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CATCH PER UNIT EFFORT AND PROPORTIONAL RECRUITMENT INDICES FROM JAPANESE KRILL FISHERY DATA IN SUBAREA 48.1

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Abstract

Proportional recruitment indices and CPUE in Subarea 48.1 (Antarctic Peninsula region) from 1980 to 1996 were calculated based on logbook data from Japanese commercial krill trawlers. Proportional recruitment rates calculated from fisheries data were similar to those from scientific data (Siegel et al., 1997) and showed a close relationship to sea-ice indices. CPUE (catch/towing volume) in the Livingston Island area showed a decreasing trend during the study period. The use of different fishing strategies in response to a demand for higher product quality and a general decrease in krill density in the study area were considered as possible reasons for this. On the other hand, CPUE in the Elephant Island area showed greater interannual variation without any trend.

Résumé

Calcul des indices de recrutement proportionnel et de la CPUE dans la sous-zone 48.1 (région de la péninsule Antarctique) de 1980 à 1996 d'après les données provenant des carnets de bord des chalutiers industriels japonais de krill. Les taux de recrutement proportionnel calculés d'après les données de pêche sont semblables à ceux dérivés des données scientifiques (Siegel et al., 1997) et se rapprochent étroitement des indices des glaces de mer. La CPUE (capture/volume d'eau chalutée) dans le secteur de l'île Livingston montre une tendance à la baisse pendant la période d'étude. Il semble que cette tendance soit due d'une part, à l'utilisation de stratégies de pêche différentes engendrées par une demande de produits de meilleure qualité et d'autre part, à un fléchissement général de la densité de krill dans la région étudiée. Par contre, la CPUE dans le secteur de l'île Éléphant met en évidence une variation interannuelle plus importante sans tendance aucune.

Резюме

Индексы пропорционального пополнения и CPUE в Подрайоне 48.1 (район Антарктического полуострова) за период 1980–1996 гг. были рассчитаны с помощью данных из журналов японских крилевых траулеров. Индексы, рассчитанные на основе промысловых данных, были схожи с таковыми, вычисленных на основе научно-исследовательских данных (Siegel et al., 1997). Была отмечена тесная связь между этими показателями и индексами морского льда. В течение исследуемого периода была выявлена тенденция к снижению величины CPUE (улов/объем протраленной воды) в районе острова Ливингстон. Возможные причины этого – применение различных промысловых стратегий в ответ на требование к более высококачественной продукции и общий спад плотности криля в районе исследования. С другой стороны, в районе острова Элефант CPUE характеризовался большей межгодовой изменчивостью, при этом каких-либо закономерностей не отмечено.

Resumen

Se han calculado los índices de la proporción reclutada y del CPUE en la Subárea 48.1 (región de la Península Antártica) desde 1980 hasta 1996, tomando como base los datos de los cuadernos de pesca de los arrastreros japoneses que faenaron el kril. Las tasas de la proporción reclutada estimadas de los datos de la pesquería fueron similares a las obtenidas a partir de datos científicos (Siegel et al., 1997), y mostraron una estrecha correlación con los índices de la condición del mar y del hielo. El CPUE (captura/volumen arrastrado) en la zona de isla Livingston mostró una tendencia a la disminución durante el período de estudio. El uso de distintas estrategias de pesca emanadas de la demanda de un producto de mejor calidad y la disminución general en la densidad de kril en la zona de estudio podrían haber causado esta disminución. Por otra parte, el CPUE en la zona de isla Elefante mostró una mayor variación interanual, sin revelar tendencias.

Keywords: Antarctic krill, CPUE, Elephant Island, fishery data, krill fishery, Livingston Island, recruitment, sea-ice, CCAMLR

INTRODUCTION

The relationship between environmental factors and krill variability was one of the major issues addressed at CCAMLR's Working Group on Ecosystem Monitoring (WG-EMM) meeting held in Siena, Italy in 1995 (SC-CAMLR, 1995). During the meeting, the long-term relationship between sea-ice cover, its duration and proportional recruitment of krill in the Elephant Island area was presented by Siegel and Loeb (1995). A preliminary calculation of relative recruitment around Livingston Island based on Japanese fisheries data was also presented by Kawaguchi and Satake (1994). Results from these two datasets showed a similar trend. Both studies pointed out that success of recruitment was closely linked to the extent of sea-ice cover during the preceding austral winter. However, the values of indices were not directly comparable because different calculation methods were used. The need for estimations of proportional recruit indices based on Japanese fisheries data was discussed by WG-EMM's Subgroup on Statistics meeting held in Cambridge, UK, in 1996 (SC-CAMLR, 1996). In this paper we present recalculated proportional recruit indices and the long-term fluctuation of catch per unit effort (CPUE) using Japanese fisheries data.

MATERIAL AND METHODS

Data Source

Krill catch data (from 1980/81 to 1995/96) recorded in logbooks of Japanese krill trawlers operating north of Livingston Island and King George Island (Livingston Island area: 60.00°–63.30°S, 57.00°–62.00°W) and around Elephant Island (Elephant Island area: 60.00°–62.30°S, 54.00°–57.00°W) were used for this investigation (Figure 1). These include data on krill length (rostrum to tip of telson) of 50 individuals from one haul per day. Detailed information on the Japanese fishing operations carried out within these areas is summarised in Table 1.

Calculation of Proportional Recruit Indices

The krill stock is known to show spatial separation in developmental stages between inner-shelf (shallower than 200 m) and outer-shelf waters (deeper than 200 m) (Siegel, 1988). Hence, length-frequency distributions from the outer shelf and inner shelf (Figure 1) were calculated separately in order to show the krill density in each area. The average frequency distributions from the inner shelf and outer shelf were weighted by their respective average CPUEs. Finally, they were combined to obtain an overall frequency distribution and subjected to the MIX program (MacDonald and Pitcher, 1979). Proportional recruits (R_2) were calculated based on numbers of age 2+ krill identified by MIX analysis. R_2 is the ratio of numbers of age 2+ krill to numbers of age 2+ and older krill combined. That is:

$$R_2 = \frac{A_2}{\sum_{i=2}^{n} Ai}$$

where A_i is the number of animals in age class i, and n is the age of the oldest age class in the stock (de la Mare, 1994). Length of age 2+ groups were identified according to the length-age relation in Siegel (1987).

Calculation of CPUE

The Antarctic Peninsula region and adjacent areas are characterised by a clear seasonal fluctuation in krill abundance (Siegel at al., 1997). Therefore, for CPUE calculation, data obtained only in the summer period (December to March), during the time of maximum abundance were used. Net-haul data with small sample sizes (i.e. less than 20 hauls per vessel per season) were not included. CPUE was defined as catch per volume of trawled water (g/m^3).

Table 1: Main operating characteristics of Japanese krill vessels fishing in the Livingston Island and Elephant Island areas.

Livingston Island Area:

Fishing Season	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88
Number of ships	1	1	1	7	5	7	7	7
Ship size	3264	3264	3264	2749–3608	2538–3608	2538–3608	2538–3910	2538–3910
Net mouth area (m^2)	615	615	615	360–550	236–907	244–1225	*	290–900
Codend mesh size (mm)	13	13	13, 15		13, 15	13, 15	*	13, 15
Number of tows	441	334	22	304	480	1316	962	4063
Total effort ($x10^9 m^3$)	0.91	0.30	0.01	0.30	0.76	1.66	2.38	9.12

Fishing Season	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96
Number of ships	7	5	5	5	3	3	4	4
Ship size	2538–3910	2538–3608	2903–3910	3058–4991	3058–4991	2903–4991	2903–4991	3058–4991
Net mouth area (m^2)	290–707	290–707	542–707	500–707	542–707	560	560–707	560–707
Codend mesh size (mm)	13, 15, 20	13, 15, 18, 20	15	15	15	15	15	15
Number of tows	4342	1815	2541	4933	2129	2192	1498	3471
Total effort ($x10^9 m^3$)	9.45	4.20	6.84	11.41	6.64	6.36	6.25	12.2

Elephant Island Area:

Fishing Season	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88
Number of ships	1	1	1	7	5	6	6	7
Ship size	3264	3264	3264	2524–3608	2538–3608	2538–3608	2538–3608	2538–3910
Net mouth area (m^2)	615	615	615	242–707	236–907	244–1225	*	290–900
Codend mesh size (mm)	13	13	13, 15		13, 15	13, 15	*	13, 15
Number of tows	100	97	10	563	757	1754	4334	2012
Total effort ($x10^9 m^3$)	0.11	0.20	0.006	0.39	1.04	2.73	9.66	3.36

Fishing Season	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96
Number of ships	6	4	5	3	2	5	2	2
Ship size	2538–3910	2538–3608	2903–3910	2903–3910	2903–3910	2903–4991	3910–4991	3910–4991
Net mouth area (m^2)	290–707	290–707	542–707	542–707	542–560	560–707	560	560
Codend mesh size (mm)	15, 20	13, 15, 18, 20	15	15	15	15	15	15
Number of tows	1293	1830	2069	50	178	1183	473	128
Total effort ($x10^9 m^3$)	4.71	4.72	4.15	0.08	0.27	2.35	1.22	0.48

RESULTS

Krill Size Composition

Size-frequency distribution and the results of polymodal analysis using the MIX program are shown in Figure 2. Thirty-one of 32 datasets were able to fit a mixture of normal distributions. Most of the datasets contained two to four components. The only data which were not able to be fitted successfully were from the Elephant Island area in the 1982/83 season. The main reason for the failure might be the small sample size involved (n = 200). Shaded components in Figure 2 show the age 2+ components. Three parameters for age 2+ components (proportion, mean size and standard deviation) are summarised in Table 2. These components appeared almost every season in both the Livingston Island and Elephant Island areas from 1980/81 to 1988/89. From 1989/90 to 1991/92, almost no age 2+ components were identified. In 1992/93 and 1993/94, age 2+ components appeared in high proportion, especially in the Livingston Island area. However, in 1994/95 age 2+ components were not identified.

Proportional Recruitment

In Table 3, calculation R_2 (proportional recruitment based on 2+ krill) values are summarised with values from scientific surveys in the Elephant Island area (Siegel et al., 1997). R_2 values calculated in this study (Figure 3A), and R_1 (proportional recruitment based on age 1+ krill) and R_2 values from scientific surveys in the Elephant Island area (Figure 3B; Siegel et al., 1997) were compared. Interannual fluctuation from each data source (our calculation (A) and results from Siegel et al., 1997 (B)) showed similar general trends. They showed peaks around the 1980/81, 1981/82 and 1985/86 year classes, and low values in between these year classes. However, apparent discrepancies were observed between our study and that of Siegel et al. (1997) for two year classes: the 1991/92 year class, which showed apparently higher values than those obtained by Siegel, and the 1987/88 year class, for which proportional recruitment was only calculated from scientific survey data (Figure 3A and B).

CPUE Frequency Distribution

CPUE frequency distribution in each season was examined. The distribution pattern using Log_{10}-transformed values mostly showed normal distributions (Figure 4). Therefore, Log_{10}-transformed CPUEs were used for the analysis.

CPUE Variability

Seasonal average of Log_{10}CPUE in both Livingston Island and Elephant Island areas are shown in Figure 5. The range of Log_{10}CPUE variation was found to be greater in the Elephant Island area than in the Livingston Island area. Kendall's Tau correlation analysis was carried out by testing Log_{10}CPUE versus year in both areas. The results of the test showed a significant negative trend of Log_{10}CPUE with increasing years in the Livingston Island area (T = -0.695, n = 15, p = 0.0003), but no significant trend in the Elephant Island area (T = -0.200, n = 11, p = 0.39).

DISCUSSION

It is noteworthy that the trends in interannual fluctuation pattern of R_2 values calculated from fisheries data were similar to those of results from the scientific surveys presented by Siegel et al. (1997). This suggests the usefulness of fisheries data for monitoring R_2. We believe that in fisheries datasets, the lack of survey design is compensated by the large number of hauls.

As described in the results, discrepancies in proportional recruitment from two year classes were observed between our study and Siegel et al. (1997). In the case of the 1991/92 year class, our calculation resulted in higher proportional recruitment (Figure 3A). This may imply a greater proportion of small krill in areas where fisheries activities took place (Livingston Island area) which was not covered by scientific surveys. In the case of the 1987/88 year class, this situation might have been reversed, and small krill might not have been present in areas where fisheries operations took place. A distinct difference between the size composition in the Livingston Island and the Elephant Island areas was observed in 1990/91 and 1991/92, resulting in lower recruit values in the latter area. In waters along the north of the Antarctic Peninsula, spatial separation in the developmental stages was dependent on bottom topography (Siegel, 1988). On the other hand, Elephant Island is close to the Weddell-Scotia Confluence (WSC) which may act as a biological boundary, and krill abundance and composition of developmental stage differ between north and south of the WSC (Nast et al., 1988). Since the

Table 2: Proportion, mean length and standard deviations (SD) of age 2+ krill estimated from MIX analysis.

Observation Season	Livingston Island Area			Elephant Island Area		
	Proportion	Mean	SD	Proportion	Mean	SD
1980/81	0.336	37.3	6.3	0.437	39.8	5.1
1981/82	0.000			0.076	37.1	2.3
1982/83	0.462	42.5	5.8	+		
1983/84	0.585	42.6	5.7	0.427	42.7	6.1
1984/85	0.156	36.7	2.8	0.142	41.3	2.7
1985/86	0.147	42.2	5.7	0.072	39.7	4.4
1986/87	0.191	40.8	6.0	0.165	36.5	4.9
1987/88	0.290	41.3	2.6	0.334	39.6	4.5
1988/89	0.142	39.5	1.2	0.290	39.8	2.1
1989/90	0.000			0.000		
1990/91	0.000			0.000		
1991/92	+			0.083	36.3	6.0
1992/93	0.574	40.5	3.9	0.129	39.8	3.5
1993/94	0.719	39.7	3.7	0.168	40.9	2.0
1994/95	0.000			0.000		
1995/96	0.051	38.3	2.0	0.000		

\+ Identification of age 2+ component was not successful by MIX analysis, but presence of age 2+ was suggested from the histogram in Figure 2.

Table 3: R_2 (proportional recruitment) estimated in this study. R_1 and R_2 from Siegel et al. (1997) are also shown.

Year Class	This Study		Siegel et al. (1997)	
	Livingston Island Area	Elephant Island Area	Elephant Island Area R_1	R_2
1975/76				0.144
1976/77			0.048	
1977/78				
1978/79	0.336	0.451		0.069
1979/80	0.000	0.086		
1980/81	0.462	+	0.757	
1981/82	0.585	0.427	0.470	0.663
1982/83	0.156	0.142	0.030	0.119
1983/84	0.147	0.072	0.028	0.214
1984/85	0.191	0.165	0.175	
1985/86	0.316	0.334		0.633
1986/87	0.194	0.360	0.156	0.219
1987/88	0.000	0.000	0.651	0.275
1988/89	0.000	0.000	0.057	0.063
1989/90	+	0.083	0.099	0.345
1990/91	0.574	0.129	0.375	0.587
1991/92	0.719	0.169	0.000	0.012
1992/93	0.000	0.000	0.068	0.029
1993/94	0.058	0.000	0.046	0.125

\+ Identification of age 2+ component was not successful by MIX analysis, but presence of age 2+ was suggested from the histogram in Figure 2.

WSC shows substantial inter- and intra-annual variations in its position (Sahrhage, 1988), its variation will influence the size composition of krill around Elephant Island. Therefore survey results only from the Elephant Island area alone may not represent the size composition of krill in the whole Antarctic Peninsula region.

Apart from local differences in size composition, another question arises: Which is the better index for the proportional recruitment in the Antarctic Peninsula region, R_1 and R_2? This question arises because of some differences between R_1 and R_2 values. Nine cases in 11 pairs showed lower R_1 and R_2 in Siegel et al. (1997) (Table 3). Since juvenile-stage krill (especially age 1+) are confined to coastal shelf waters and in some years they are mainly distributed close to the Peninsula (Siegel, 1988), age 1+ krill might be insufficiently covered by scientific surveys. On the other hand, age 2+ krill are more widely distributed than age 1+ during the spawning season, but it is sometimes difficult to separate them from other year classes in the histogram. That is to say, both indices have their advantages and disadvantages.

Siegel and Loeb (1995) have demonstrated a close relationship between sea-ice and krill recruitment by using proportional recruitment estimated from a scientific survey around Elephant Island. The main thrust of their hypothesis is that heavy sea-ice coverage increases the survival rate of young krill, and as a result, proportional recruitment of young krill in the next summer season becomes high. In order to examine if the proportional recruitment estimated in this study has any relationship with sea-ice extent, the significance of the regression of sea-ice indices (Hewitt, 1997) against proportional recruitment was tested (Figure 6). Proportional recruitment in the Elephant Island area showed a strong positive correlation with sea-ice (r = 0.562, p = 0.028, n = 15). Although in the case of the Livingston Island area, the correlation was not as strong (r = 0.259, p = 0.358, n = 15), the results from these two areas supported the sea-ice/krill hypothesis in general.

Siegel et al. (1997) implied higher krill density during the late 1970s to early 1980s and lower variability during the late 1980s to early 1990s around Elephant Island, suggesting a statistically-significant fluctuation in krill density over the period from 1977 to 1994. Since krill trawlers search for krill aggregations before deploying their nets, CPUE (g/m^3) expresses krill density at the trawl location, and is not directly comparable with krill abundance over the study area. However, there was a great deal of interest in whether any trends would be observed in CPUE over time.

A decreasing trend in CPUE was observed in the Livingston Island area. Two reasons for this decreasing trend are suggested. One of the possible reasons is the use of different fishing strategies. During the early 1980s, the demands of the Japanese market in terms of quality were rather low, and so the vessels tended to operate in areas with high krill densities. However, the market demand then became more exacting regarding the krill quality, especially in respect of krill colouration. Krill with a greenish hepatopancreas (because of active feeding of krill on phytoplankton) fell in value (Endo and Ichii, 1989). Therefore, vessels tended to avoid areas in which 'green' krill concentrated, and did not always fish areas of high krill density, even though these might seem to be good fishing grounds. Another possible reason is a general decrease in krill density in the study area. At this point however, we cannot say which possibility is the principal reason. On the other hand, CPUE rates did not show any clear trend in the Elephant Island area (Figure 5). In this area, abundance and distribution of krill are known to show great variability because of the variable position of the WSC (Nast et al., 1988). Therefore, even if some trends in krill density around Elephant Island do exist, CPUE values may have been masked by the high variability of krill abundance.

CONCLUSION

(i) Interannual variation of proportional recruitment indices calculated from fisheries data agreed with the trend observed by Siegel et al. (1997) in general.

(ii) Proportional recruit and sea-ice indices were closely correlated, and supported the sea-ice/krill recruitment hypothesis in general.

(iii) CPUE values showed interannual variations. In the Livingston Island area, a decreasing trend over time was observed. The use of varying fishing strategies by krill trawlers during the study period and a general decrease in krill abundance were suggested as possible reasons. However, no clear trend was observed in the Elephant Island area.

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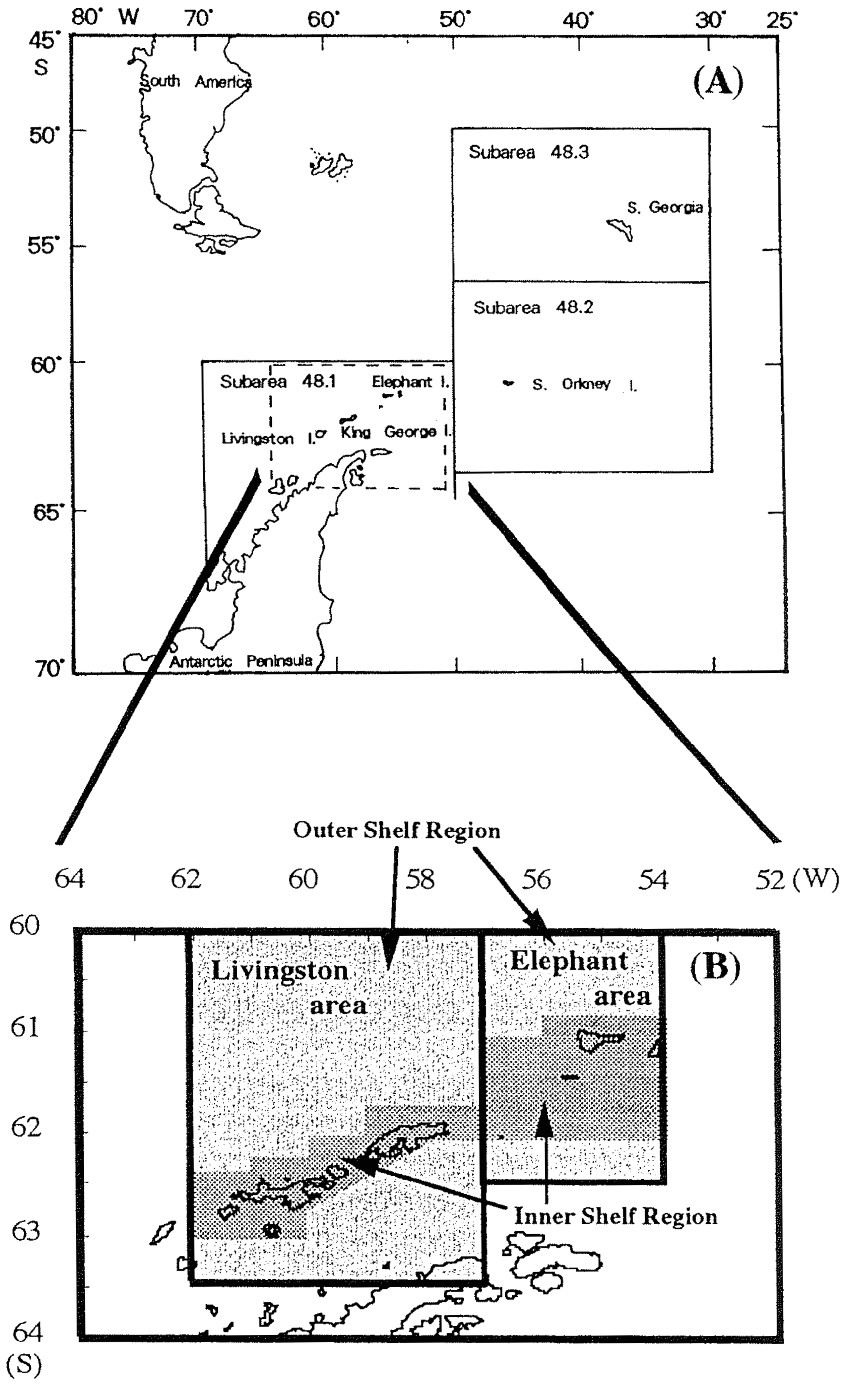


Figure 1: Map of the study area: (A) map of statistical subarea; (B) two areas (Livingston and Elephant Islands) defined for analysis. These areas were further separated into the inner-shelf region (dark hatch) and outer-shelf region (light hatch) for length-frequency analysis.

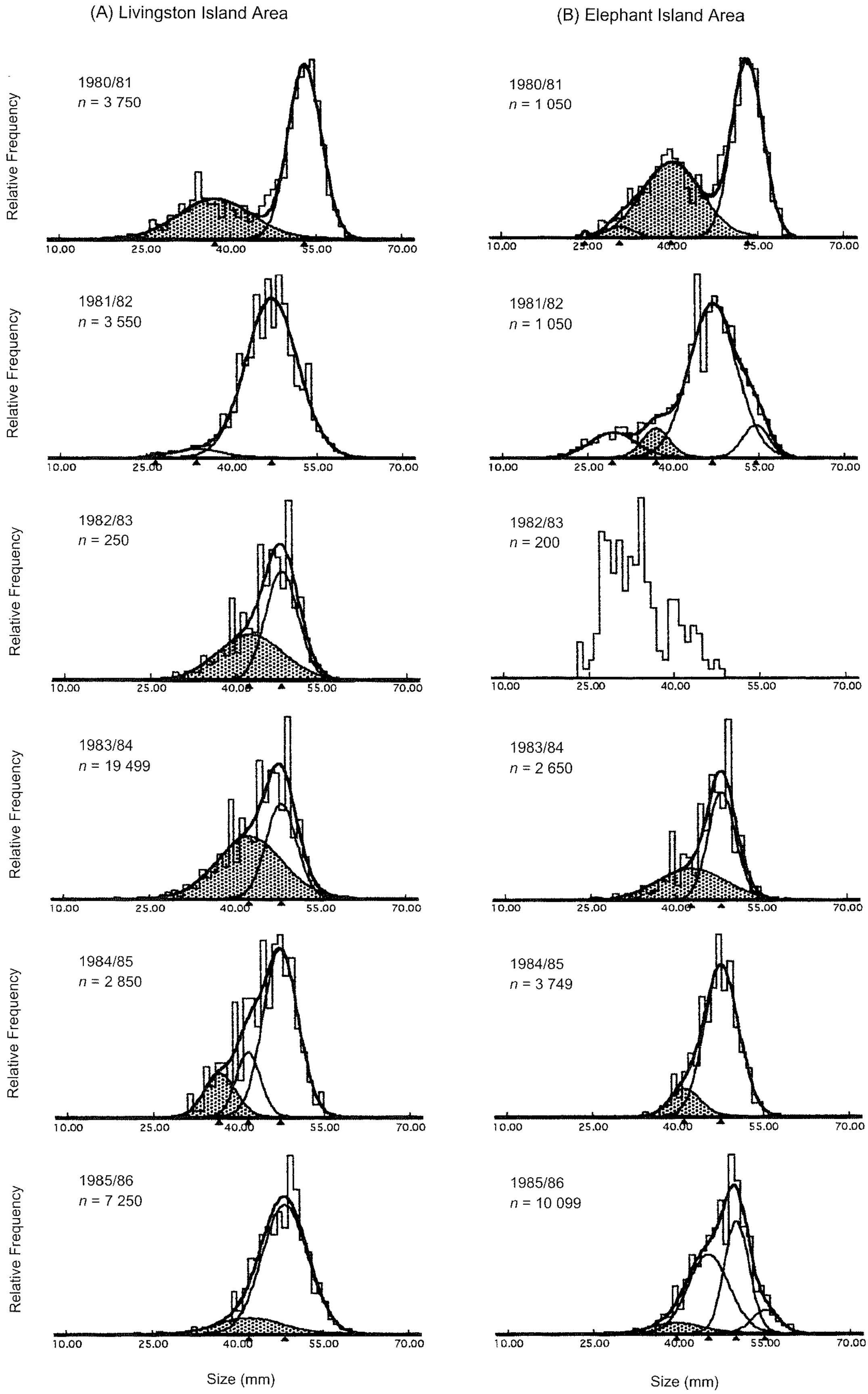
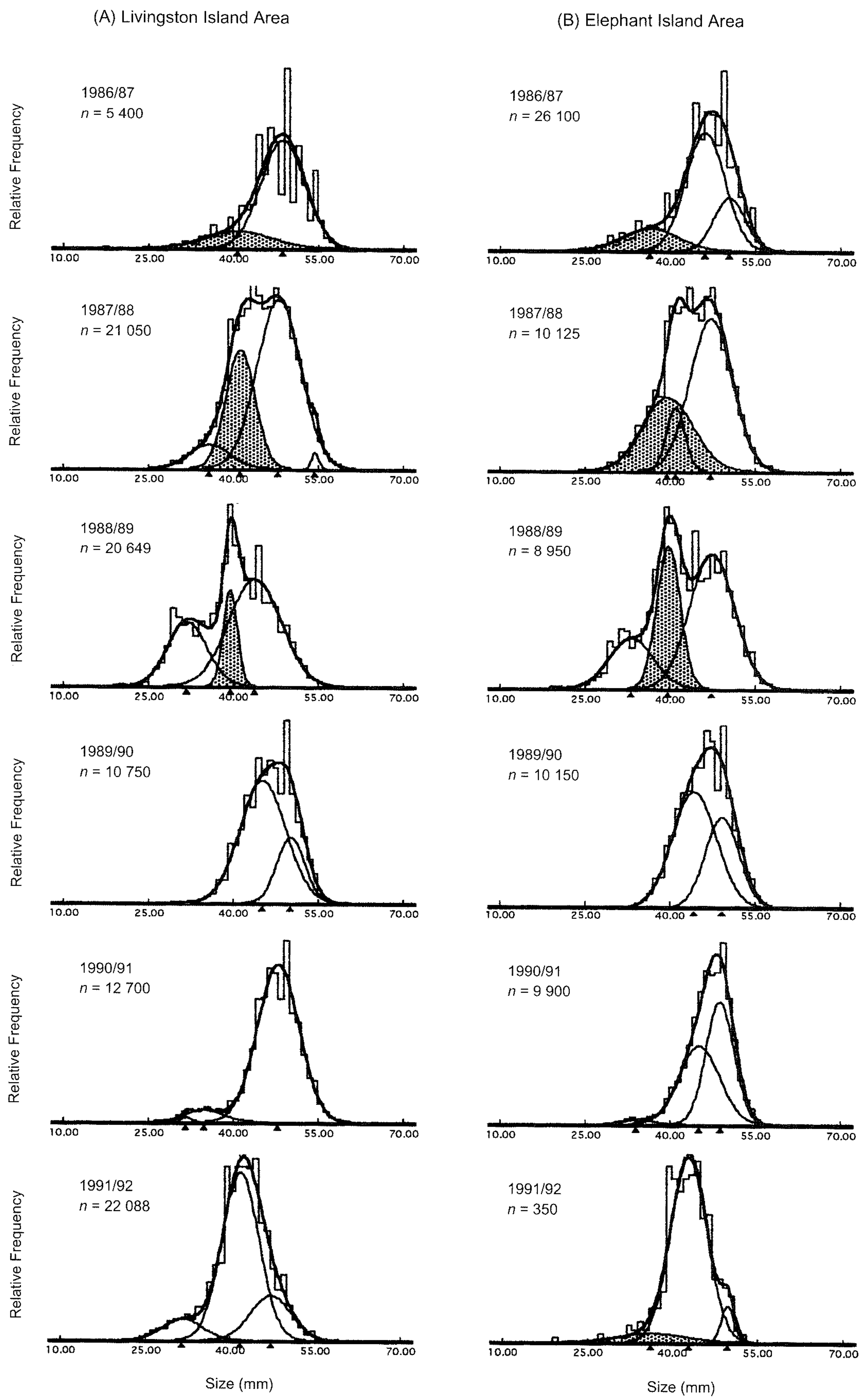


Figure 2: Size-frequency distribution of krill caught in the Livingston Island area (A) and the Elephant Island area (B) during the fishing seasons from 1980/81 to 1995/96.



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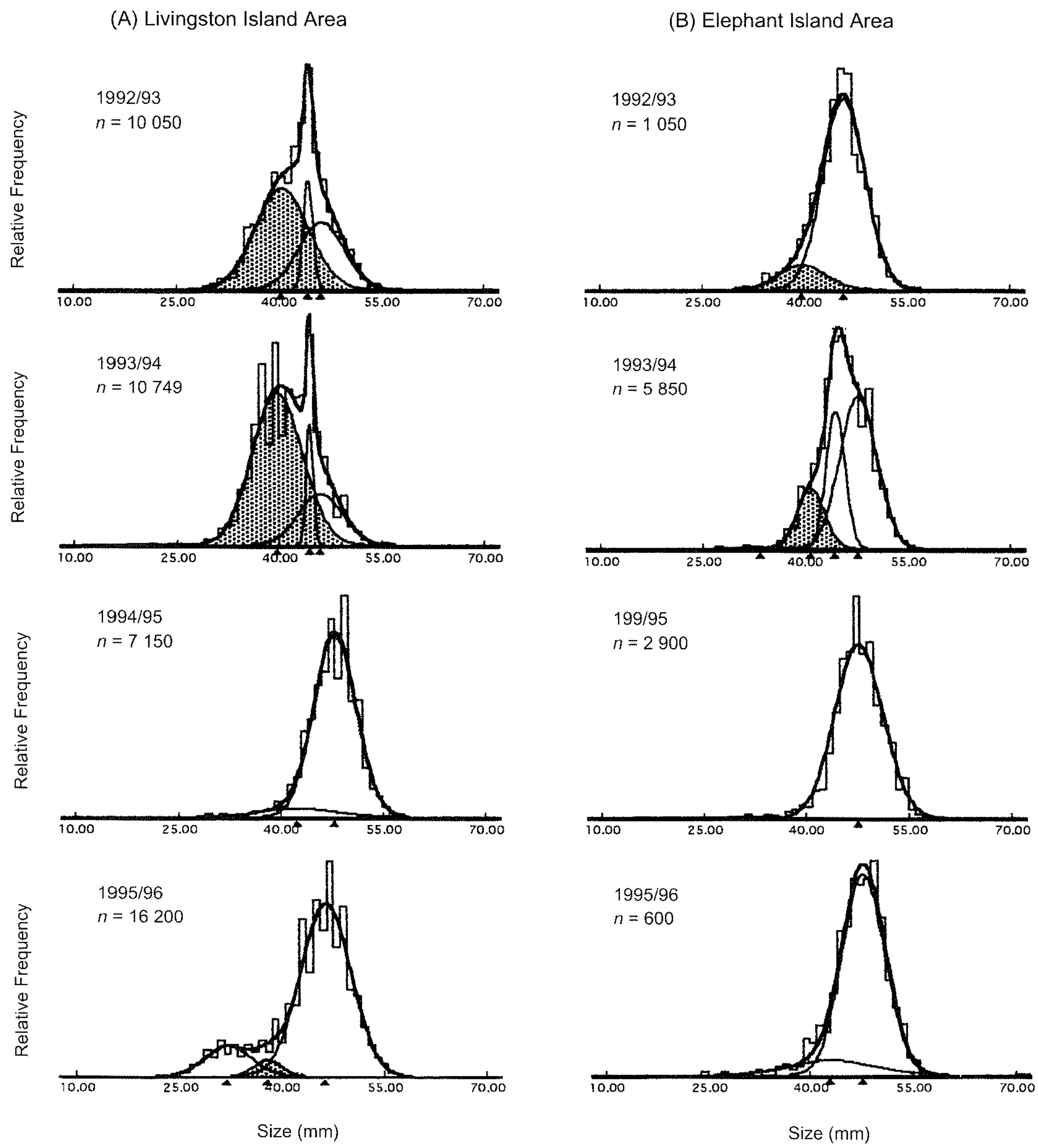

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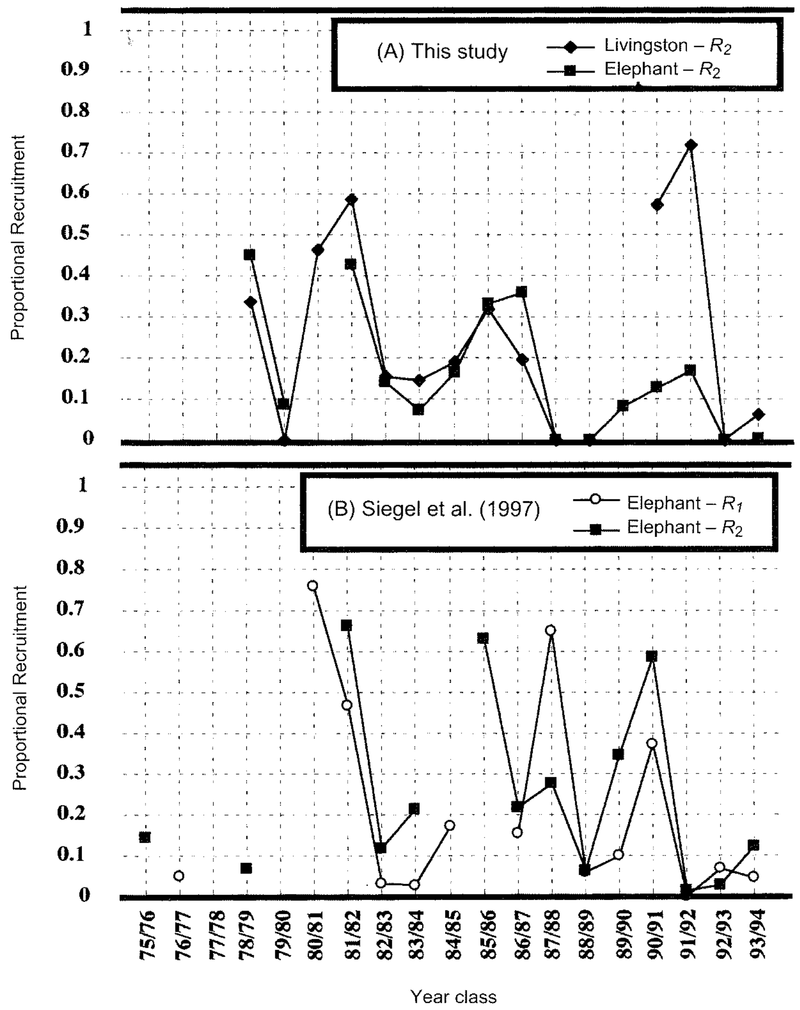


Figure 3: Proportional recruitment of each year class: (A) calculated from R_2 values derived from fisheries data from the Livingston Island and Elephant Island areas; (B) R_1 and R_2 values around Elephant Island (Siegel et al., 1997).

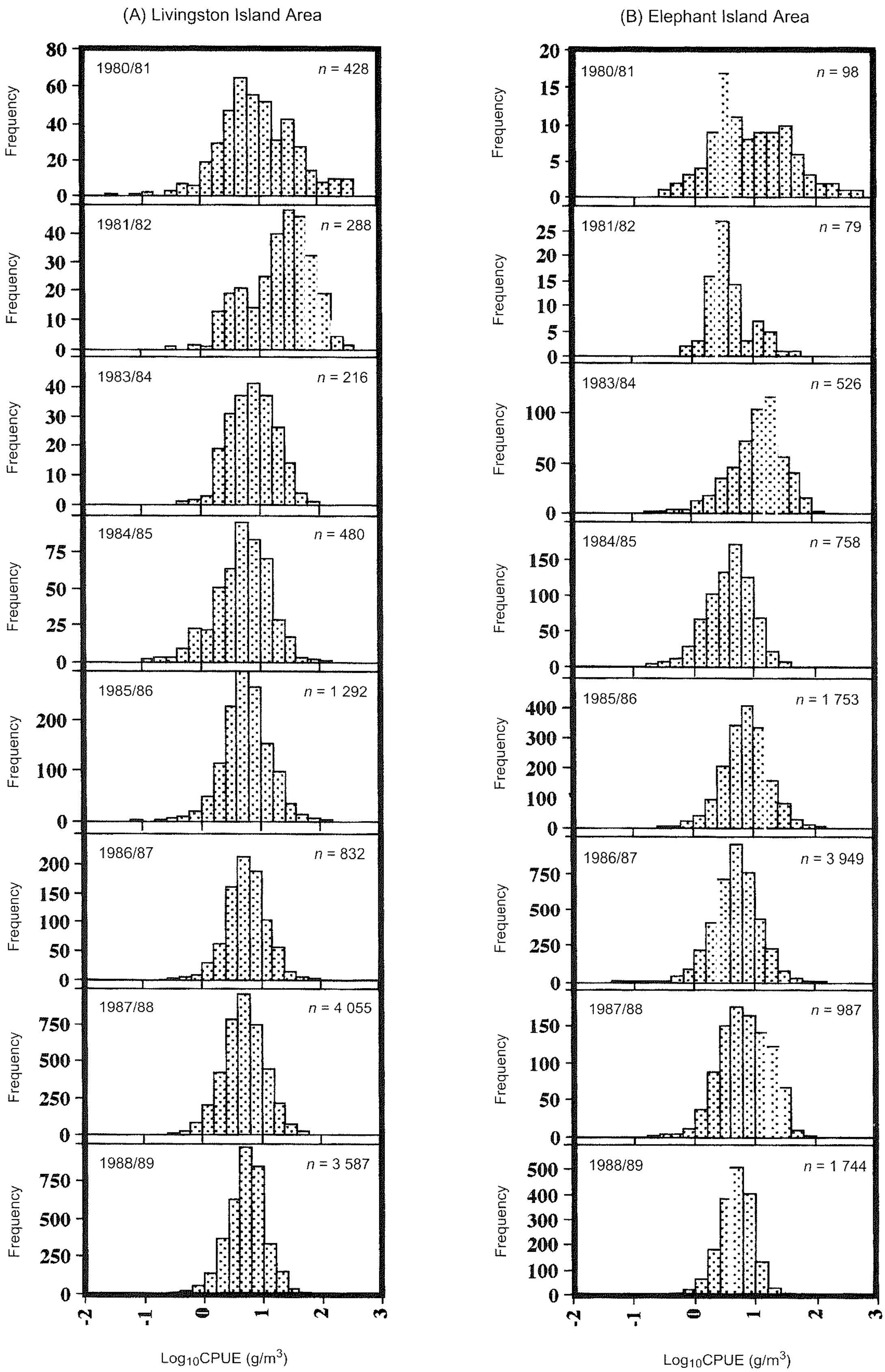
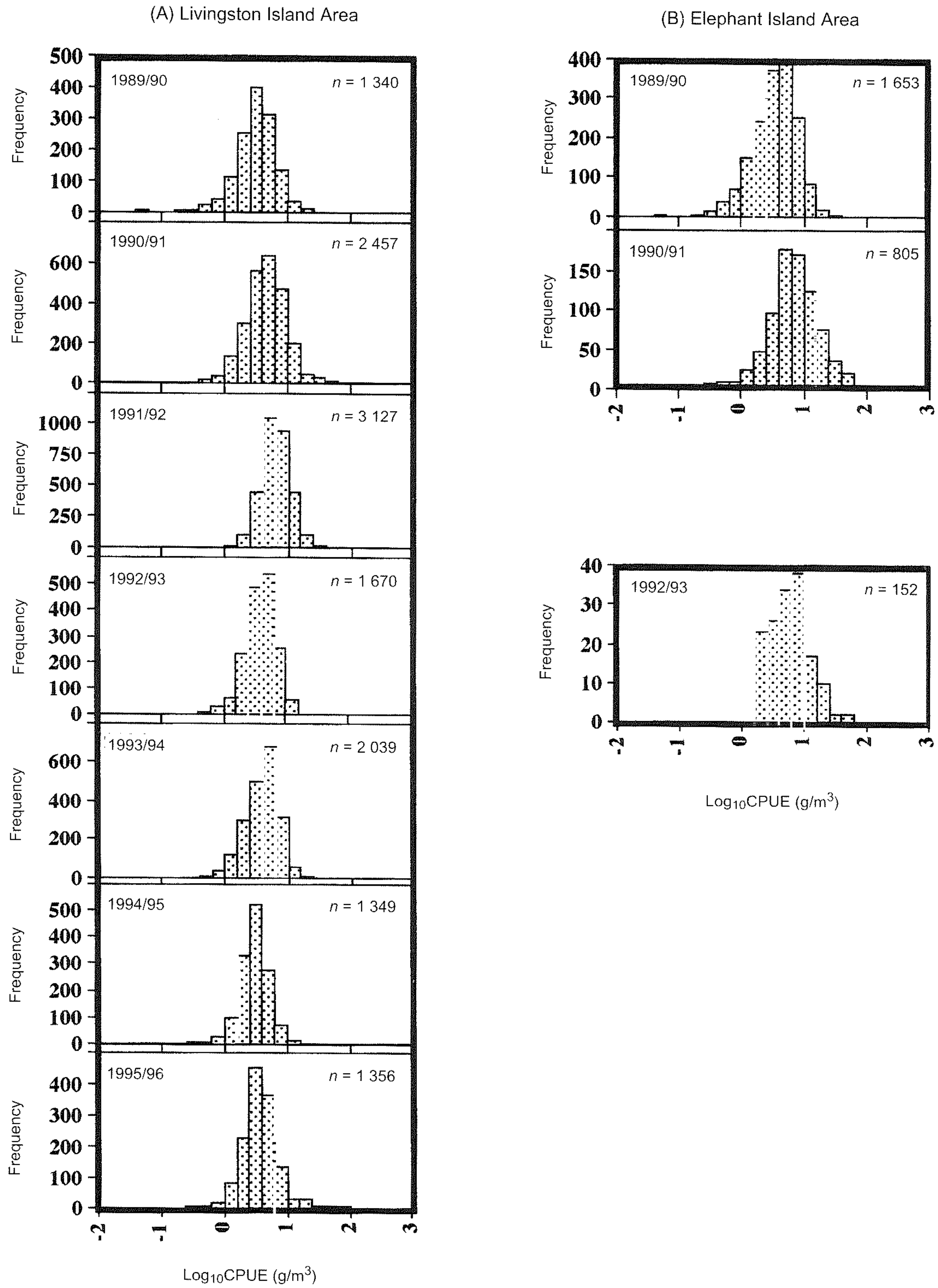


Figure 4: Histogram of $Log_{10}CPUE$ for all fishing seasons: (A) Livingston Island area; (B) Elephant Island area.



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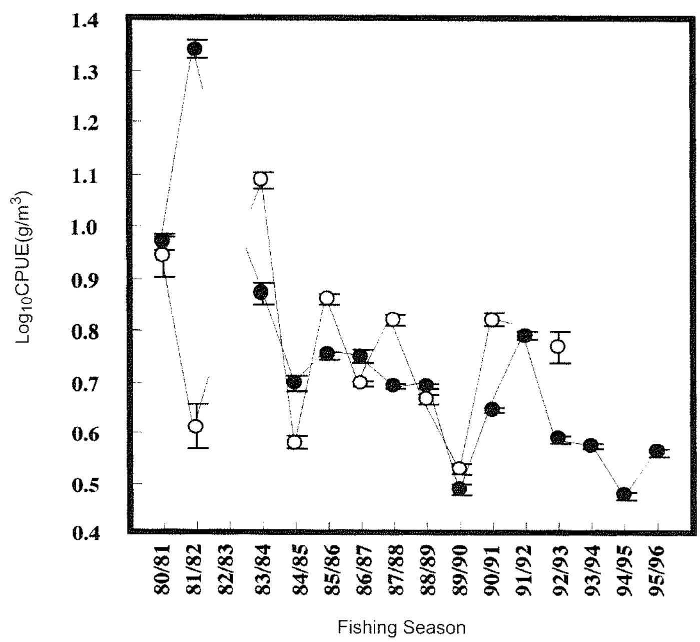

Figure 5: Interannual variation of seasonal average $Log_{10}CPUE$ in the Livingston Island area (closed circles) and Elephant Island area (open circles). Vertical bars express standard errors for each season.

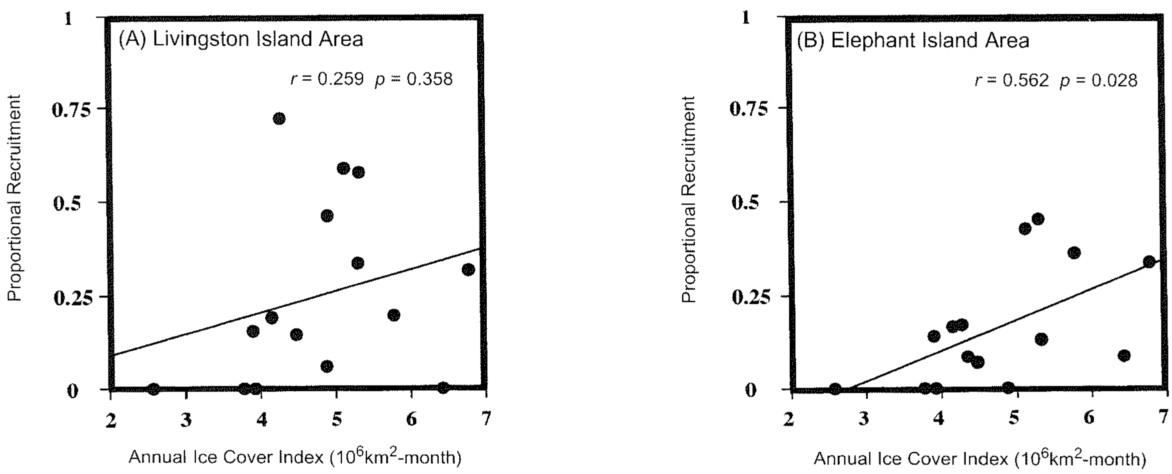

Figure 6: Correlation between annual ice cover index (Hewitt, 1997) and proportional recruitment in the Livingston Island area (A) and the Elephant Island area (B).

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