APPENDIX D

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

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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 1993/94	1990/91 1993/94
High R1	1982/83 1987/88 1994/95	No Data No Data 1994/95
Low R1	1988/89 1989/90 1991/92 1992/93	1988/89 1989/90 1991/92 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	sssts	0.630	0.083
3.	BIG3ps	acd483	sssts sois soiw	0.970	0.060
4.	BIG3ps	acd483	sssts sois	0.950	0.004
5.	BIG3ps	acd483	ssstw	0.644	0.075
Predators, Subarea 48.3 (winter)					
6.	BIG3pw	acd483		0.002	0.971
7.	BIG3pw	acd483	sssts	0.575	0.117
8.	BIG3pw	acd483	sssts sois soiw	0.822	0.325
9.	BIG3pw	acd483	sssts sois	0.707	0.103
10.	BIG3pw	acd483	ssstw	0.481	0.194
Predators, Subarea 48.1 (summer)					
11.	ADB3ps	acd483		0.161	0.284
12.	ADB3ps	acd483	sssts	0.025	0.938
13.	ADB3ps	acd483	sssts sois soiw	0.216	0.953
14.	ADB3ps	acd483	sssts sois	0.096	0.930
15.	ADB3ps	acd483	ssstw	0.024	0.940
Predators, Subarea 48.1 (winter)					
16.	ADB3pw	acd483		0.115	0.338
17.	ADB3pw	acd483	sssts	0.025	0.938
Predators, Subarea 48.3 (summer)					
18.	BIG3ps	acd481		0.278	0.05
19.	BIG3ps	acd481	sssts	0.362	0.132
20.	BIG3ps	acd481	sssts sois soiw	0.540	0.306
21.	BIG3ps	acd481	sssts sois	0.383	0.253
22.	BIG3ps	acd481	ssstw	0.364	0.130
Predators, Subarea 48.3 (winter)					
23.	BIG3pw	acd481		0.002	0.871
24.	BIG3pw	acd481	sssts	0.082	0.679
25.	BIG3pw	acd481	sssts sois soiw	0.246	0.744
26.	BIG3pw	acd481	sssts sois	0.086	0.875
27.	BIG3pw	acd481	ssstw	0.411	0.093
Predators, Subarea 48.3 (summer)					
28.	ADB3ps	acd481	sssts	0.118	0.613
29.	ADB3ps	acd481	sssts sois soiw	0.176	0.887
30.	ADB3ps	acd481	sssts sois	0.174	0.698
31.	ADB3ps	acd481	ssstw	0.255	0.030
Predators, Subarea 48.1 (winter)					
32.	ADB3pw	acd481		0.002	0.890
33.	ADB3pw	acd481	sssts	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	sssts	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

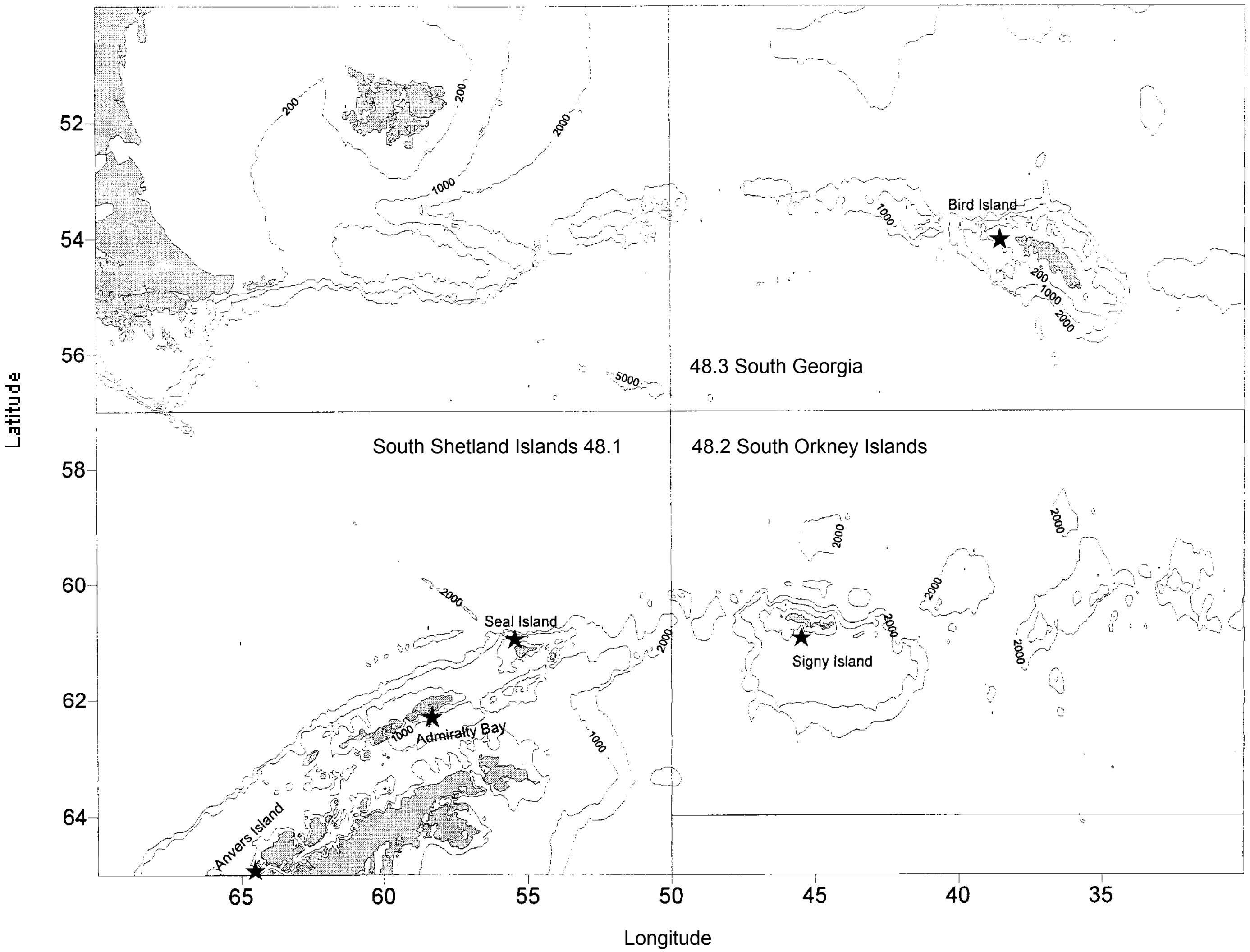


Figure 1: Map of the three statistical areas (Subareas 48.1, 48.2 and 48.3) examined during the workshop. Surveys were generally conducted in waters adjacent to South Georgia and the South Shetland Islands, and most of the data on predators were collected at Admiralty Bay, Anvers Island, Bird Island, Seal Island and Signy Island.

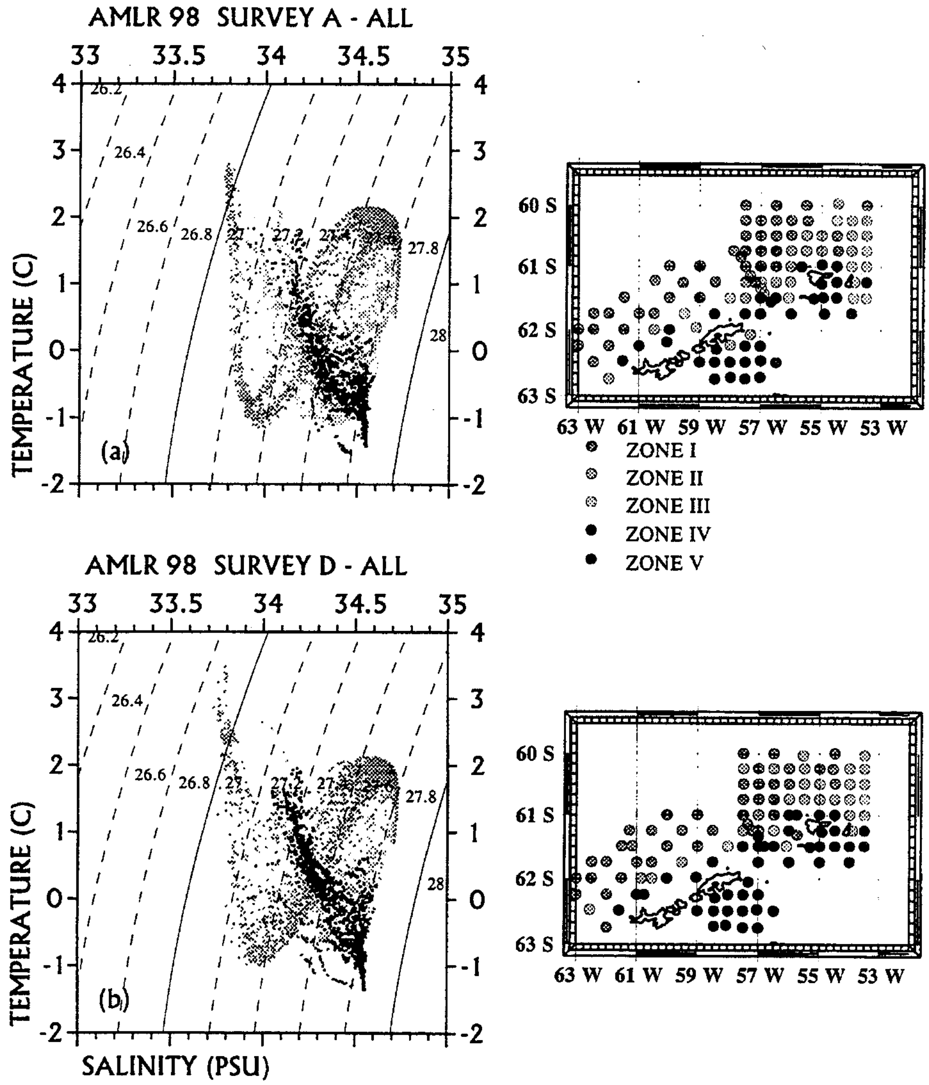
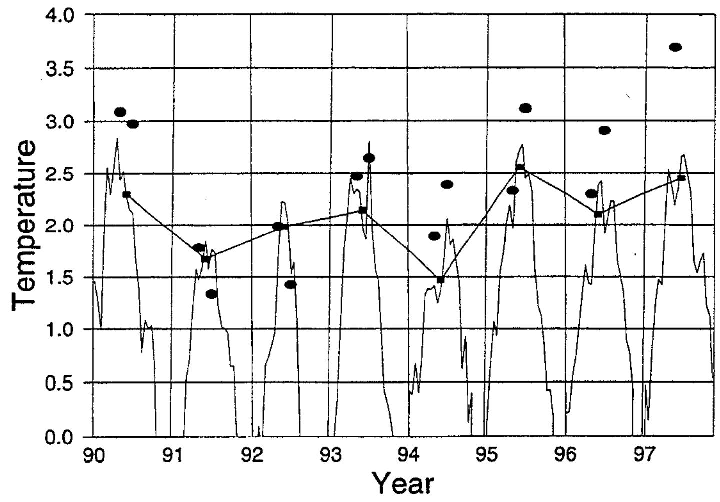
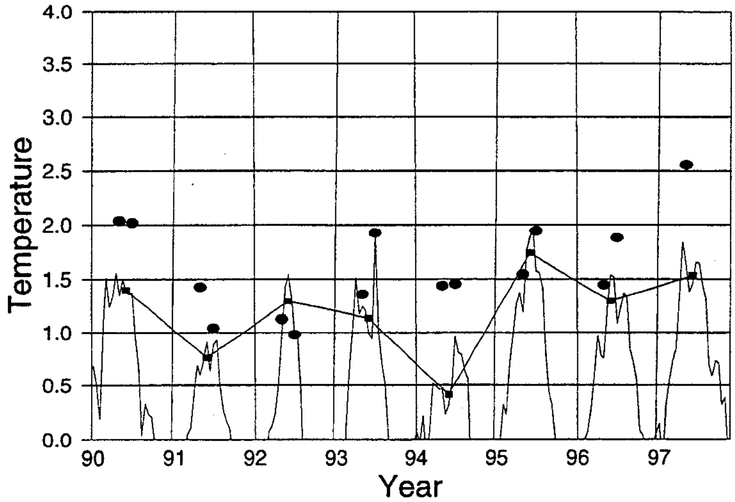


Figure 2: Typical AMLR CTD temperature and salinity diagram and station grid for all stations from the area: (a) Leg I (January/February); (b) Leg II (February/March). Symbols on inset maps show station locations shaded by zones of similar temperature and salinity characteristics.





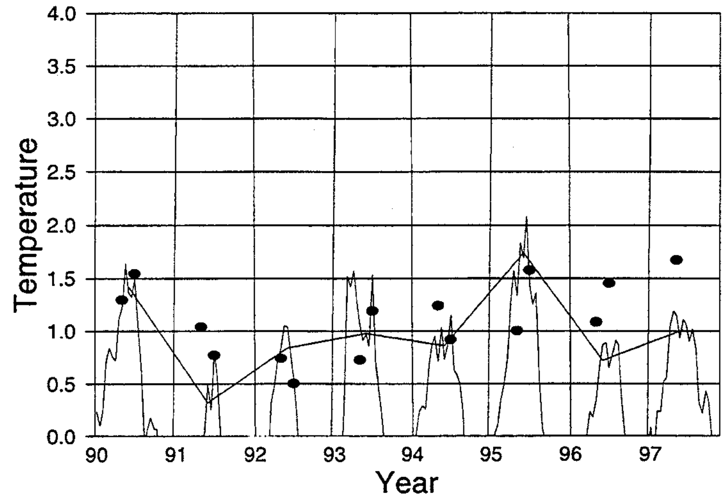


Figure 3: Comparison of AMLR CTD surface (4 m) temperatures with NCAR SST. Weekly NCAR SST data for December through to April and monthly NCAR SST data for February are shown. Average values for both the AMLR cruises carried out each year are shown (one cruise only in 1998). Years are identified by the 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).

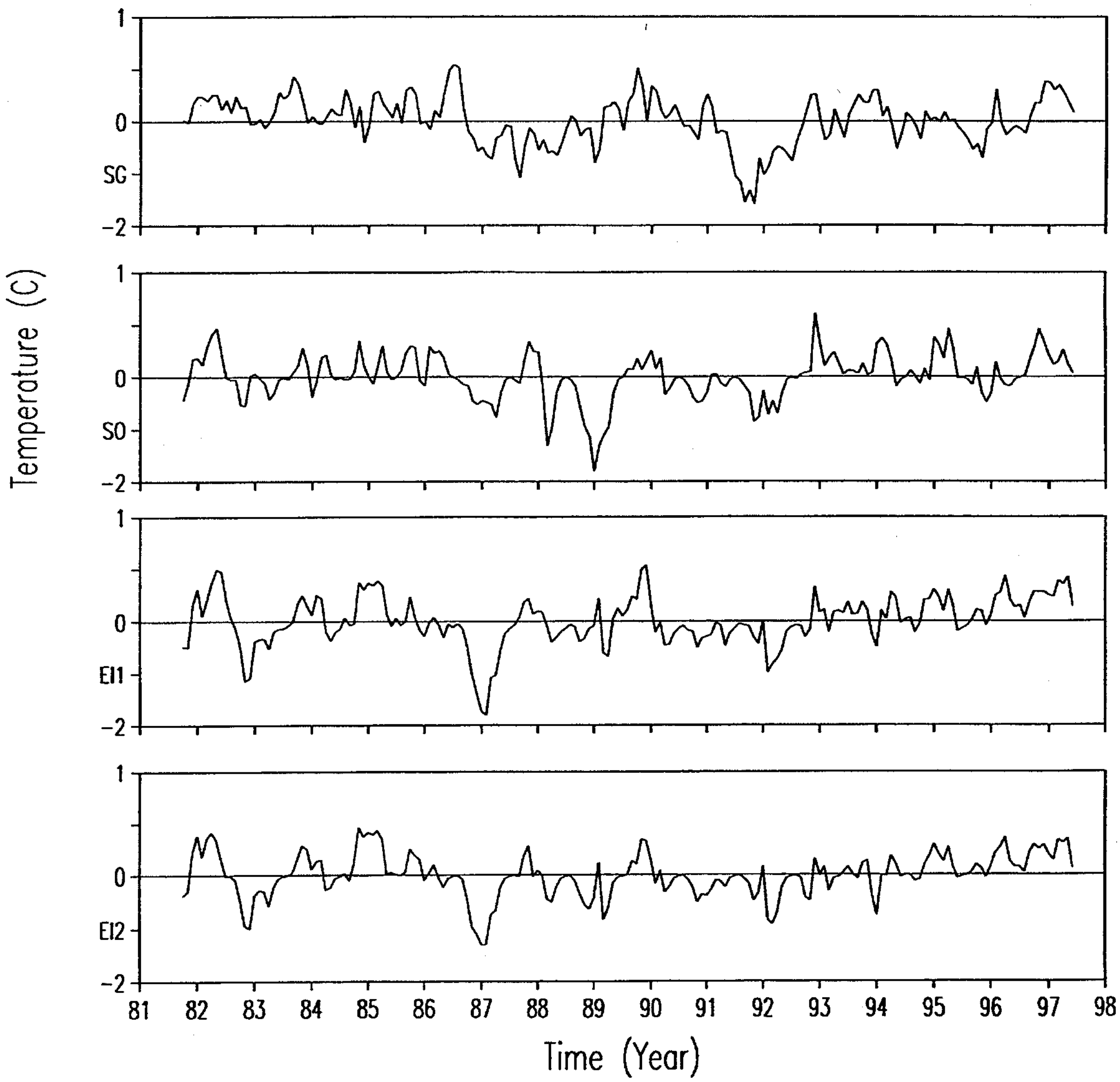


Figure 4: Time series plots for selected NCAR SST monthly time series: (a) South Georgia (54°30′S, 34°30′W); (b) South Orkneys (60°30′S, 47°30′W); (c) Elephant Island EI1 (60°30′S, 56°30′W); (d) Elephant Island EI2 (61°30′S, 56°30′W).

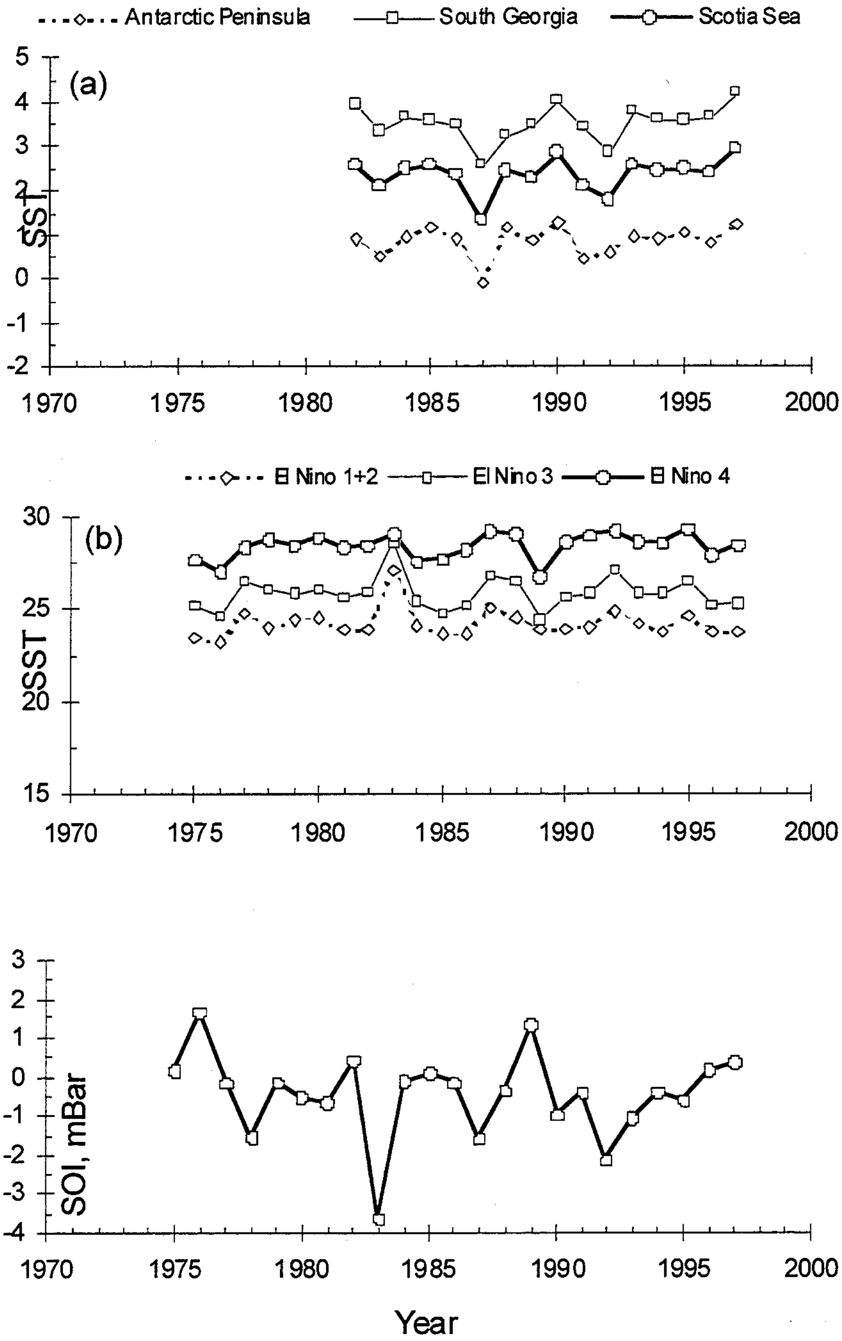


Figure 5: Annual summer index plots: (a) NCAR SST at the Antarctic Peninsula, South Georgia and the Scotia Sea; (b) sea-surface temperature for El Niño 1+2, El Niño 3 and El Niño 4; (c) SOI.

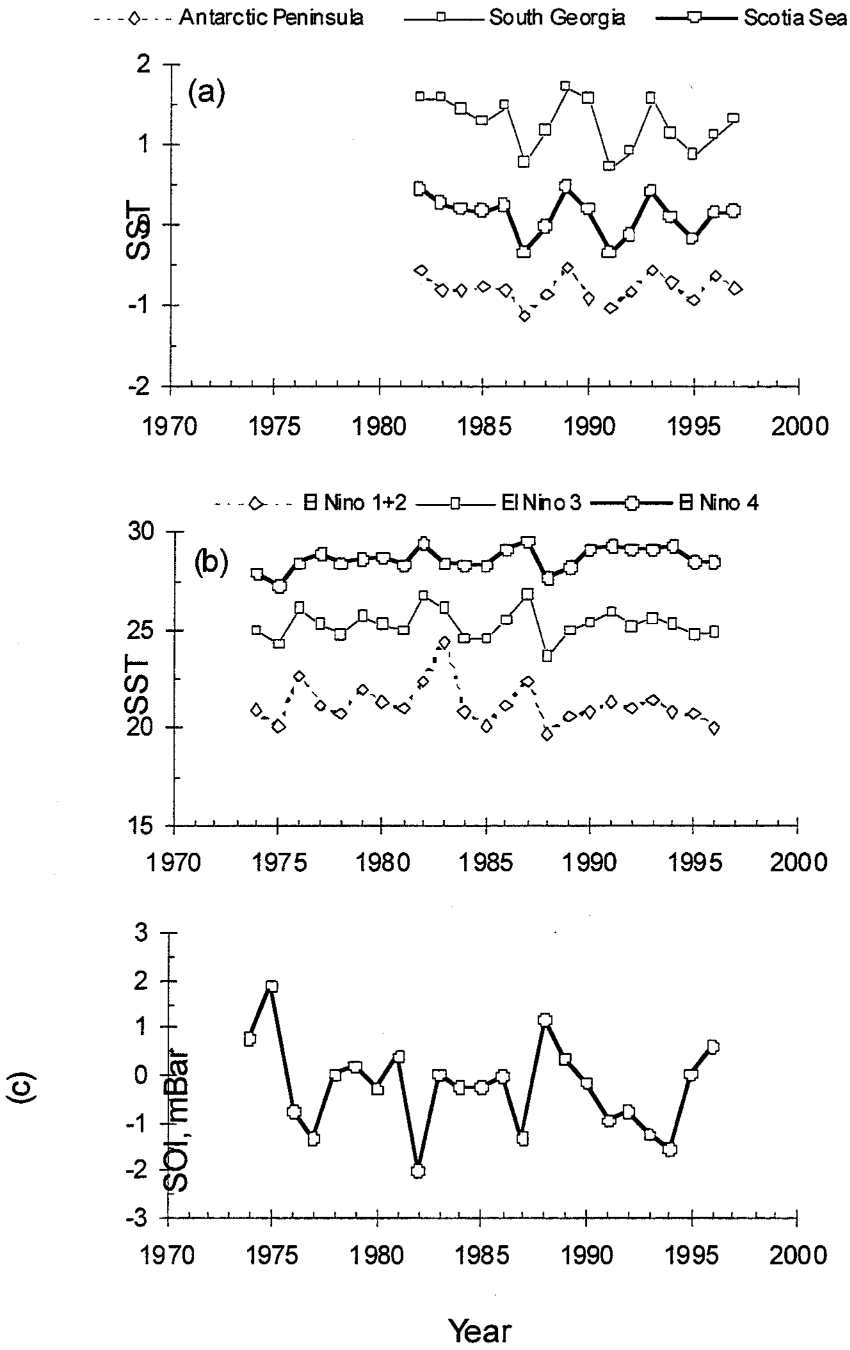


Figure 6: Annual winter index plots: (a) NCAR SST at the Antarctic Peninsula, South Georgia and the Scotia Sea; (b) sea-surface temperature for El Niño 1+2, El Niño 3 and El Niño 4; (c) SOI.

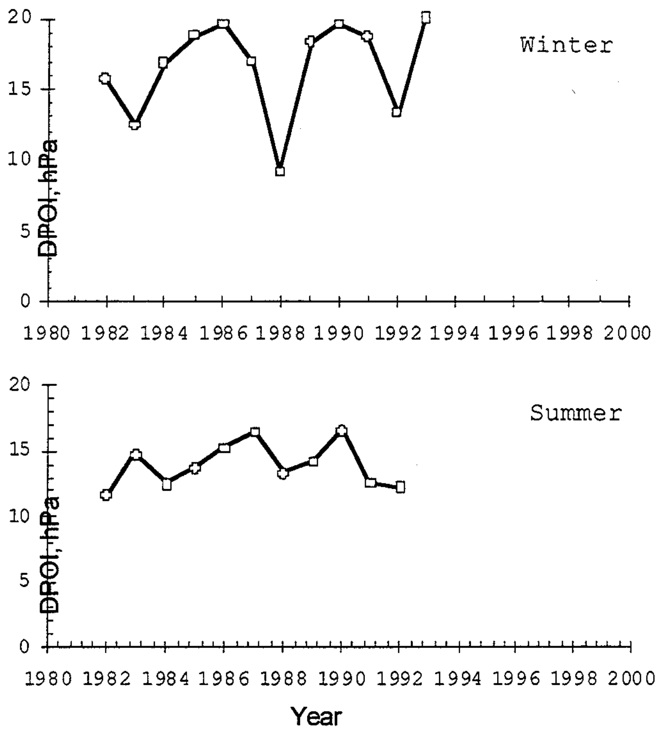


Figure 7: Annual index plots for DPOI: (a) winter; (b) summer.

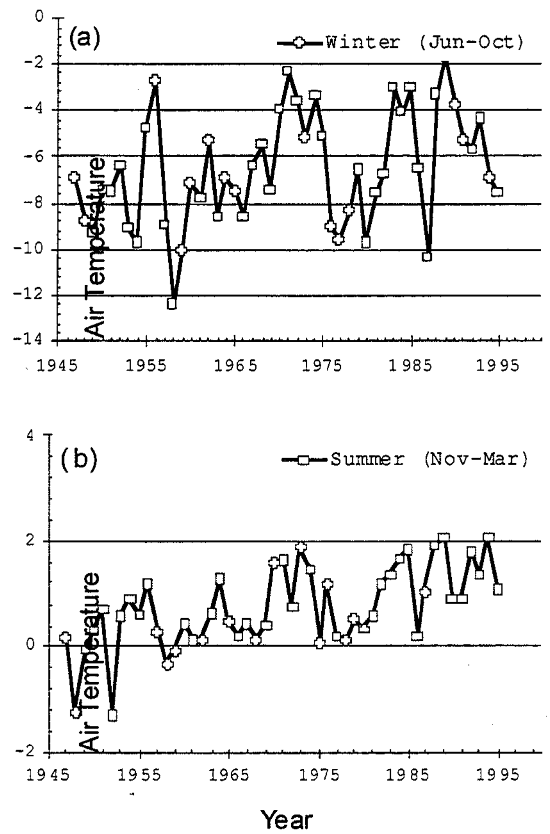


Figure 8: Annual index plots for Palmer Station air temperatures: (a) winter; (b) summer.

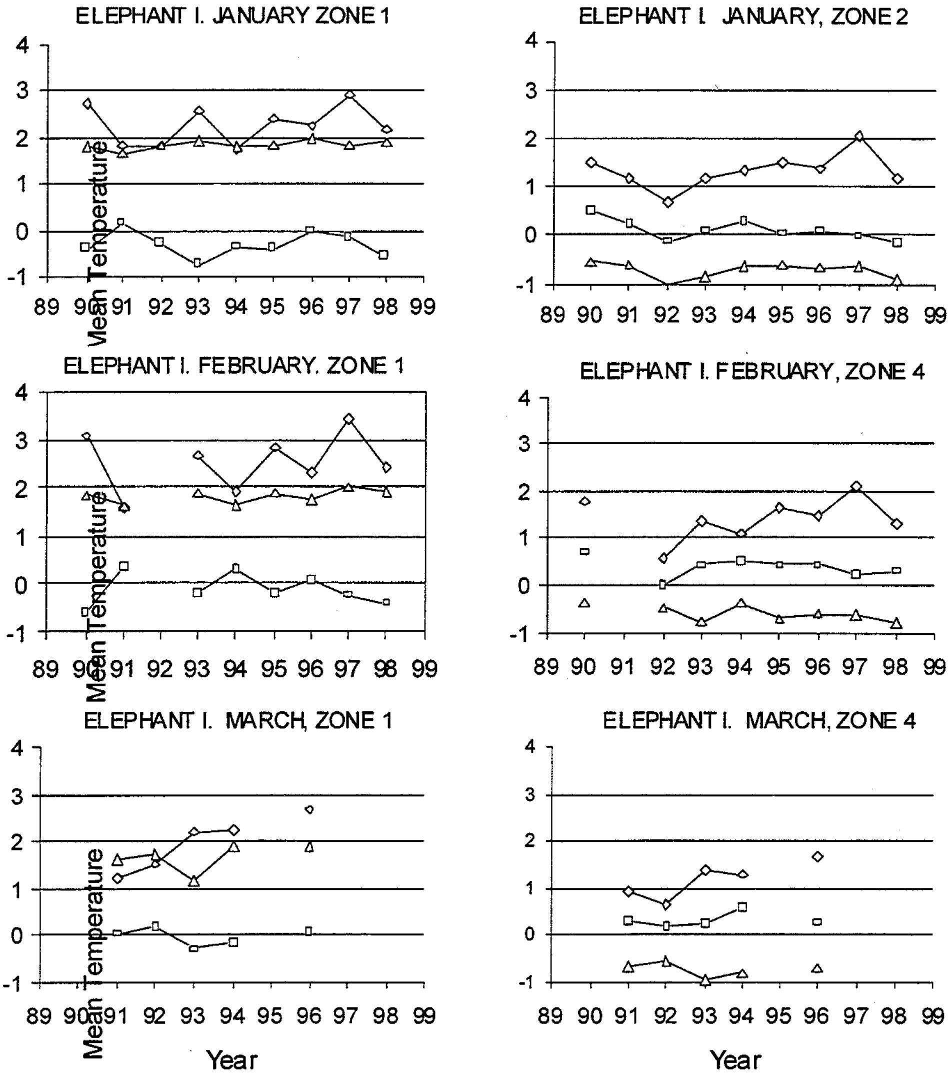


Figure 9: Sea temperature at 4 m (◊), 100 m (□) and 500 m (Δ) in the Elephant Island area from 1990 to 1998. Zones of similar temperature and salinity characteristics (see Figure 2) are compared for January, February and March. Data from AMLR CTD stations in Zone 1 (Drake Passage) and Zone 4 (Bransfield Strait).

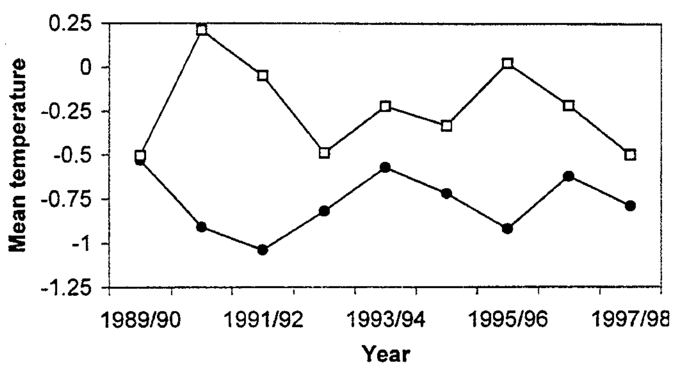


Figure 10: Temperature at 100 m (□) in the Drake Passage winter water from AMLR CTD data compared to NCAR winter SST (●) in the Antarctic Peninsula Area.

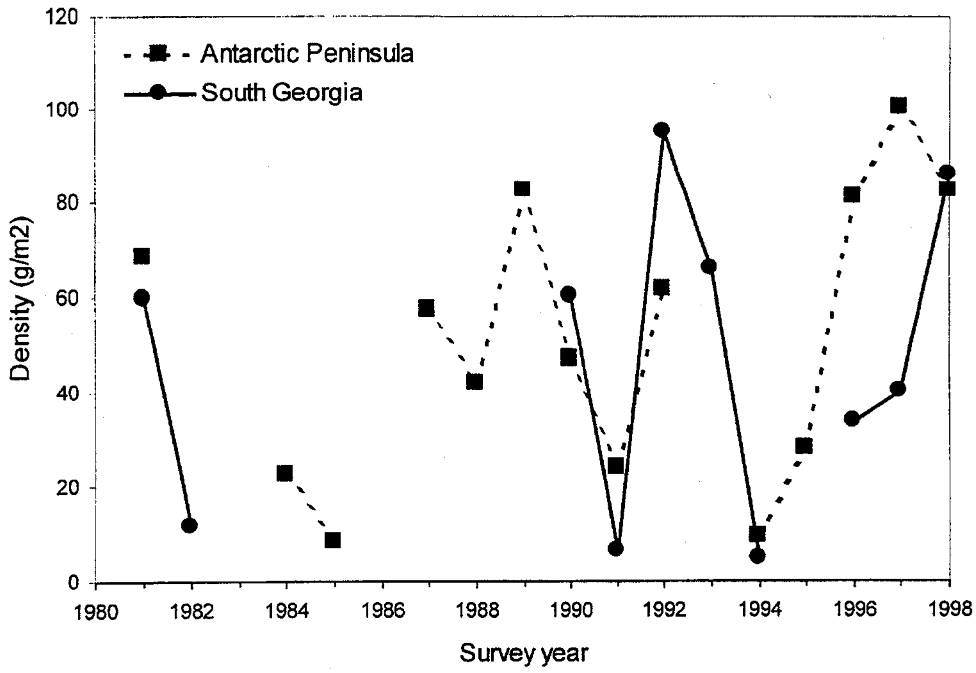


Figure 11: Interannual changes in acoustic krill density estimates for Subareas 48.1 and 48.3.

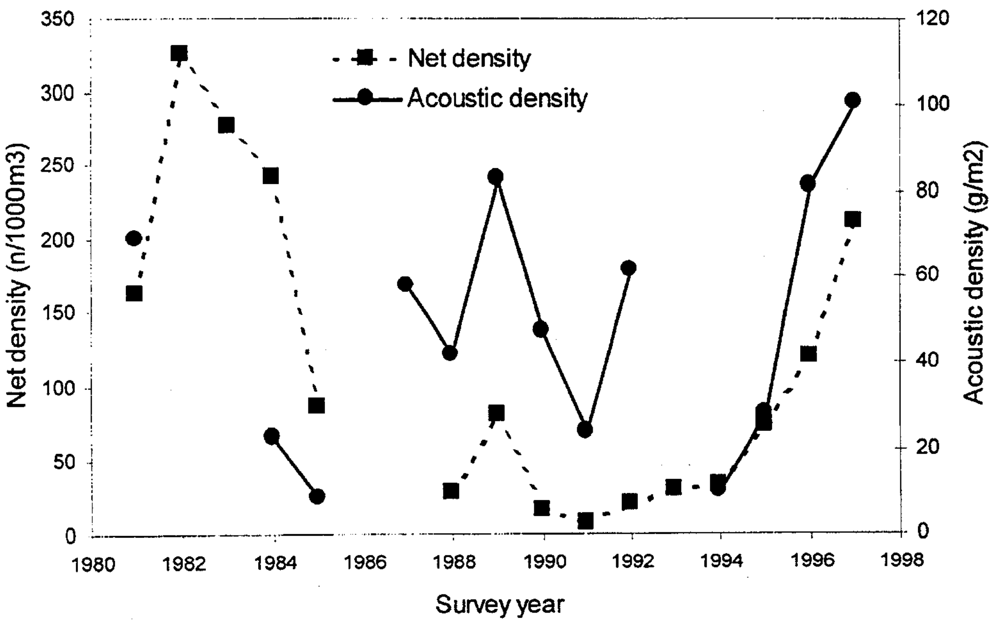


Figure 12: Interannual changes in net and acoustic estimates of krill density in Subarea 48.1.

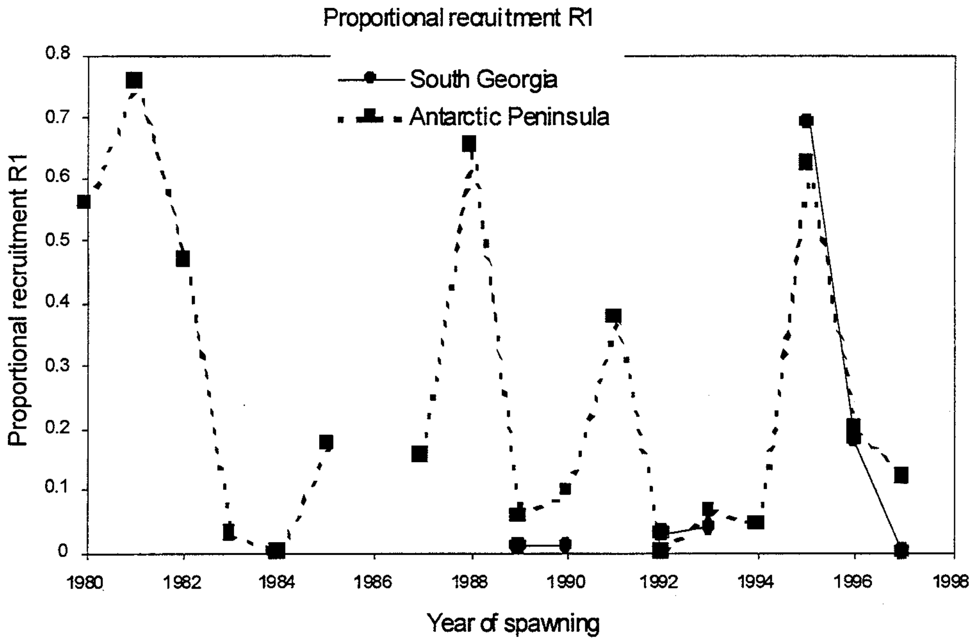


Figure 13: Interannual changes in proportional krill recruitment index (R1) in Subareas 48.1 and 48.3.

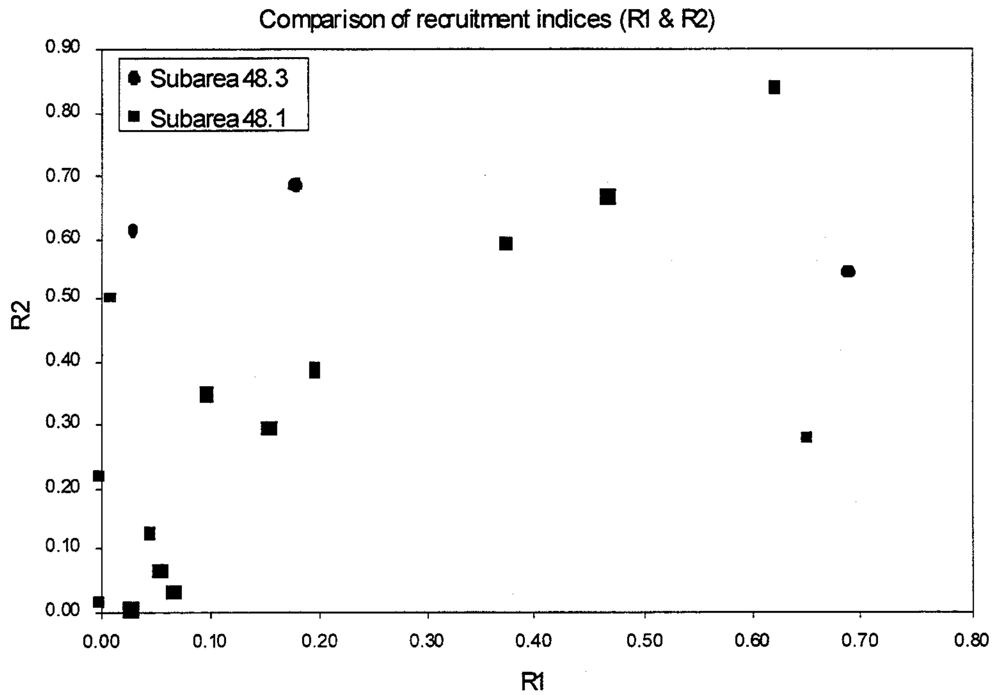


Figure 14: Comparison of R1 and R2 proportional krill recruitment indices.

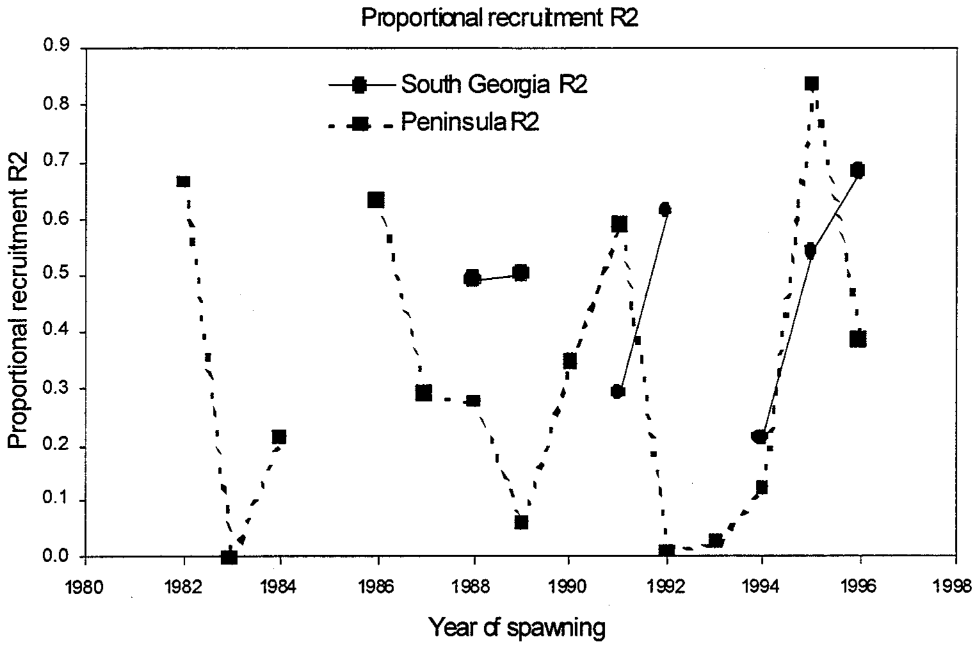


Figure 15: Interannual changes in proportional krill recruitment index (R2) in Subareas 48.1 and 48.3.

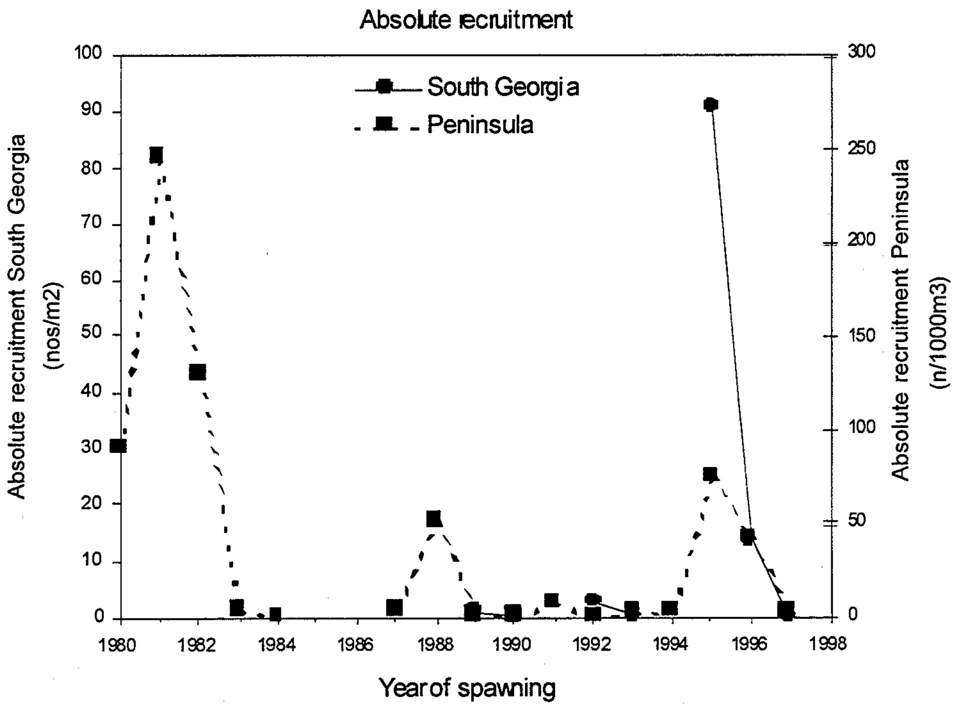


Figure 16: Interannual changes in absolute recruitment of 1+ krill in Subareas 48.1 and 48.3.

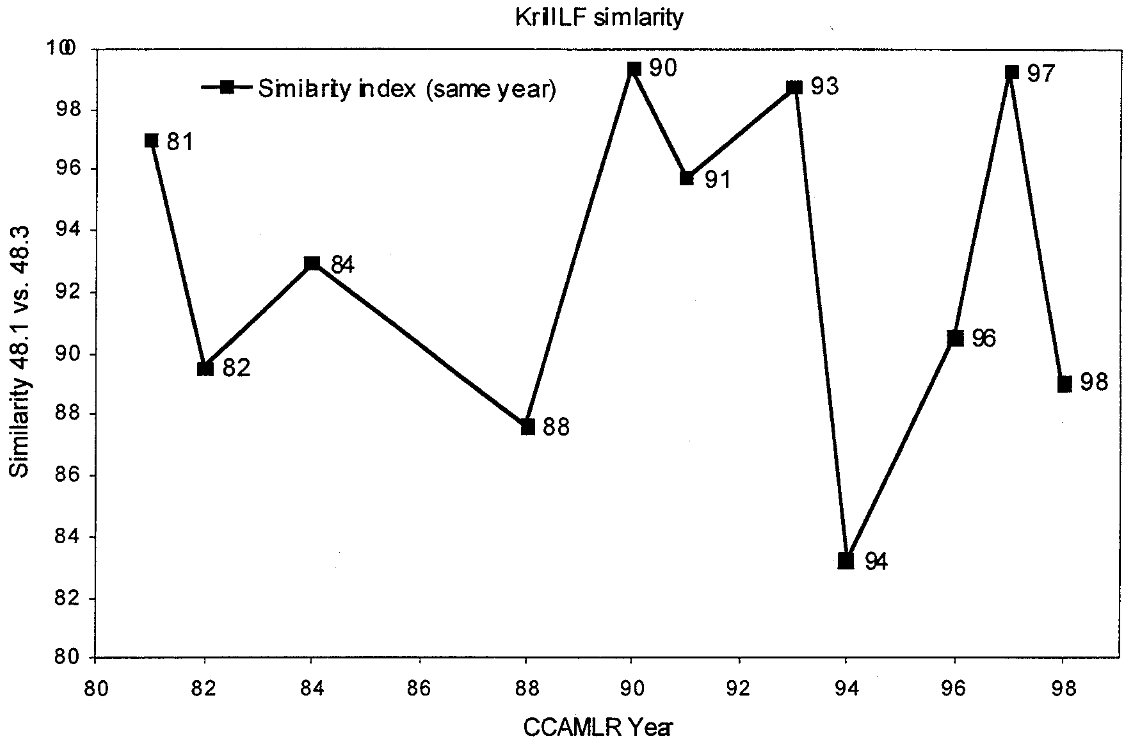


Figure 17: Interannual changes in krill length-frequency similarity index derived from cluster analysis of haul-by-haul length-frequency data in Area 48.

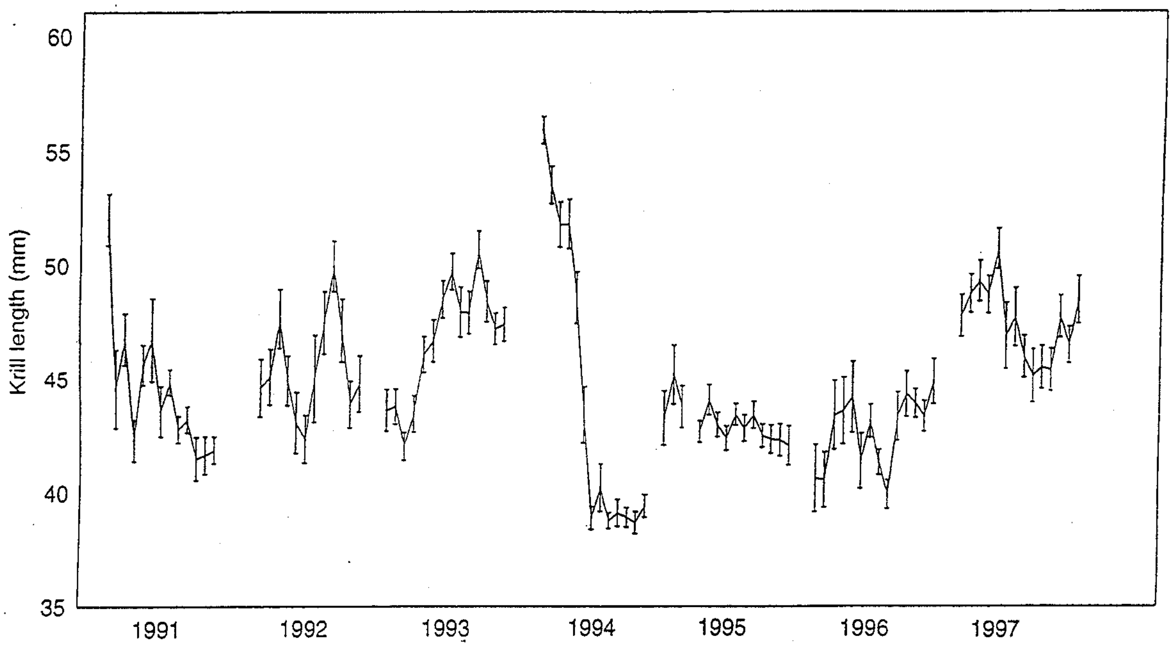


Figure 18: Weekly variation in mean krill length in the diet of Antarctic fur seals during the breeding seasons of 1991 to 1997 (error bars are shown at ±1 standard error). Figure taken from WS-Area48-98/15.

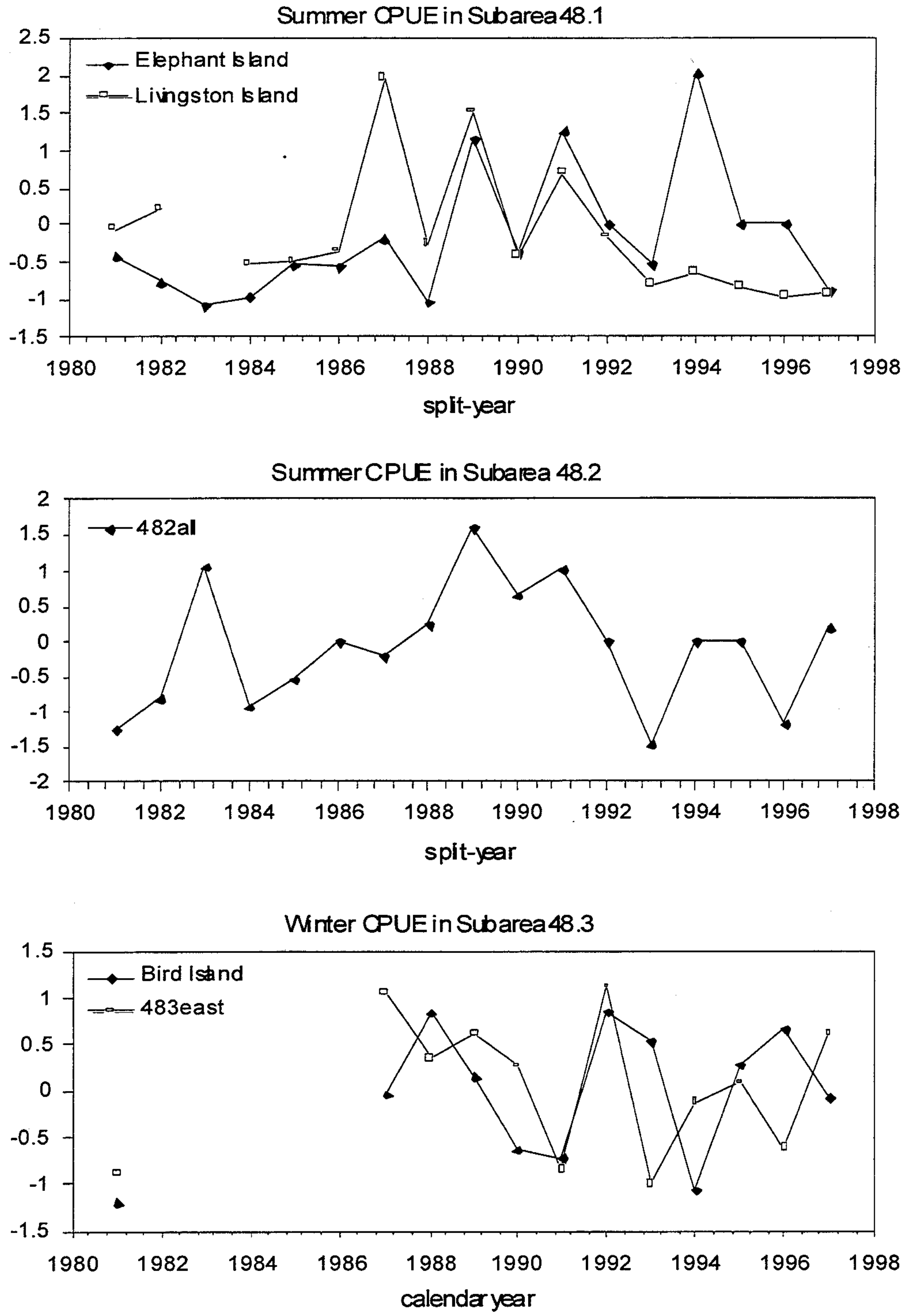


Figure 19: Indices of summer CPUE for krill fishery in Subareas 48.1 and 48.2 and winter CPUE for krill fishery in Subarea 48.3.

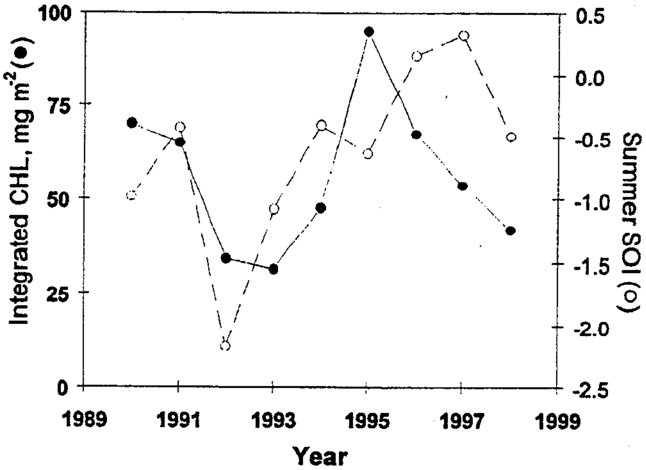


Figure 20: Integrated chlorophyll concentrations (mg·m-2) averaged over US AMLR survey grid (●) and the summer SOI (O) from 1990 onwards.

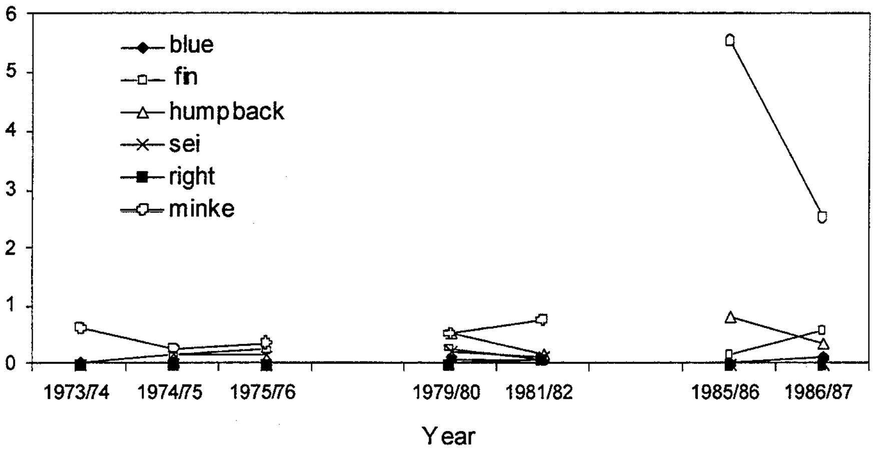


Figure 21: Japanese scouting vessel indices of whale abundance in Subarea 48.1.

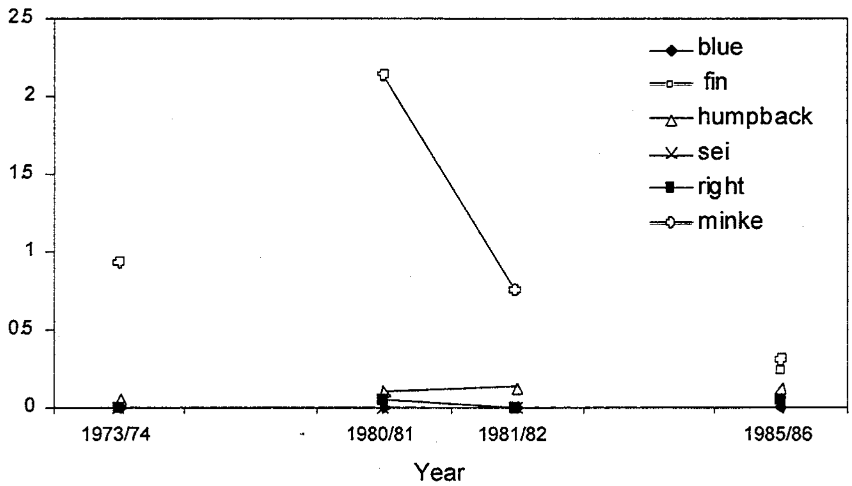


Figure 22: Japanese scouting vessel indices of whale abundance in Subarea 48.2.

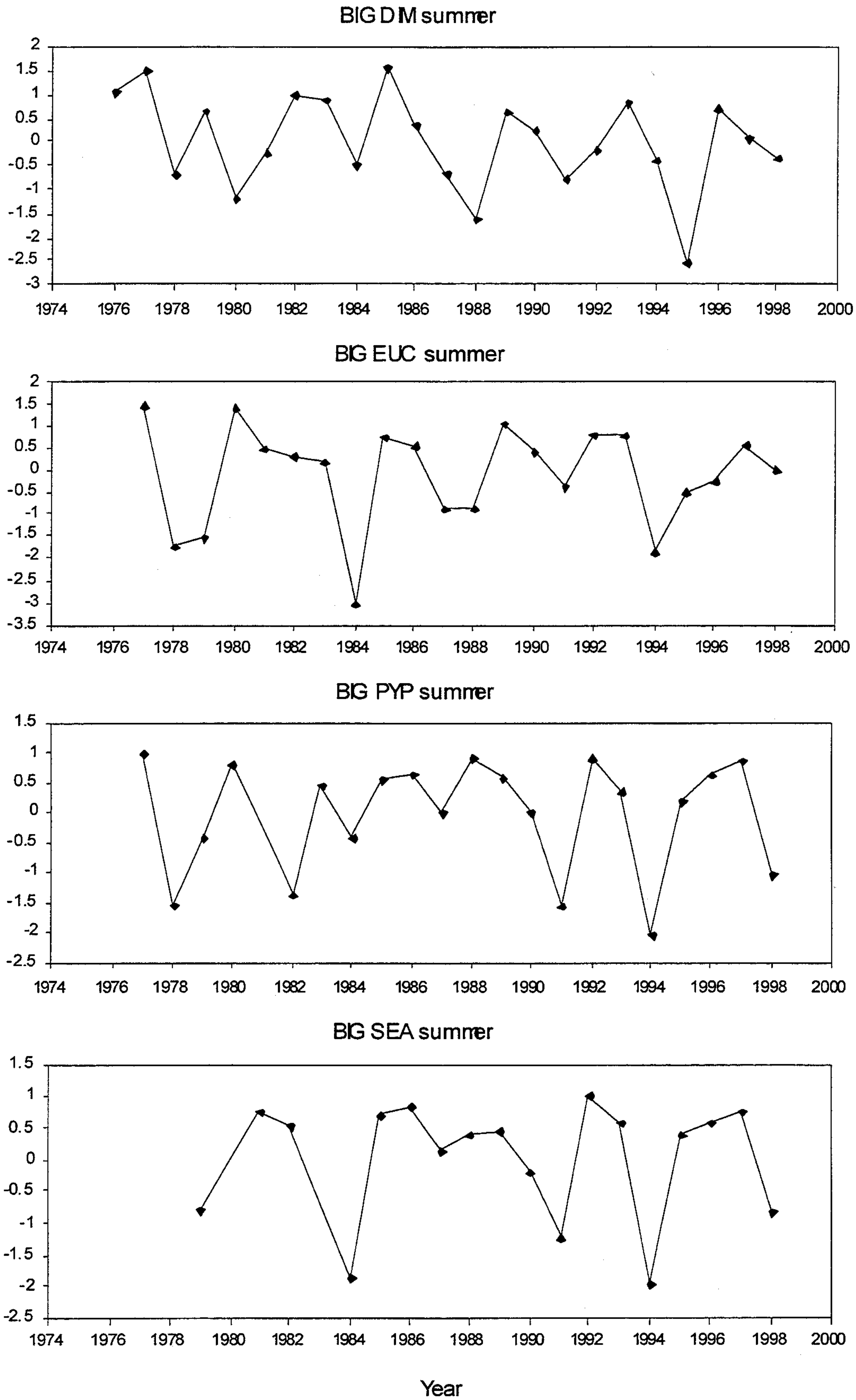


Figure 23a: Bird Island, South Georgia (BIG) CSIs for black-browed albatross (DIM), macaroni penguin (EUC), gentoo penguin (PYP) and Antarctic fur seal (SEA) in summer.

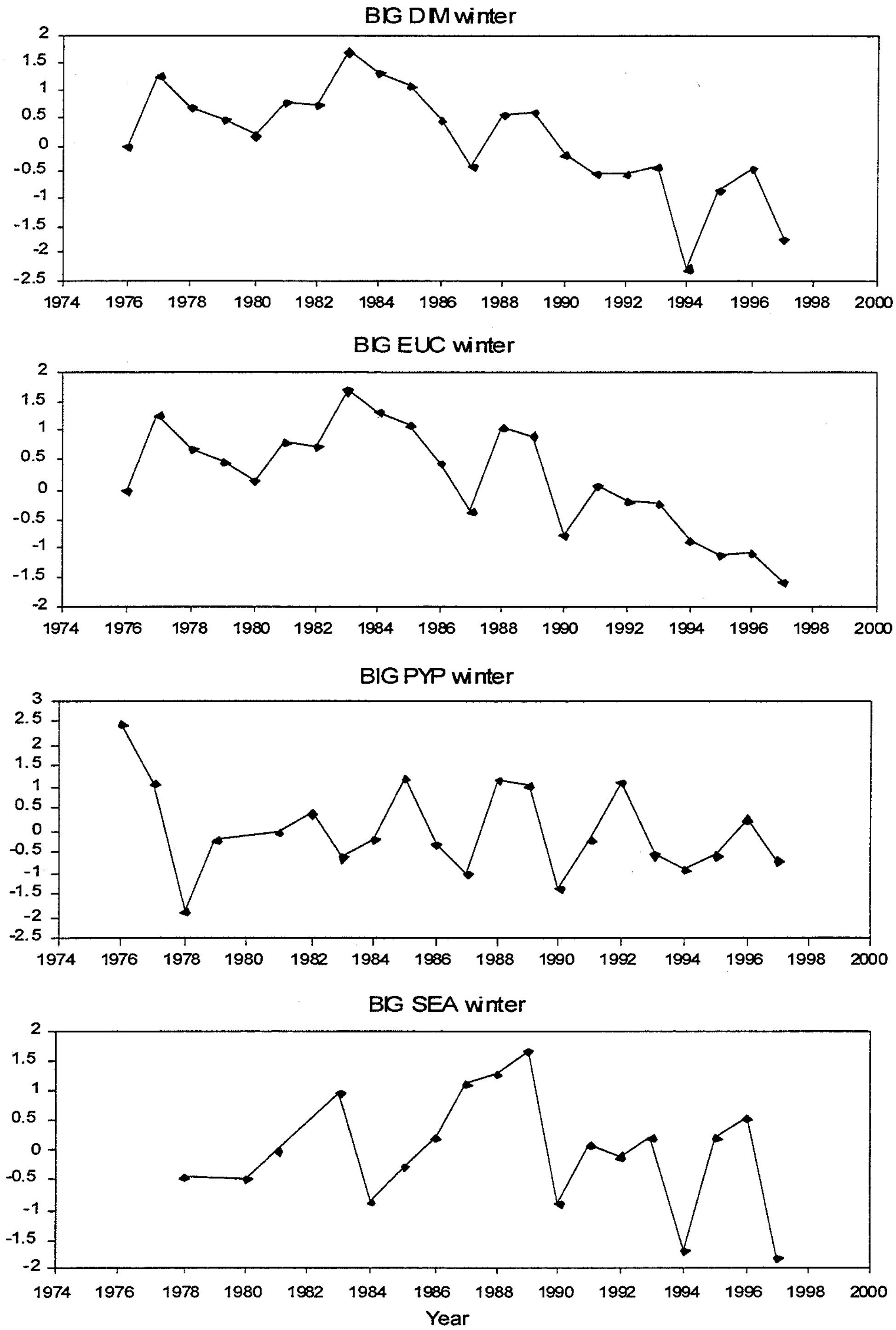


Figure 23b: Bird Island, South Georgia (BIG) CSIs for black-browed albatross (DIM), macaroni penguin (EUC), gentoo penguin (PYP) and Antarctic fur seal (SEA) in winter.

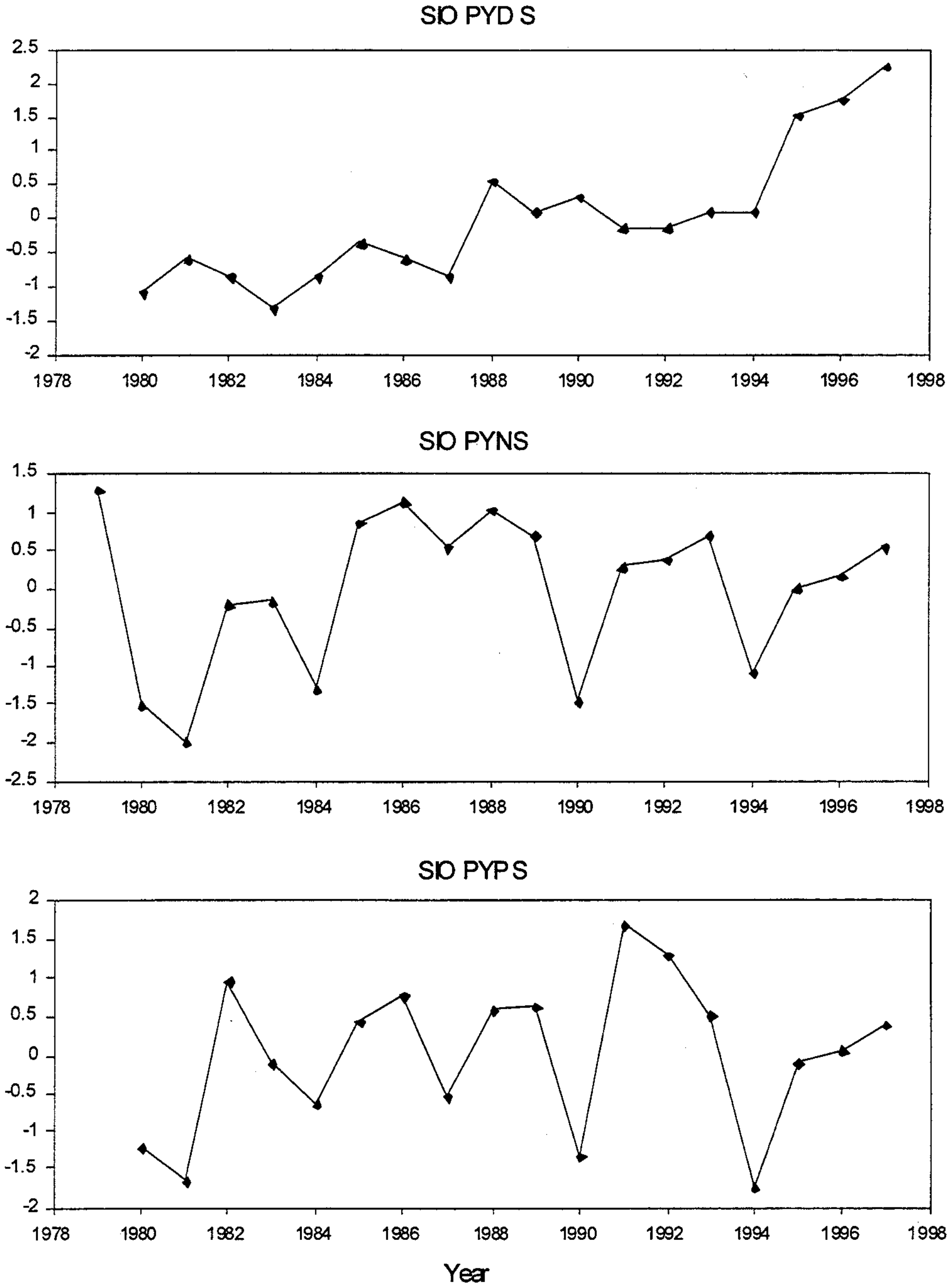


Figure 24a: Signy Island, South Orkney Islands (SIO) CSIs for Adélie (PYD), chinstrap (PYN) and gentoo (PYP) penguins in summer.

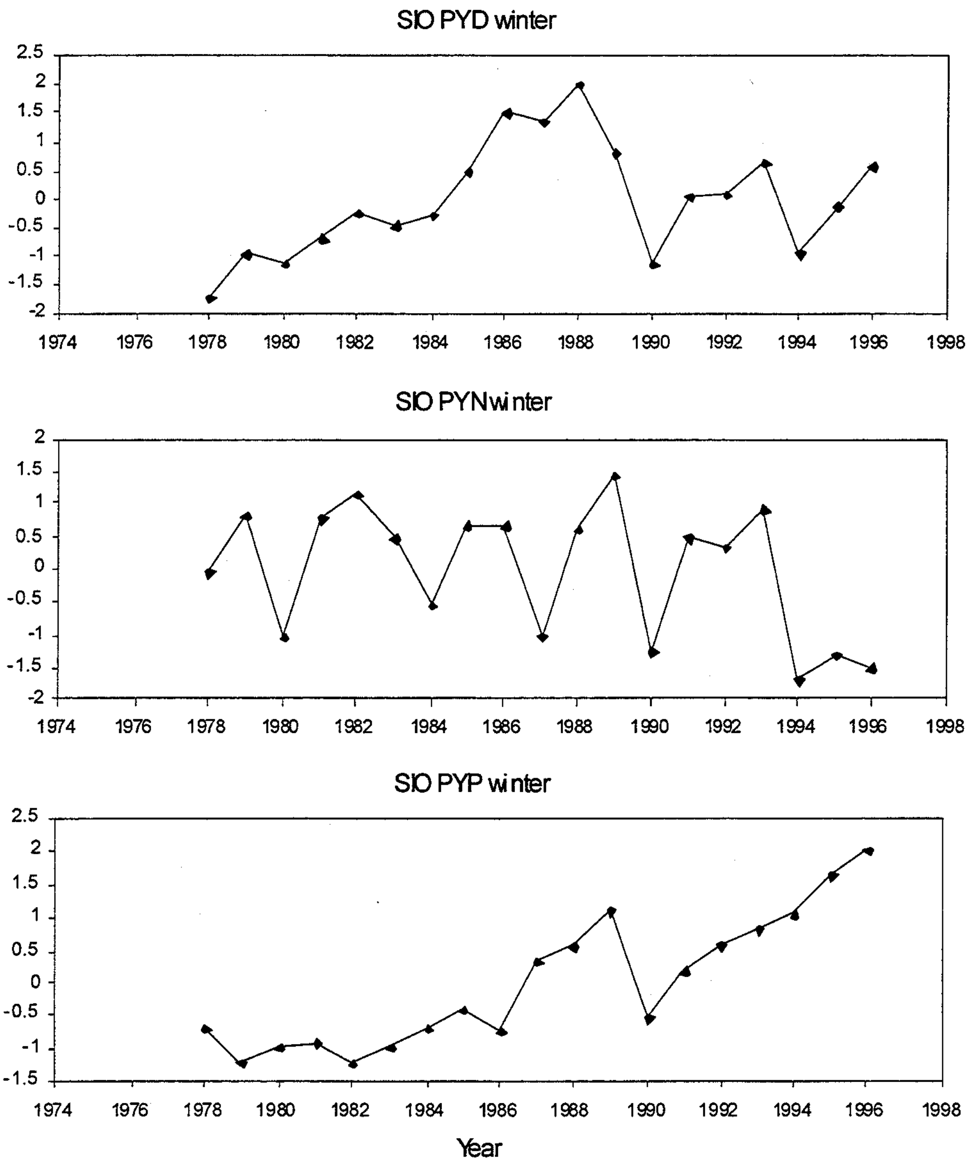


Figure 24b: Signy Island, South Orkney Islands (SIO) CSIs for Adélie (PYD), chinstrap (PYN) and gentoo (PYP) penguins in winter.

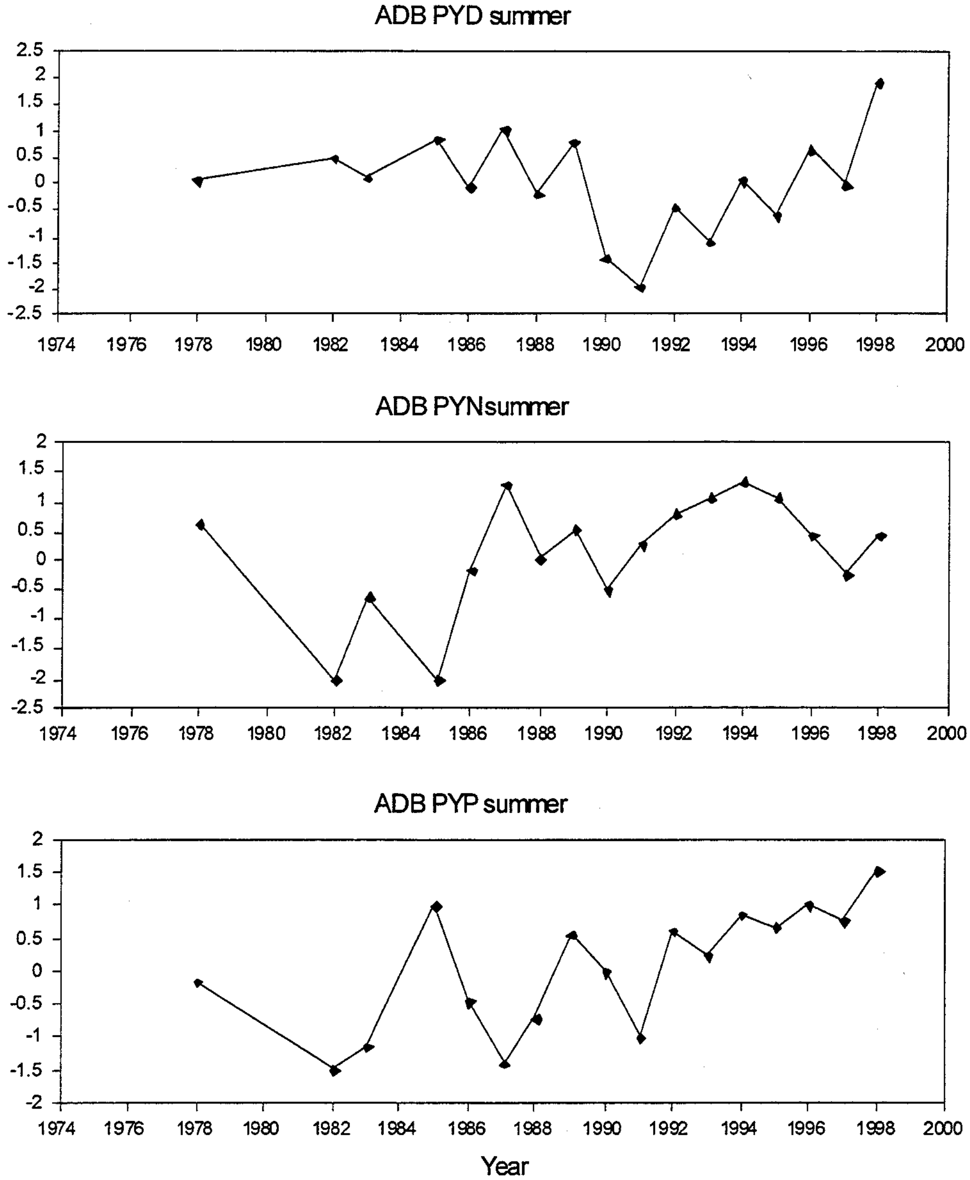


Figure 25a: Admiralty Bay, King George Island, South Shetland Islands (ADB) CSIs for Adélie (PYD), chinstrap (PYN) and gentoo (PYP) penguins in summer.

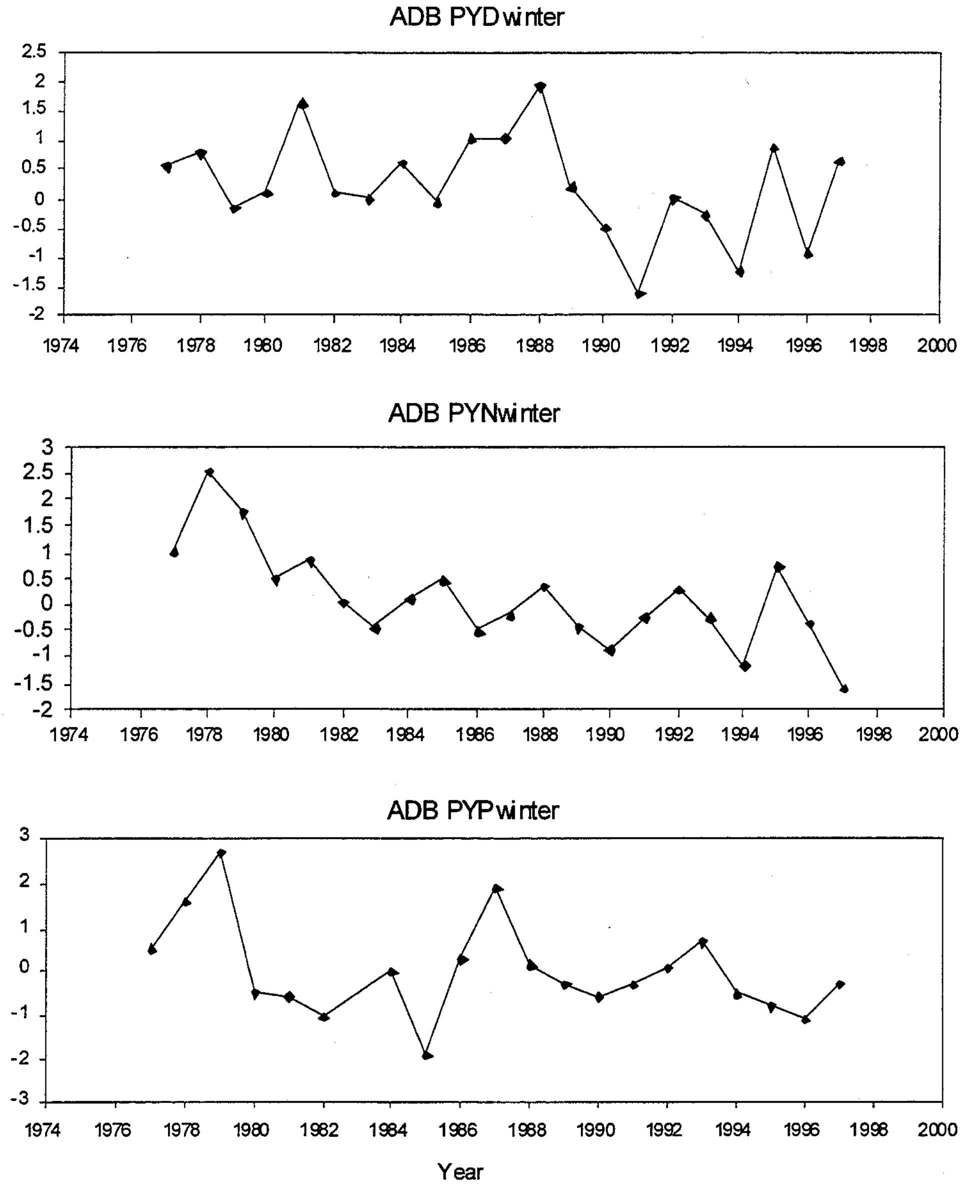


Figure 25b: Admiralty Bay, King George Island, South Shetland Islands (ADB) CSIs for Adélie (PYD), chinstrap (PYN) and gentoo (PYP) penguins in winter.

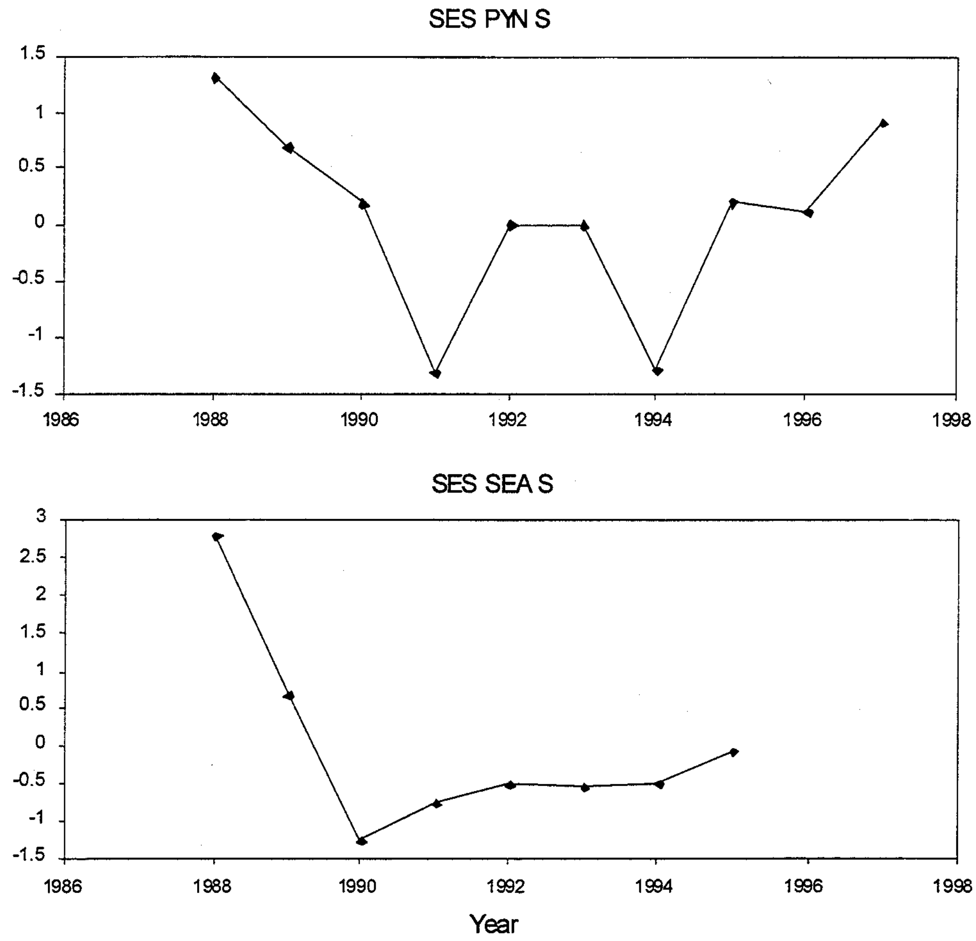


Figure 26: Seal Island, South Shetland Islands group (SES) CSIs for chinstrap penguin (PYN) and Antarctic fur seal (SEA) in summer (S).

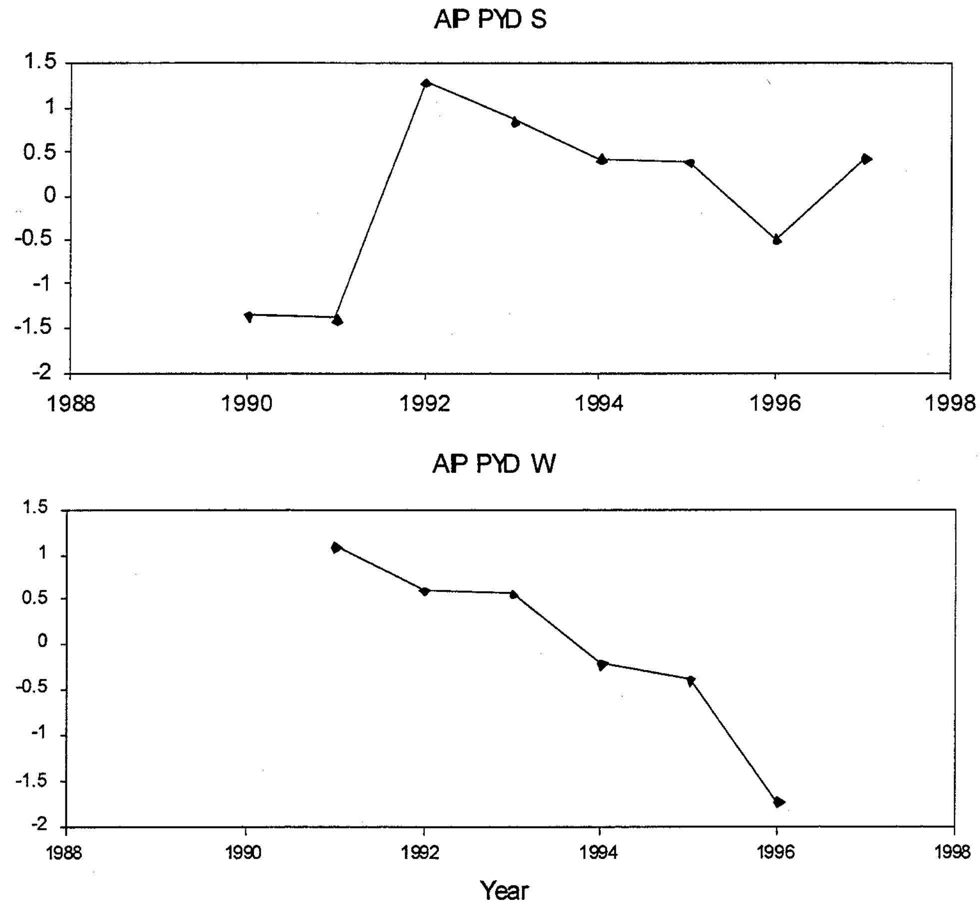


Figure 27: Anvers Island, Antarctic Peninsula (AIP) CSIs for Adélie penguins (PYD) in summer (S) and winter (W).

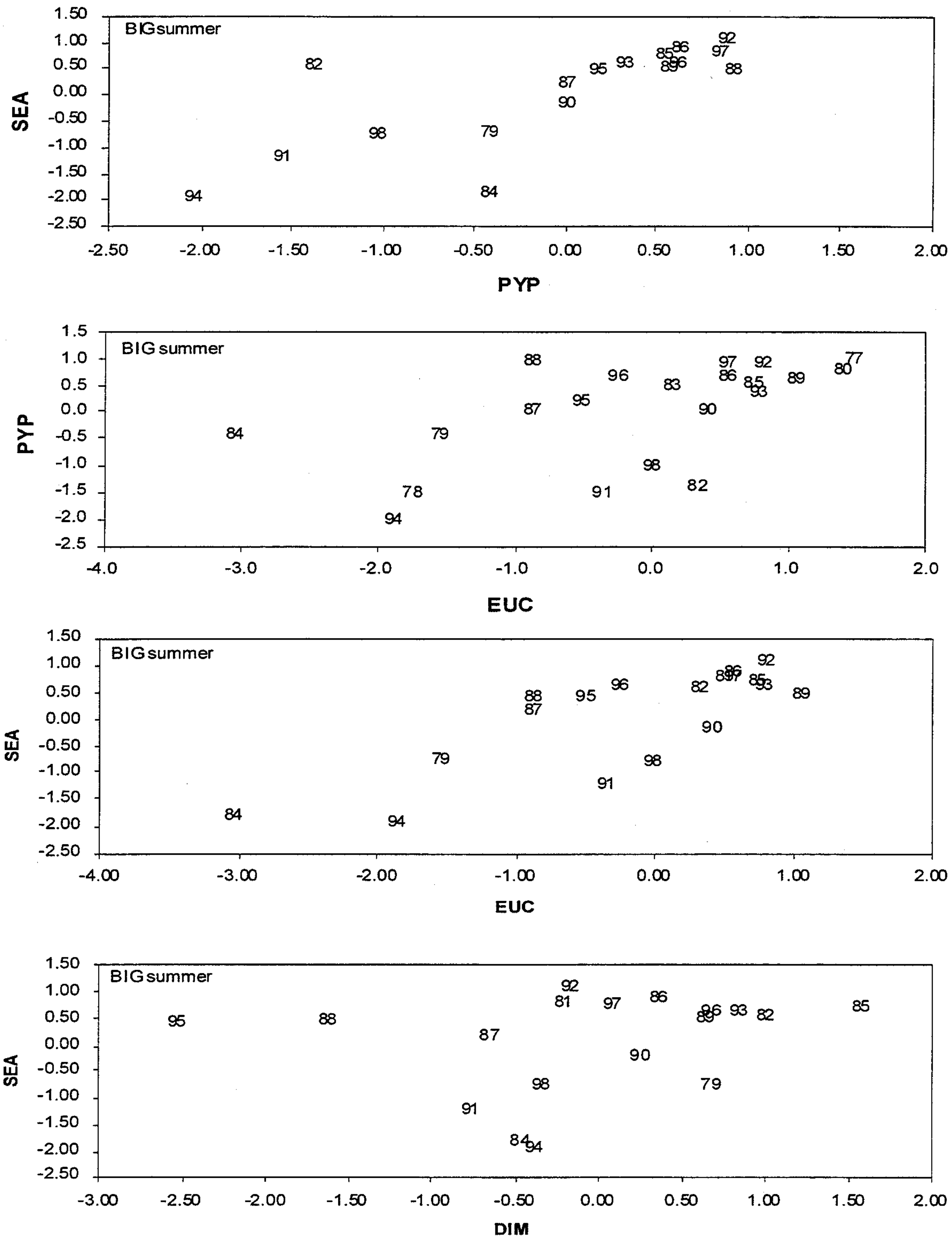


Figure 28: Relationships between summer CSIs at Bird Island (BIG) for different pairwise combinations of predators. Abbreviations as in Table 2 and Figure 23.

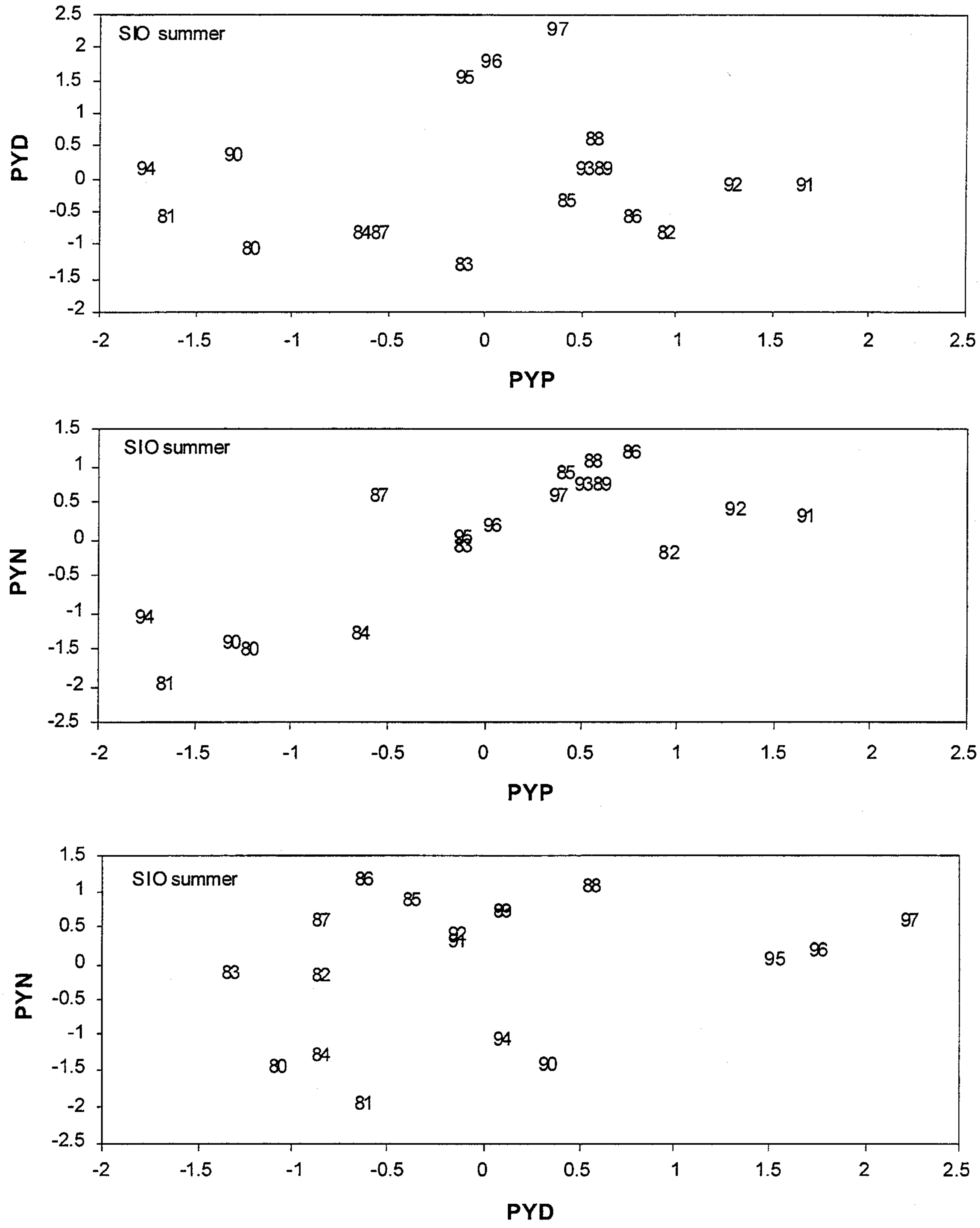


Figure 29a: Relationships between summer CSIs for different pairwise combinations of penguin species at Signy Island (SIO) for Adélie (PYD), chinstrap (PYN) and gentoo (PYP) penguins.

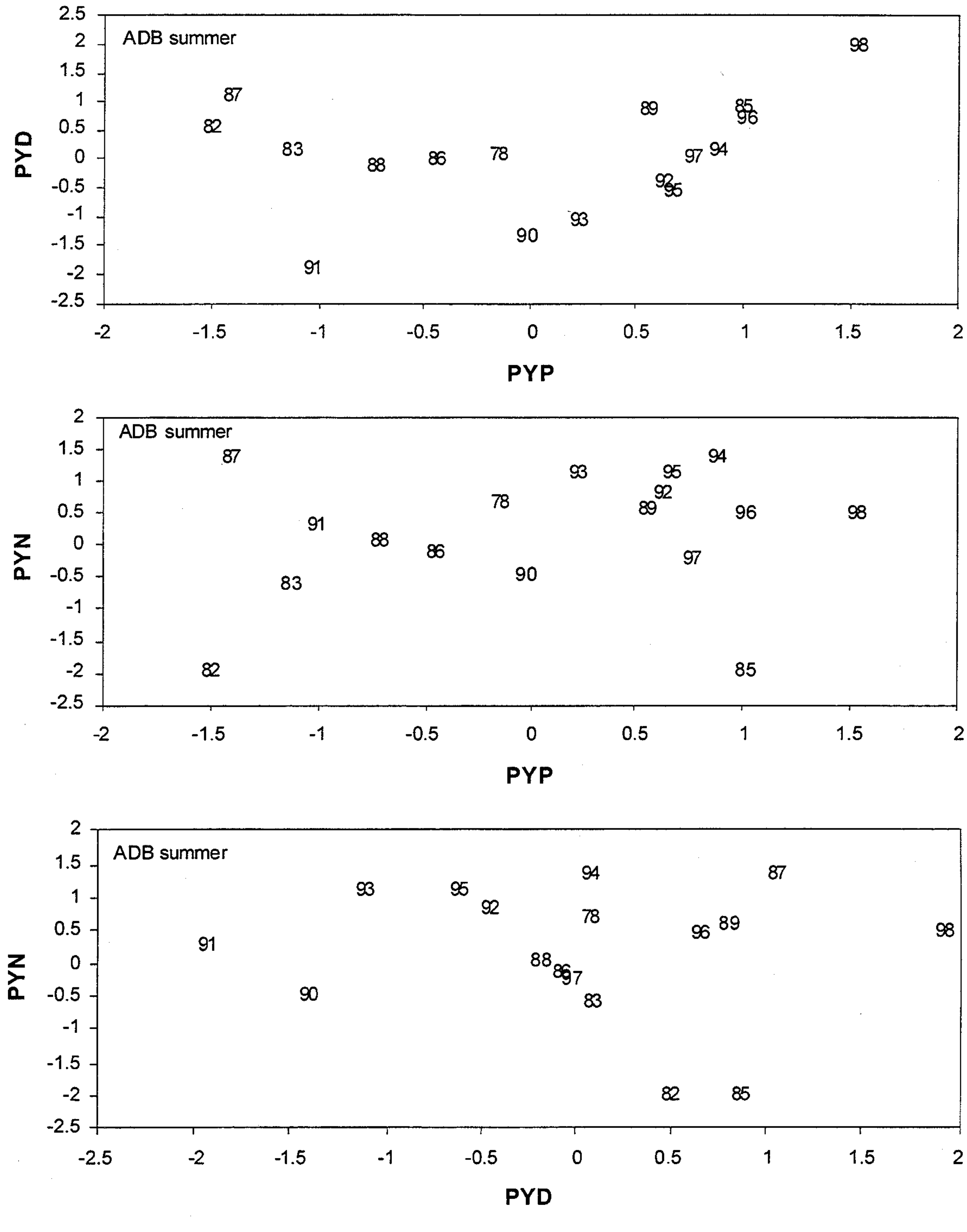


Figure 29b: Relationships between summer CSIs for different pairwise combinations of penguin species at Admiralty Bay (ADB) for Adélie (PYD), chinstrap (PYN) and gentoo (PYP) penguins.

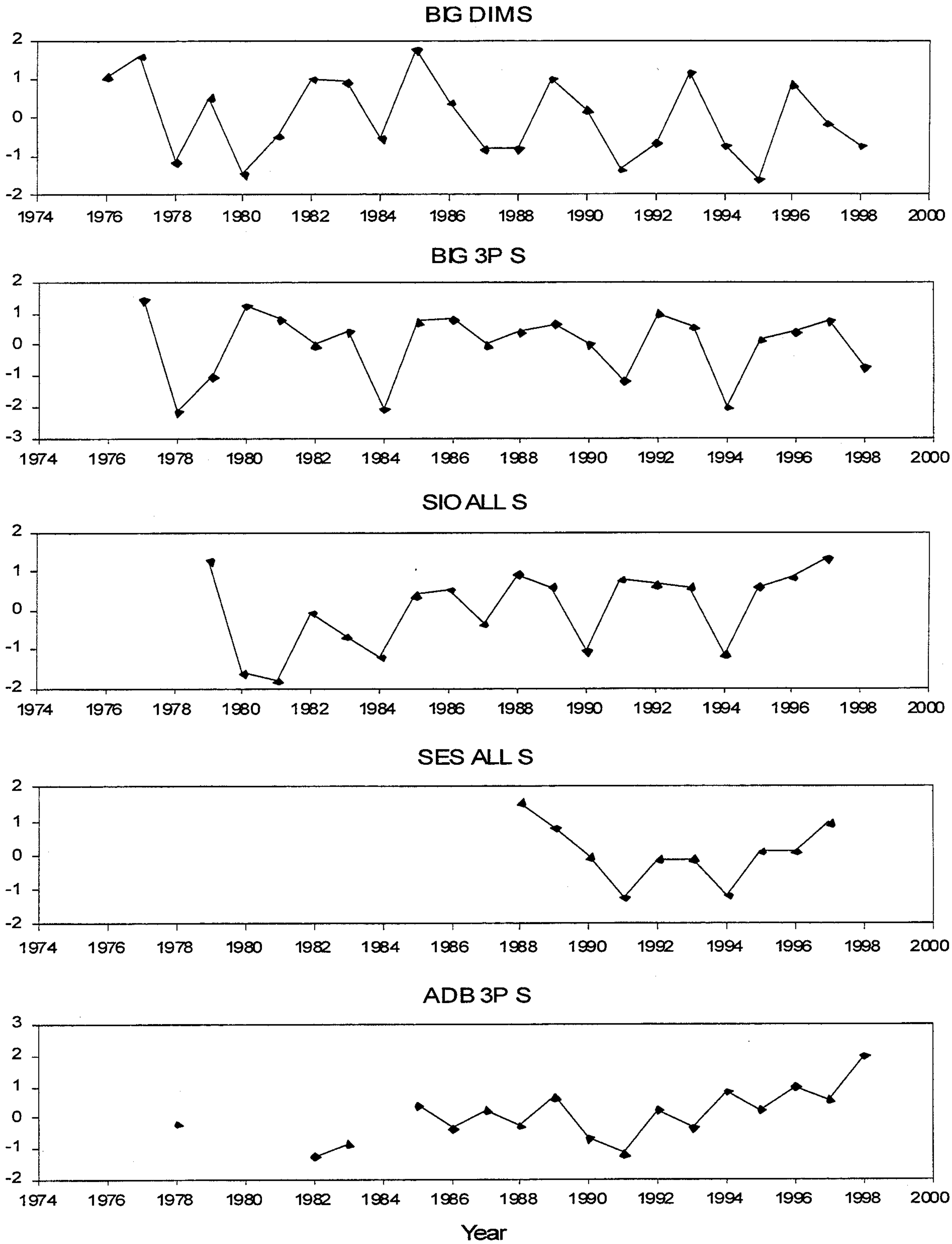


Figure 30: Summer CSIs grouped across species within sites (see paragraph 7.16). BIG 3 PS involves the combination of gentoo penguin, macaroni penguin and Antarctic fur seal at Bird Island; ADB 3 PS and SIO ALL S involve the combination of Adélie, chinstrap and gentoo penguins at Admiralty Bay and Signy Island respectively; SES ALL S involves the combination of chinstrap penguin and Antarctic fur seal at Seal Island.

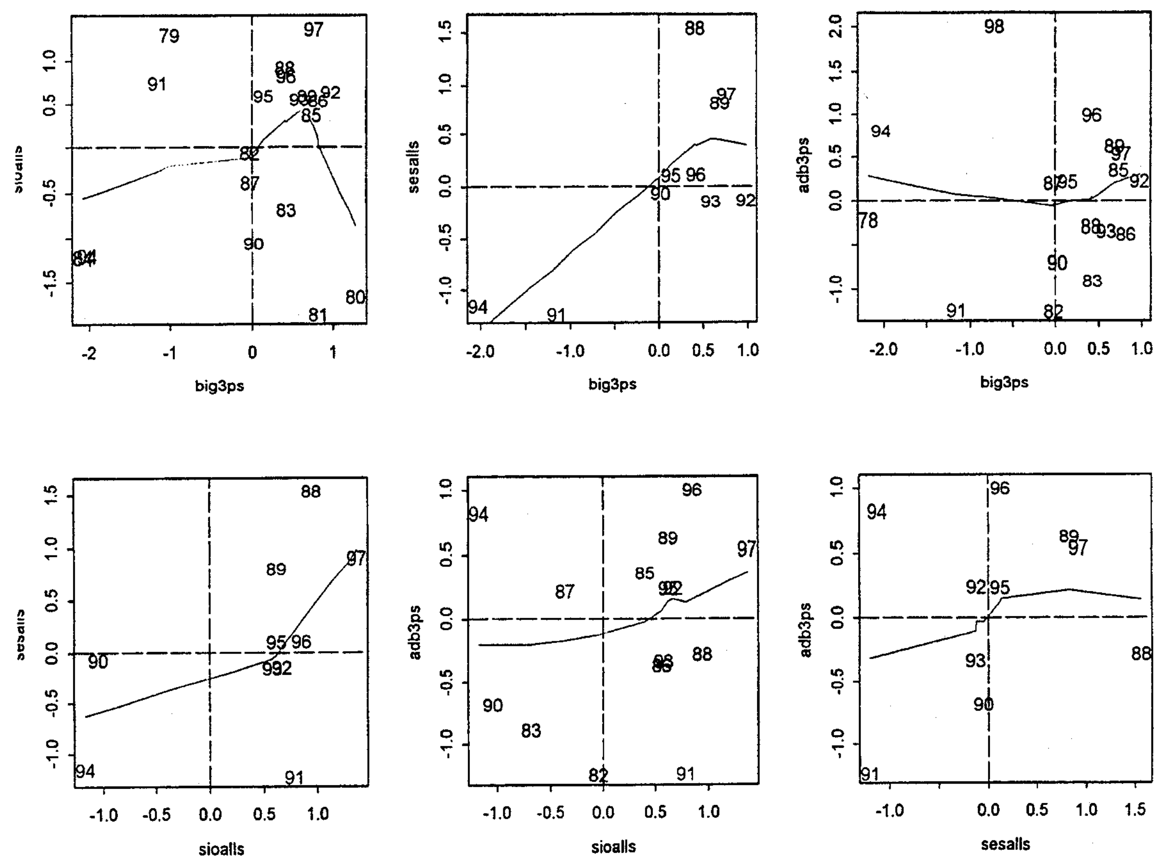


Figure 31: Comparison of predator performance between sites/areas based on summer CSIs for species group within sites. Four quadrants are shown that indicate concordance between variables in each year. Points in the top-right and bottom-left quadrants indicate relatively high concordance whereas those 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.

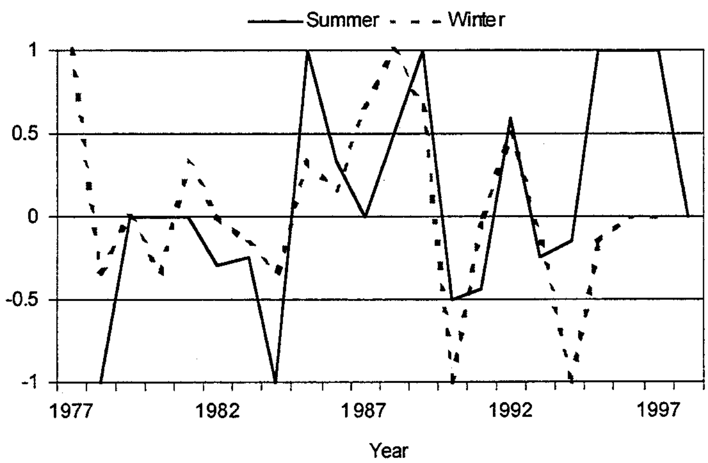


Figure 32: Similarity plot of indices of coherence derived from summer data in Figure 31 and winter data in Figure 35 (see paragraph 7.30 for explanation).

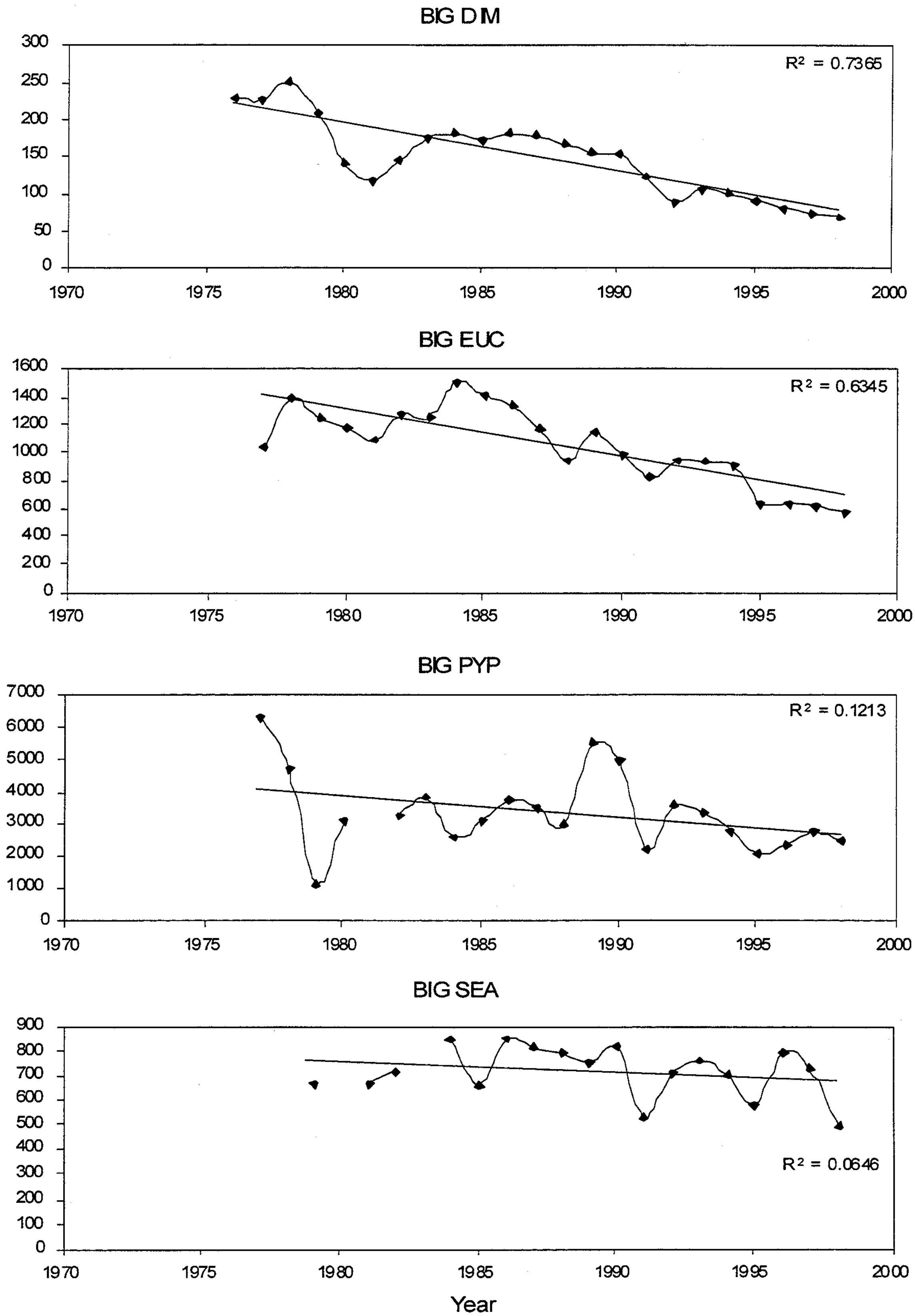
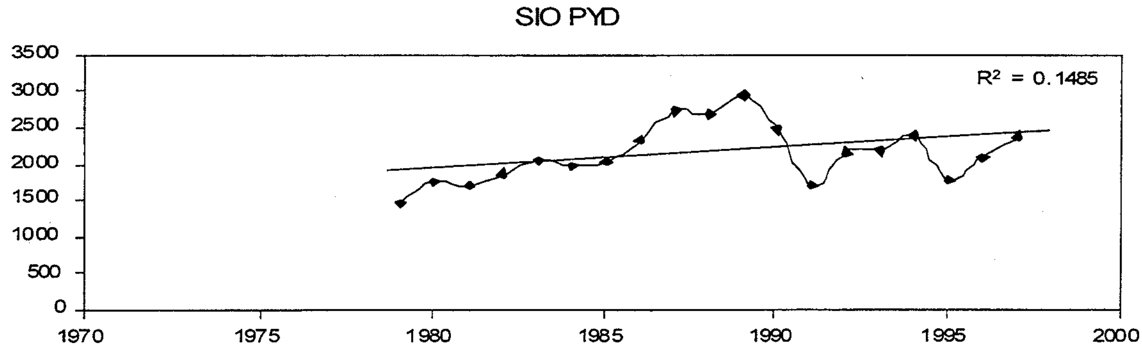
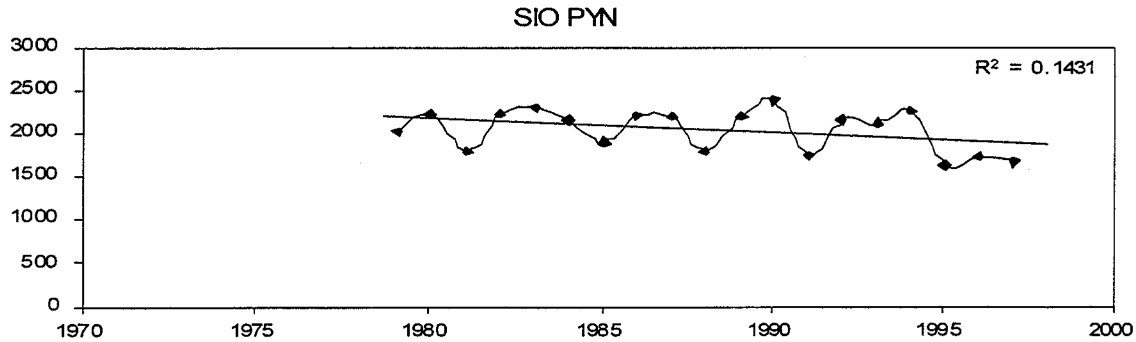
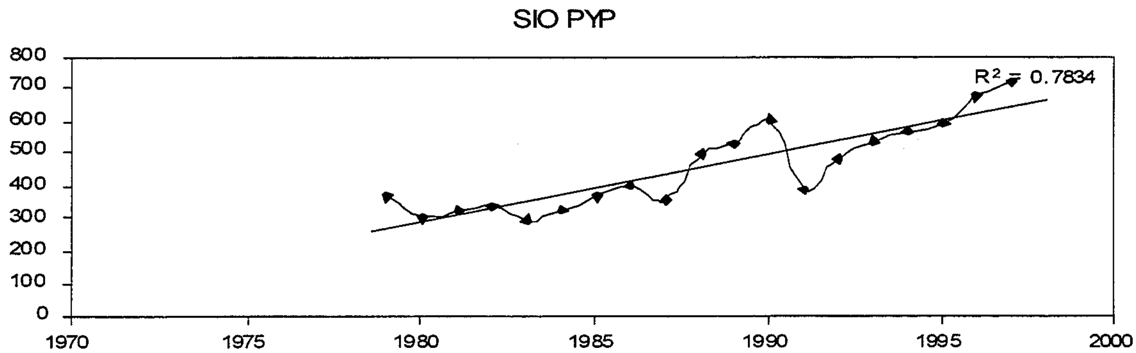


Figure 33: Changes in breeding population size in land-based marine predators at: (a) Bird Island (BIG), (b) Signy Island (SIO), (c) Admiralty Bay (ADB), (d) Anvers Island (AIP). Species abbreviations as in Table 2. Solid lines are least squares linear regression, with R2 as indicated.







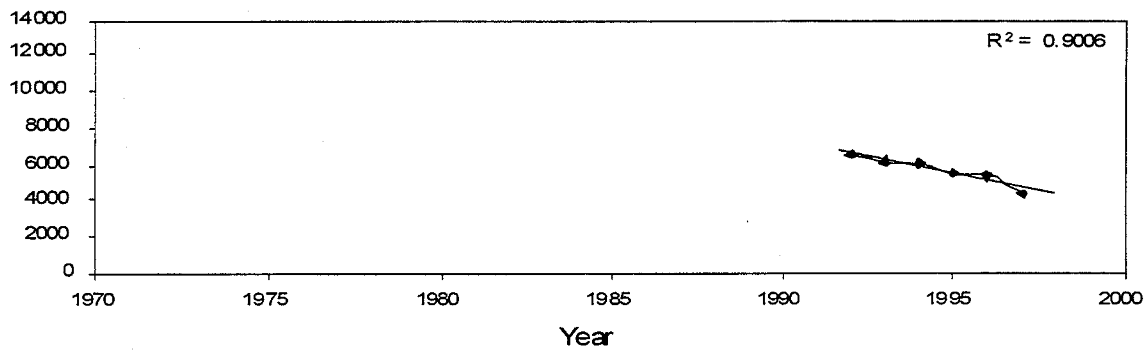


Figure 33 (continued)

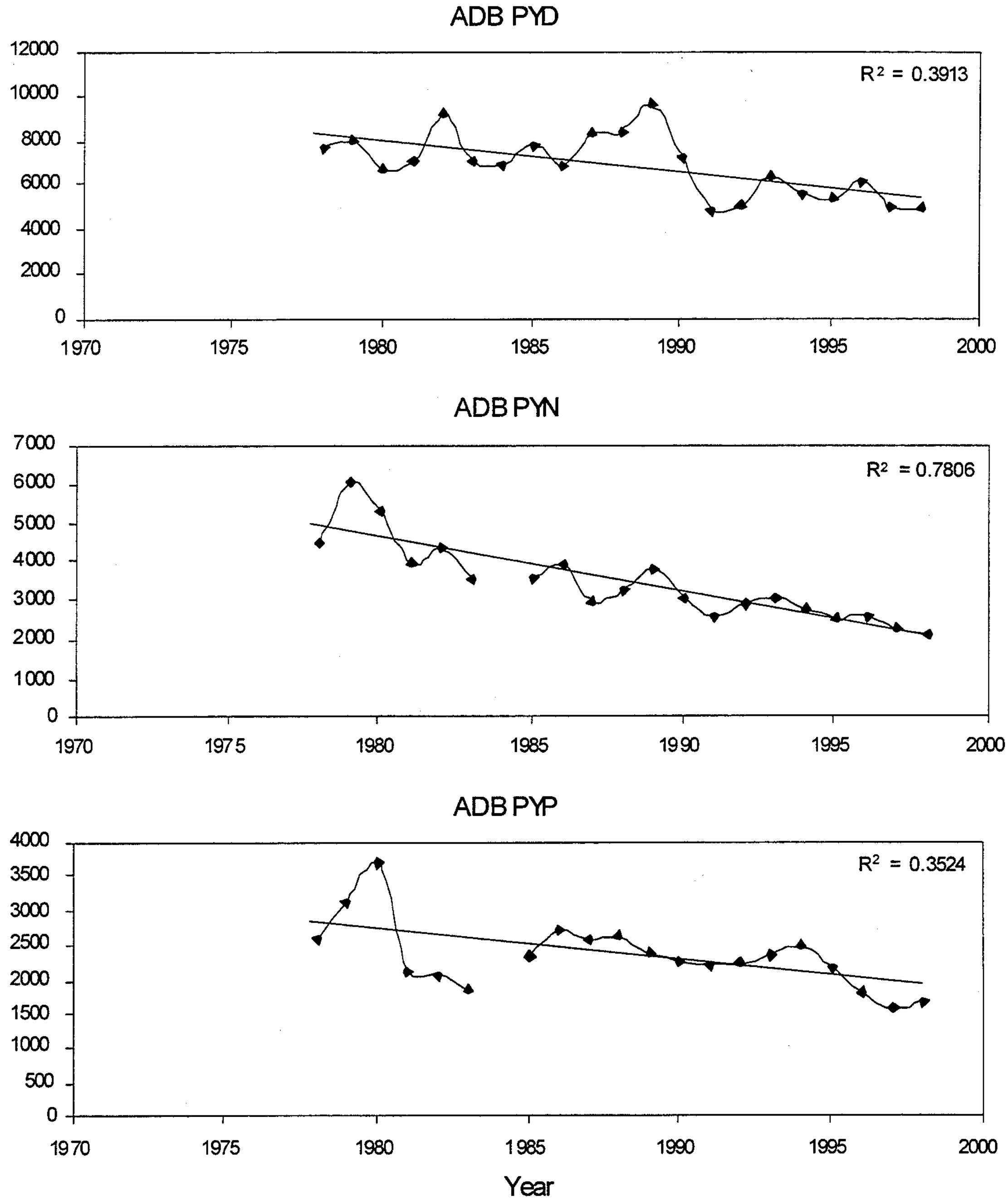


Figure 33 (continued)

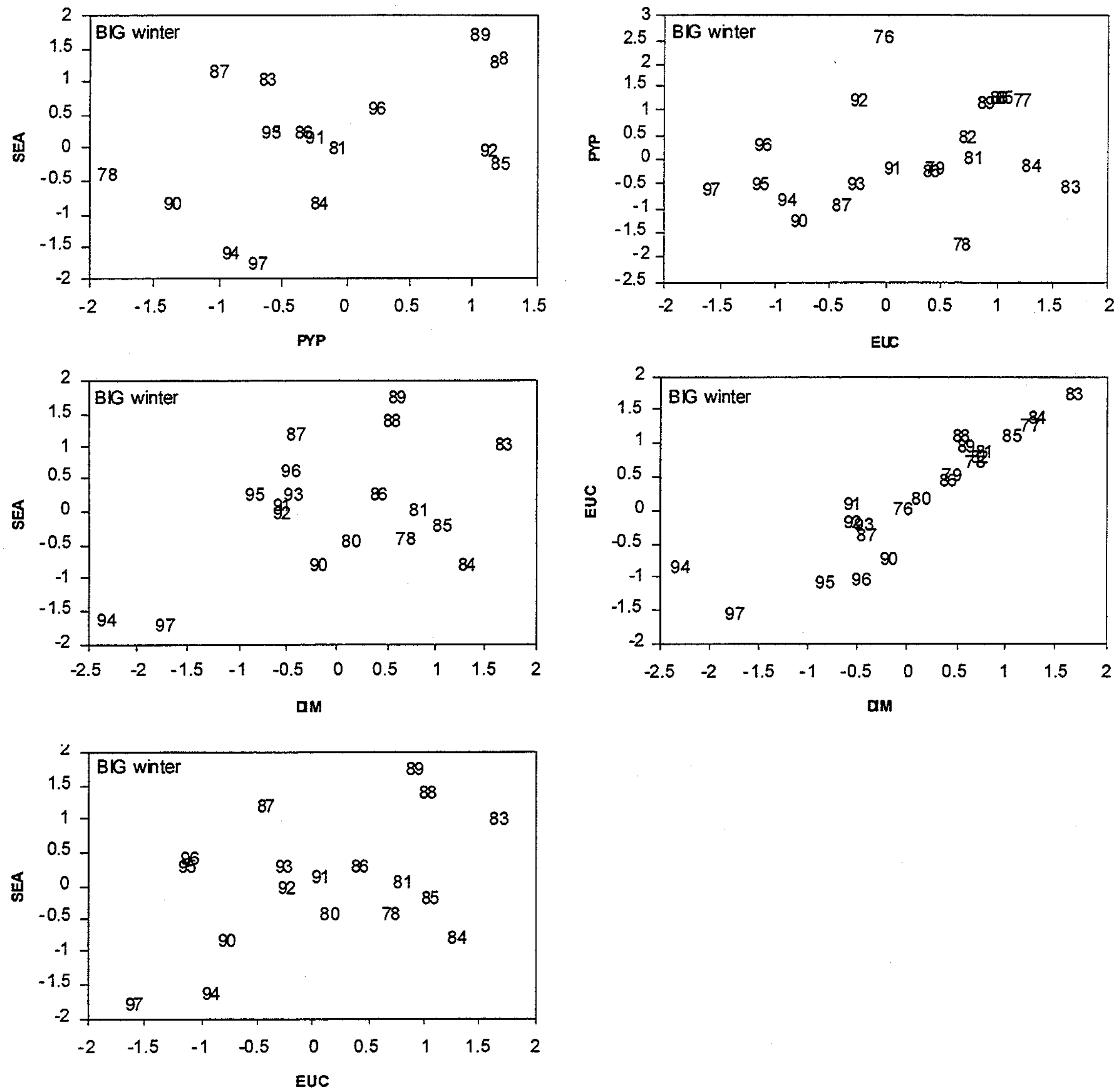


Figure 34a: Relationships between winter CSIs for various pairwise comparisons of predator species at Bird Island (BIG). Species abbreviations as in Table 2.

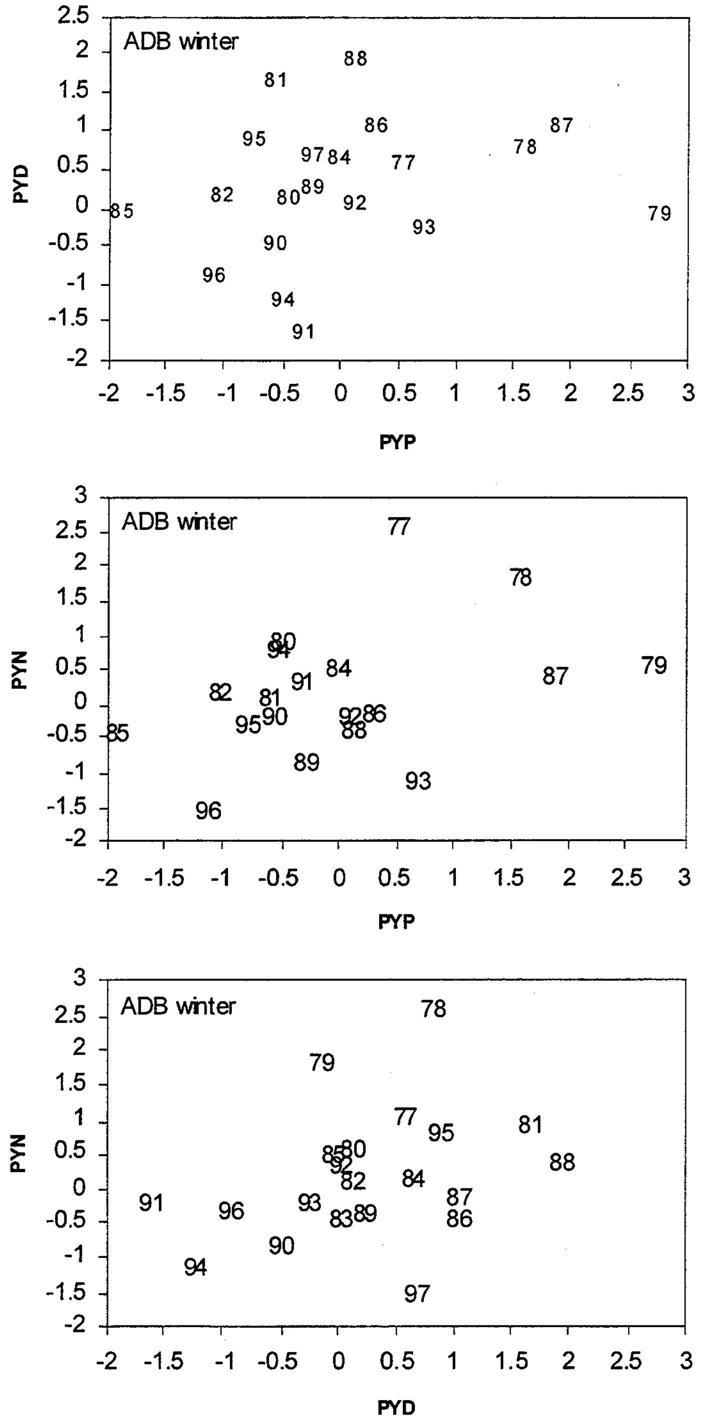


Figure 34b: Relationships between winter CSIs for various pairwise comparisons of predator species at Signy Island (SIO). Species abbreviations as in Table 2.

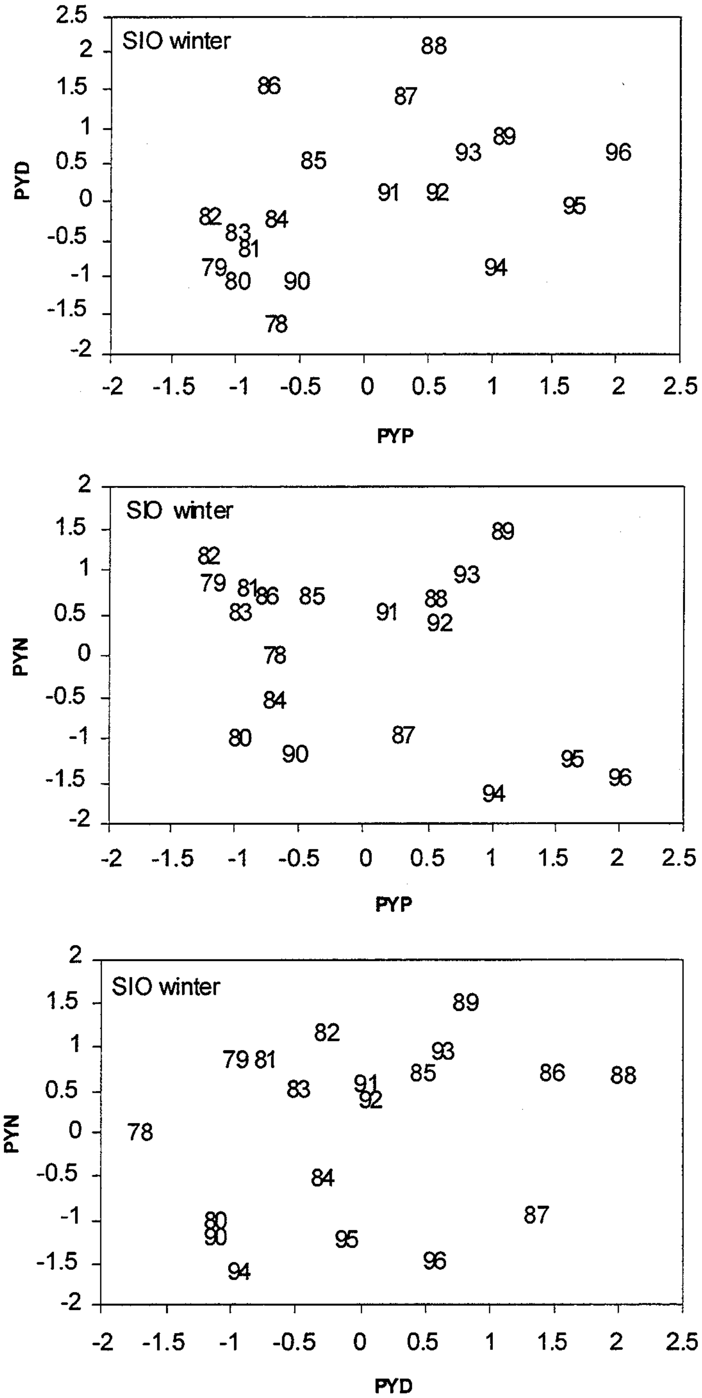


Figure 34c: Relationships between winter CSIs for various pairwise comparisons of predator species at Admiralty Bay (ADB). Species abbreviations as in Table 2.

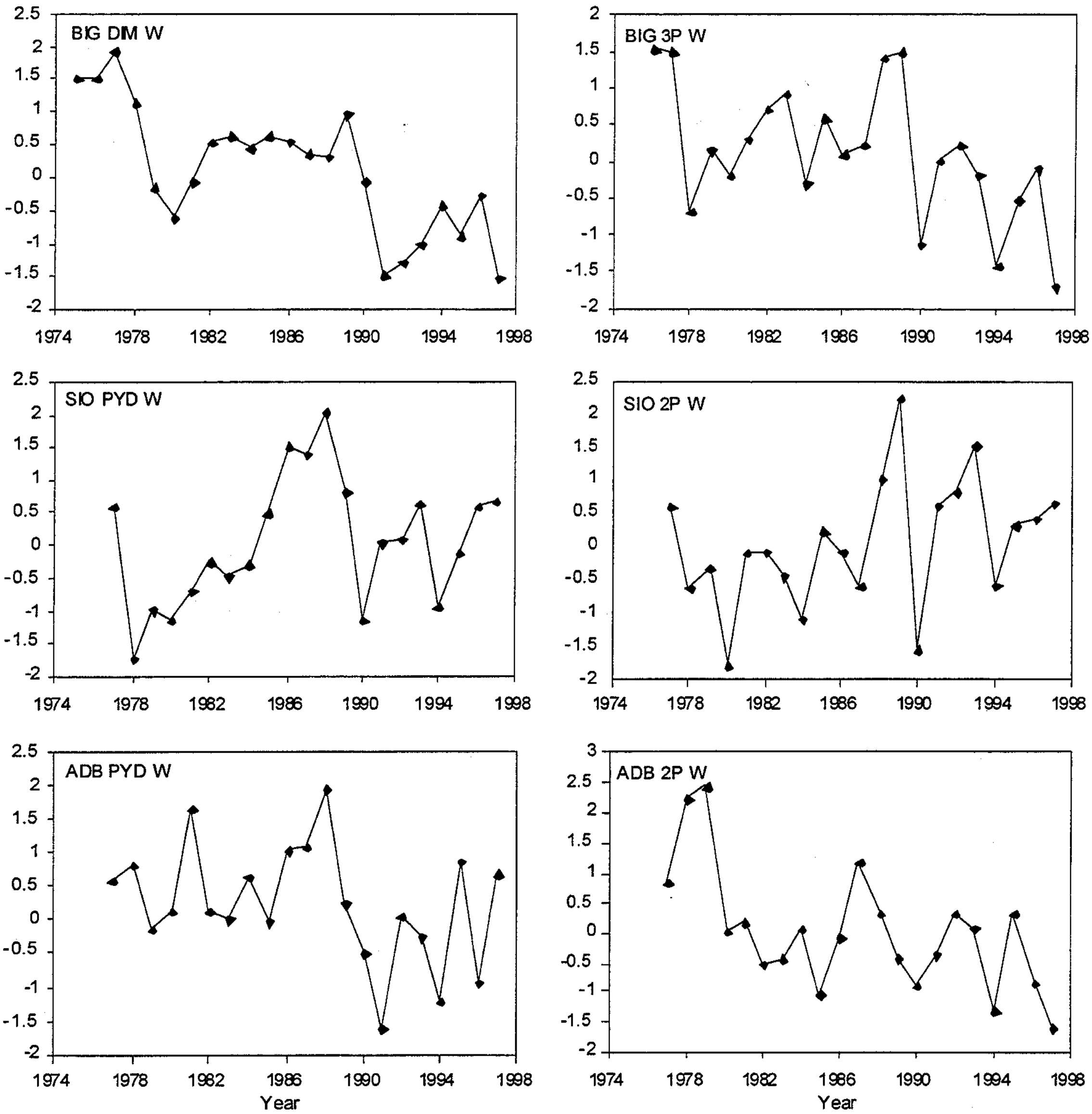


Figure 35: Winter CSIs grouped across species within sites (see paragraph 7.35). BIG 3 PS involves the combination of gentoo penguin, macaroni penguin and Antarctic fur seal at Bird Island; SIO 2 PW and ADB 2 PW involve the combination of chinstrap and gentoo penguins.

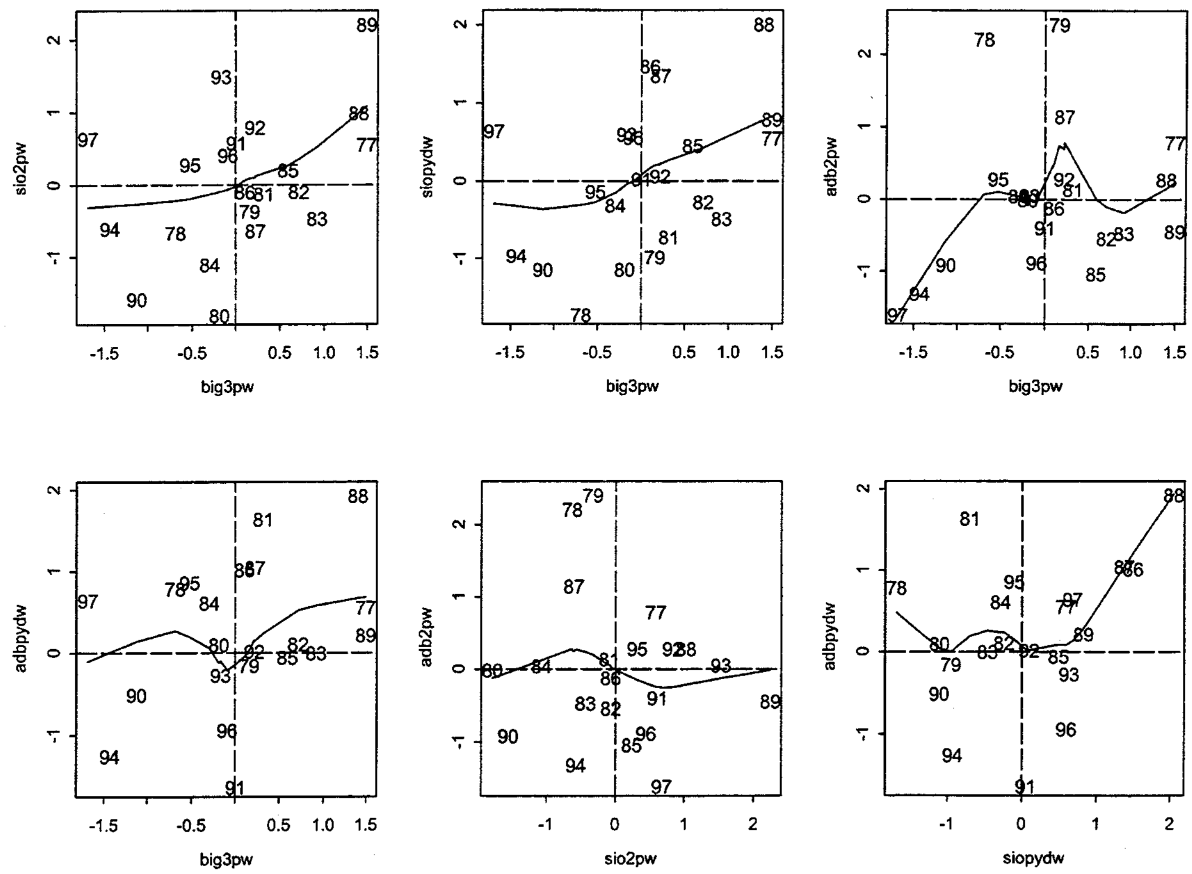


Figure 36: Comparison of predator performance between sites/areas based on winter CSIs for species group within sites. Four quadrants are shown that indicate concordance between variables in each year. Points in the top-right and bottom-left quadrants indicate relatively high concordance whereas those 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.

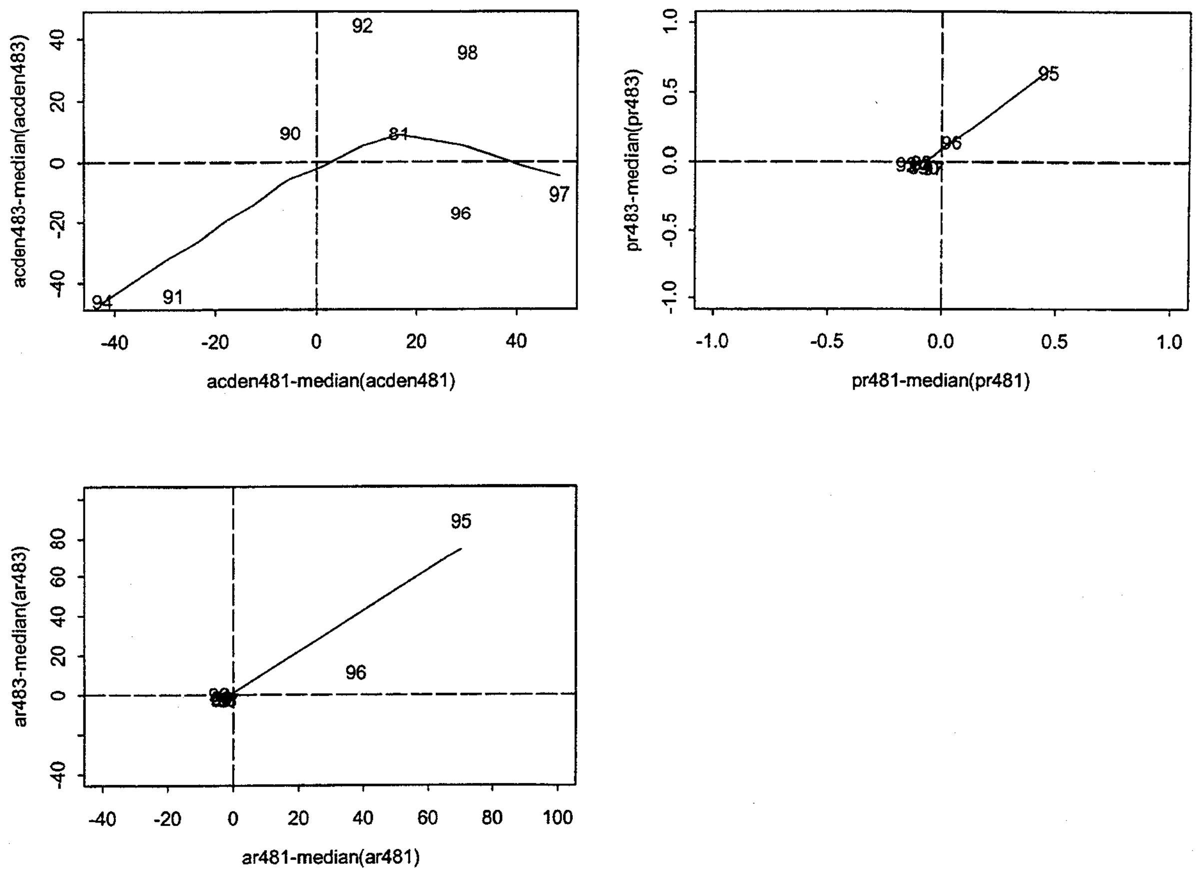


Figure 37: Comparisons of krill indices between areas. Each index is expressed relative to its median value. Four quadrants are shown that indicate concordance between variables in each year. Points in the top-right and bottom-left quadrants indicate relatively high concordance whereas those falling in the other two quadrants indicate relatively low concordance. Points are denoted by the number of the calendar year.

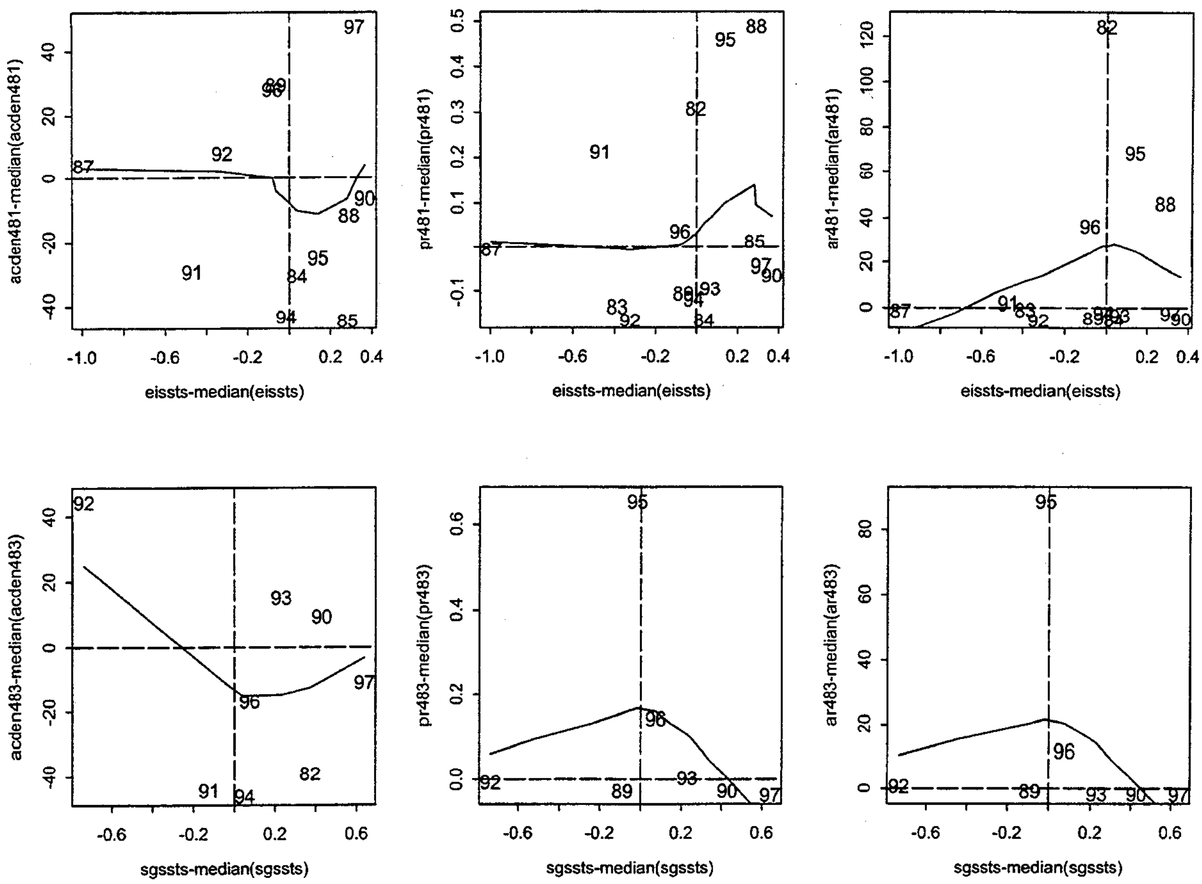


Figure 38: Krill indices in relation to SST within areas. Each index is expressed relative to its median value. Four quadrants are shown that indicate concordance between variables in each year. Points in the top-right and bottom-left quadrants indicate relatively high concordance whereas those falling in the other two quadrants indicate relatively low concordance. Points are denoted by the number of the calendar year.

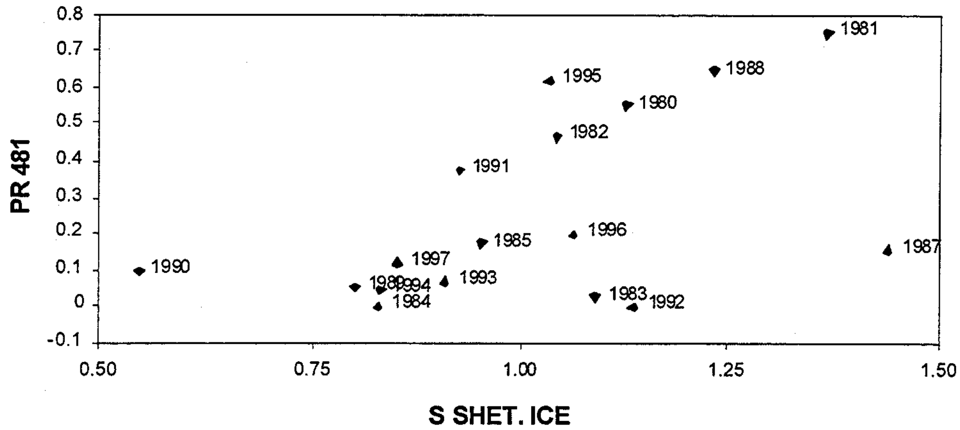


Figure 39: The relationship between proportional krill recruitment in Subarea 48.1 and sea-ice in the South Shetlands. Each point is labelled with the year in which data were collected.

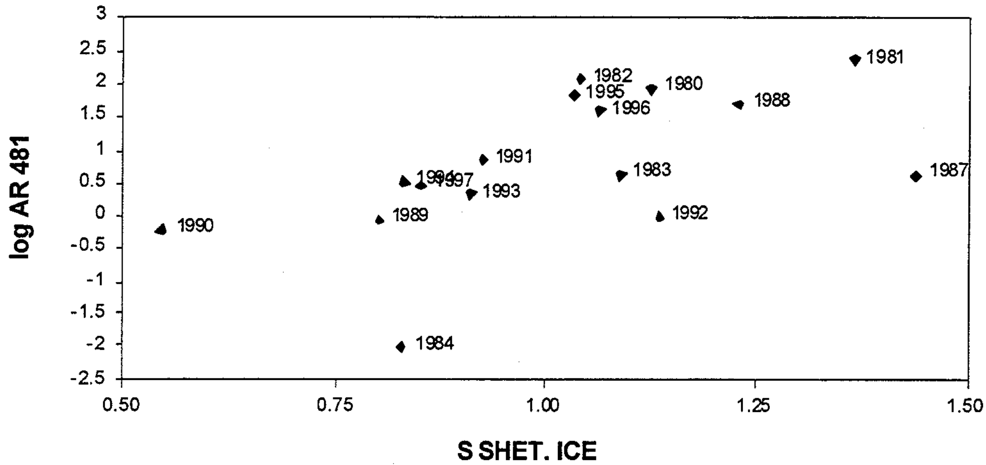


Figure 40: The relationship between the log of proportional krill recruitment in Subarea 48.1 and sea-ice in the South Shetlands. Each point is labelled with the year in which data were collected.

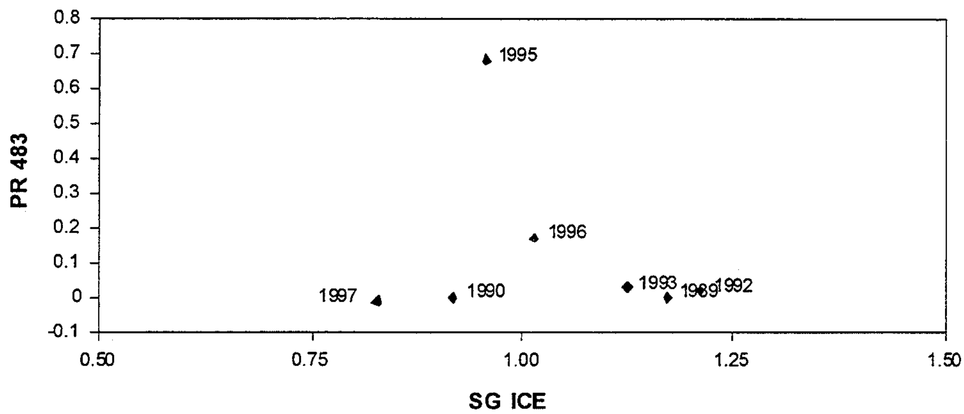


Figure 41: The relationship between proportional recruitment in Subarea 48.3 and the South Georgia sea-ice index. Each point is labelled with the year in which data were collected.

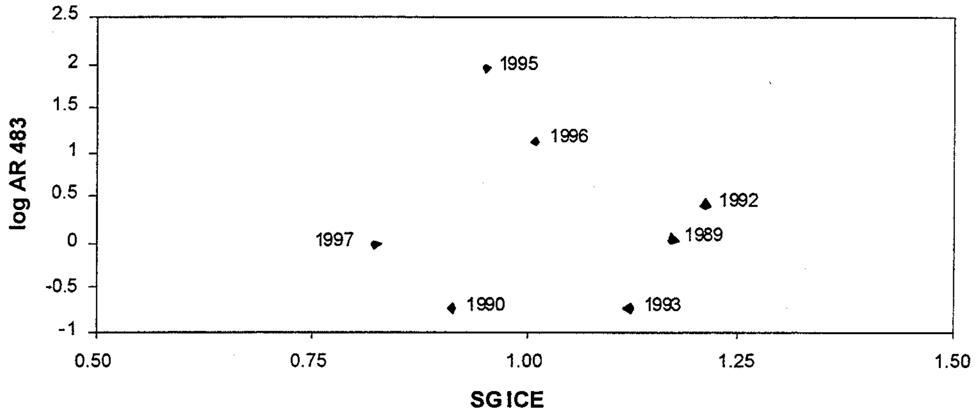


Figure 42: The relationship between the log of proportional recruitment in Subarea 48.3 and the South Georgia sea-ice index. Each point is labelled with the year in which data were collected.

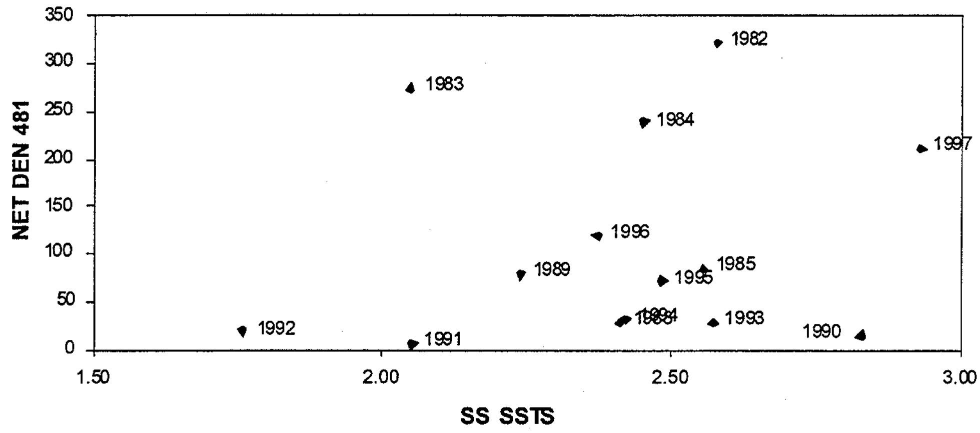


Figure 43: The relationship between krill density determined using net sampling in Subarea 48.1 and the Scotia Sea summer SST. Each point is labelled with the year in which data were collected.

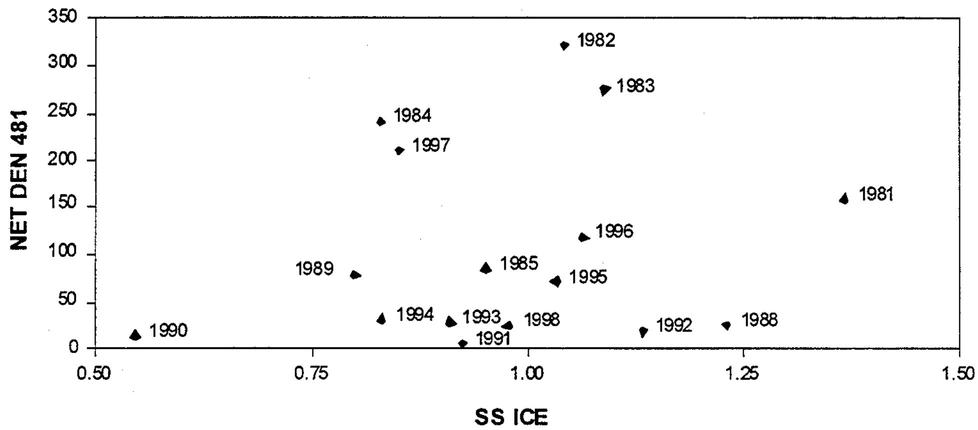


Figure 44: The relationship between krill density determined using net sampling in Subarea 48.1 and the Scotia Sea sea-ice index. Each point is labelled with the year in which data were collected.

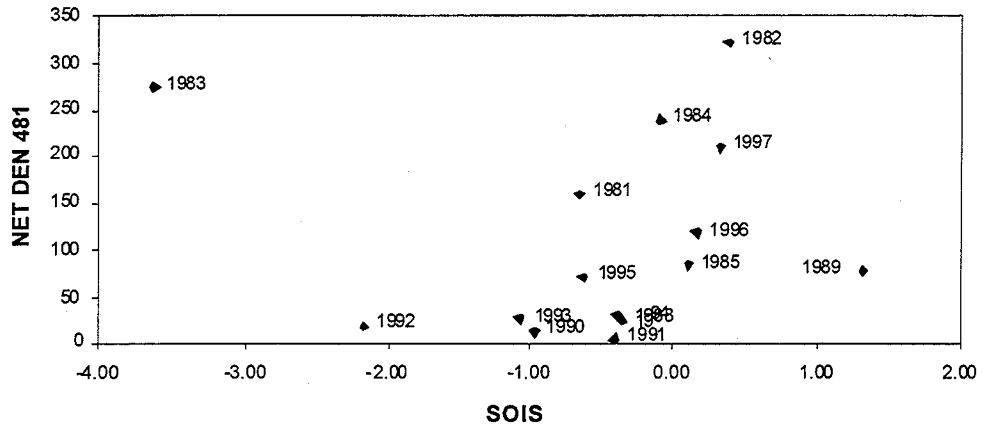


Figure 45: The relationship between krill density determined using net sampling in Subarea 48.1 and the summer SOI. Each point is labelled with the year in which data were collected.

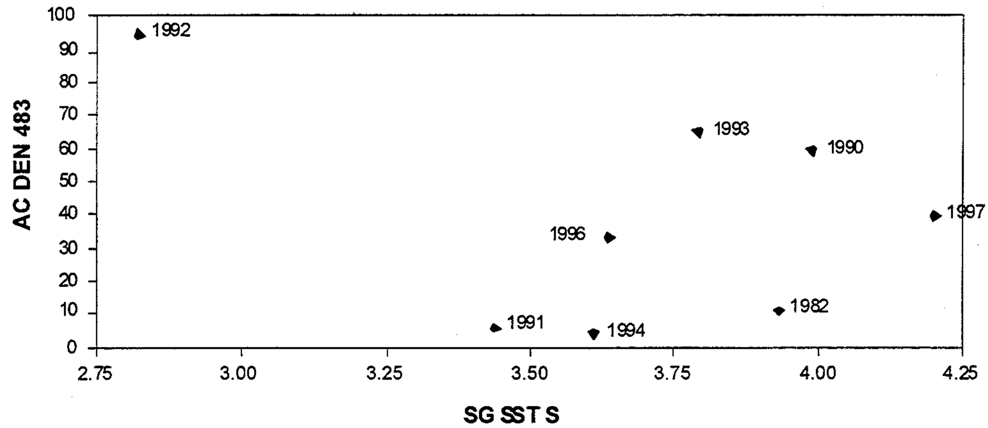


Figure 46: The relationship between krill density determined using acoustic sampling in Subarea 48.3 and the South Georgia summer SST. Each point is labelled with the year in which data were collected.

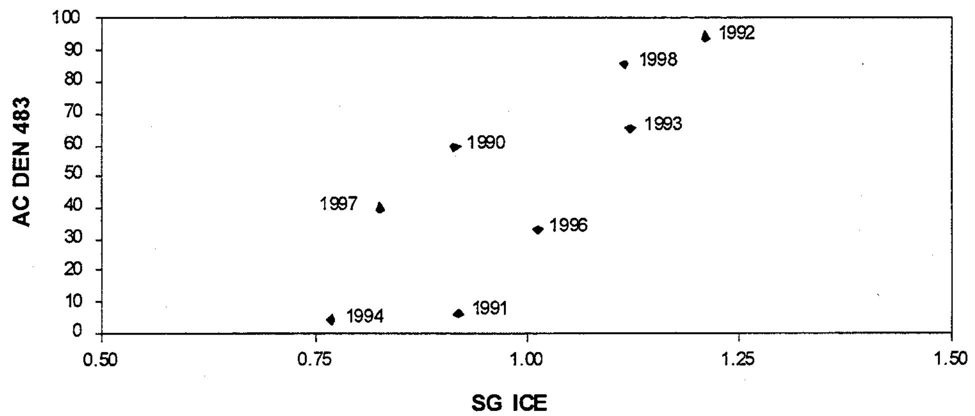


Figure 47: The relationship between krill density determined using acoustic sampling in Subarea 48.3 and the South Georgia sea-ice index. Each point is labelled with the year in which data were collected.

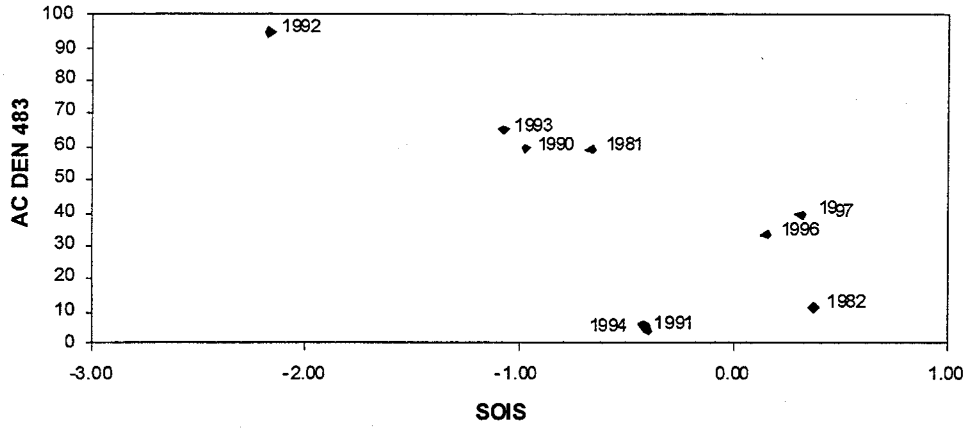


Figure 48: The relationship between krill density determined using acoustic sampling in Subarea 48.3 and the summer SOI. Each point is labelled with the year in which data were collected.

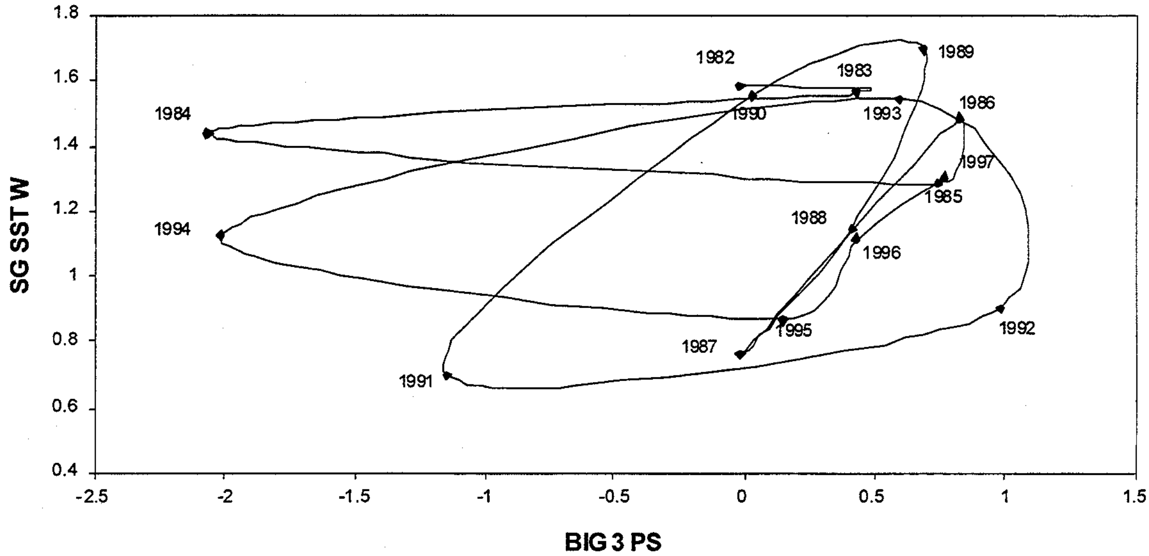


Figure 49: The relationship between the South Georgia winter SST index and the combined index of diving predators at Bird Island in summer. Each point is labelled with the year in which data were collected and they are connected in date order.

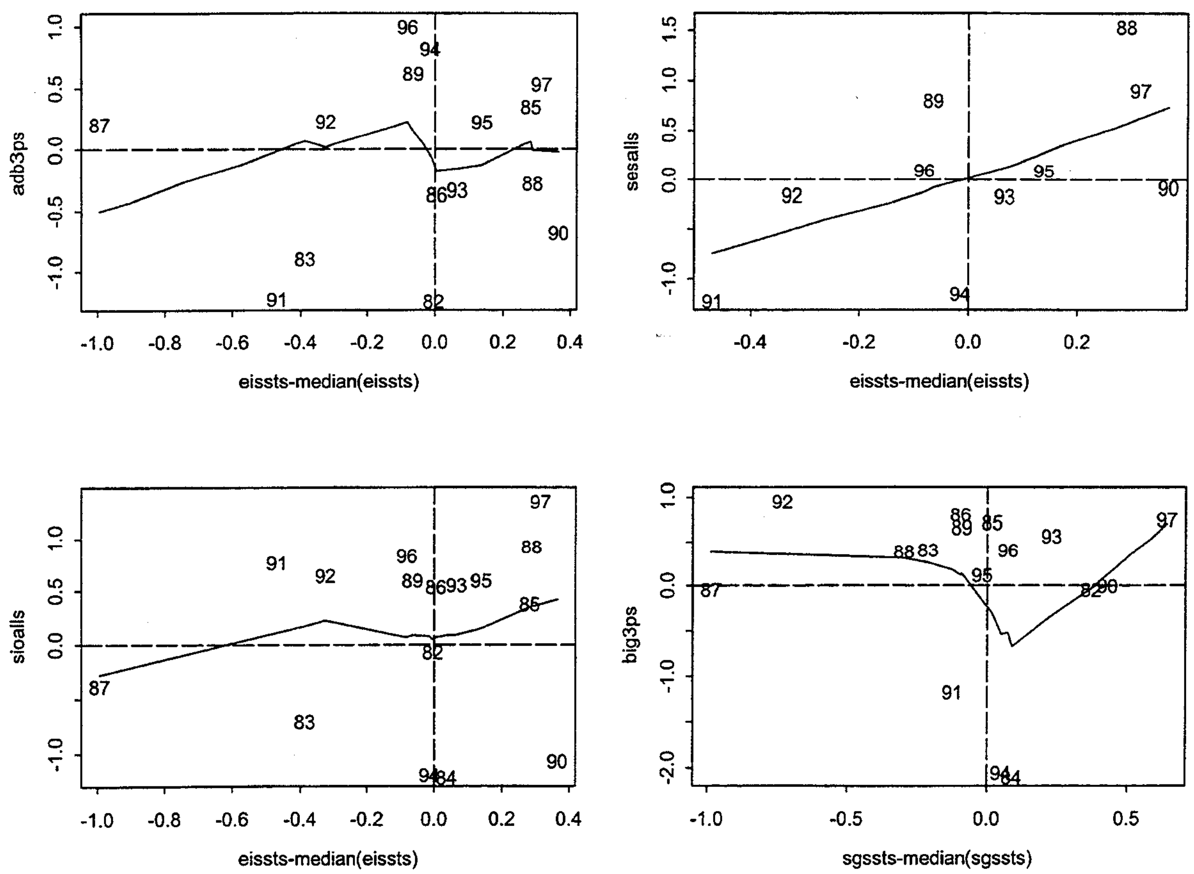


Figure 50: Predator performance indices in relation to SST within areas. Each index is expressed relative to its median value. Four quadrants are shown that indicate concordance between variables in each year. Points in the top-right and bottom-left quadrants indicate relatively high concordance whereas those falling in the other two quadrants indicate relatively low concordance. Points are denoted by the number of the calendar year.

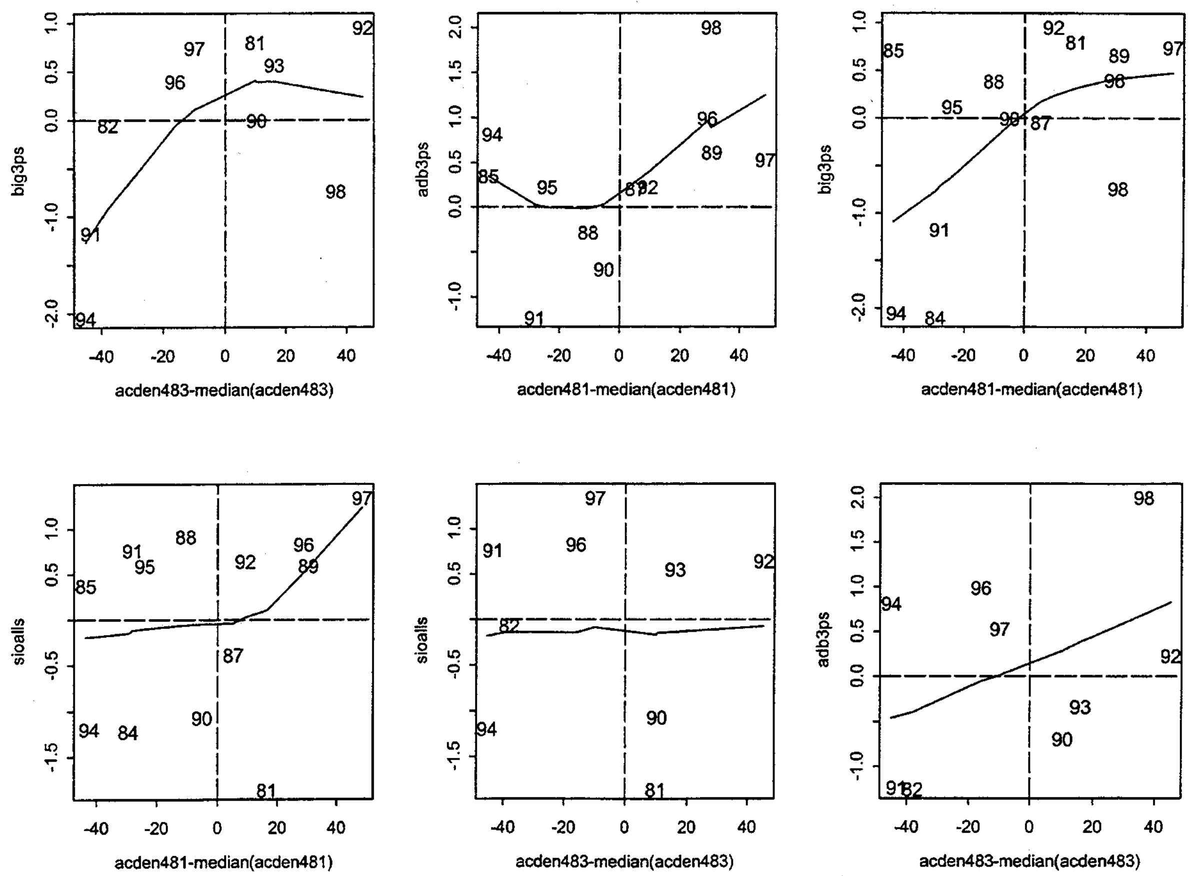


Figure 51: Predator performance indices in relation to acoustic krill density within areas. Each index is expressed relative to its median value. Four quadrants are shown that indicate concordance between variables in each year. Points in the top-right and bottom-left quadrants indicate relatively high concordance whereas those falling in the other two quadrants indicate relatively low concordance. Points are denoted by the number of the calendar year.

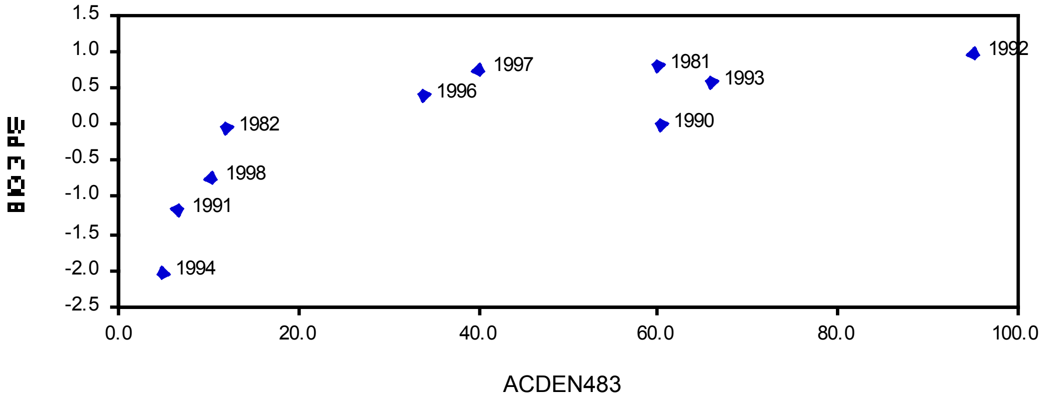


Figure 52: Composite index of the summer performance of diving predators at Bird Island in relation to the acoustic density of krill recorded in the South Georgia area (Subarea 48.3).

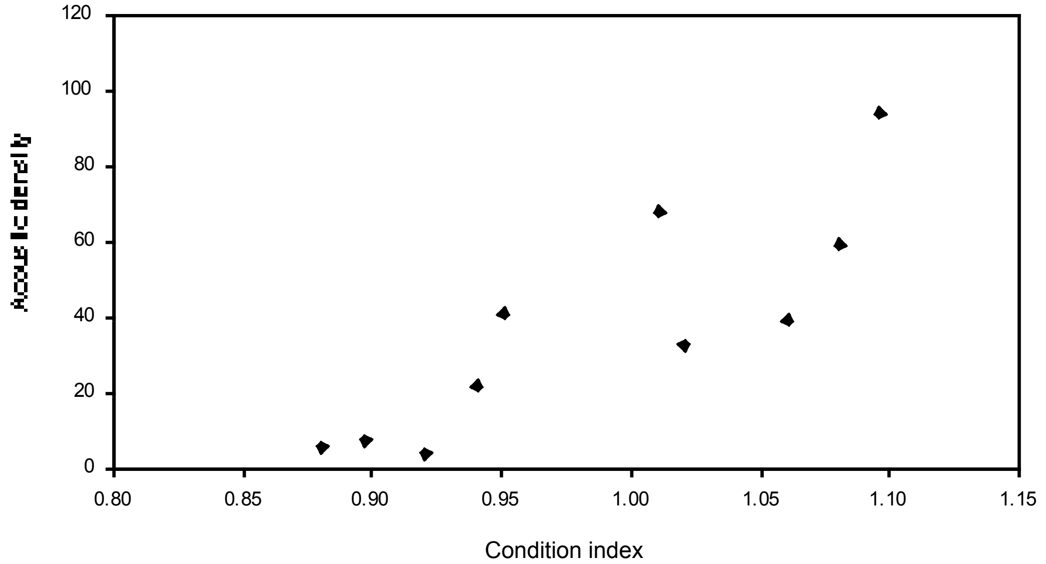


Figure 53: Icefish condition index in relation to acoustic density of krill based on combined data from Subareas 48.1 and 48.3.

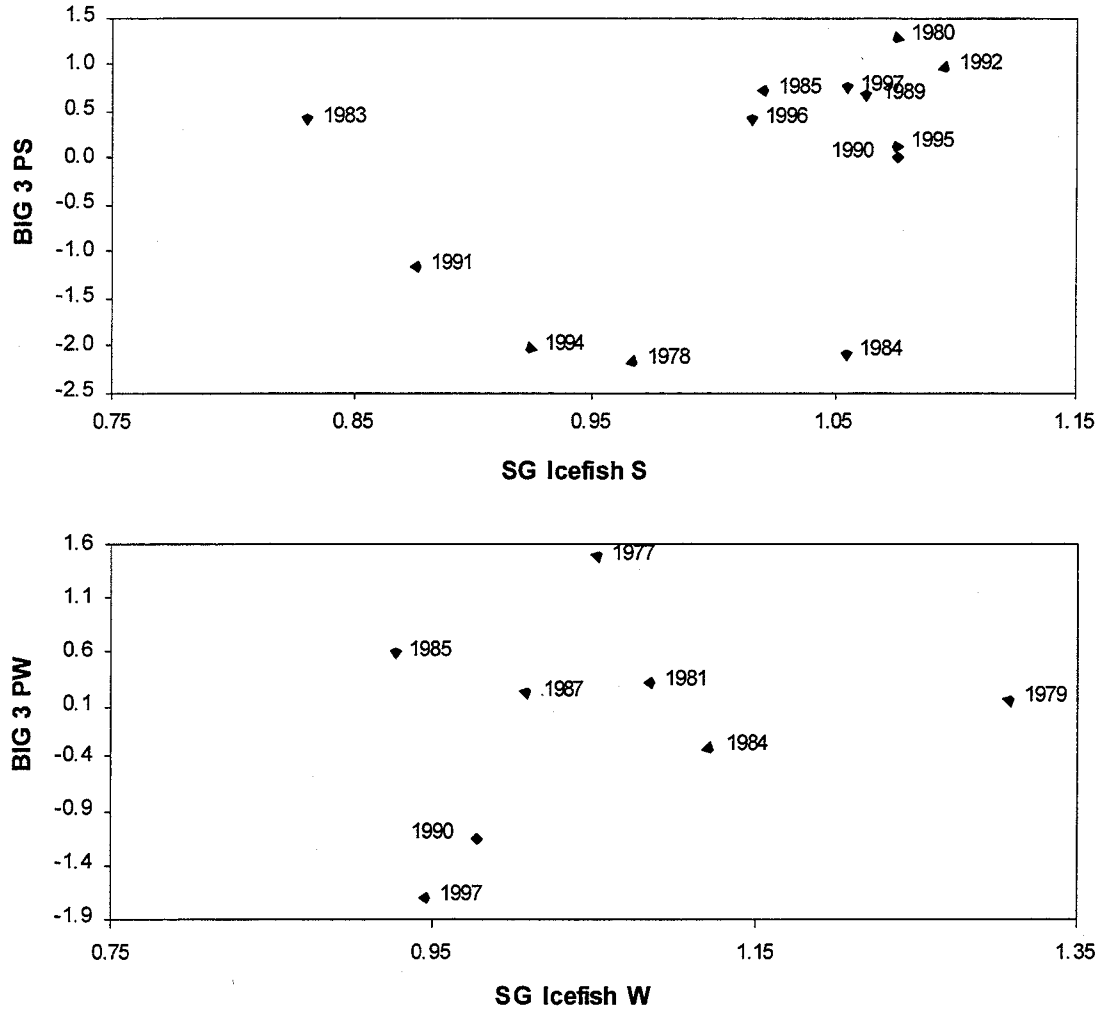


Figure 54: Relationship between the CSI for icefish at South Georgia (SG) in summer (S) and winter (W) and the CSI for gentoo and macaroni penguins and Antarctic fur seal in summer (BIG 3 PS) and winter (BIG 3 PW).

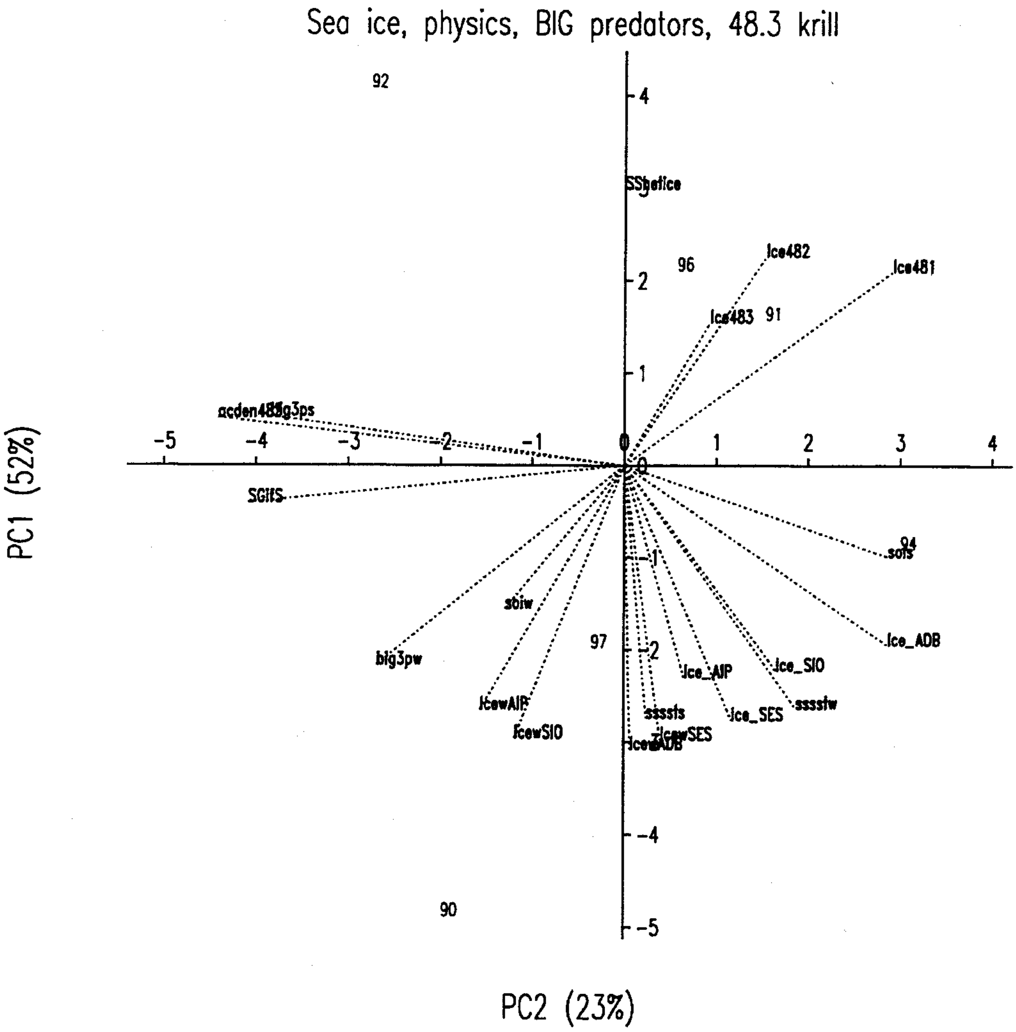


Figure 55: The first two components from a PCA of selected variables. Variables are represented by vectors and points to represent years (indicated by the year in which the season ended) from 1989/90 to 1996/97 but omitting 1992/93 and 1994/95 when no acoustic survey data are available.

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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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.

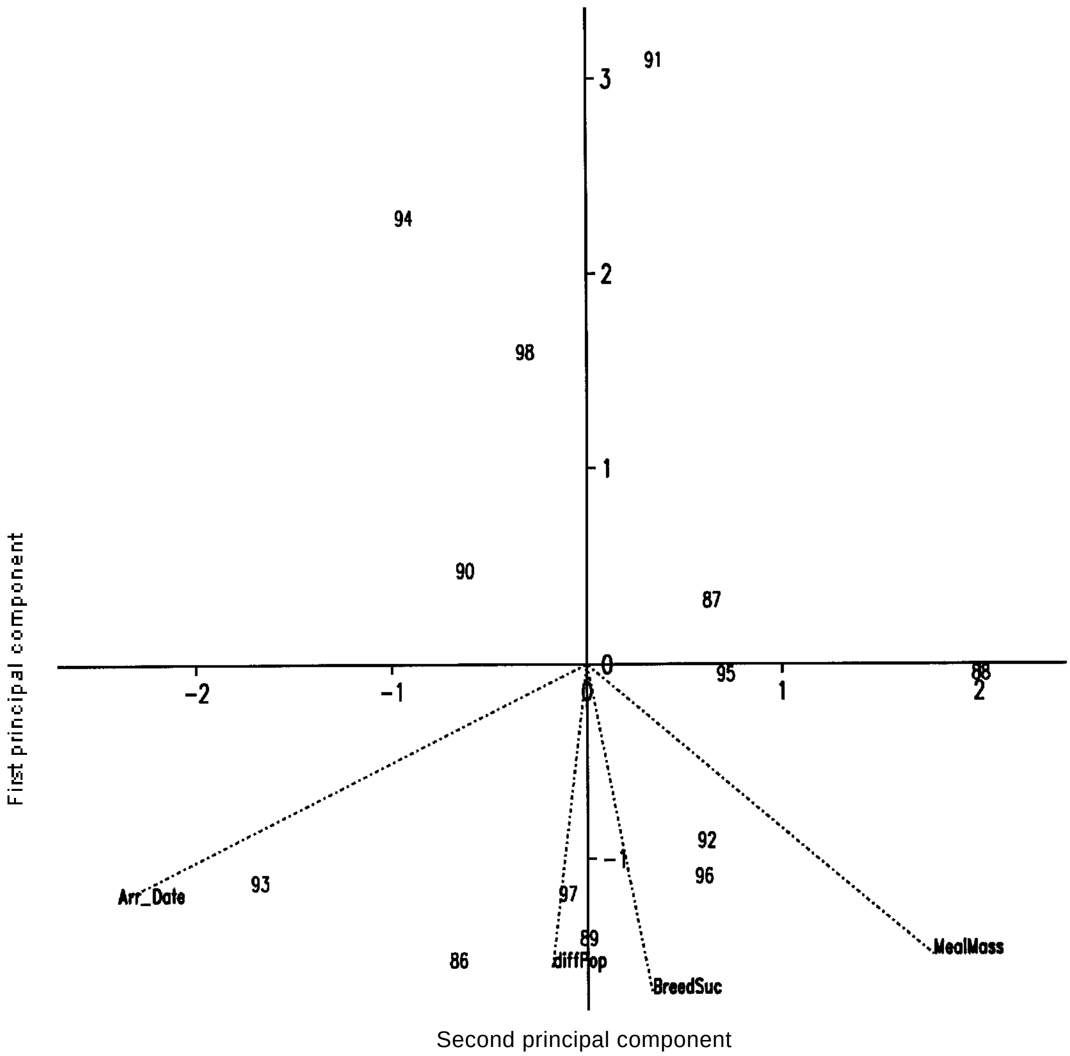

Figure E.1: PCA for Bird Island (BIG) gentoo penguin (PYP) using arrival date (days before 31 December), meal mass, breeding success, and annual change in population size. Variables are displayed as vectors and years as points labelled with the year in which the breeding season ended.

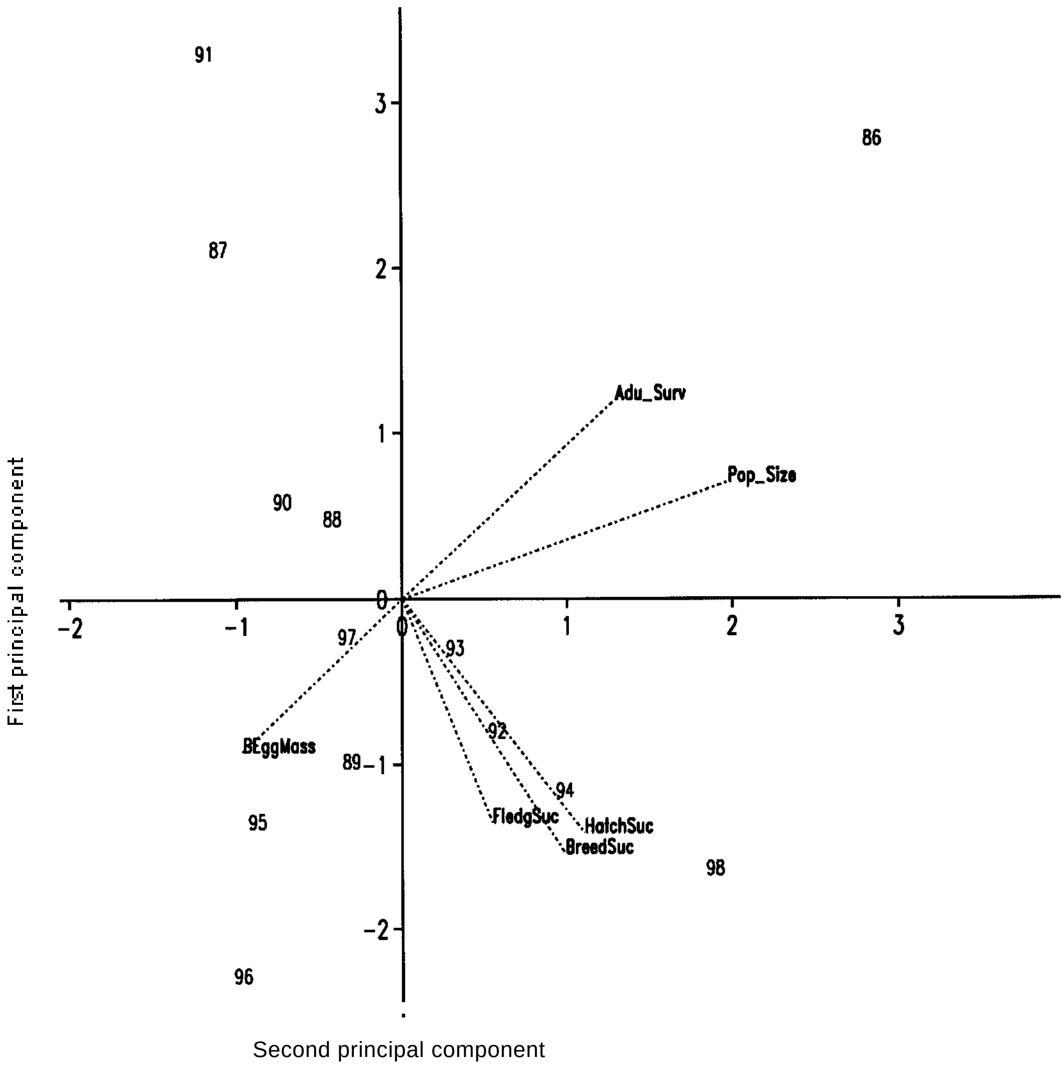

Figure E.2: PCA for Admiralty Bay (ADB) gentoo penguin (PYP) using adult survival, B egg size, hatching, fledging and breeding success, and annual change in population size. Variables are displayed as vectors and years as points labelled with the year in which the breeding season ended.

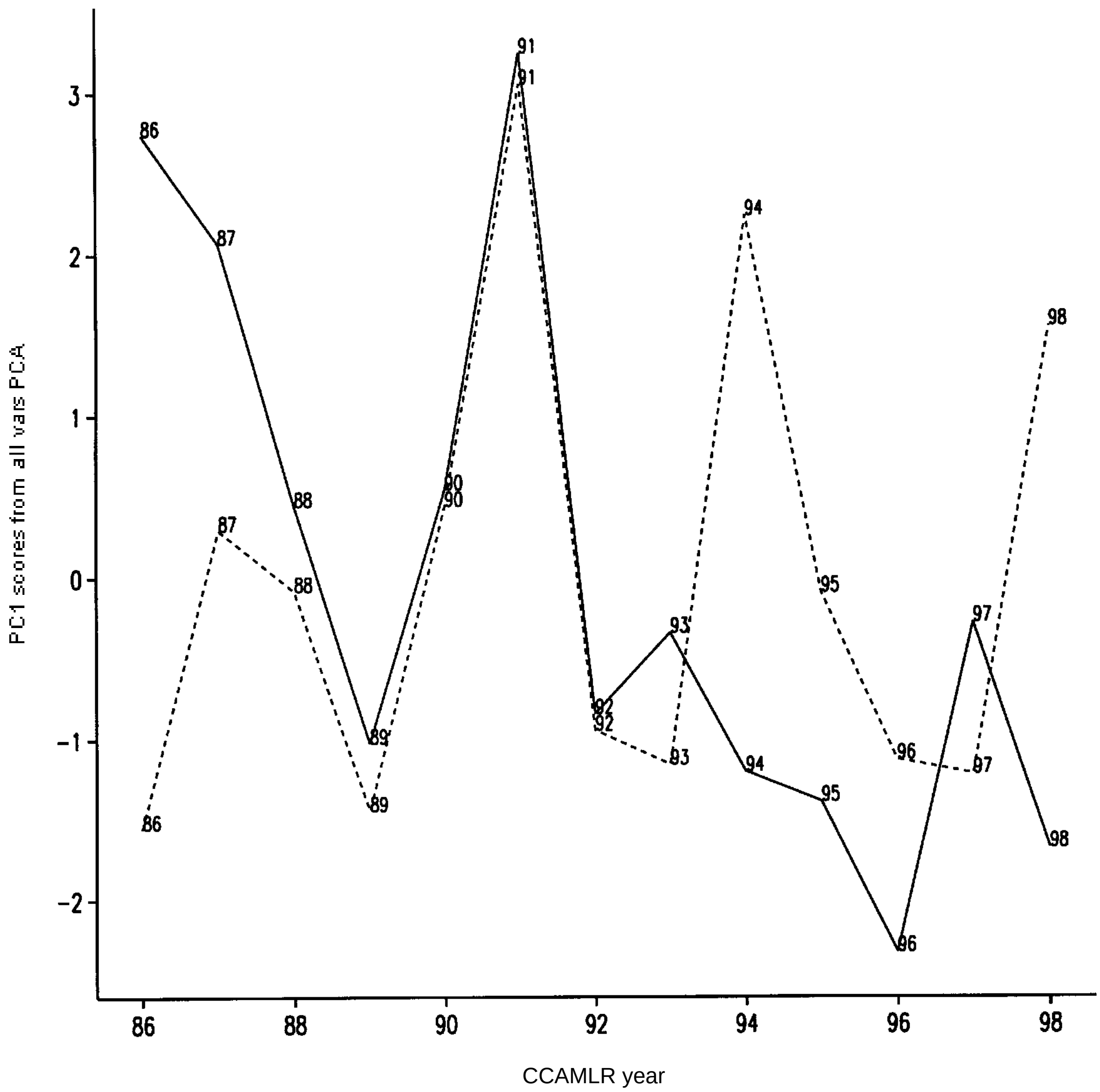

Figure E.3: Plot of the first principal component scores for the analyses shown in Figures E.1 and E.2 against time (year in which the breeding season ended). Solid line for Admiralty Bay (ADB), dotted line for Bird Island (BIG).