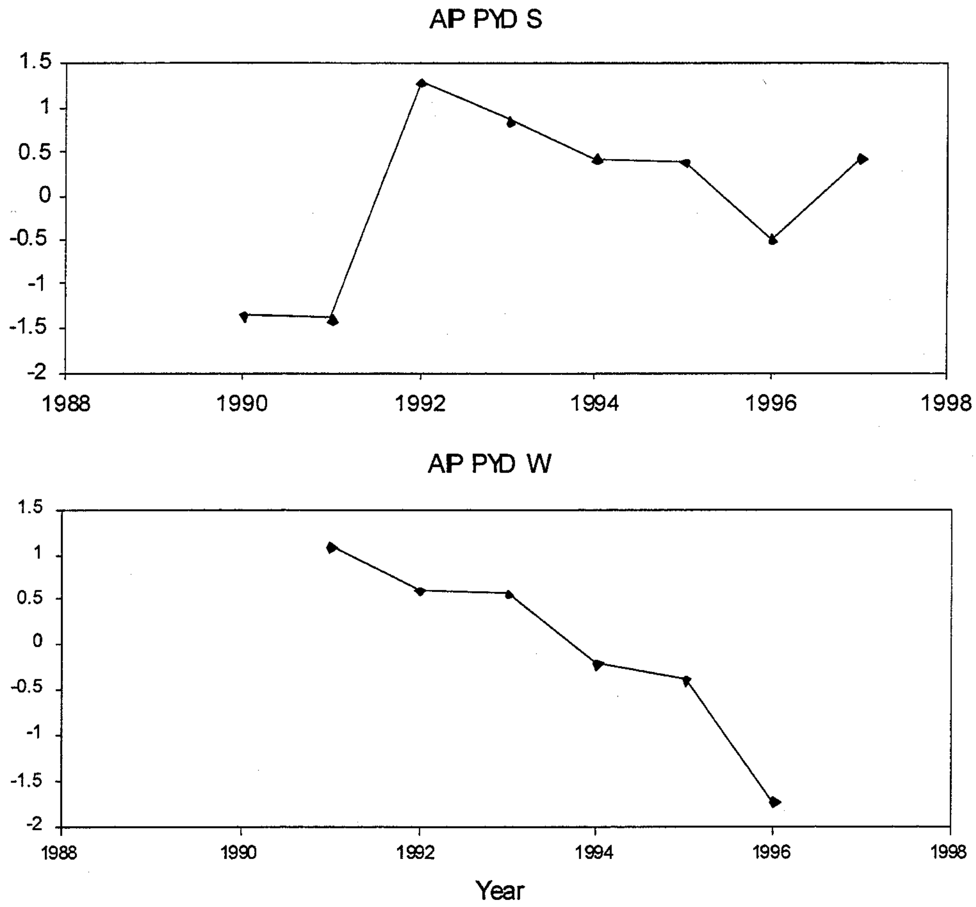

Figure 27: Anvers Island, Antarctic Peninsula (AIP) CSIs for Adélie penguins (PYD) in summer (S) and winter (W).

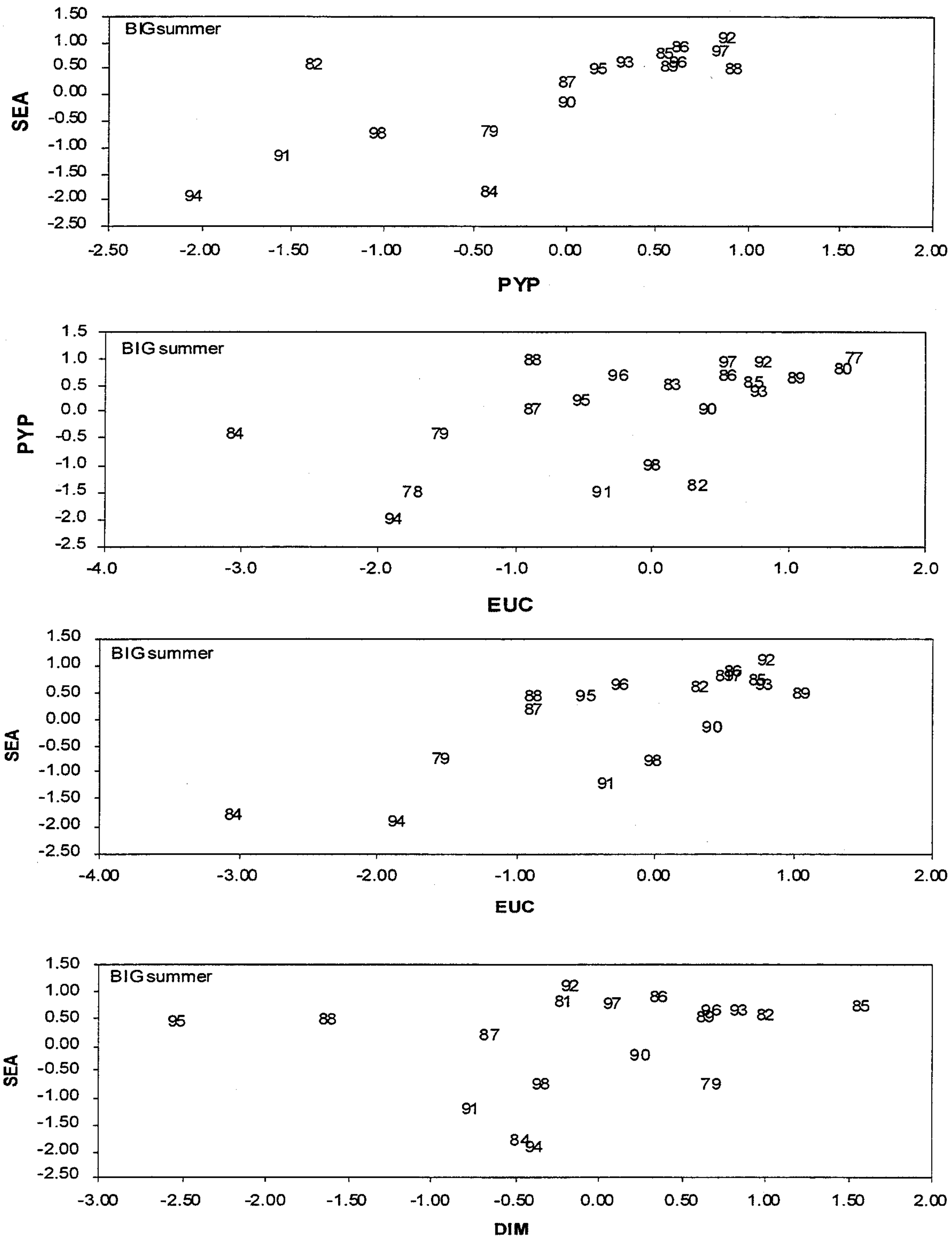

Figure 28: Relationships between summer CSIs at Bird Island (BIG) for different pairwise combinations of predators. Abbreviations as in Table 2 and Figure 23.

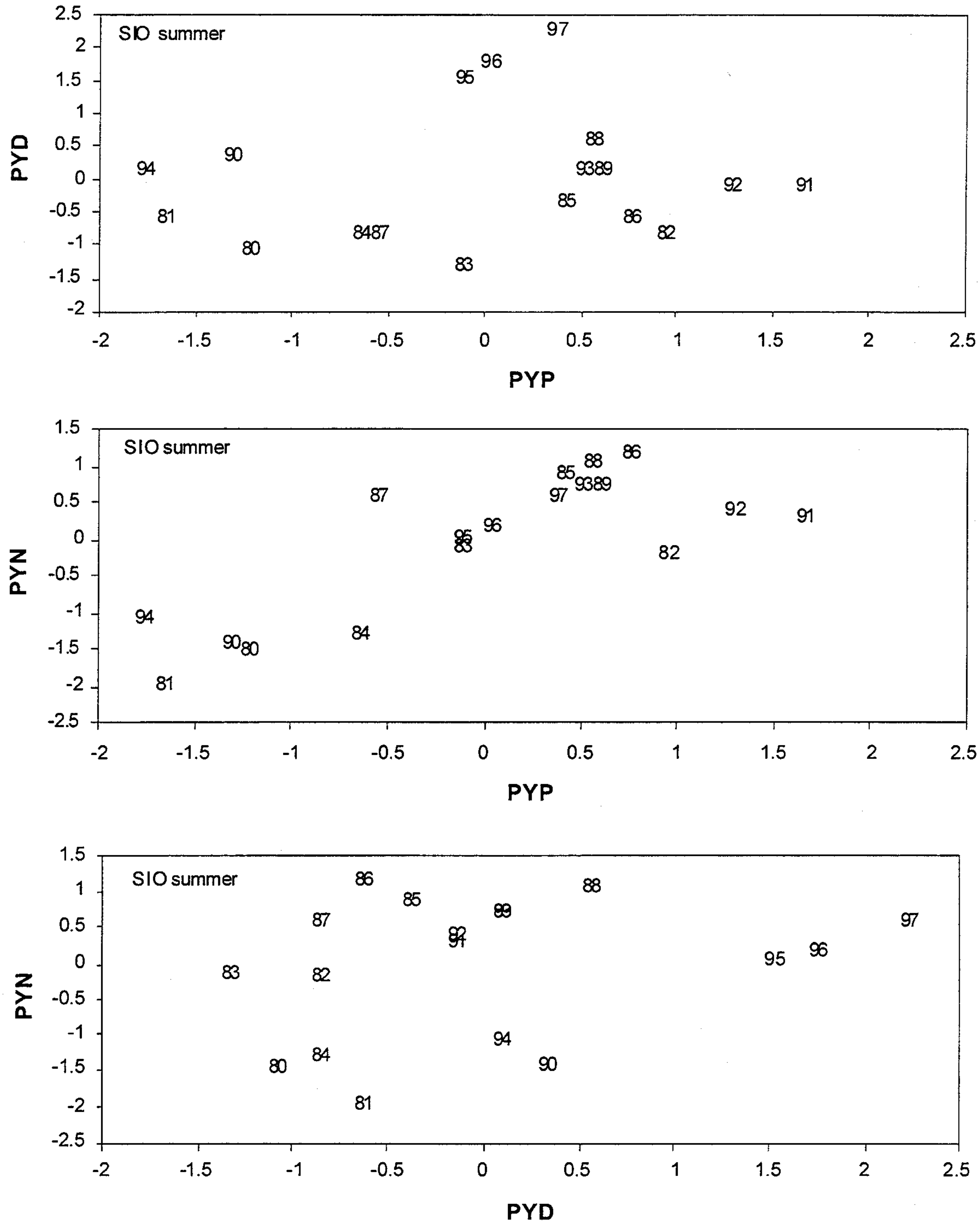

Figure 29a: Relationships between summer CSIs for different pairwise combinations of penguin species at Signy Island (SIO) for Adélie (PYD), chinstrap (PYN) and gentoo (PYP) penguins.

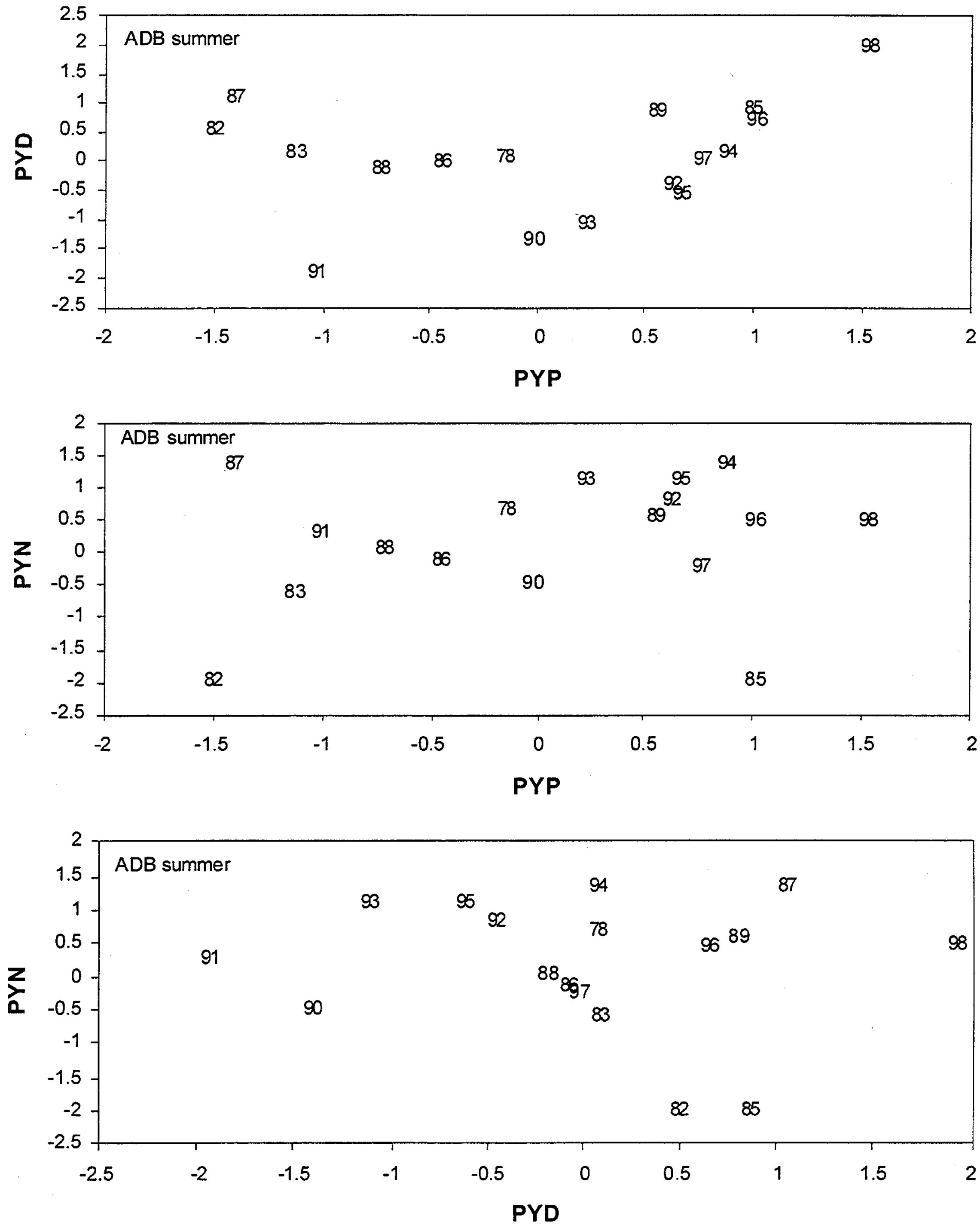

Figure 29b: Relationships between summer CSIs for different pairwise combinations of penguin species at Admiralty Bay (ADB) for Adélie (PYD), chinstrap (PYN) and gentoo (PYP) penguins.

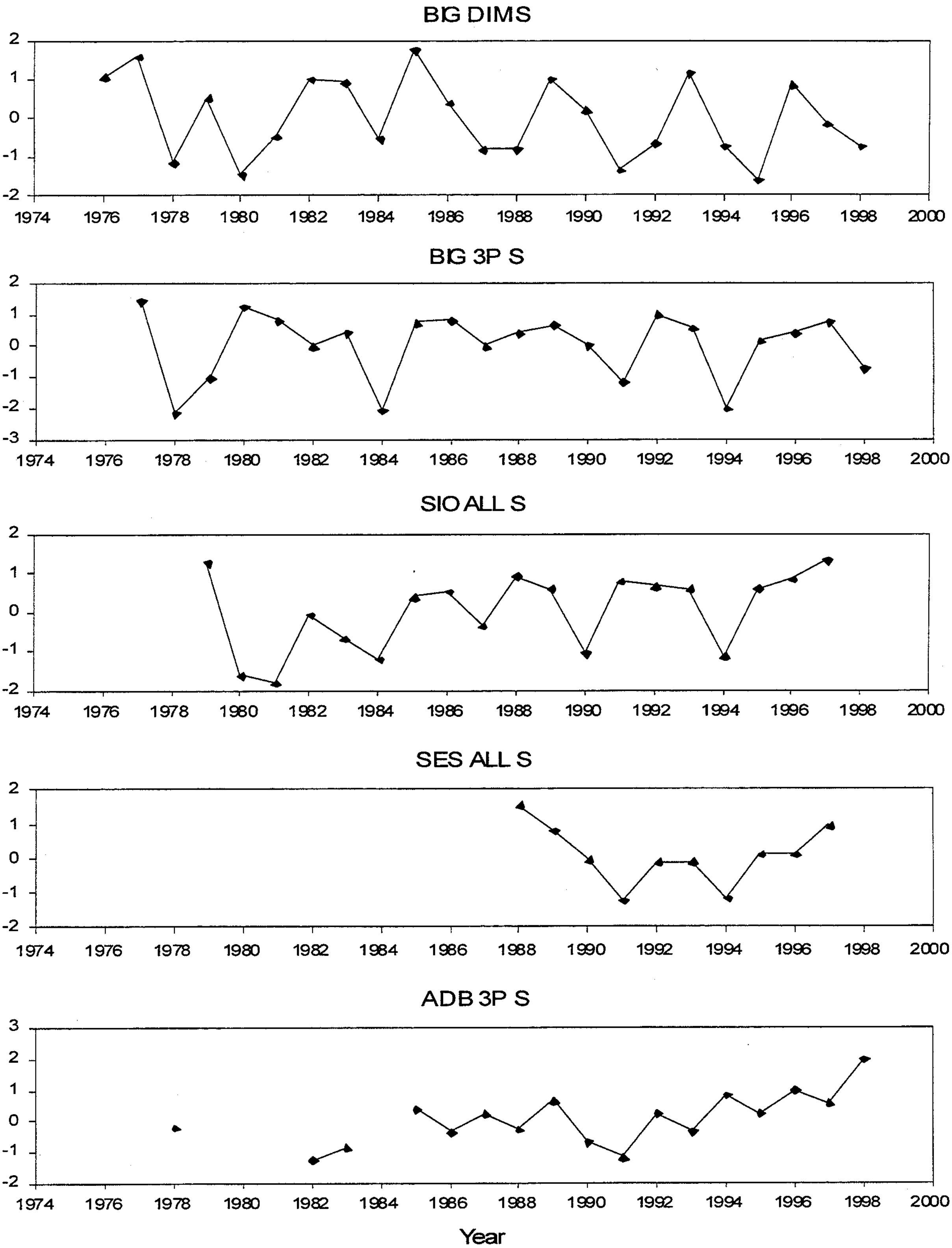

Figure 30: Summer CSIs grouped across species within sites (see paragraph 7.16). BIG 3 PS involves the combination of gentoo penguin, macaroni penguin and Antarctic fur seal at Bird Island; ADB 3 PS and SIO ALL S involve the combination of Adélie, chinstrap and gentoo penguins at Admiralty Bay and Signy Island respectively; SES ALL S involves the combination of chinstrap penguin and Antarctic fur seal at Seal Island.

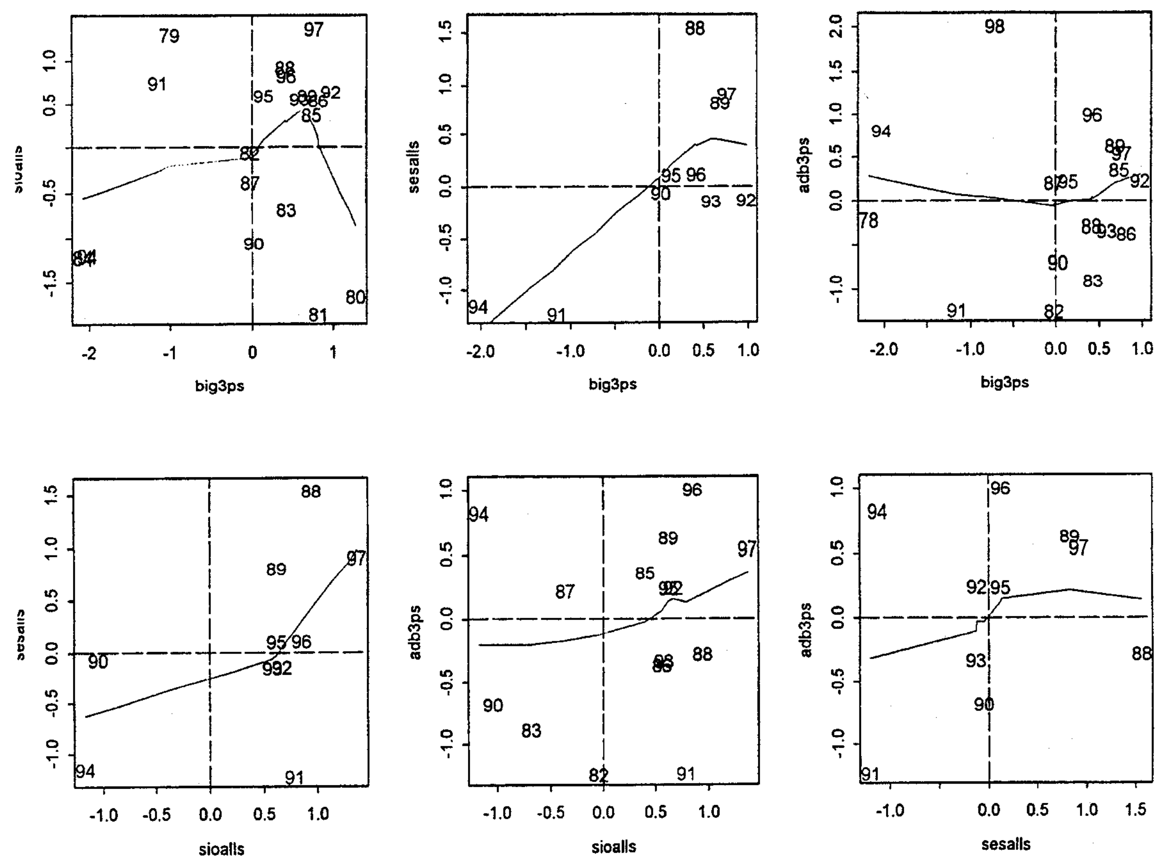

Figure 31: Comparison of predator performance between sites/areas based on summer CSIs for species group within sites. Four quadrants are shown that indicate concordance between variables in each year. Points in the top-right and bottom-left quadrants indicate relatively high concordance whereas those falling in the other two quadrants indicate relatively low concordance. Points are denoted by the number of the calendar year. The solid lines are non-parametric smoothers. BIG 3 PS involves the combination of gentoo penguin, macaroni penguin and Antarctic fur seal at Bird Island; ADB 3 PS and SIO ALL S involve the combination of Adélie, chinstrap and gentoo penguins at Admiralty Bay and Signy Island respectively; SES ALL S involves the combination of chinstrap penguin and Antarctic fur seal at Seal Island.

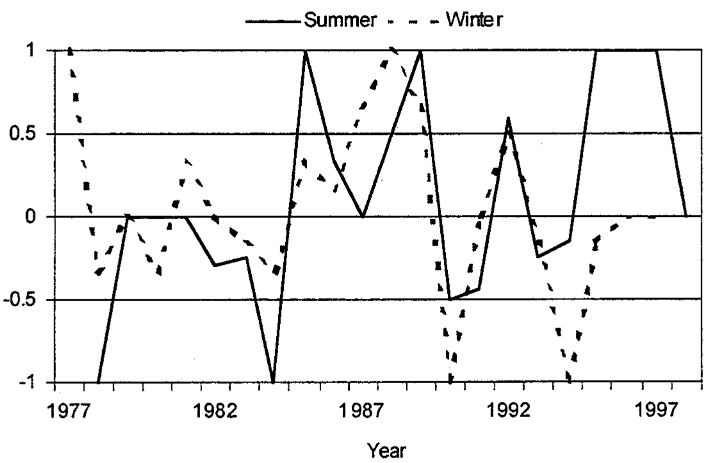

Figure 32: Similarity plot of indices of coherence derived from summer data in Figure 31 and winter data in Figure 35 (see paragraph 7.30 for explanation).

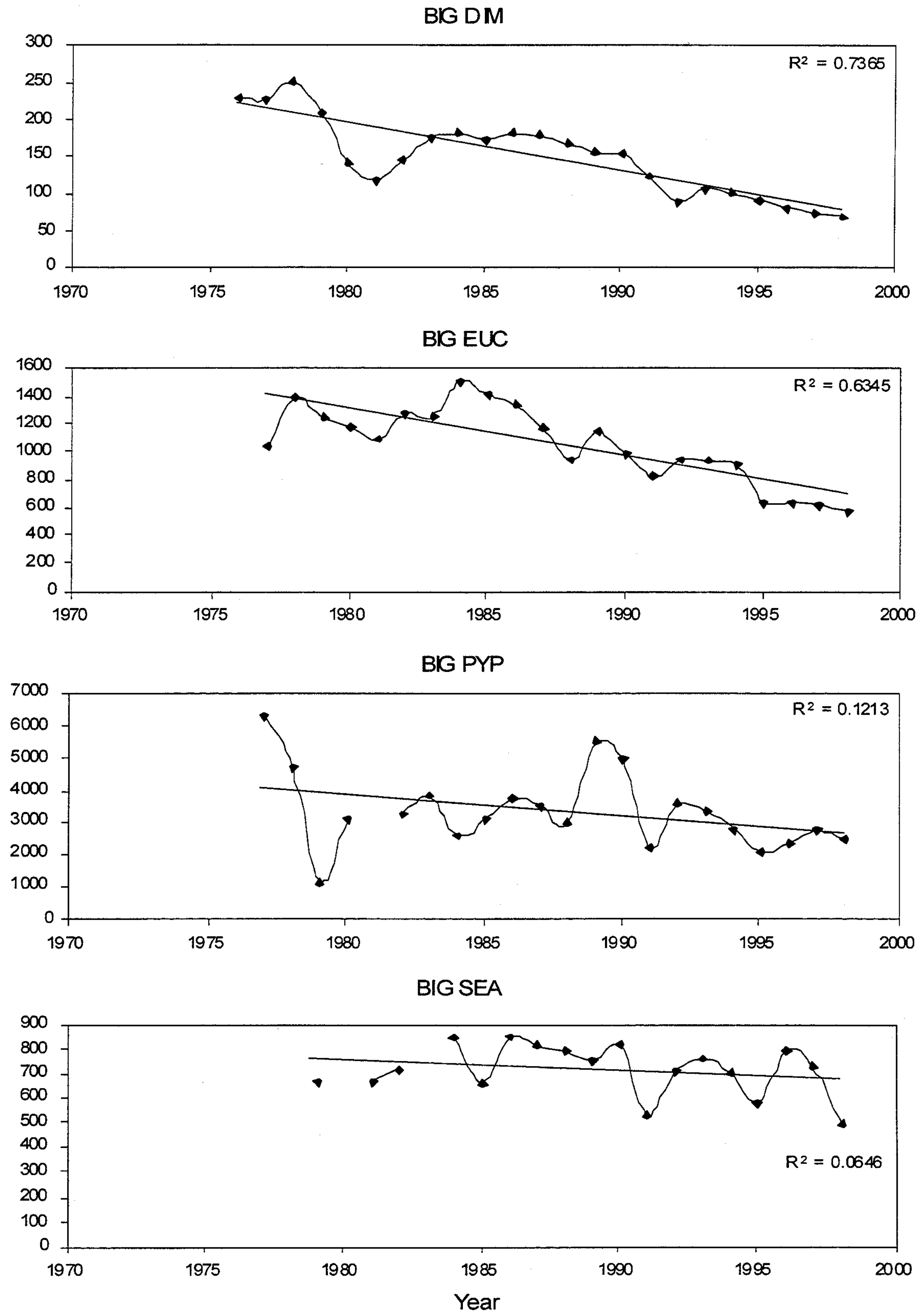

Figure 33: Changes in breeding population size in land-based marine predators at: (a) Bird Island (BIG), (b) Signy Island (SIO), (c) Admiralty Bay (ADB), (d) Anvers Island (AIP). Species abbreviations as in Table 2. Solid lines are least squares linear regression, with R2 as indicated.

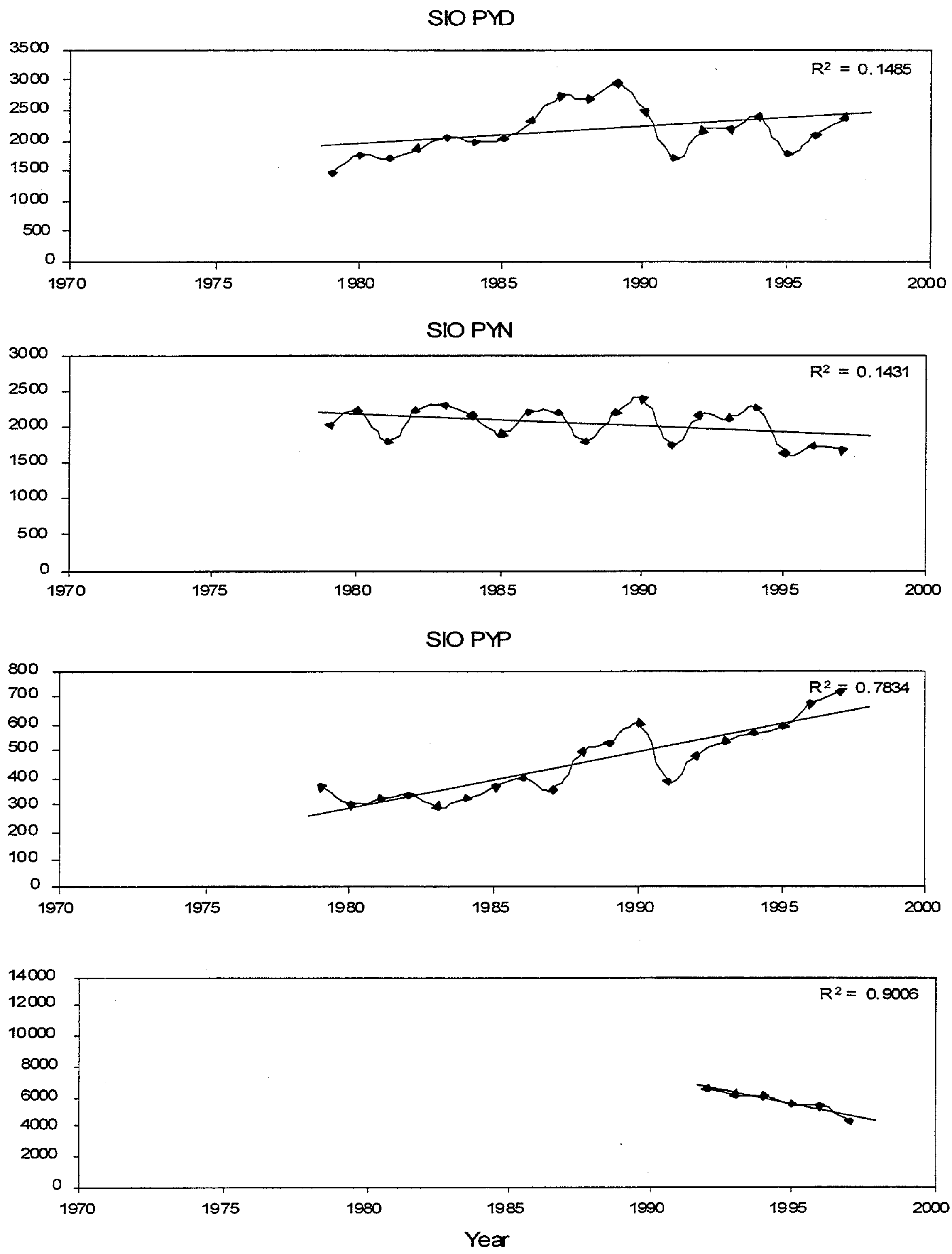

Figure 33 (continued)

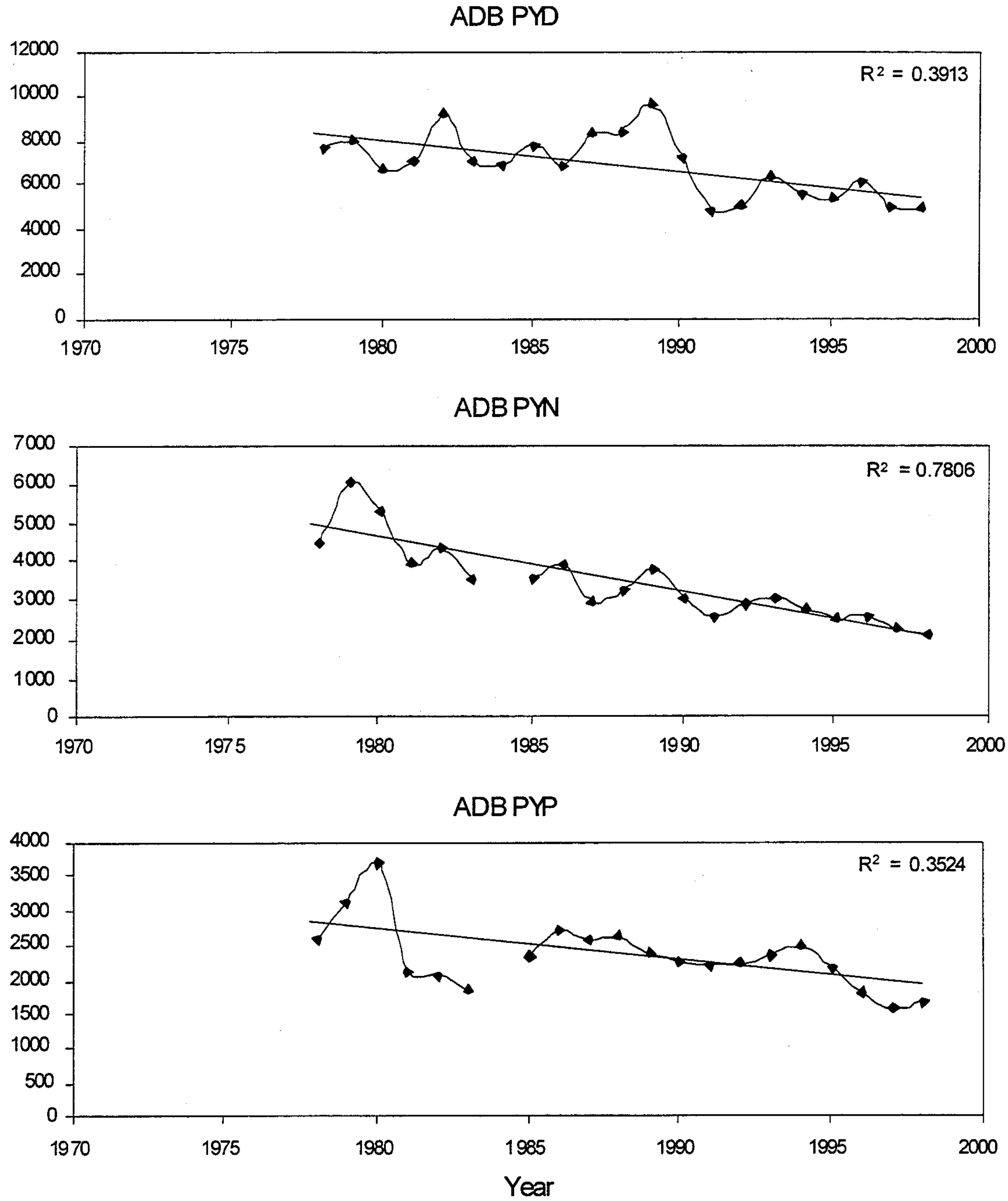

Figure 33 (continued)

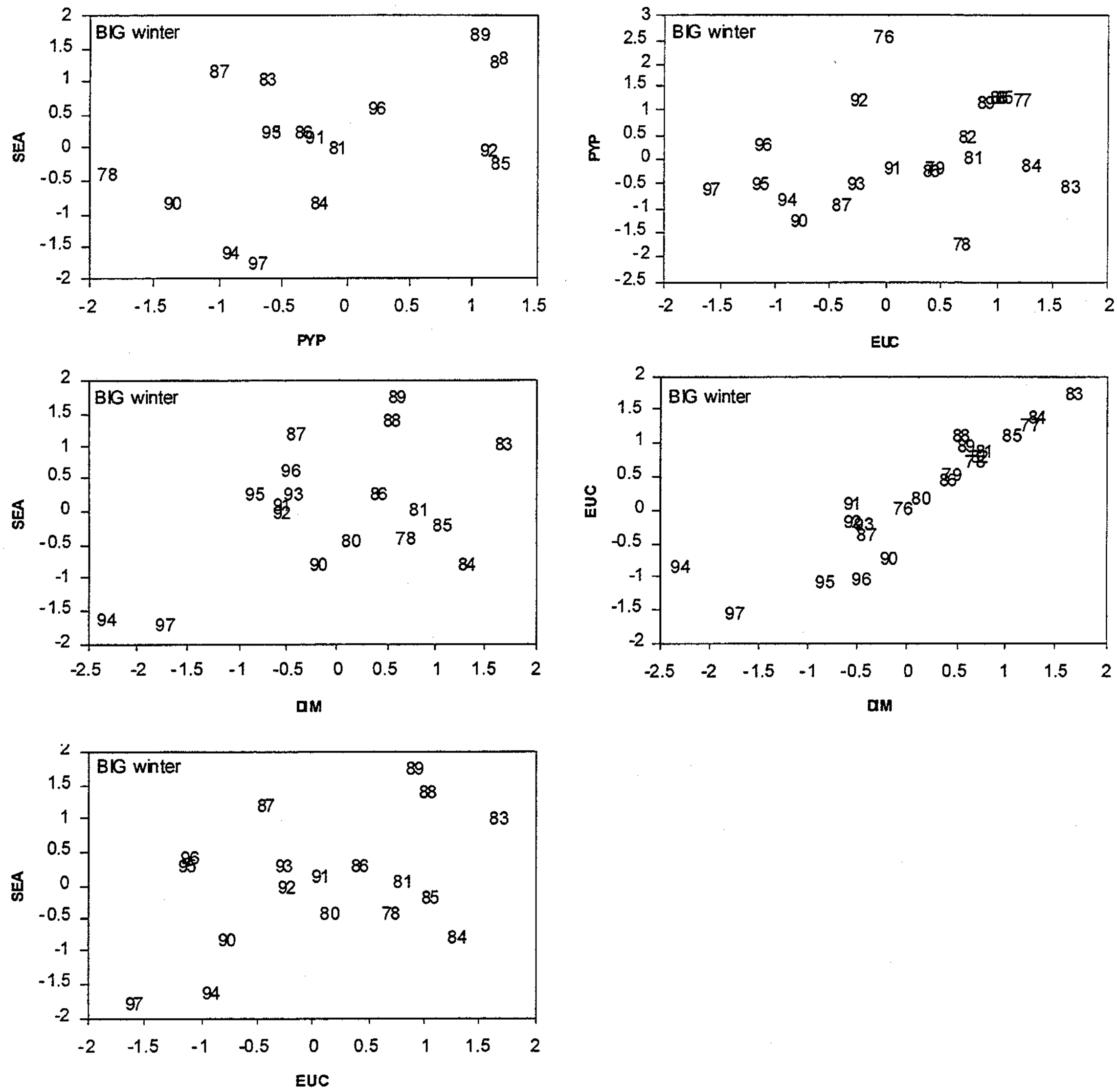

Figure 34a: Relationships between winter CSIs for various pairwise comparisons of predator species at Bird Island (BIG). Species abbreviations as in Table 2.

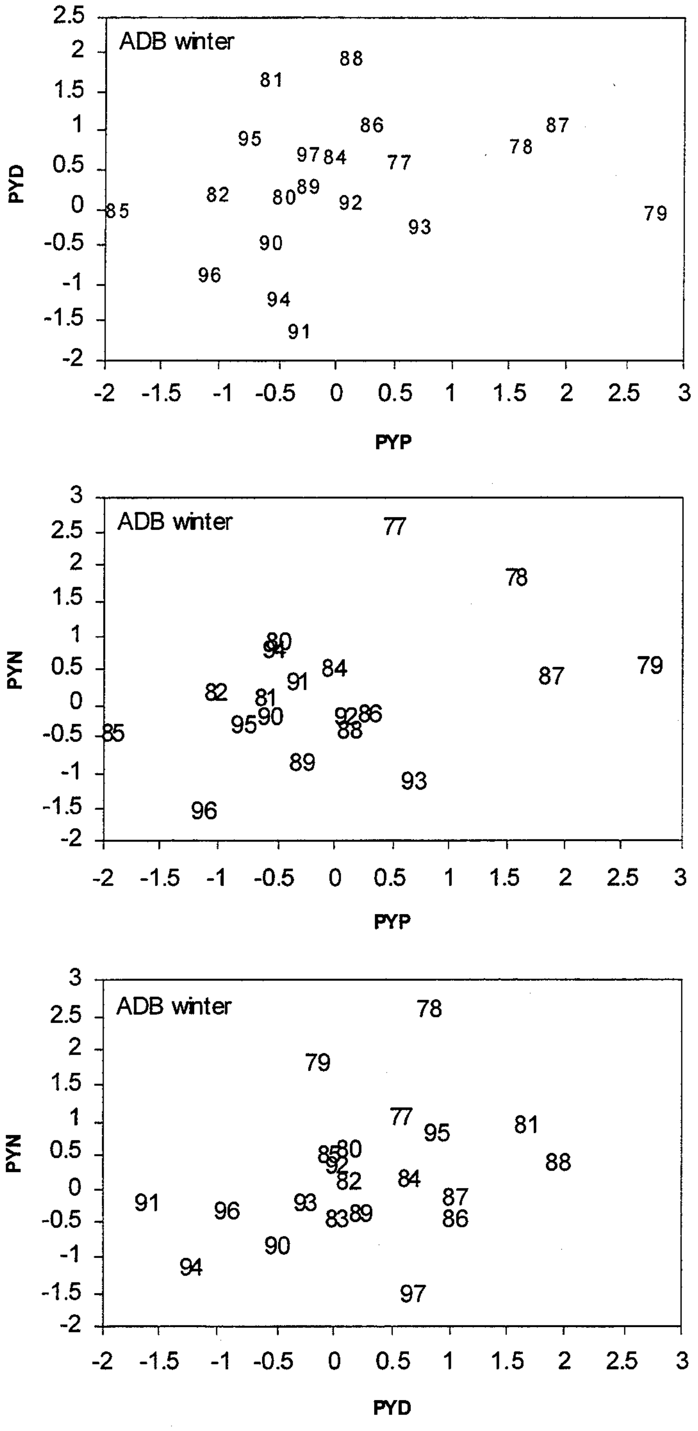

Figure 34b: Relationships between winter CSIs for various pairwise comparisons of predator species at Signy Island (SIO). Species abbreviations as in Table 2.

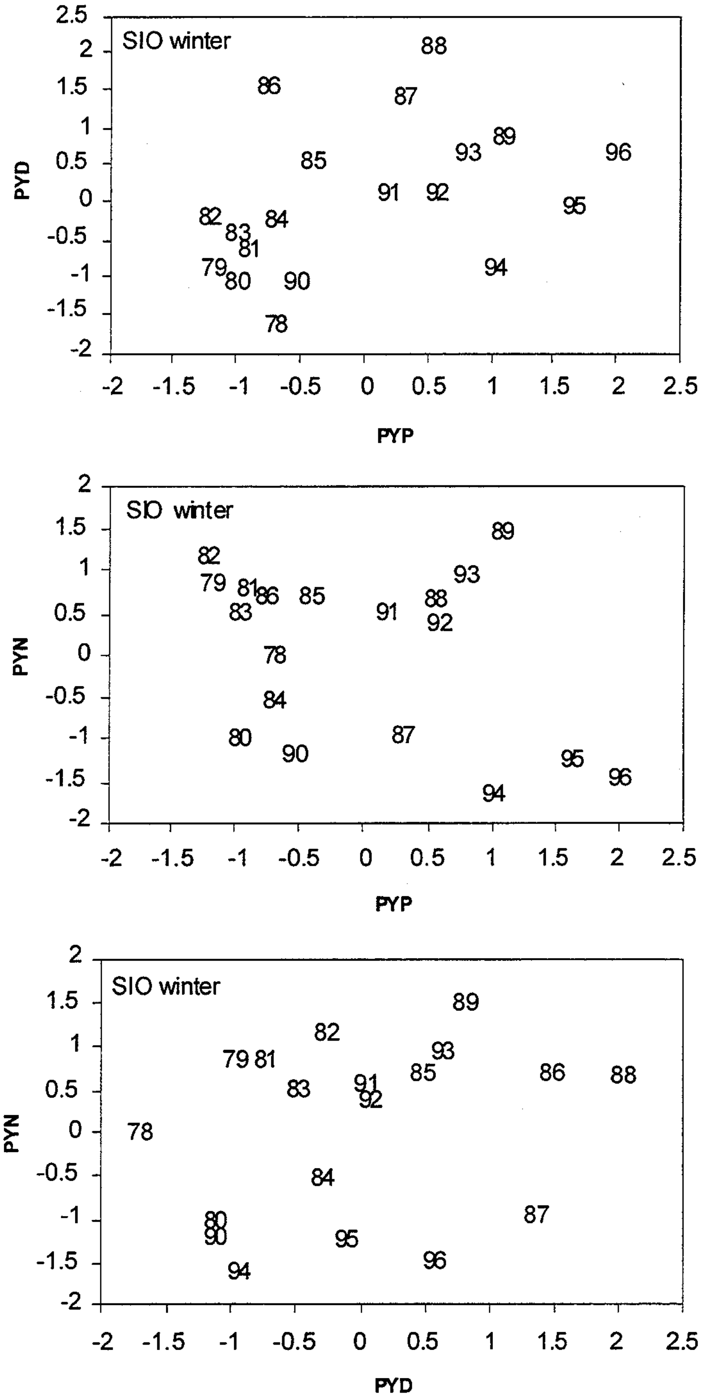

Figure 34c: Relationships between winter CSIs for various pairwise comparisons of predator species at Admiralty Bay (ADB). Species abbreviations as in Table 2.

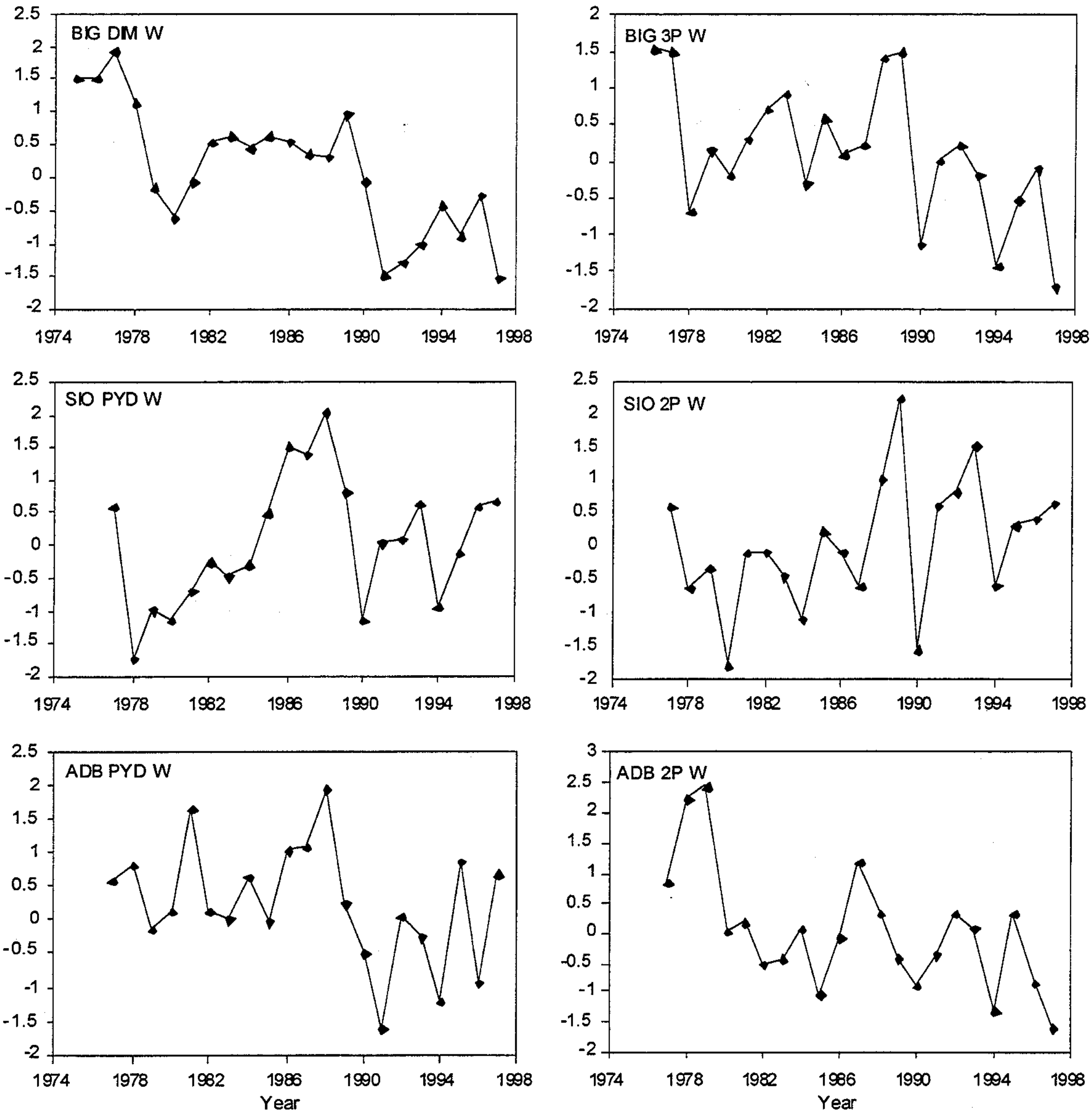

Figure 35: Winter CSIs grouped across species within sites (see paragraph 7.35). BIG 3 PS involves the combination of gentoo penguin, macaroni penguin and Antarctic fur seal at Bird Island; SIO 2 PW and ADB 2 PW involve the combination of chinstrap and gentoo penguins.

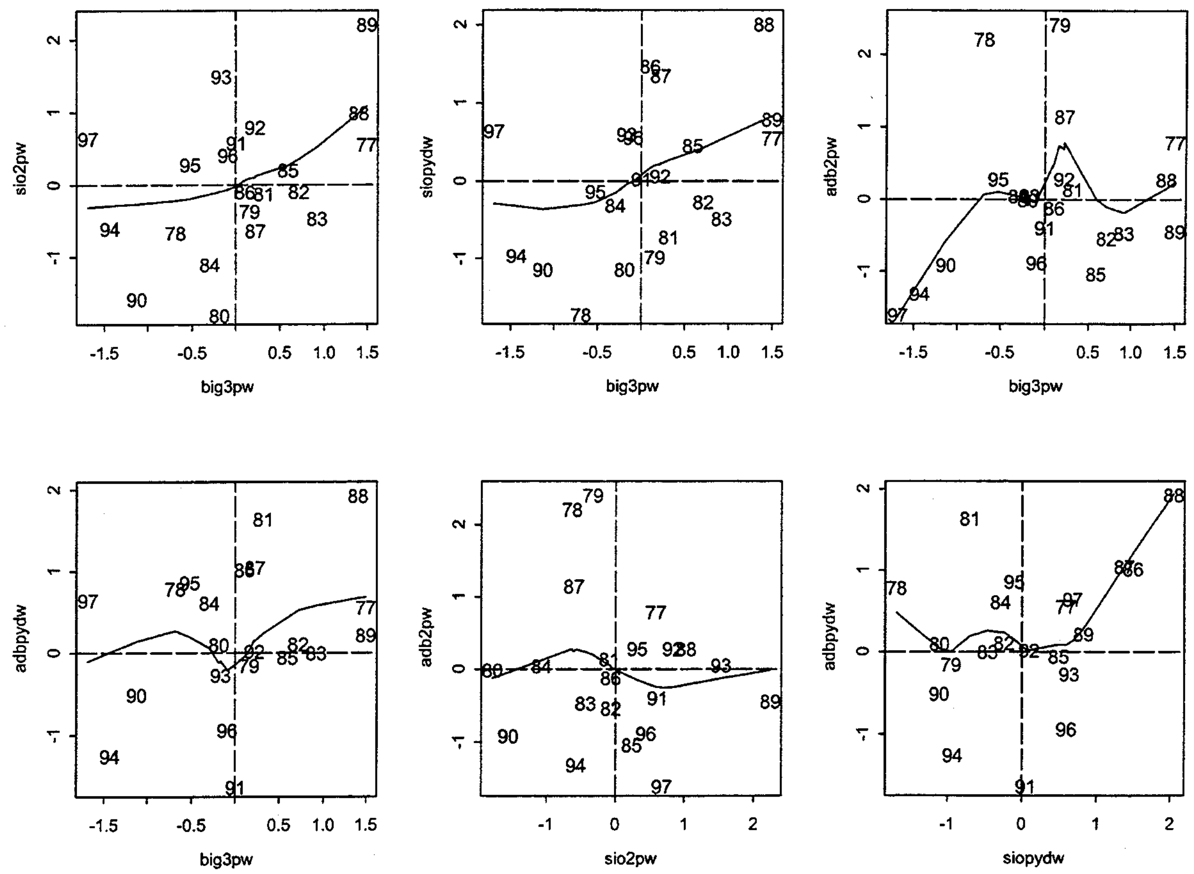

Figure 36: Comparison of predator performance between sites/areas based on winter CSIs for species group within sites. Four quadrants are shown that indicate concordance between variables in each year. Points in the top-right and bottom-left quadrants indicate relatively high concordance whereas those falling in the other two quadrants indicate relatively low concordance. Points are denoted by the number of the calendar year. The solid lines are non-parametric smoothers. BIG 3 PW involves the combination of gentoo penguin, macaroni penguin and Antarctic fur seal at Bird Island; SIO 2 PW and ADB 2 PW involve the combination of chinstrap and gentoo penguins. SIO PYD W and ADB PYD W are Adélie penguins at Signy Island and Admiralty Bay respectively.

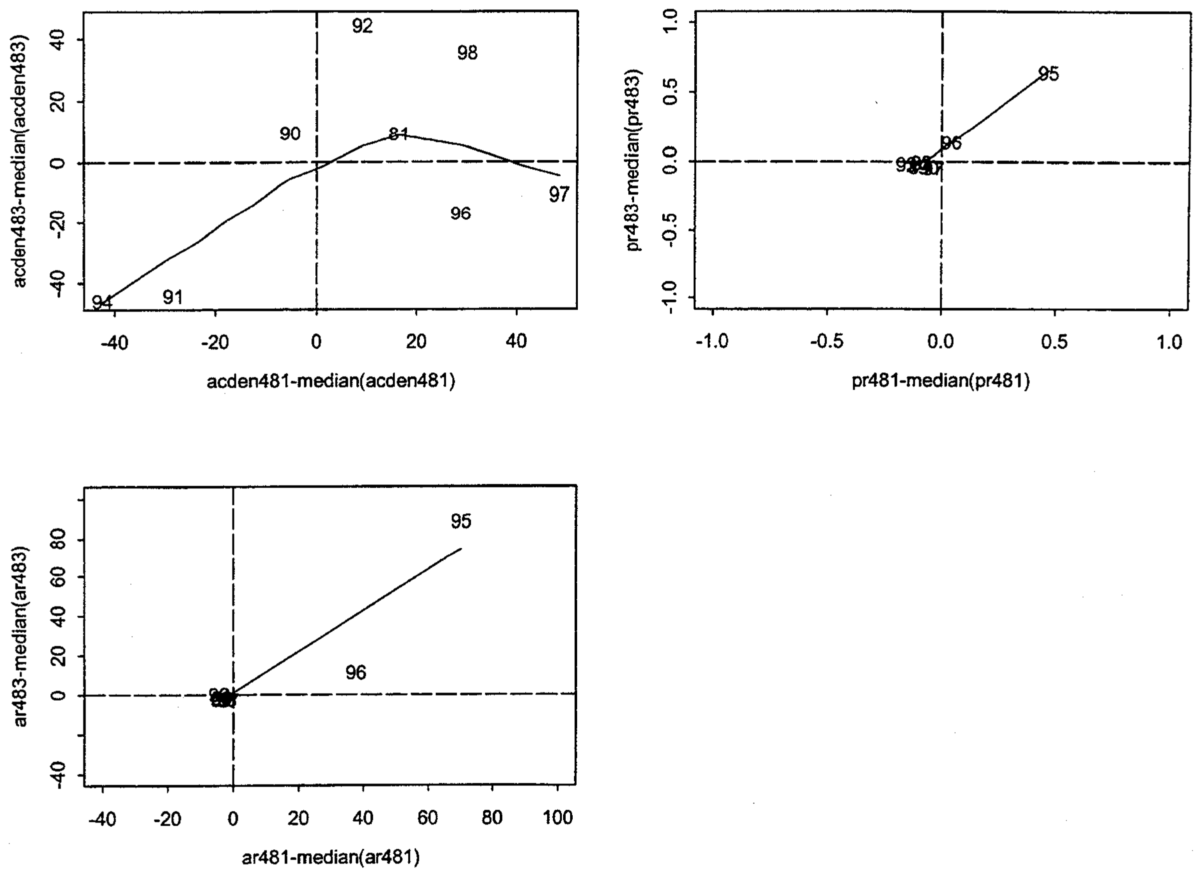

Figure 37: Comparisons of krill indices between areas. Each index is expressed relative to its median value. Four quadrants are shown that indicate concordance between variables in each year. Points in the top-right and bottom-left quadrants indicate relatively high concordance whereas those falling in the other two quadrants indicate relatively low concordance. Points are denoted by the number of the calendar year.

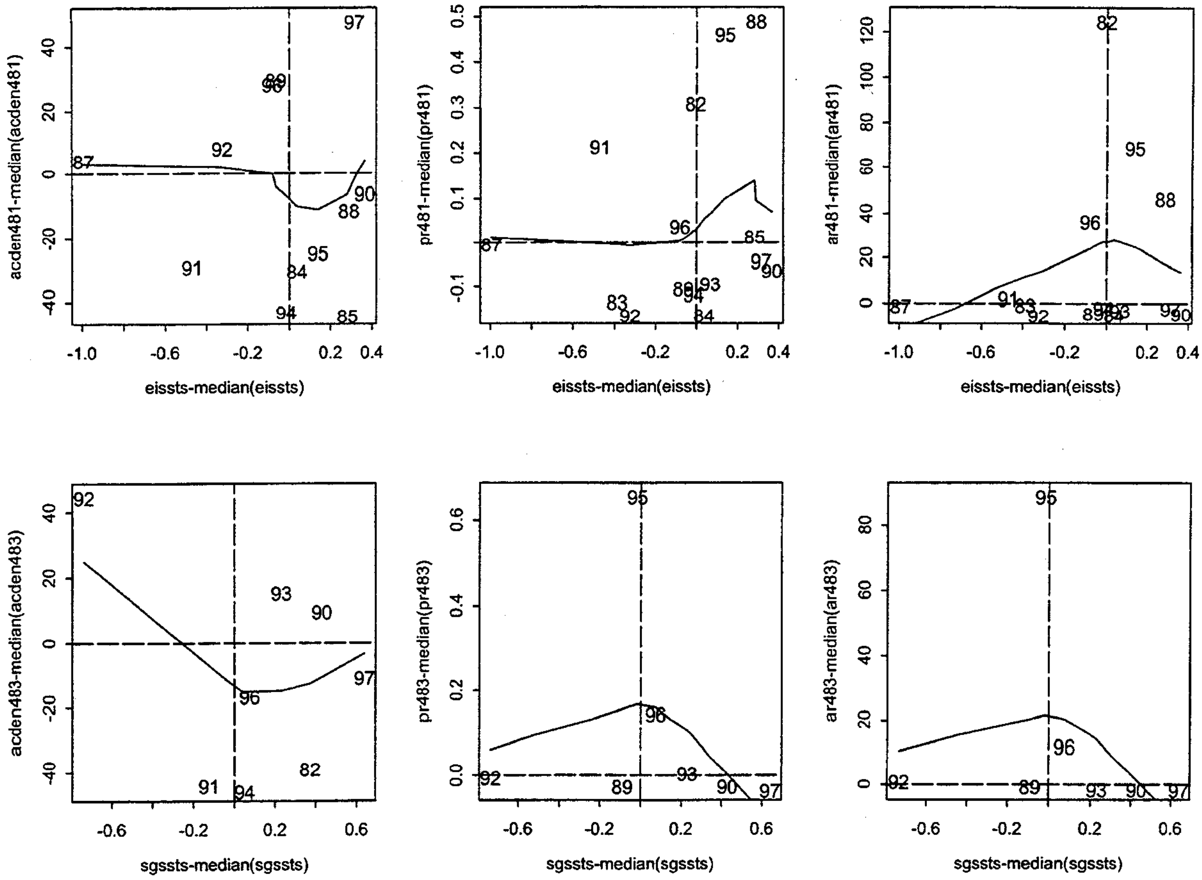

Figure 38: Krill indices in relation to SST within areas. Each index is expressed relative to its median value. Four quadrants are shown that indicate concordance between variables in each year. Points in the top-right and bottom-left quadrants indicate relatively high concordance whereas those falling in the other two quadrants indicate relatively low concordance. Points are denoted by the number of the calendar year.

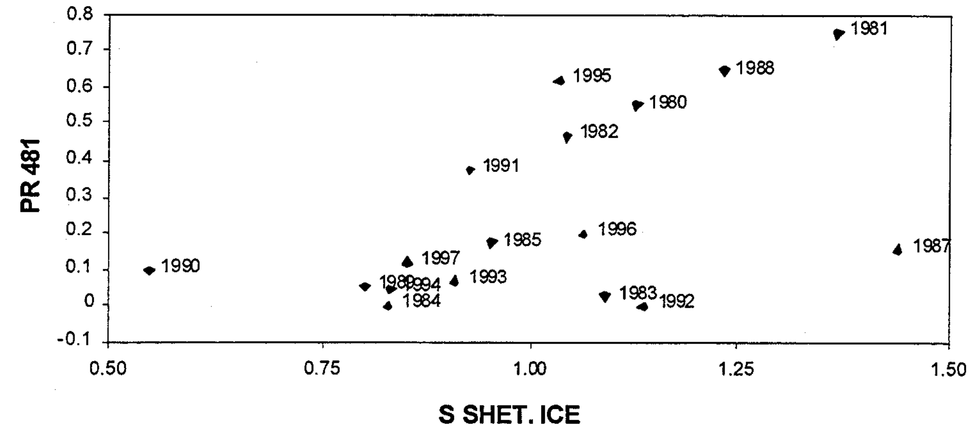

Figure 39: The relationship between proportional krill recruitment in Subarea 48.1 and sea-ice in the South Shetlands. Each point is labelled with the year in which data were collected.

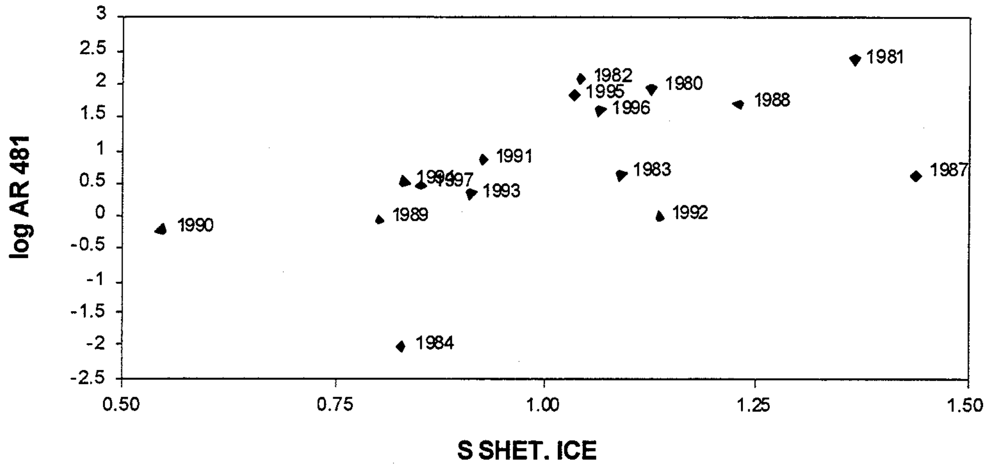

Figure 40: The relationship between the log of proportional krill recruitment in Subarea 48.1 and sea-ice in the South Shetlands. Each point is labelled with the year in which data were collected.

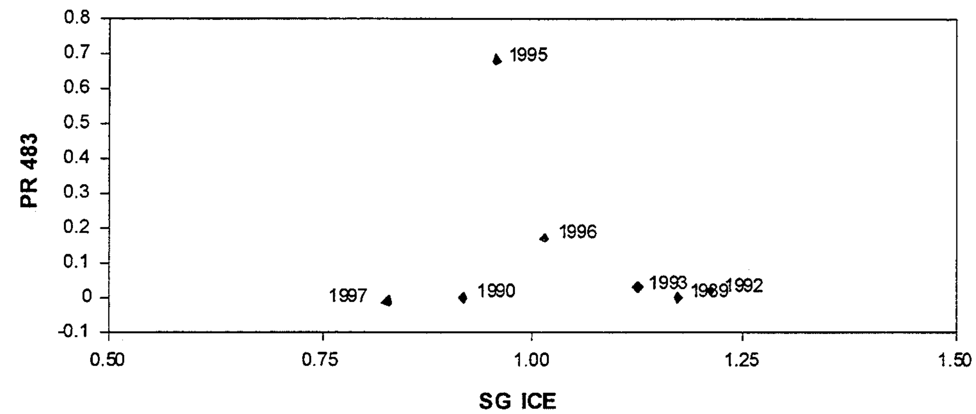

Figure 41: The relationship between proportional recruitment in Subarea 48.3 and the South Georgia sea-ice index. Each point is labelled with the year in which data were collected.

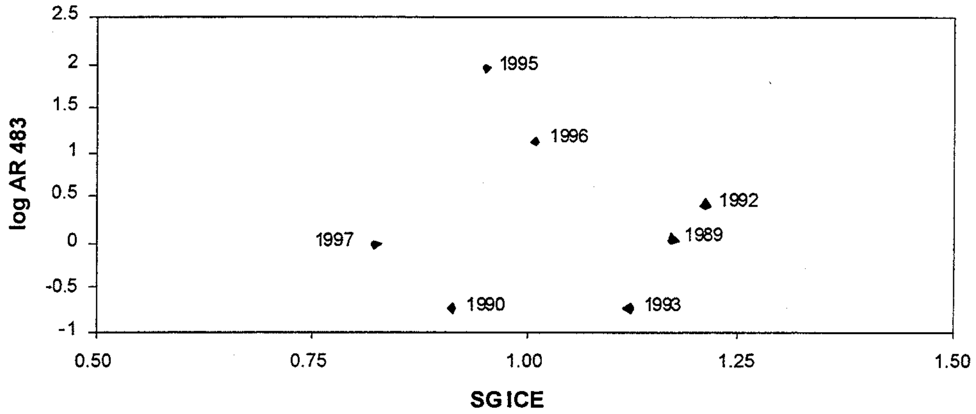

Figure 42: The relationship between the log of proportional recruitment in Subarea 48.3 and the South Georgia sea-ice index. Each point is labelled with the year in which data were collected.

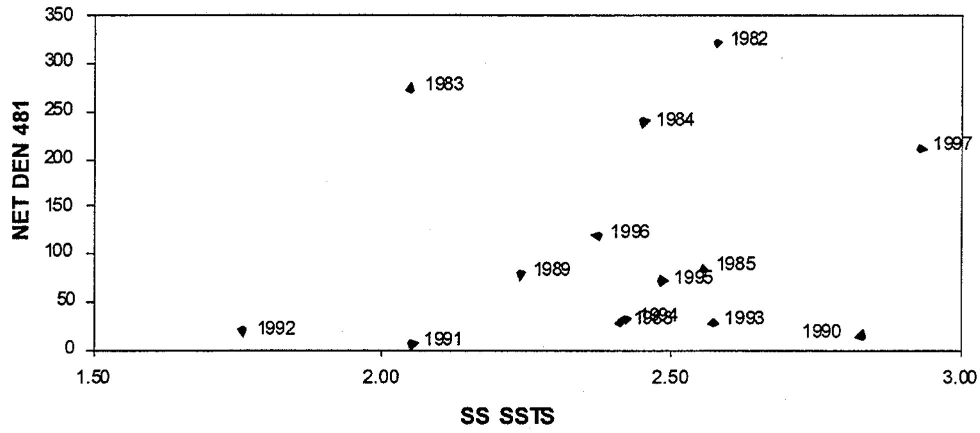

Figure 43: The relationship between krill density determined using net sampling in Subarea 48.1 and the Scotia Sea summer SST. Each point is labelled with the year in which data were collected.

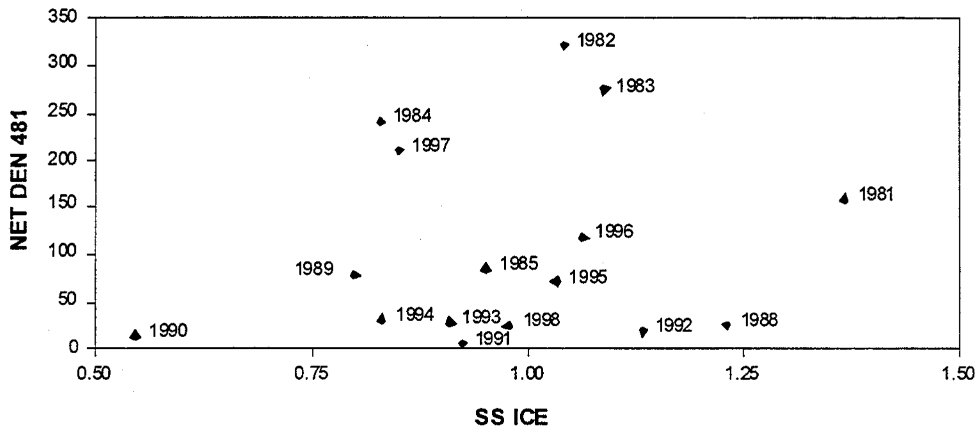

Figure 44: The relationship between krill density determined using net sampling in Subarea 48.1 and the Scotia Sea sea-ice index. Each point is labelled with the year in which data were collected.

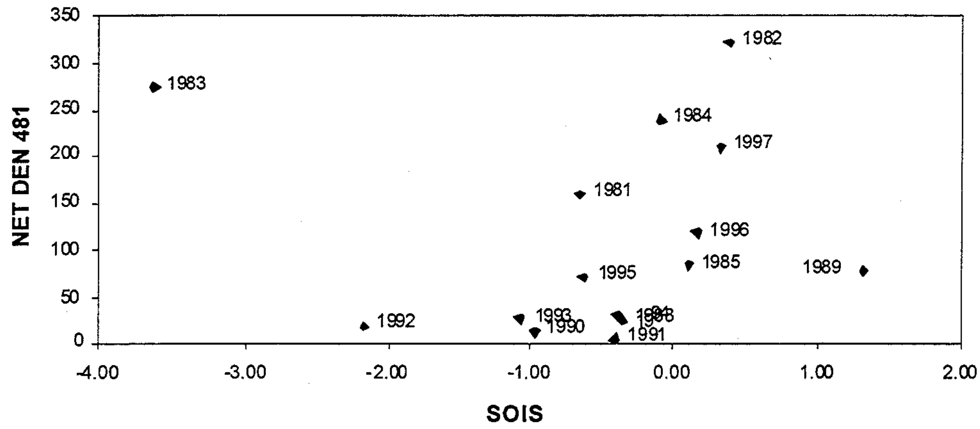

Figure 45: The relationship between krill density determined using net sampling in Subarea 48.1 and the summer SOI. Each point is labelled with the year in which data were collected.

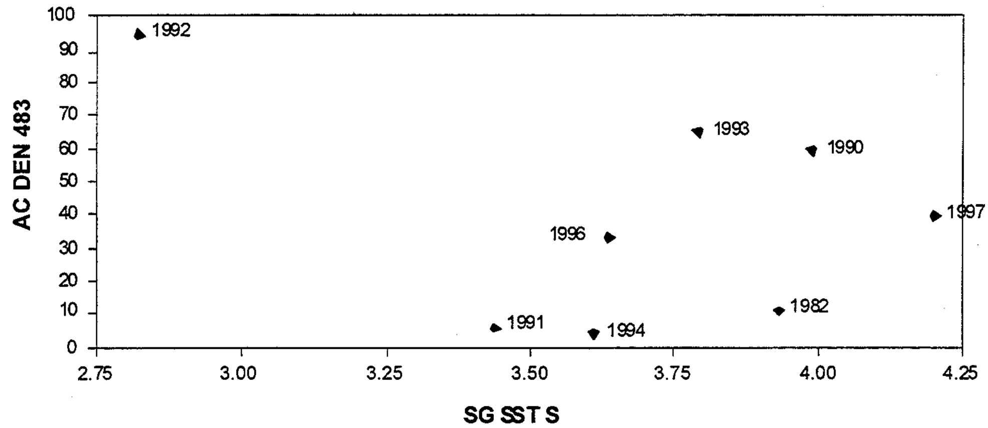

Figure 46: The relationship between krill density determined using acoustic sampling in Subarea 48.3 and the South Georgia summer SST. Each point is labelled with the year in which data were collected.

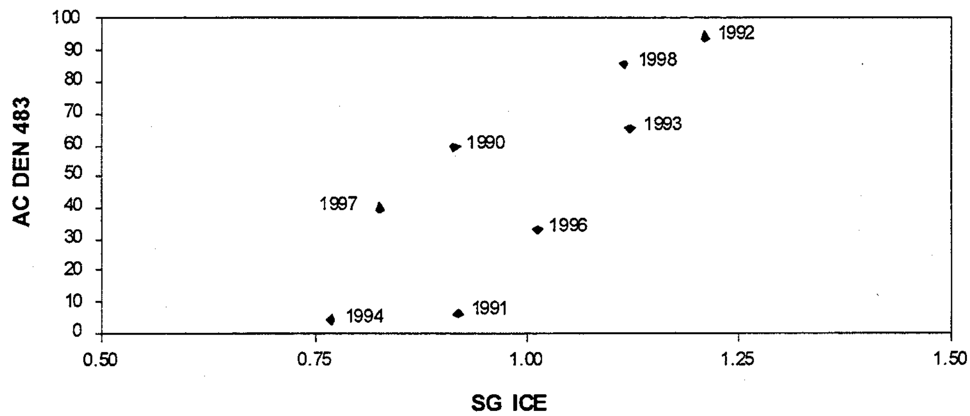

Figure 47: The relationship between krill density determined using acoustic sampling in Subarea 48.3 and the South Georgia sea-ice index. Each point is labelled with the year in which data were collected.

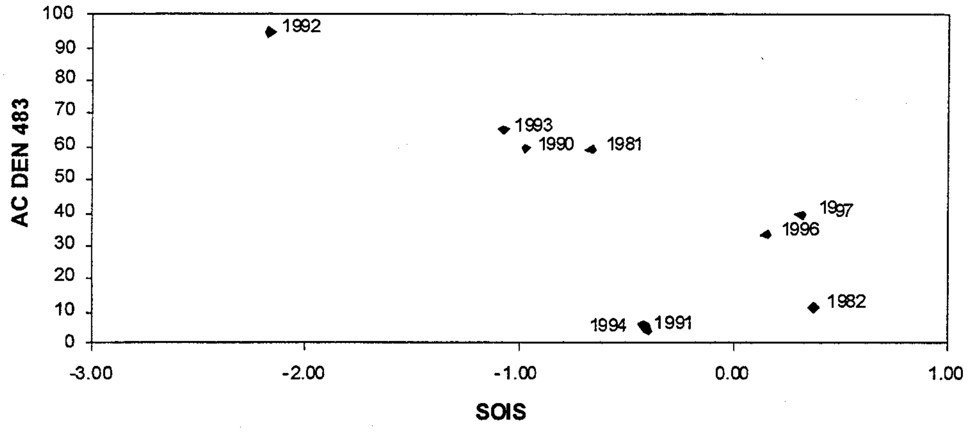

Figure 48: The relationship between krill density determined using acoustic sampling in Subarea 48.3 and the summer SOI. Each point is labelled with the year in which data were collected.

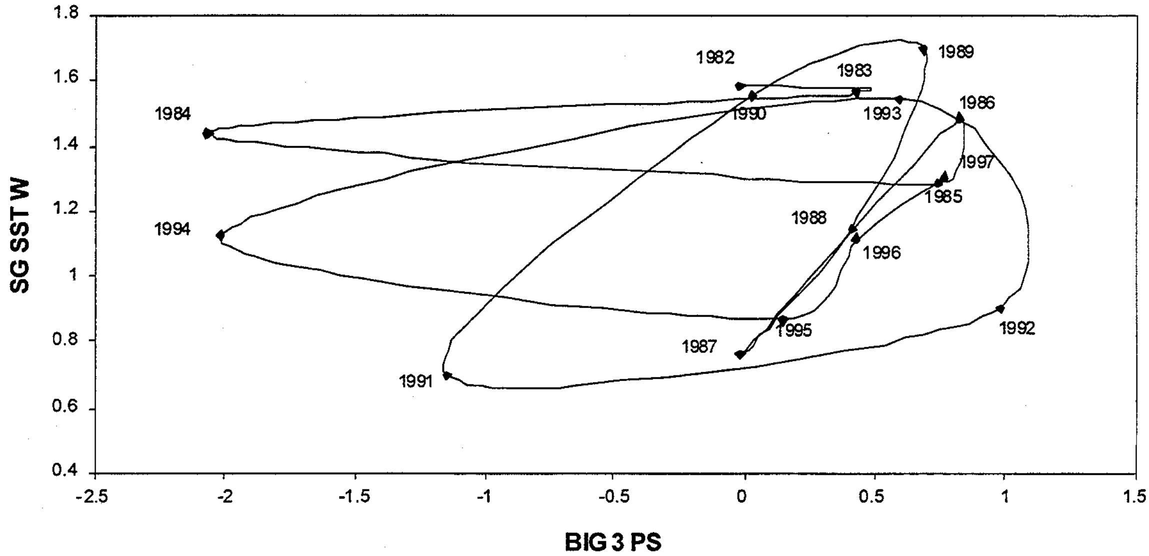

Figure 49: The relationship between the South Georgia winter SST index and the combined index of diving predators at Bird Island in summer. Each point is labelled with the year in which data were collected and they are connected in date order.

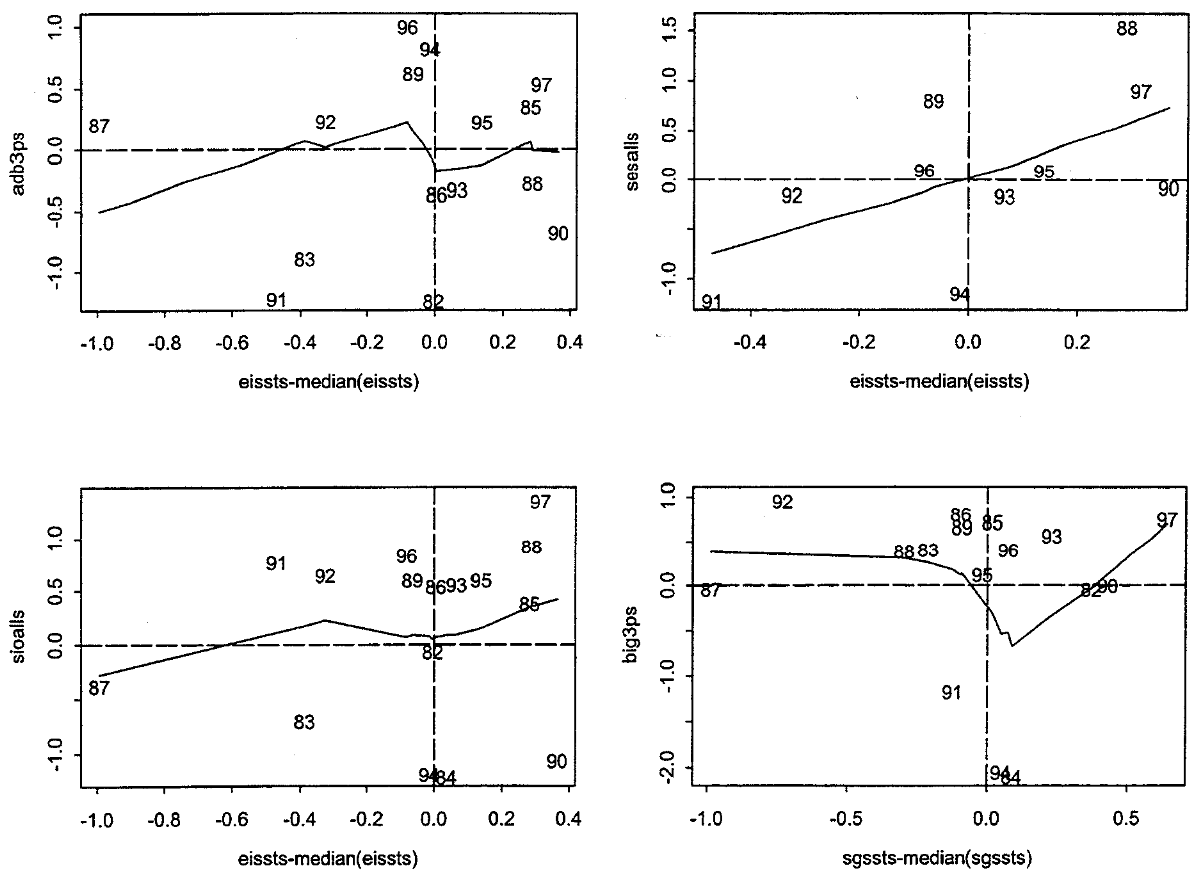

Figure 50: Predator performance indices in relation to SST within areas. Each index is expressed relative to its median value. Four quadrants are shown that indicate concordance between variables in each year. Points in the top-right and bottom-left quadrants indicate relatively high concordance whereas those falling in the other two quadrants indicate relatively low concordance. Points are denoted by the number of the calendar year.

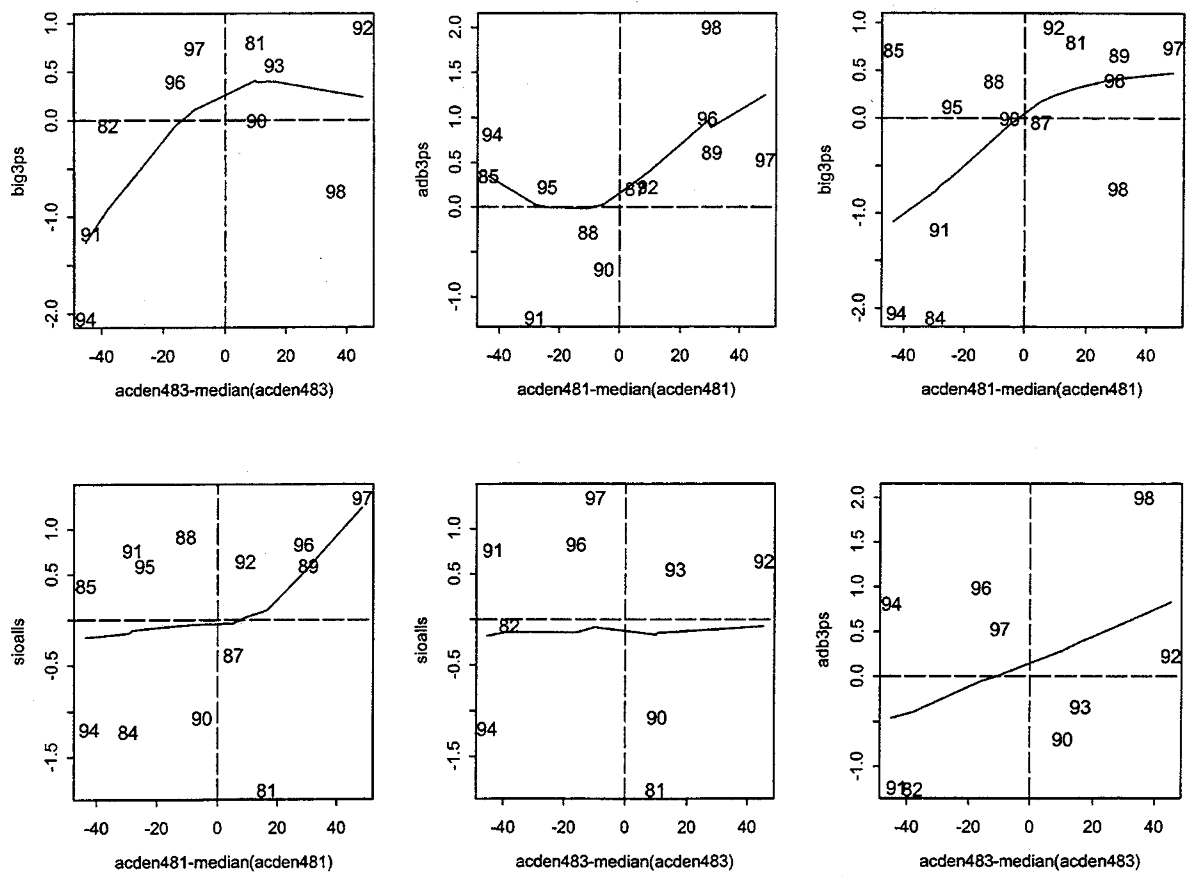

Figure 51: Predator performance indices in relation to acoustic krill density within areas. Each index is expressed relative to its median value. Four quadrants are shown that indicate concordance between variables in each year. Points in the top-right and bottom-left quadrants indicate relatively high concordance whereas those falling in the other two quadrants indicate relatively low concordance. Points are denoted by the number of the calendar year.

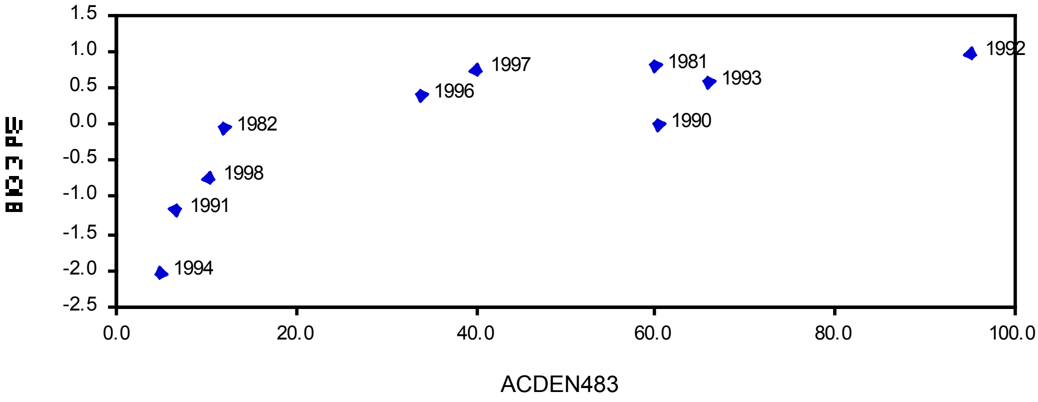

Figure 52: Composite index of the summer performance of diving predators at Bird Island in relation to the acoustic density of krill recorded in the South Georgia area (Subarea 48.3).

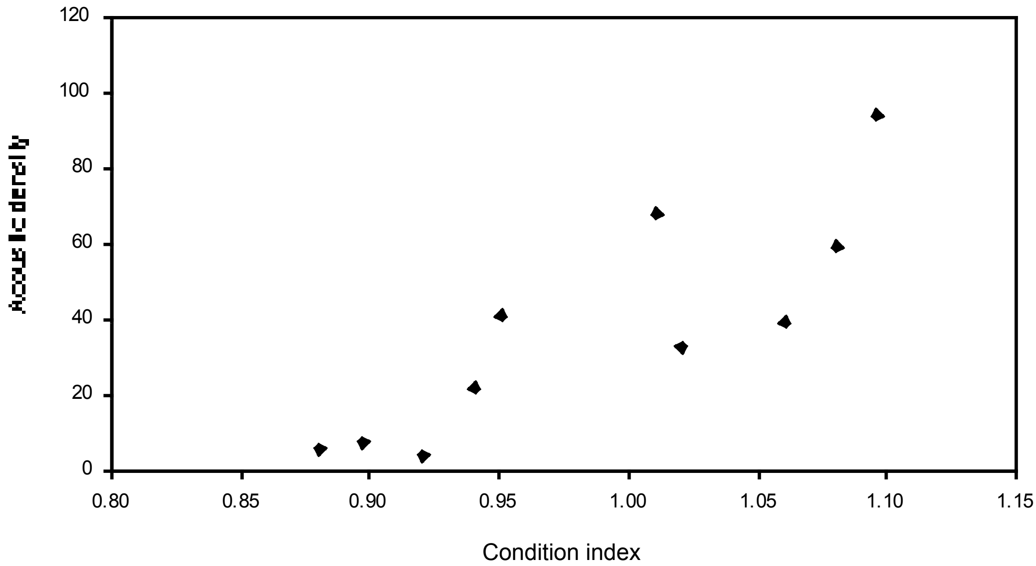

Figure 53: Icefish condition index in relation to acoustic density of krill based on combined data from Subareas 48.1 and 48.3.

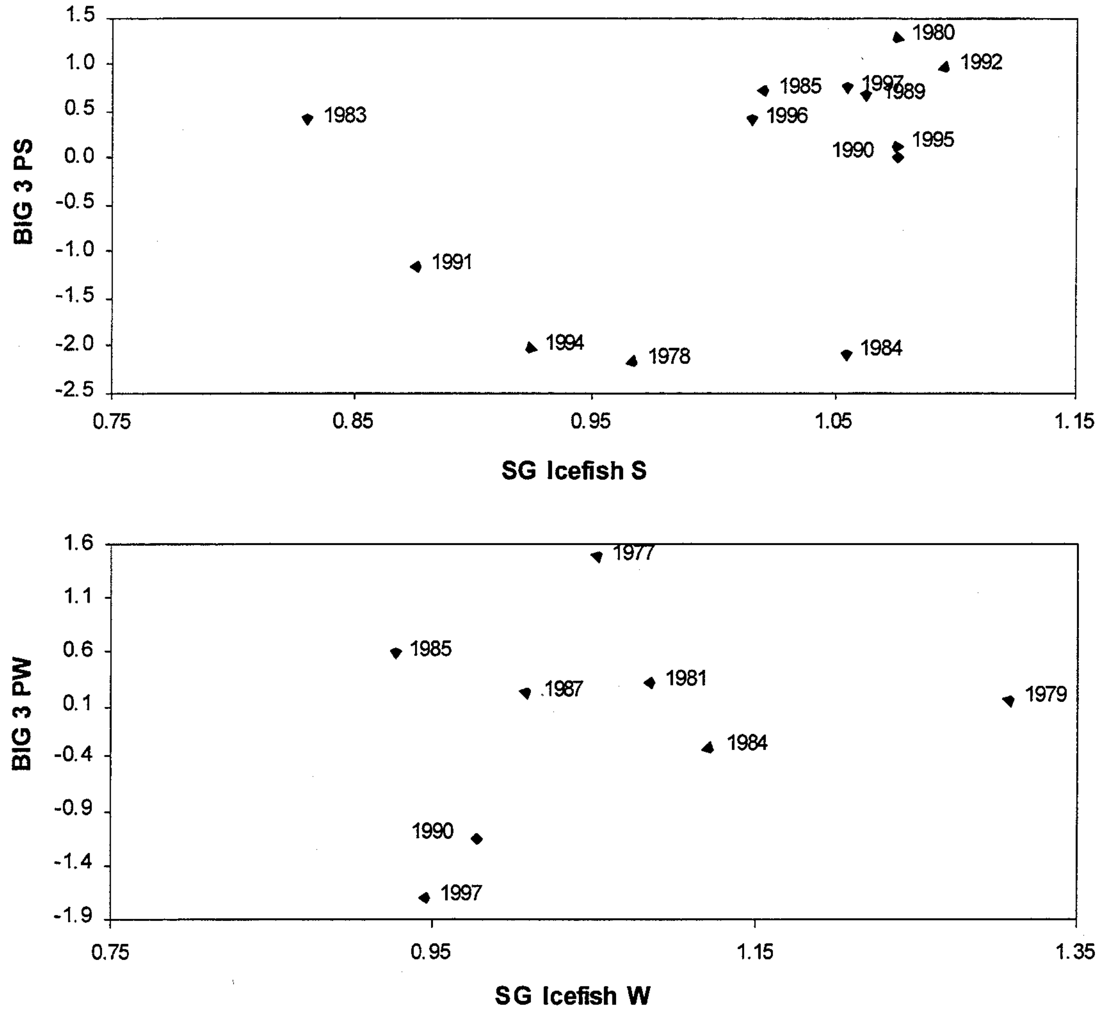

Figure 54: Relationship between the CSI for icefish at South Georgia (SG) in summer (S) and winter (W) and the CSI for gentoo and macaroni penguins and Antarctic fur seal in summer (BIG 3 PS) and winter (BIG 3 PW).

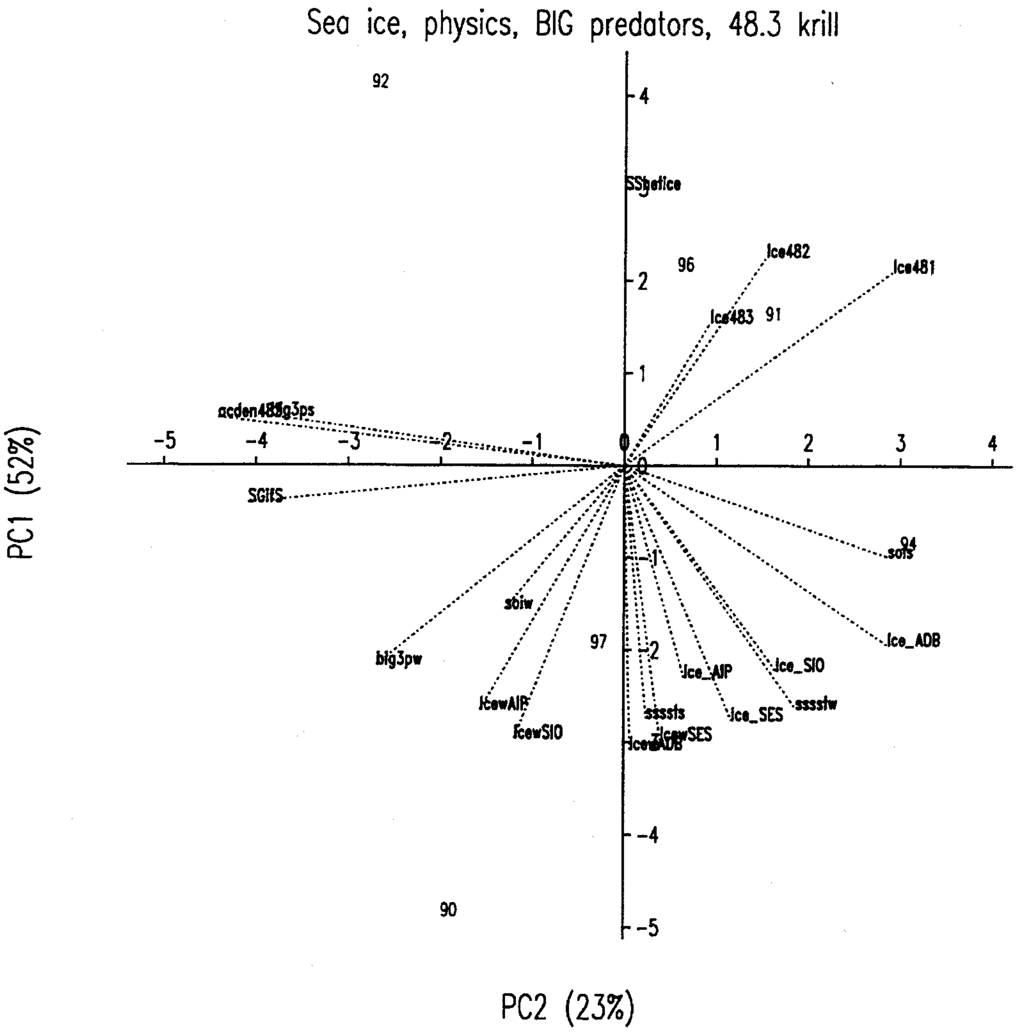

Figure 55: The first two components from a PCA of selected variables. Variables are represented by vectors and points to represent years (indicated by the year in which the season ended) from 1989/90 to 1996/97 but omitting 1992/93 and 1994/95 when no acoustic survey data are available.

ATTACHMENT A

AGENDA

Workshop on Area 48
(La Jolla, USA, 15 to 26 June 1998)

1. Introduction:

    1.1 Discussion of, and agreement to, the policy regarding data ownership, sharing, collaboration and authorship.

    1.2 Description of local facilities and infrastructure for accessing datasets and using analytical tools.

    1.3 Discussion of, and agreement to, work timetable and output of workshop.

    1.4 Appointment of subgroup coordinators and rapporteurs.

1a. Presentation of background material with a particular emphasis on Area 48.

2. Presentation and discussion of indices.

2a. Presentation and discussion of methods for combining indices and integrating indices, and solutions for handling missing values in datasets.

3. General discussion including elaboration of hypotheses from the work of subgroups:

    3.1 Evaluation and comparison of indices and, in some cases, the underlying datasets.

    3.2 Identification of solutions for handling missing values in datasets.

4. Presentation and discussion of the results from the subgroups, including graphic displays, summaries of analyses and conclusions.

5. Outline report:

    5.1 Outline the format and contents of the report.

    5.2 Delegate work for writing sections and generating graphs.

6. Write report.

7. Adopt report.

ATTACHMENT B

LIST OF PARTICIPANTS

Workshop on Area 48
(La Jolla, USA, 15 to 26 June 1998)

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WATTERS, George (Dr)	Inter-American Tropical Tuna Commission 8604 La Jolla Shores Drive San Diego, Ca. 92037 USA g.watters@iattc.ucsd.edu
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ATTACHMENT C

LIST OF DOCUMENTS

Workshop on Area 48
(La Jolla, USA, 15 to 26 June 1998)

WS-Area48-98/1	Provisional Agenda for the 1998 Workshop on Area 48
WS-Area48-98/2	List of Participants
WS-Area48-98/3	List of Documents
WS-Area48-98/4	Do krill and salp compete? Contrary evidence from the krill fisheries (*CCAMLR Science*, in press) S. Kawaguchi (Japan), W.K. de la Mare (Australia), T. Ichii and M. Naganobu (Japan)
WS-Area48-98/5	Relationships of Antarctic krill (*Euphausia superba* Dana)variability with westerlies fluctuations and ozone depletion in the Antarctic Peninsula area (*Journal of Geophysical Research*, submitted) M. Naganobu, K. Kutsuwada, Y. Sasai and S. Taguchi (Japan)
WS-Area48-98/6	A method for providing a statistical summary of CEMP indices I.L. Boyd and A.W.A. Murray (UK)
WS-Area48-98/7	Ecosystem monitoring and management, past, present and future I. Everson (UK)
WS-Area48-98/8	Interannual variability of the South Georgia marine ecosystem: biological and physical sources of variation in the abundance of krill E.J. Murphy, J.L. Watkins, K. Reid, P.N. Trathan, I. Everson, J.P. Croxall, J. Priddle, M.A. Brandon, A.S. Brierley (UK) and E. Hofmann (USA)
WS-Area48-98/9	Acoustic estimates of krill abundance at South Georgia, 1981–1998 A.S. Brierley, J.L. Watkins, C. Goss, M.T. Wilkinson and I. Everson (UK)
WS-Area48-98/10	Sea-surface temperature anomalies near South Georgia: relationships with the South Atlantic and the Pacific El Niño regions P. Trathan and E.J. Murphy (UK)
WS-Area48-98/11	Concordance of interannual fluctuations in densities of krill around South Georgia and Elephant Islands: biological evidence of same-year teleconnections across the Scotia Sea A.S. Brierley (UK), D.A. Demer, R.P. Hewitt (USA) and J.L. Watkins (UK)
WS-Area48-98/12	Indices of predator performance from Signy Island, South Orkney Islands 1979–1997 A.S. Lynnes and A.W.A. Murray (UK)
WS-Area48-98/13	Indices of predator performance from South Georgia 1976–1998 D.R. Briggs, K. Reid, J.P. Croxall, I.L. Boyd and D.J. Brown (UK)

WS-Area48-98/14	Combined indices of predator performance at South Georgia 1976–1998 K. Reid, D.R. Briggs, I.L. Boyd and J.P. Croxall (UK)
WS-Area48-98/15	Krill population dynamics at South Georgia 1991–1997, based on data from predators and nets K. Reid, J.L. Watkins, J.P. Croxall and E.J. Murphy (UK)
WS-Area48-98/16	Environmental variability and the behavioural dynamics of Antarctic fur seals in the South Atlantic I.L. Boyd (UK)
WS-Area48-98/17	Diet, provisioning and productivity responses of predators to differences in availability of Antarctic krill J.P. Croxall, K. Reid and P.A. Prince (UK)
WS-Area48-98/18	Antarctic fur seal (*Arctocephalus gazella*) pup growth rates obtained at Cape Shirreff, Livingston Island, South Shetlands: 1994/95 to 1997/98 (CEMP index C2, procedure B) R. Hucke-Gaete, V. Vallejos and D. Torres (Chile)
WS-Area48-98/19	Variation in condition of the mackerel icefish (draft only for discussion at Area 48 Workshop) I. Everson (UK) and K.-H. Kock (Germany)
WS-Area48-98/20	Population structure and recruitment indices of *Euphausia superba* around South Georgia J.L. Watkins (UK)
WS-Area48-98/21	IWC whale data indices for CCAMLR Area 48 Workshop S. Reilly, C. Allison, H. Kato and D. Borchers

Other documents:

WG-EMM-98/4 Rev. 1	CEMP indices 1998: summary of anomalies and trends Secretariat
WG-EMM-98/5	Draft revision of the fishery–foraging overlap model Secretariat
WG-EMM-98/6	Draft development of standard methods for environmental data Secretariat
WG-EMM-98/7	Draft report on fine-scale krill data for the 1996/97 season Secretariat

ATTACHMENT D

DATASETS AVAILABLE TO THE WORKSHOP ON AREA 48

PHYSICAL ENVIRONMENT DATASETS

- Sea-ice extent (passive microwave imagery)
  - South Shetland Islands
    - Methods
    - Monthly estimates of ice cover (1979–1997)
    - Annual indices of ice cover spatial and temporal extent (1979–1997)
  - South Orkney Islands
    - Methods
    - Monthly estimates of ice cover (1987-1997)
    - Annual indices of ice cover spatial and temporal extent (1987–1997)
  - South Georgia
    - Methods
    - Monthly estimates of ice cover (1987–1997)
    - Annual indices of ice cover spatial and temporal extent (1987–1997)
  - Scotia Sea
    - Methods
    - Monthly estimates of ice cover (1987–1997)
    - Annual indices of ice cover spatial and temporal extent (1987–1997)
- Air temperature at Palmer Station
    - Methods
    - Monthly mean air temperature (January 1947–June 1996)
    - Annual mean air temperature (1947–1995)
- Sea-surface temperature
  - Methods
  - Annual SST values and indices at South Georgia (1982–1996)
  - Monthly Pacific El Niño indices and anomalies (January 1974–July 1997)
  - Monthly SST values at Georgia Basin (38°5’W, 51°5’S, November 1981–December 1997)
  - Monthly SST values at South Georgia East Cell (34°5’W, 54°5’S, November 1981–December 1997)
  - Monthly SST values at South Georgia West Cell (38°5’W, 53°5’S, November 1981–December 1997)
  - SST anomalies for February and September at South Georgia (1982–1997)
- Sea-surface temperature and sea-ice at CEMP sites
  - Methods
  - CEMP sea-ice and SST
- Sea-level pressure gradient across Drake Passage
  - Methods
  - Sea-level pressure gradient across Drake Passage (1982–1993)
- Sea temperatures near Elephant Island from US AMLR program
  - Average CTD temperatures at 4 100 and 500 m

BIOTIC ENVIRONMENT DATASETS

- Chl-*a* concentrations near Elephant Island
  - Integrated Chl-*a* over entire US AMLR survey area
  - Chl-*a* concentration for shelf area between Elephant and King George Islands
- Salp abundance near Elephant Island
  - Methods
  - Annual estimates of salp abundance near Elephant Island
- Major zooplankton constituents in the South Shetlands
  - *Salpa Thompsoni*, copepods, *Thysanoessamacrura*, *Themistogaudichaudii* from US AMLR surveys
- Salps and *Thysanoessa macrura* near Elephant Island
  - Methods
  - *Salpa thompsoni* and *Thysanoessa macrura* from German surveys (1976–1997)
- Salps and *Thysanoessa macrura* near South Orkney Islands
  - Methods
  - *Salpa thompsoni* and *Thysanoessa macrura* from German surveys (1976 and 1989)
- Salp abundance near South Georgia
  - Methods
  - Salp abundance from German surveys (1975/76)

KRILL DATASETS

- Krill length distributions
  - US AMLR surveys near Elephant Island
    - Methods
    - Krill length distributions for January of each year (1988–1997)
  - German surveys near Elephant Island
    - Methods
    - Krill length distributions by survey year and quarter (1978–1997)
  - German surveys near South Orkney Islands
    - Methods
    - Krill length distributions (1984, 1988, 1989)
  - German surveys near South Georgia
    - Methods
    - Krill length distributions (1984 and 1988)
- Krill maturity distributions
  - German surveys near Elephant Island
    - Methods
    - Krill maturity distributions by survey year and quarter (1978–1997)
- Krill recruitment indices
  - Elephant Island region
    - Methods
    - Annual estimates of krill density, proportional recruitment and absolute recruitment (1980–1996)
  - South Georgia region
    - Krill recruitment indices near South Georgia (1987–1997)
- Acoustic estimates of krill biomass
  - Elephant Island region
    - Methods
    - Annual estimates of krill density near Elephant Island (1998–1997)
    - US AMLR surveys (1992-1997)
  - South Georgia region
    - Annual estimates of krill density near South Georgia (1981–1998)

- Krill diet samples
  - Methods
  - Krill diet samples from Admiralty Bay penguins by 5 mm size classes
  - Krill diet samples from Admiralty Bay penguins by 1 mm size classes

PREDATOR DATASETS

- Macaroni penguins (*Eudyptes chrysolophus*)
  - Macaroni penguins at Bird Island (CEMP data base)
  - Macaroni penguins at South Georgia
  - Macaroni penguins at Stinker Point and Seal Island (CEMP data base)
- Gentoo penguins (*Pygoscelis papua*)
  - Gentoo penguins at Signy Island (CEMP data base)
  - Gentoo penguins at Bird Island (CEMP data base)
  - Gentoo penguins at South Georgia
  - Gentoo penguins at Signy Island
  - Gentoo penguins at Admiralty Bay
  - Notes on methods used to monitor penguins at Admiralty Bay
- Adélie penguins (*Pygoscelis adeliae*)
  - Adélie penguins at Signy and Laurie Islands (CEMP data base)
  - Adélie penguins at Signy Island
  - Adélie penguins at Anvers Island, Esperanza Station and Stranger Point (CEMP database)
  - Adélie penguins at Admiralty Bay
  - Notes on methods used to monitor penguins at Admiralty Bay
- Chinstrap penguins (*Pygoscelis antarctica*)
  - Chinstrap penguins at Signy Island (CEMP data base)
  - Chinstrap penguins at Signy Island
  - Chinstrap penguins at Seal Island, Stinker Point and Cape Shirreff (CEMP data base)
  - Chinstrap penguins at Admiralty Bay
  - Notes on methods used to monitor penguins at Admiralty Bay
- Black-browed albatross (*Diomedea melanophrys*)
  - Black-browed albatrosses at Bird Island (CEMP data base)
  - Black-browed albatrosses at South Georgia
- Antarctic fur seals (*Arctocephalus gazella*)
  - Antarctic fur seals at Bird Island (CEMP data base)
  - Antarctic fur seals at South Georgia
  - Antarctic fur seals at Seal Island and Cape Shirreff (CEMP data base)
- Krill diet samples
  - Methods
  - Krill diet samples from Admiralty Bay penguins by 5 mm size classes
  - Krill diet samples from Admiralty Bay penguins by 1 mm size classes
- IWC baleen whale surveys
  - Methods
  - IWC/IDCR sightings surveys (1981, 1982, 1983, 1986, 1987, 1989, 1990, 1994)
  - Japanese scouting vessel sightings Surveys (1973, 1975, 1976, 1980, 1981, 1982, 1986)
  - Map IWC/IDCR Survey Effort
  - Map of Japanese scouting vessel survey effort
  - Map of krill distribution by size based on whale stomach samples
  - Minke whale take (1957–1987)
  - Minke whale blubber and Stomach Contents (1976)
- Icefish condition indices
  - Methods
  - Icefish condition index at South Georgia and Shag Rocks
  - Icefish condition at South Shetlands and Elephant Island

SUMMARY INDICES

- Physical Environment
    - Summer sea-surface temperatures, SOI, El Niño indices, DPOI and Palmer air temperature (November–March)
    - Winter sea-surface temperatures, SOI, El Niño indices, DPOI and Palmer air temperature (June–October)
    - Normalised annual ice cover indices for South Shetlands, South Orkneys, South Georgia and Scotia Sea
    - Graph of monthly proportions of ice cover for South Shetlands, South Orkneys, South Georgia and Scotia Sea
    - 4 100 and 500 m temperatures at Elephant Island Zones 1 and 4
- Biotic Environment
    - *Salpa thompsoni*, copepods, *Thysanoessamacrura*, *Themistogaudichaudii*, integrated Chl-*a* for January in the Elephant Island area (1990–1998)
- Krill
    - Krill acoustic and net density, proportional and absolute recruitment for Subareas 48.1 and 48.3
    - Krill CPUE indices
- Predators
    - Summer predator performance at Bird Island, Signy Island, Seal Island, Admiralty Bay and Anvers Island
    - Winter predator performance at Bird Island, Signy Island and Admiralty Bay
    - Baleen whale sightings in Subareas 48.1, 48.2 and 48.3
    - Icefish condition index at South Georgia and Shag Rocks
    - Icefish condition at South Shetlands and Elephant Island

ATTACHMENT E

PRINCIPAL COMPONENTS ANALYSIS (PCA)

BACKGROUND

1. Advantages of this method include:

   (i) a descriptive technique – not formal testing so no requirement for 'normality' of underlying distributions;

   (ii) identification of new 'synthetic' variables (principal components) which are linear combinations of the original (standardised, $\mu = 0$, $\sigma = 1$) variables;

   (iii) summary of most of the variation in a dataset in two or three such principal components (PCs), thereby reducing the 'dimensionality' of the data;

   (iv) works on the correlation matrix of the variables encapsulating their inter-relationships;

   (v) allows ordering of the observations which can then be compared with known physical or environmental gradients;

   (vi) displays results in an intuitively easy to understand graph showing both the observations and the original variables (a 'biplot'); and

   (vii) methods are available for comparison between PCAs.

2. Limitations include:

   (i) may not find well-fitting low dimensional solution;

   (ii) method is 'linear' and so may not do full justice to any non-linear patterns in the data;

   (iii) the more variables are included, the less well the low dimensional solution will fit due to random noise in the variables and consequential weakening of the observed correlations; and

   (iv) requires a 'complete' dataset – any missing observations (columns) result in omission of that unit (row) from the analysis.

APPLICATION TO ANALYSIS OF GENTOO PENGUIN DATA

3. All variables for this species at the Bird Island and Admiralty Bay sites from 1986 to 1998 were used. Population size was included as the difference between population size in successive years.

4. For Bird Island (Figure E.1) the first two principal components comprise 75% and 13% of the overall variation respectively. The first component essentially separates these strong bad years of 1991, 1994 and 1998 and the weak bad years of 1997 and 1990 from the rest.

5. The second principal component indicates some separation between the summer variables (meal mass and breeding success) and the proximate winter variable (arrival date) with the winter/multi-year variable (differential population size) intermediate. This may indicate a degree of difference between the characteristics of some of the good years (e.g. 1998 and 1993).

6. For Admiralty Bay (Figure E.2) the first two principal components comprise 76% and 14% of the overall variation respectively. The first component differentiates the bad years of 1987 and 1991 from the rest. Summer variables (breeding success and its components) are orthogonal to winter variables (survival population change and egg mass). 1986 is also identified as distinctive, probably reflecting the exceptional recruitment failure (low juvenile survival) in this year.

7. Comparing the gentoo penguins at the two sites by direct comparison of their Combined Standardised Index (CSI) scores (Figure E.3) identifies strong similarity in response in the bad year of 1991, good coherence over the years 1988 to 1992 and weaker coherence in 1995 and 1996. The years 1986, 1994 and 1998 (and to a lesser extent 1993) show least coherence essentially opposite responses.

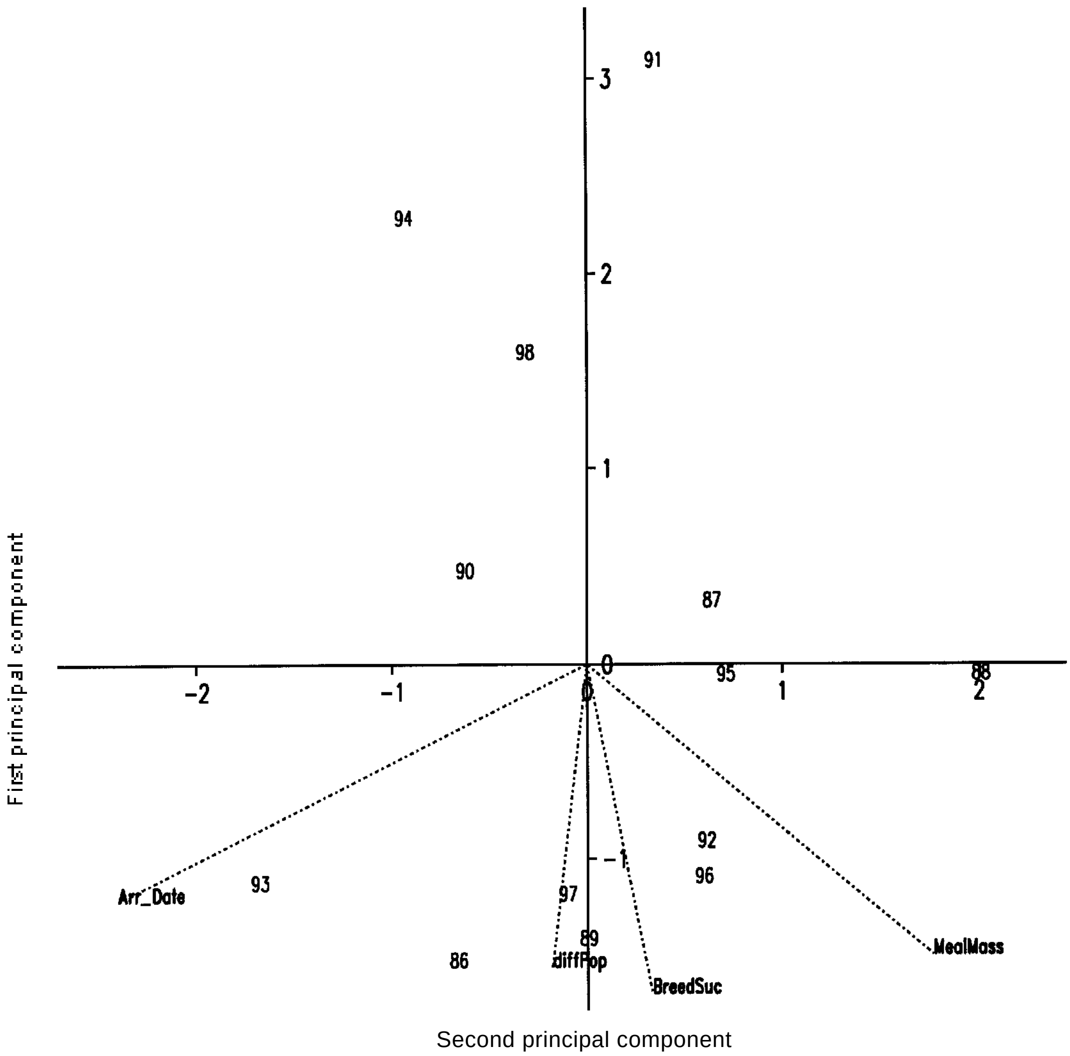

Figure E.1: PCA for Bird Island (BIG) gentoo penguin (PYP) using arrival date (days before 31 December), meal mass, breeding success, and annual change in population size. Variables are displayed as vectors and years as points labelled with the year in which the breeding season ended.

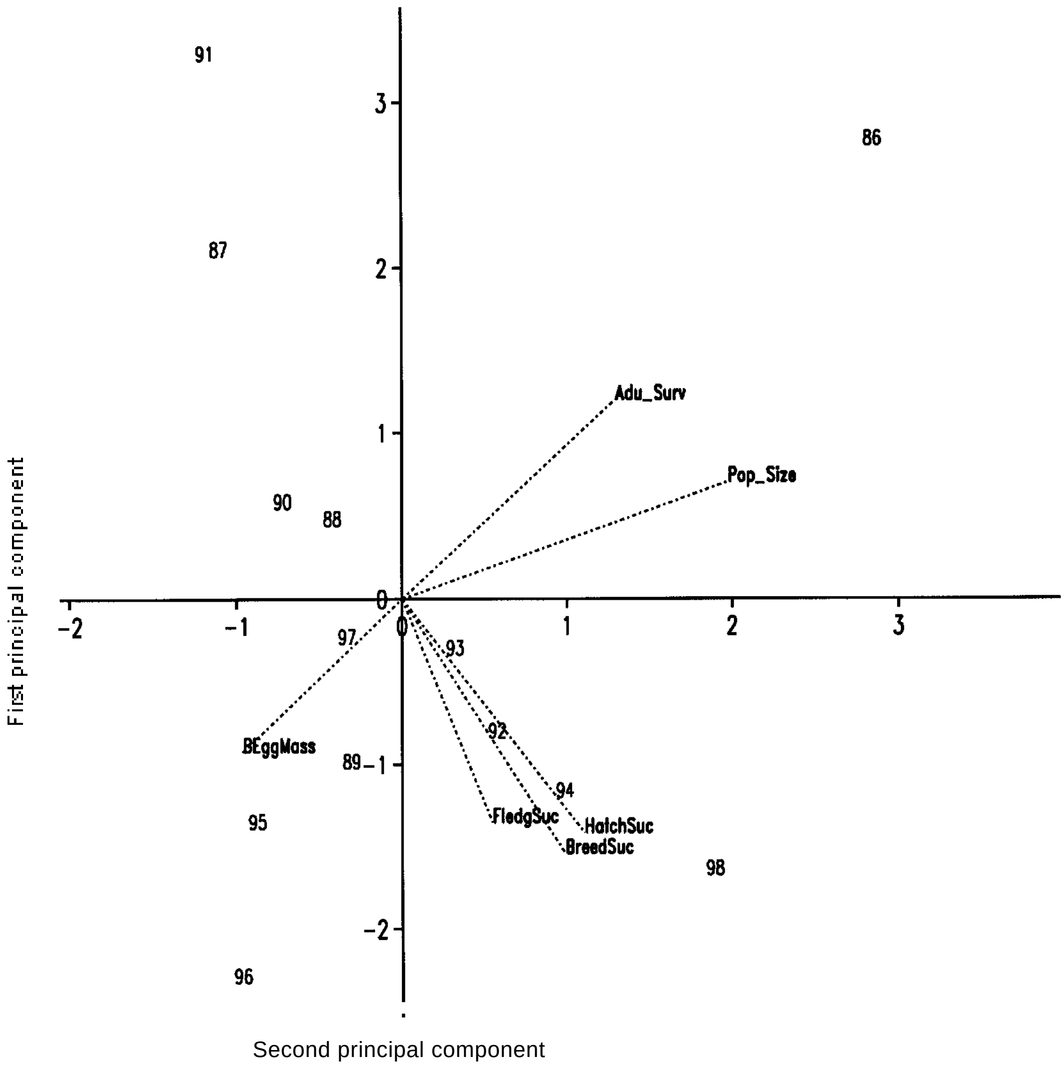

Figure E.2: PCA for Admiralty Bay (ADB) gentoo penguin (PYP) using adult survival, B egg size, hatching, fledging and breeding success, and annual change in population size. Variables are displayed as vectors and years as points labelled with the year in which the breeding season ended.

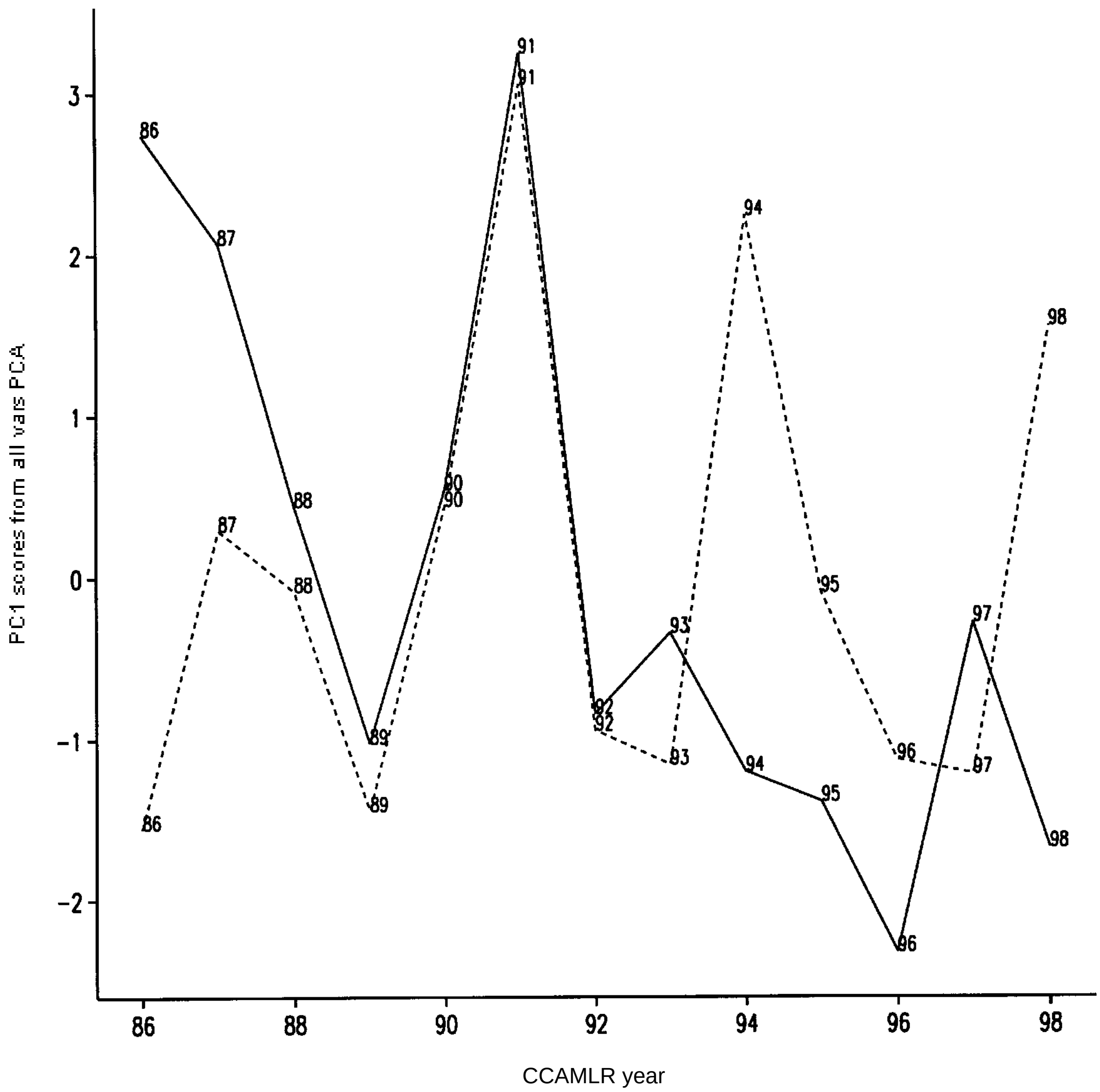

Figure E.3: Plot of the first principal component scores for the analyses shown in Figures E.1 and E.2 against time (year in which the breeding season ended). Solid line for Admiralty Bay (ADB), dotted line for Bird Island (BIG).