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CATCH PER UNIT EFFORT (CPUE) DATA FROM THE EARLY YEARS OF COMMERCIAL KRILL FISHING OPERATIONS IN THE ATLANTIC SECTOR OF THE ANTARCTIC

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Abstract

Catch per unit effort (CPUE) data are presented from krill fishing operations in CCAMLR Subareas 48.1, 48.2, 48.3 (South Atlantic) for the period 1975/76 to 1987/88. Comparisons are carried out between subareas in single years, between years on a subarea and area basis, and between oceanic and shelf regions. Results show that the CPUE may differ between subareas, years and shelf/oceanic regions. Obviously, a consistent pattern of CPUE values does not occur over time for the entire area. High average CPUE were observed in the years 1975/76 and 1980/81, whereas the lowest CPUE occurred in Subarea 48.3 in 1977/78. The validity of the CPUE index is discussed as an indicator of krill abundance/biomass and caution is expressed in this regard. Depending on the circumstances, a commercial CPUE index may seriously under- or overestimate the amount of krill available in a statistical subarea. Overall length-frequency distributions from commercial fishing operations in general tend to show little interannual variation because several factors influence the representativeness of krill smaller than 35 mm in the catches.

Résumé

Cette communication a pour but de présenter les données de capture par unité d'effort (CPUE) provenant des opérations de pêche de krill menées dans les sous-zones 48.1, 48.2 et 48.3 (Atlantique sud) au cours de la période 1975/76 à 1987/88. Des comparaisons ont été effectués entre les sous-zones au cours d'années simples, entre les années sur une base de sous-zones et de zones et entre les régions océaniques et les plateaux continentaux. D'après les résultats, la CPUE a tendance à varier selon les sous-zones, les années et les régions océaniques et des plateaux contintentaux. De toute évidence, les valeurs de CPUE ne suivent pas toujours la même tendance au cours d'une certaine période temporelle pour la zone tout entière. Une CPUE moyenne élevée a été observée pendant les années 1975/76 et 1980/81 tandis que la plus basse a été relevée dans la sous-zone 48.3 en 1977/78. La validité de l'indice CPUE en tant qu'indice de l'abondance/biomasse de krill est examiné et il est recommandé de ne l'utiliser qu'avec prudence. Selon les circonstances, un indice commercial de CPUE pourrait sérieusement surestimer ou sous-estimer la quantité de krill présente dans une sous-zone statistique. En raison de l'influence de plusieurs facteurs sur la représentation de krill inférieur à 35mm dans les captures, les distributions longueur-frequence globales enregistrées dans les opérations commerciales de pêche ont en général tendance à indiquer des variations interannuelles peu significatives.

Резюме

Представлены данные по уловам и усилию (CPUE), полученные при промысле криля в подрайонах АНТКОМа 48.1, 48.2 и 48.3 (южная часть Атлантического океана) за период 1975/76 - 1987/88 гг. Были проведены сравнения между подрайонами в отдельные годы, между годами по подрайонам и районам, а также между океаническими и шельфовыми регионами. Результаты показали, что CPUE может различаться между подрайонами, годами и шельфовыми/

океаническими регионами. Очевидной временнóй последовательности в величинах CPUE по всему району не наблюдалось. Высокие средние величины CPUE наблюдались в 1975/76 и 1980/81 гг., а самая низкая - в Подрайоне 48.3 в 1977/78 г. Авторы предлагают относиться к применению индекса CPUE в качестве показателя численности/биомассы криля с осторожностью. В зависимости от обстоятельств, использование индекса коммерческого CPUE может привести к весьма заниженным или завышенным оценкам объема криля в каком-либо статистическом подрайоне. Как правило данные по частотному распределению общей длины, полученные в ходе коммерческой промысловой деятельности, указывают на незначительную степень межгодовой изменчивости в связи с тем, что на репрезентативность присутствующих в уловах рачков длиной менее 35 мм оказывает влияние ряд факторов.

Resumen

Se presentaron los datos de la captura por unidad de esfuerzo (CPUE) de las operaciones pesqueras de kril en las Subáreas 48.1, 48.2, y 48.3 (Atlántico Sur) de la CCRVMA realizadas durante el período 1975/76 a 1987/88. Se efectuaron comparaciones entre las subáreas en una base anual, entre años en una base regional, y entre las regiones oceánicas y de la plataforma. Los resultados demuestran que el CPUE puede variar entre subáreas, entre años y entre las regiones oceánicas o de la plataforma. Obviamente, con el transcurrir del tiempo no se observa un patrón consecuente de valores de CPUE para la totalidad del área. Se observó un promedio alto de CPUE en los años 1975/76 y 1980/81, en tanto que el CPUE más bajo ocurrió en la Subárea 48.3 en 1977/78. Se discute la validez del índice CPUE como indicador de la abundancia/biomasa del kril y se expresa debida cautela al respecto. Según las circunstancias, es posible que un índice comercial de CPUE subestime, o sobrestime, en gran medida la cantidad de kril disponible en una subárea estadística determinada. Las distribuciones totales por frecuencia de tallas obtenidas de las operaciones pesqueras comerciales en general tienden a demostrar escasa variación interanual debido a que hay varios factores que afectan la representatividad del kril de talla menor a 35 mm en las capturas.

Keywords: krill, *Euphausia superba*, Scotia Sea, catch per unit effort, CPUE, length-frequency distributions, CCAMLR

INTRODUCTION

Commercial krill fishing commenced in the early 1970s and the annual catches rose gradually to a maximum around 500 000 tonnes in 1981/82 (Miller, 1989). After dropping to a low level in 1983/84, total catches increased again during the late 1980s but have currently declined again to a level of around 100 000 tonnes. Data from commercial fishing activities were thought to supply valid information on changes in stock biomass. Some models were developed which use CPUE data to manage the harvesting of krill stocks (Mangel, 1988; Butterworth, 1988).

Shimadzu (1985) and Everson (1988) (cited from Miller, 1989) suggested that the most appropriate CPUE index is derived from catch/hour spent fishing. Miller (1989) introduced three possible indices:

(i) total catch/total hours for the split-year (1 July to 30 June);

(ii) mean catch/hour for the fishing season; and

(iii) mean monthly catch/hour for the split-year.

Krill abundance and biomass are known to fluctuate seasonally in at least part of Area 48 (Siegel, 1988; Siegel et al., 1997). We reduce this effect in the CPUE data by using the mean catch per hour for the summer period December to March only, instead of the entire fishing season or the split-year as suggested above. Soviet and German haul-by-haul data were not available to Miller (1989) to use in his analysis of the krill fishery. We therefore take the opportunity to present this information here. The aim of this paper is not simply to calculate the CPUE index for the CCAMLR subareas where major fishing concentrates, we also try to find indications of possible differences in the CPUE index between subareas, between years or between oceanic and shelf regions. Length-frequency data are used to study differences or similarities between areas and years.

Table 1: Average CPUE (kilogram/hour), standard error and number of hauls for Subareas 48.1 (Antarctic Peninsula), 48.2 (South Orkney Islands) and 48.3 (South Georgia).

Year	Subarea 48.1			Subarea 48.2			Subarea 48.3		
	CPUE	SE	N	CPUE	SE	N	CPUE	SE	N
1975/76	15 020	3 214	33	6 582	1 742	45	16 558	5 697	50
1976/77									
1977/78	2 127	292	65	7 853	1 069	110	1 782	123	97
1978/79	5 410	610	40	3 506	293	49	6 850	999	31
1979/80									
1980/81	9 915	972	141	28 418	3 702	33	3 217	843	17
1981/82	2 861	198	126	1 950	226	20			
1982/83									
1983/84									
1984/85	5 315	186	309	9 599	1 217	109			
1985/86	7 672	1 072	77	7 915	652	135			
1986/87									
1987/88	6 732	1 428	16	5 340	1 856	10			

MATERIAL AND METHODS

Haul-by-haul catch and effort data were available from fishing operations of former Soviet vessels (1977/78, 1978/79, 1980/81, 1981/82 1984/85, 1985/86 and 1987/88) and German trawlers operating during 1975/76 and 1977/78 from CCAMLR Subareas 48.1 to 48.3, Antarctic Peninsula, South Orkney Islands, Scotia Sea and South Georgia. For the geographical location of subareas see also Figure 2a. More data were available from other years, however these were either from a particular subarea during that year only or the catches were taken outside the time frame to which we restricted our analysis, i.e. the summer months December to March. The CPUE index is calculated as catch in kilogram/hour trawling and is therefore directly comparable to one (catch in tonnes/minute) introduced by Marín et al. (1991) to analyse the Chilean krill fishery. Unfortunately, this index is not comparable to the one calculated by Kawaguchi et al. (1996) for the Japanese fishery, because the latter index is standardised by square metre of the net opening in addition to fishing time per minute. For comparisons between shelf and oceanic waters, we defined the shelf as the region between the 800-metre depth contour at the continental slope and the coast. Oceanic regions are the waters beyond the 2 500-metre depth contour.

Krill length measurements were taken as total length rounded down to the nearest millimetre. Generally, a minimum of 200 krill were measured from each catch.

Statistical tests for year and area differences were carried out using rank methods, since the distribution of CPUE was apparently non-normal as shown by the skewed distribution in Figure 1. The Mann-Whitney or U-test was used in the two-sample case, and the Kruskal-Wallis or H-test (equivalent to a one-way ANOVA) for subsequent multiple comparisons in other cases (Conover, 1980 – for a posteriori calculations see especially Chapter 5.2). The significance level was set to 0.01.

RESULTS

Comparison between Subareas in Single Years

Average values of the CPUE indices for Subareas 48.1 to 48.3 are given in Table 1. The CPUE index clearly shows a high degree of variability between the different subareas. One example is for the season 1980/81 when the CPUE was highest in Subarea 48.2 (28 418 kg/hour), second highest in 48.1 (9 915 kg/hour) and relatively low in Subarea 48.3 (3 217 kg/hour). All these differences in the various subareas were statistically significant for the 1980/81 season (multiple comparison test – Conover, 1980). Significant differences were also found for the split-year 1975/76, when the CPUE was highest in Subarea 48.3. In other seasons, however, the picture was less clear, sometimes because of very high variances, which may obscure differences between subareas. In 1977/78 it was Subarea 48.2 which showed the highest CPUE, however this result was not significantly different to the one obtained for the South Georgia region. In 1978/79 there was no significant difference at all between the CPUEs of the various subareas. There is obviously no tendency for any subarea to have generally higher CPUE values than others.

Furthermore, summary data from fishing reports indicate that data from a single commercial vessel may not be representative of the entire

Table 2: CPUE (in kilogram/hour) of the Soviet commercial krill fishery. Numbers give the range of average over vessels. (na = CPUE data absent in original fishing reports though fishing was carried out; - = no fishing was carried out.)

Year	Subarea	CPUE (kg/hour) December	January	February	March
1977/78	48.1	-	-	-	-
	48.2	-	-	na	na
	48.3	2 700–3 800	6 700–7 200	-	-
1978/79	48.1	na	3 100–5 200	na	4 900
	48.2	na	3 100–4 000	2 500–6 700	3 400–5 200
	48.3	-	-	3 500–5 700	4 500–7 200
1979/80	48.1	3 400–7 400	na	na	-
	48.2	-	3 500–5 400	6 600–9 100	4 300–8 000
	48.3	-	-	-	-
1980/81	48.1	-	5 500–7 700	7 700–12 400	6 100–10 700
	48.2	-	-	3 300	4 500
	48.3	-	na	na	-
1981/82	48.1	na	4 900–5 700	5 400–5 800	6 000–7 000
	48.2	na	na	na	na
	48.3	-	-	-	-
1982/83	48.1	na	-	5 200	-
	48.2	-	-	na	4 400
	48.3	-	na	na	-
1983/84	48.1	-	-	-	-
	48.2	na	6 000–7 400	5 800–8 400	2 400
	48.3	-	3 100	3 100	-
1984/85	48.1	-	na	-	-
	48.2	na	4 900–7 900	3 300–13 100	4 400
	48.3	-	-	-	-
1985/86	48.1	-	-	-	-
	48.2	5 200–6 600	na	7 100–10 400	3 200–8 000
	48.3	-	-	-	-

Table 3: Results of multiple comparison tests ($p < 0.01$) for differences in CPUE data from various years and subareas (ns = not significant).

48.1	78	79	81	82	85	86	88
76	0.001	ns	ns	0.001	ns	ns	ns
78		0.001	0.001	0.001	0.001	0.001	0.001
79			ns	0.001	ns	ns	ns
81				0.001	ns	ns	ns
82					0.001	0.001	0.001
85						ns	ns
86							ns

48.2	78	79	81	85	86	88
76	ns	ns	0.001	0.001	0.001	ns
78		ns	0.001	ns	0.01	ns
79			0.001	0.001	0.001	ns
81				0.001	0.001	0.001
85					ns	ns
86						ns

Total	78	79	81	82	85	86	88
76	ns	ns	0.001	0.001	0.01	0.001	ns
78		ns	0.001	ns	0.001	0.001	ns
79			0.001	0.001	ns	0.001	ns
81				0.001	ns	ns	ns
82					0.001	0.001	0.01
85						ns	ns
86							ns

fishing fleet. The high CPUE in 1980/81 in Subarea 48.2 for example, is not seen in the average CPUE reported from Table 2, which was created on the basis of annual maps of fishing grounds kept on board fishing vessels by trawl masters. Therefore, it cannot be completely ruled out that results for various areas and periods obtained by one fishing vessel only may be biased due to some specific features of the datasets (e.g. they may reflect differences in the efficiency of various types of vessel operations). CPUE values in Table 1 exceeding 10 tonnes/hour may be overestimations if one considers the entire summer fishing season. Such high values may only be representative of short periods (e.g. one month), not of the entire season and the entire fishing fleet.

Comparison between Years for Single Subareas

Despite the possible caveats expressed regarding the representativeness of some of the data, the CPUE data in Table 1 were tested for possible interannual differences in the various subareas. Since the overall test (Kruskal-Wallis) was significant for any subarea, pairwise comparisons between years were conducted. Results for the subareas are listed in Table 3.

For Subarea 48.1 it is evident that the summer seasons of 1977/78 and 1981/82 differ significantly from all other years. These two seasons are both characterised by very low CPUE values.

For Subarea 48.2 the season 1980/81 seems to be extraordinary because it differs from all other years. This subarea shows the highest average CPUE for the entire dataset. This is interesting, because during the same season the adjacent Subarea 48.1 showed only average CPUE values. Other significant differences are listed in Table 3, but years such as 1975/76 or 1978/79 are significantly different to only a few other years, which can be attributed to a high degree of overlap between these medium-level CPUE data for different years.

The summer datasets for Subarea 48.3 are very limited and no clear picture can be drawn from the results of the comparisons. However, it is noteworthy that the 1977/78 CPUE data show no significant difference to any other year, although the average CPUE of this season was the lowest of the entire dataset.

Comparison of Oceanic and Shelf Regions

The available datasets were separated into shelf and oceanic regions. For the 1975/76 season it was possible to separate the data on a subarea basis because fishing effort was spread more widely over all subareas than in later years. Since 1978, for example, the CPUE data from Subarea 48.1 almost exclusively originated from outer-shelf and continental-slope areas. Therefore CPUE data from all other years were combined from the entire Scotia Sea region to allow a comparison of shelf and oceanic regions. Average CPUE estimates are summarised in Table 4. Figures 1a and b display the median values and the percentiles in order to show the skewed distribution pattern of the CPUE values.

In 1975/76 CPUE data were much higher in shelf regions for all three subareas compared to oceanic areas. During this year the overall

Table 4: Average CPUE (kilogram/hour) in oceanic and shelf regions.

Year	Area	Oceanic CPUE	Oceanic SE	Oceanic N	Shelf CPUE	Shelf SE	Shelf N
1975/76							
	48	5 340	1 226	47	14 532	3 112	32
	48.1	1 216	679	4	14 710	6 343	7
	48.2	3 397	1 311	11	12 699	3 651	5
	48.3	2 878	1 784	12	14 928	4 656	20
1977/78							
	48	6 742	901	113	3 490	1 337	10
1978/79							
	48	3 190	321	38	5 954	591	65
1980/81							
	48	1 455	390	12	14 446	1 280	157
1981/82							
	48	1 950	226	20	3 058	242	98
1984/85							
	48	4 643	262	152	7 648	535	204

average CPUE for the entire shelf region of Area 48 was also higher than for the oceanic zone. Despite the big deviation in the average values, however, these differences were not statistically significant (U-test, $p > 0.05$), obviously due to the very high variances of the data (Figures 1a and b). Results obtained from data of some other years indicate a significant difference between the CPUE from shelf and oceanic areas while others do not (U-test, $p = 0.01$). A very distinct difference can be seen in 1980/81, with shelf CPUE values about one order of magnitude higher than in oceanic regions of the Scotia Sea. For the 1984/85 data, shelf CPUE values were again significantly (U-test, $p < 0.001$) higher than oceanic values, but the difference in average CPUE values was less pronounced than in 1980/81.

Generally the highest CPUE values are observed in the shelf region. The overall average CPUE values were significantly different for oceanic and shelf areas (p-level < 0.001).

Comparison of Overall CPUE Data

During the early phase of the commercial fishery fishing effort was widely spread over Area 48 in the Scotia Sea (see Figure 2a for 1975/76). Catches were also taken close to the distribution limit of krill in Subareas 48.1 and 48.3, which partly explains the low CPUE values for many hauls and the very high variances in the data of those earlier years.

The season 1977/78 is quite interesting in that high CPUE values were obtained from the central Scotia Sea in oceanic waters (Figure 3a). At the same time, a scientific survey indicated extremely low krill abundance in the area around South Georgia (Figure 3b). However, as shown in Figure 3a, commercial fishing operations yielded a relatively high CPUE in a restricted area just to the north of this island.

The example of 1987/88 is given in Figure 4 to show the change in fishing operations compared to earlier years (Figure 4a). In these later years fishing mainly occurred in smaller localities close to the South Shetland, South Orkney and South Georgia Islands. Although a scientific net sampling survey recorded areas of higher krill abundance in the Scotia Sea region (Figure 4b), commercial vessels preferred to fish on their traditional fishing grounds close to the islands.

To get a general impression about krill CPUE data in various years, all data were pooled from Subareas 48.1 to 48.3 irrespective of shelf, slope or oceanic origins (Table 5). Significant differences mostly occurred for the 1980/81 and 1985/86 CPUE data (Table 3). These are the years with the highest average catch rate. The 1981/82 CPUE values also differed significantly to most other years. They represent the lower end of the CPUE range.

Table 5: Average CPUE (kilogram/hour) for Area 48.

Split-Year	CPUE	SE	N
1975/76	10 079	1 250	163
1976/77			
1977/78	5 698	678	186
1978/79	4 923	366	122
1979/80			
1980/81	12 516	1 102	191
1981/82	2 861	198	126
1982/83			
1983/84			
1984/85	6 418	360	419
1985/86	7 795	566	213
1986/87			
1987/88	5 611	277	30

Length-frequency Data

Figures 5a and b show the pooled haul-by-haul length-frequency data for the entire fishing area. In most years length frequencies show the typical shape of a distribution influenced by net selectivity. Krill smaller than 35 mm were rarely caught, which corresponds to the 50% retention length found by Czubek (1981) and Klages and Nast (1981) for commercial trawls. However, we can find exceptions in some seasons. In 1975/76 a clear peak can be observed around 25 mm (Figure 5a), a mode which represents age class 1+ and the year class 1974/75, although the net was identical to the one in which, in accordance with mesh selectivity estimates, larger krill of up to 35 mm should also be caught. This size group must have been extraordinarily abundant to be retained in such quantities in the mesh (12 mm stretched in the codend) of the commercial trawl. However, it is interesting to note that this size mode occurred in catches in Subarea 48.3 only (see also Figure 6a).

A similar situation was observed in 1980/81. A bimodal distribution was formed with peaks around 35 and 50 mm. In this year the first mode represented the 2-year-old krill and again, this peak was mostly due to the high abundance of this size group in the Subarea 48.3 data (Figure 6d). Finally, the 1981/82 length frequency (Figure 5b) shows the presence of a strong 1+ age group (modal size around 28 mm) in Subarea 48.1. This very strong age group had already been reported from scientific net surveys (Siegel, 1985; Siegel and Loeb, 1995).

In general, all other length-frequency distributions show very little variation between years and subareas and are characterised by a unimodal distribution pattern. Subareas 48.1 and 48.2 in particular show almost the same length-frequency distributions (Figure 6).

DISCUSSION AND CONCLUSIONS

In the season 1980/81 CPUE values (the overall CPUE index and the CPUE in Subarea 48.2 and, to some degree, in Subarea 48.1) for the total area were significantly higher than in other years. This result again indicates that during FIBEX krill abundance/biomass was probably far above average, as was already indicated by scientific net survey results (Siegel and Loeb, 1995; Siegel et al., 1996). In this respect it is interesting to note that these maximum CPUE values were obtained during fishing operations with the shortest average haul duration, as shown in Figure 7. However, some caution should be expressed here because some of these results were obtained from single-vessel fishing operations only and, as Table 2 (see 'Results') shows, these average CPUE values for the entire group of fishing vessels does not always correspond with the mean CPUE of operations where single or a few ships are involved.

On the other hand, the poor overall CPUE of the 1981/82 season contrasts with the high krill abundance reported from Subarea 48.1 (Siegel and Loeb, 1995). However, it has to be kept in mind that in the 1981/82 season the krill stock was dominated by age group 1+ (comprising more than 75%), and these small juveniles concentrated on the shelf (Siegel, 1988) south of the major fishing activities, which were primarily targeted at larger adult krill on the outer shelf and above the continental slope (see the haul-by-haul data and also the distribution of hauls reported by Kawaguchi et al., 1996 for the Japanese fishery). This fishing strategy is not surprising because the inshore juvenile krill were still so small that they would have been subject to very strong negative net selectivity (Czubek, 1981). Moreover, very small krill are less attractive as a commercial product. In any case, these CPUE and length-frequency data demonstrate that under certain conditions they do not reflect the actual status and composition of the stock. In this case the CPUE index would underestimate the total stock biomass (although in this case maybe not the spawning stock biomass) if used as a biomass indicator.

Under various circumstances, a CPUE index may seriously overestimate the amount of krill when used as an indicator for krill biomass or availability. In 1977/78, Subarea 48.3 showed the lowest reported average CPUE, although this was not significantly different to most CPUEs of the other periods and areas. We know from published results, however, that this year was one of the poorest krill years around South Georgia (Bonner et al., 1978; Hempel et al., 1979; Croxall et al., 1988). The analysis of the haul-by-haul CPUE data showed that these catches had been taken in a very small area to the north of South Georgia. Furthermore, Figure 7 shows that the trawling duration in Subarea 48.3 in that particular season was considerably longer than in other areas and periods. It seems as if fishermen tried to compensate for low krill availability by increasing trawling duration to catch a minimum amount of krill. A prolonged towing time may reduce the average CPUE when krill is scattered over a wider area, but it may show the opposite effect or obscure effects if krill is concentrated and fished very locally.

This case shows that a commercial fishing operation may still find local patches of krill and react to low krill availability by changing the fishing strategy to sustain a fishery while the overall krill biomass/abundance in the subarea in reality is substantially reduced and even predators struggle to find enough krill to ensure their own or their offspring's survival. The use of commercial CPUE data as a biomass index or as a parameter to monitor changes in krill abundance is questionable when catches are taken from small areas. Compensation between towing time and catch rate has to be considered when evaluating CPUE data, otherwise the standardised CPUE value might give a false impression of stability between annual or regional catch rates. Overall length-frequency/density distributions will, for a number of reasons, certainly be biased when commercial catches are clustered in small areas. Firstly, fishing is mostly targeted at larger-sized krill, secondly, the mesh size selects krill larger than 35 mm (which is about the mode of age class 2+ during summer), thirdly, the various size groups show a different spatial distribution, and, finally, smaller krill generally occur south of the preferred traditional fishing grounds. These factors in combination influence the length frequencies in a way that they are generally very uniform unimodal distributions of krill larger than 35 mm. Only in years with an extremely high abundance of smaller krill did we find these size groups represented in commercial catches. This clearly shows the disadvantage of using data from commercial catches to estimate recruitment indices for 1- or 2-year-old krill. Scientific net and hydroacoustic surveys are of fundamental importance for verifying data obtained from commercial operations, even when haul-by-haul data are available.

The comparison between oceanic shelf CPUE data often indicates a higher CPUE in shelf areas, however this is not a consistent phenomenon. Does this mean that in some years, when krill abundance is high, that krill may also spread over wider oceanic areas and the CPUE is similar for shelf and oceanic regions? The results do not suggest this simple linkage (e.g. Table 4). Another possibility would be that there are strong influences on the spatial distribution of krill affected by recruiting age groups (juvenile krill prefer the shelf habitat, whereas adults concentrate in continental slope and oceanic regions – Siegel, 1988).

The distribution pattern of fishing vessels seems to be governed by the greater spatio–temporal stability of krill aggregations in shelf areas compared to oceanic areas. Commercial krill aggregations in the shelf zone usually form and exist for long periods in similar areas found in association with stable hydrographic structures. These hydrographic structures (doubling currents, eddies, local water circulations caused by bottom topography and islands) are favourable for krill aggregations.

In oceanic areas the influence of islands and bottom-relief features is not a decisive factor in hydrodynamic structures forming krill concentrations. Here major current interactions along frontal zones (e.g. Weddell–Scotia Confluence Zone) are of primary importance. Hydrodynamic structures (such as meanders or eddies of various orientation) are usually characterised by significant spatio-temporal fluctuations. Therefore, krill aggregations (sometimes very large ones) forming as a result of the above impacts are also characterised by temporal and spatial instability. As an example of this is the krill aggregation fished by Soviet vessels in the South Orkney region during November 1989 (Sushin, 1998).

Uncertainty and variability in the location of relatively short-lived oceanic krill aggregations tend to deter fishing vessels. Time and effort spent searching and travelling far outweigh the profits made from the fishery.

This conclusion is analogous to those made by Butterworth (1988) and Mangel (1988), whose analyses showed that commercial CPUE (measured in terms of catch/time fishing) is probably not an appropriate index of abundance, but a more meaningful measure of swarm structure. It was therefore thought that the introduction of some measure of search time would be needed to obtain a measure of abundance. However, no progress has been made in this regard. Further data and discussions are needed before the reasons for these possible differences between shelf and oceanic CPUE data can be explained more satisfactorily.

On the other hand, this phenomenon does have some practical implication: in years when there is no significant difference in krill CPUE indices between shelf and oceanic regions (this was observed at least in some years), can we expect krill density to be similar in the two regions? And, before we know the actual situation in a given year, can we then reduce research effort during biomass surveys in oceanic regions and concentrate it in shelf areas just because it was suspected that higher krill densities occur in the shelf regions? These questions are based on a general perception of the commercial krill fishery in the area studied. We have shown, however, that the commercial fishery does not necessarily concentrate in areas of highest krill abundance, because random scientific net surveys indicated high, or even higher, krill densities in oceanic parts of the Scotia Sea, while the krill fishery restricted its effort to more traditional fishing grounds closer to the islands. The phenomenon of oceanic and shelf distribution needs some very careful consideration, at least with regard to minimising bias in designing scientific biomass surveys.

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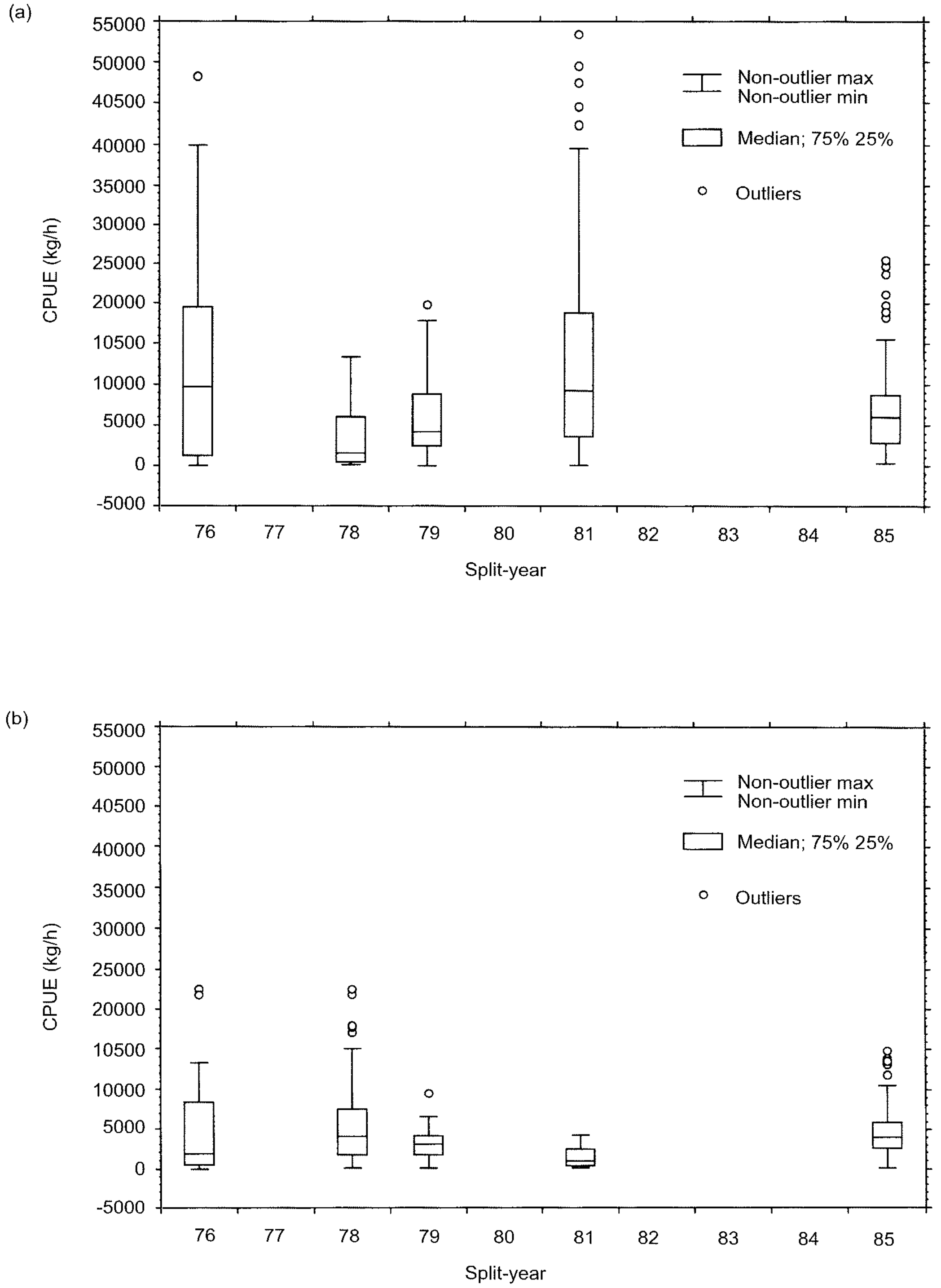
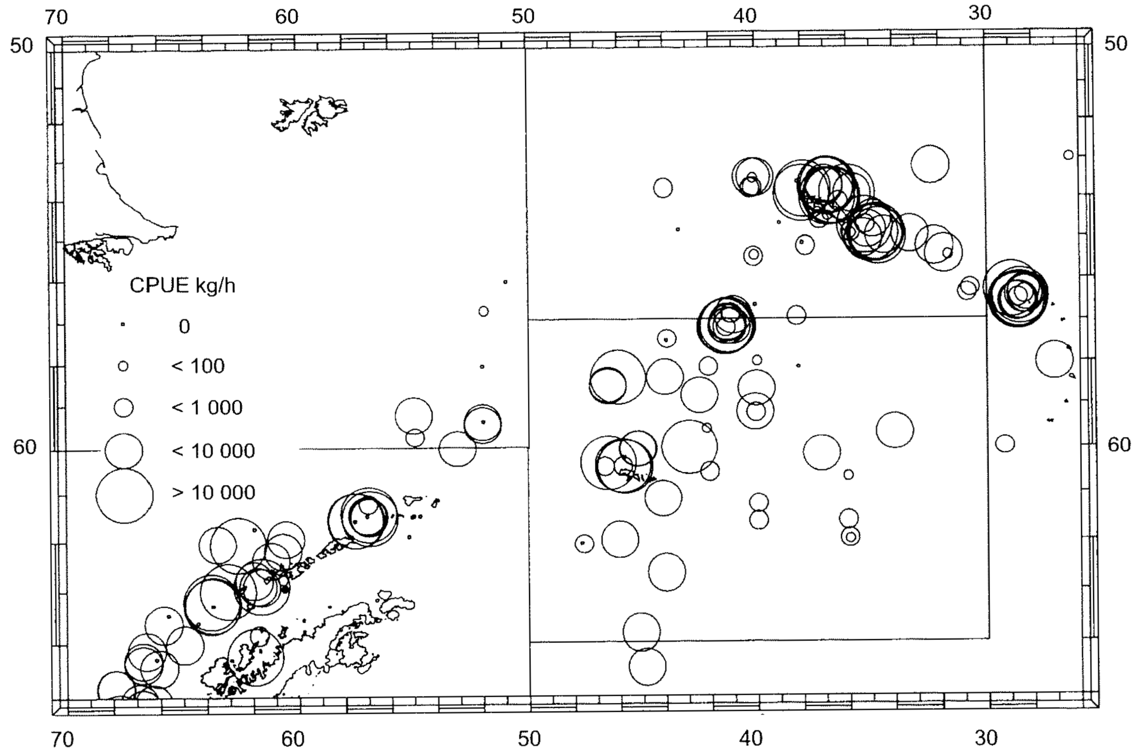


Figure 1: CPUE data (kilogram/hour) shown as box and whisker plots for different years and separated into (a) shelf and (b) oceanic regions of the Scotia Sea.

(a)



(b)

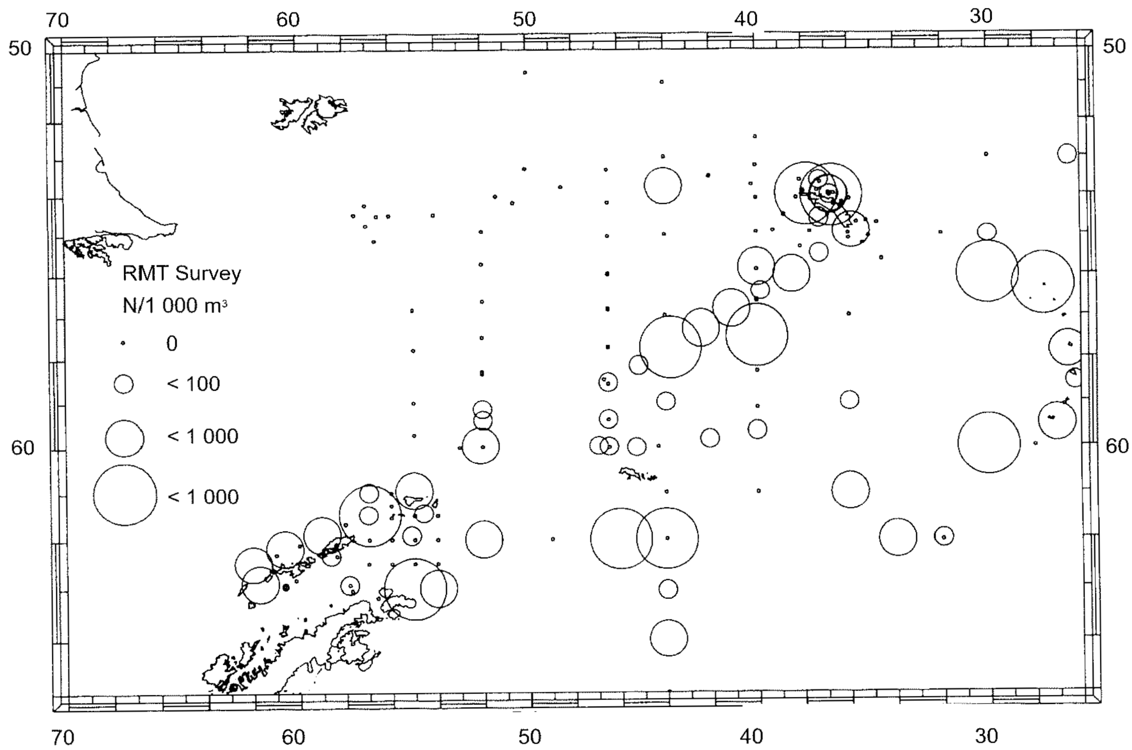


Figure 2: Distribution map of CPUE data during summer 1975/76 in the Scotia Sea: (a) from commercial haul-by-haul data; (b) from a scientific (RMT) net sampling survey.

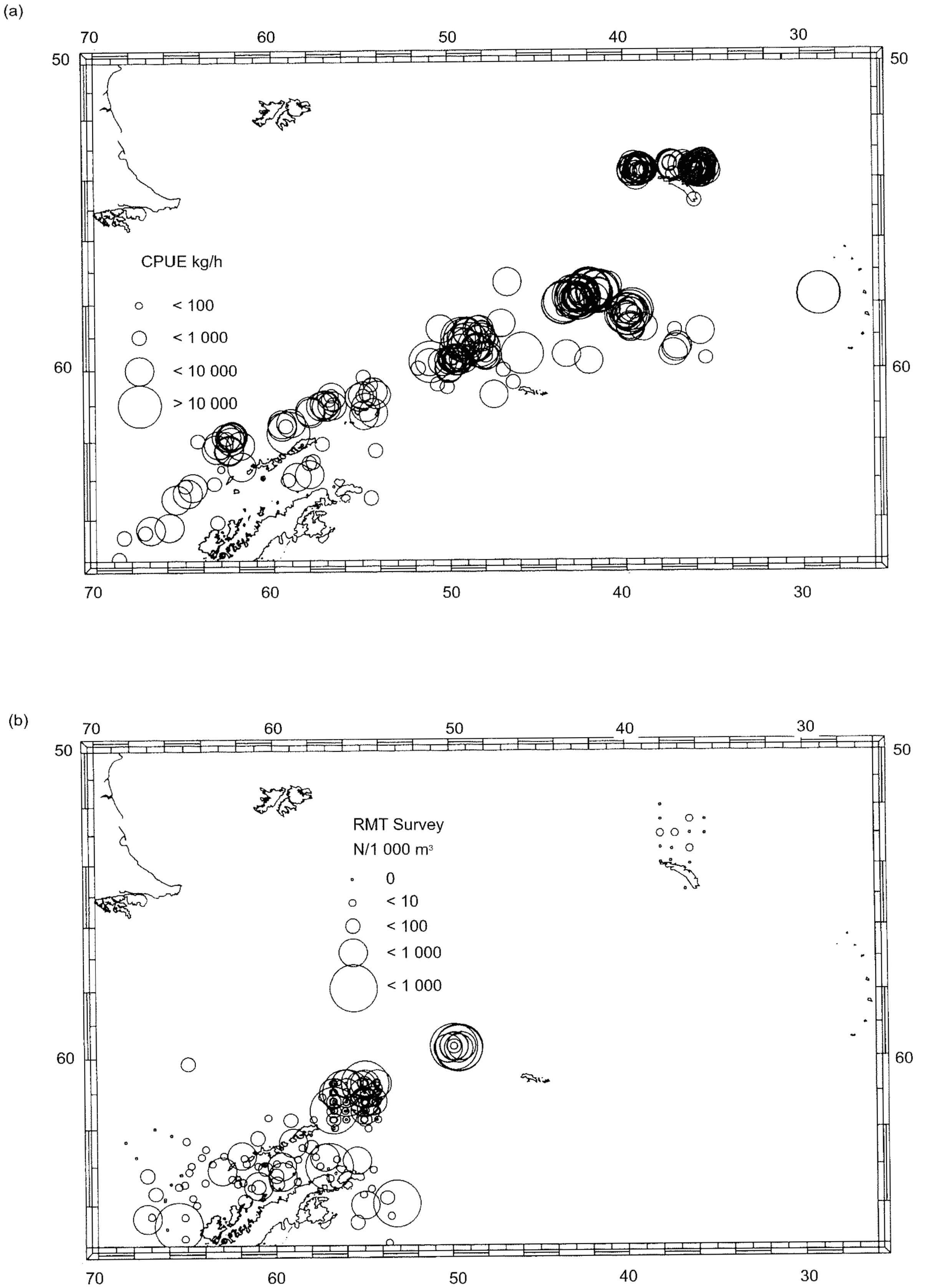


Figure 3: Distribution map of CPUE data during summer 1977/78 in the Scotia Sea: (a) from commercial haul-by-haul data; (b) from a scientific (RMT) net sampling survey.

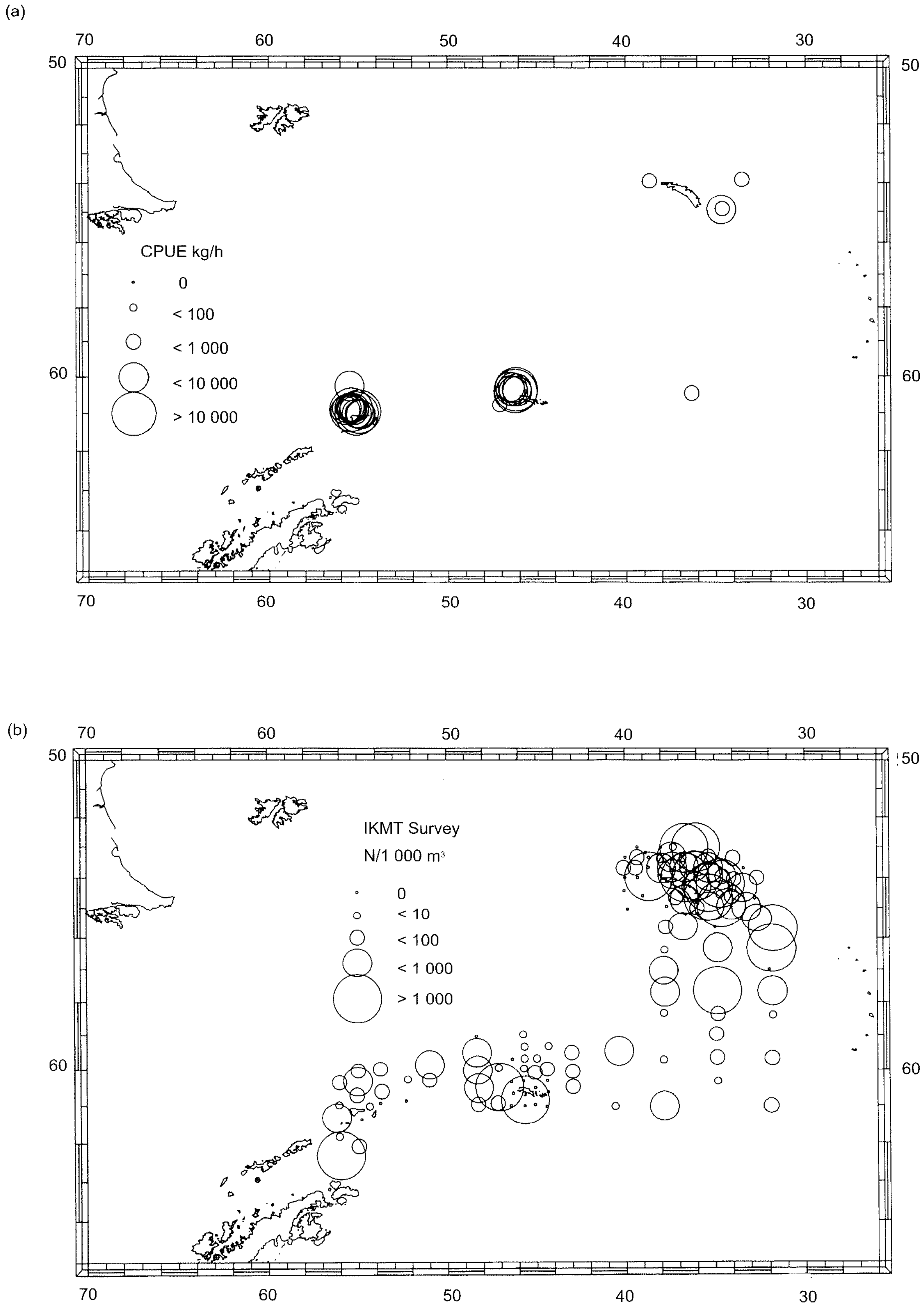
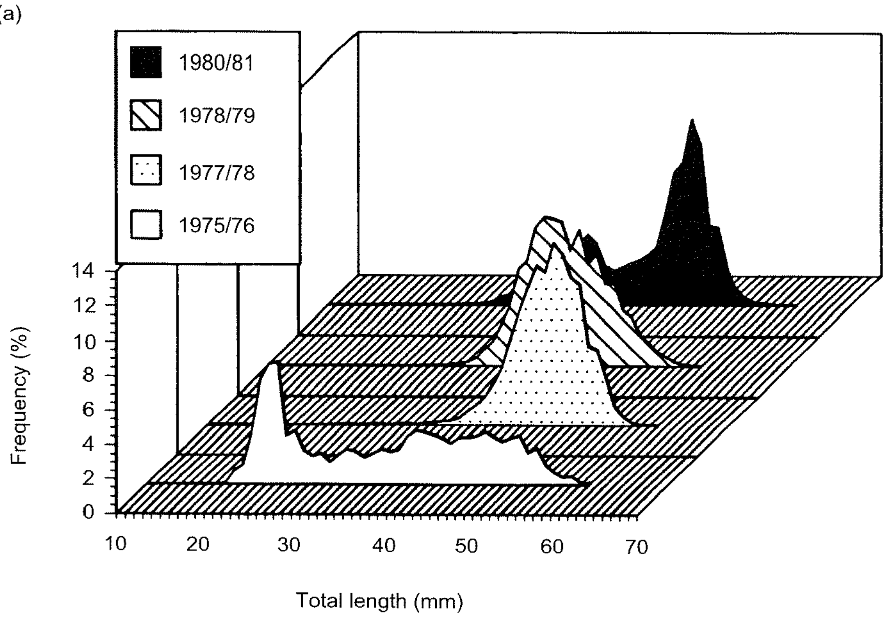


Figure 4: Distribution map of CPUE data during summer 1987/88 in the Scotia Sea: (a) from commercial haul-by-haul data; (b) from a scientific (IKMT) net sampling survey.

(a)



(b)

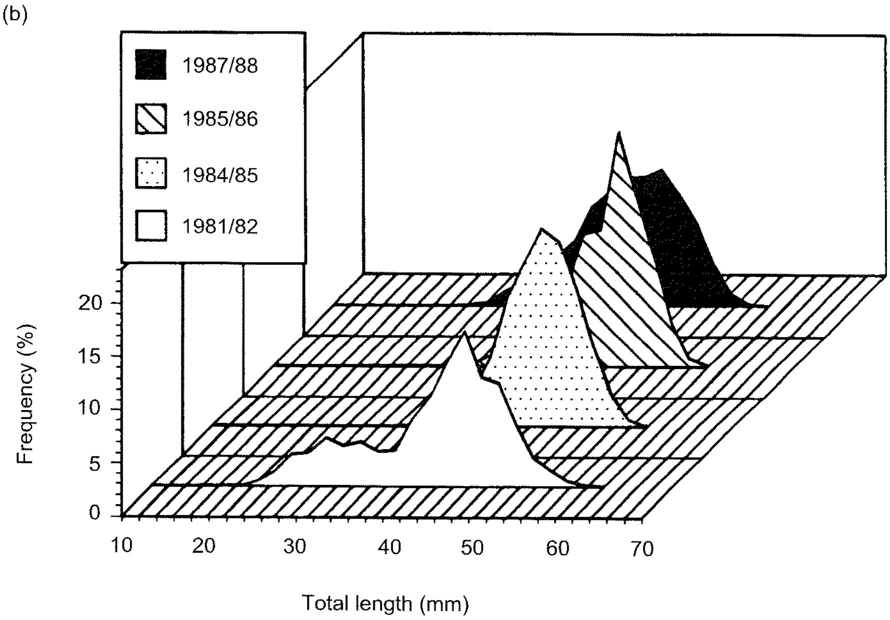


Figure 5: Overall length-frequency distributions from commercial nets for different years pooled for Subareas: (a) 48.1 to 48.3; and (b) 48.1 and 48.2.

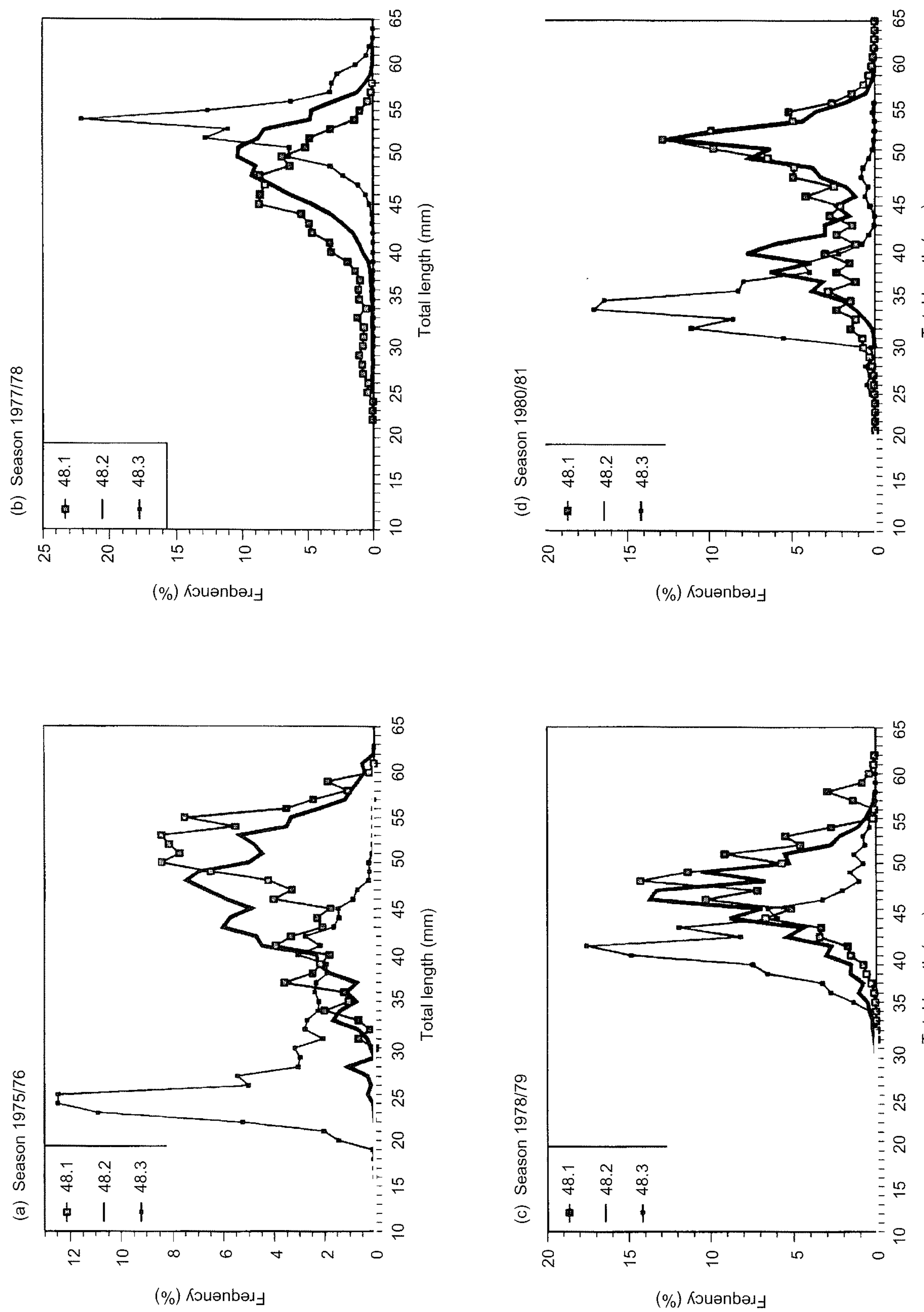


Figure 6: Length-frequency distributions from commercial nets for different subareas in Area 48 and for different years (a to g).

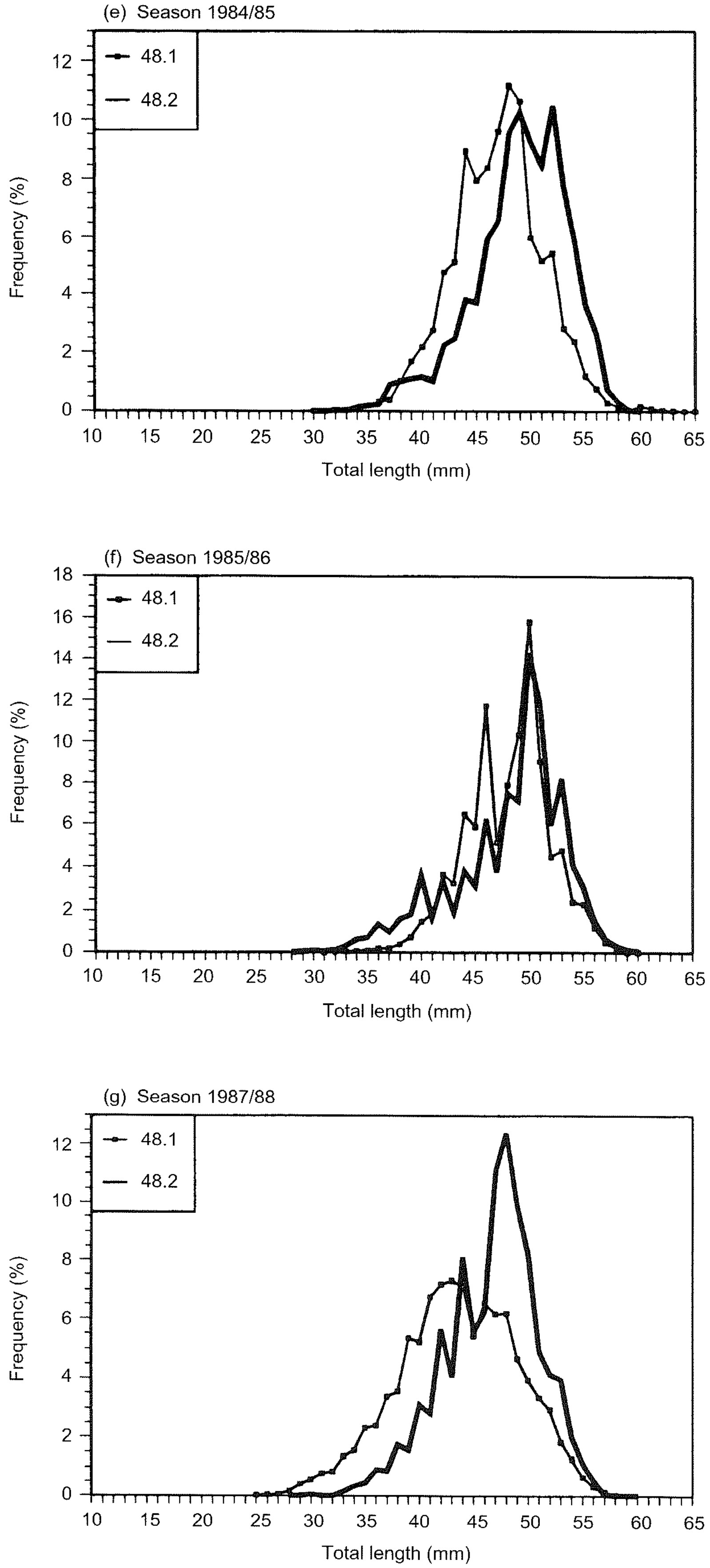


Figure 6 (continued)

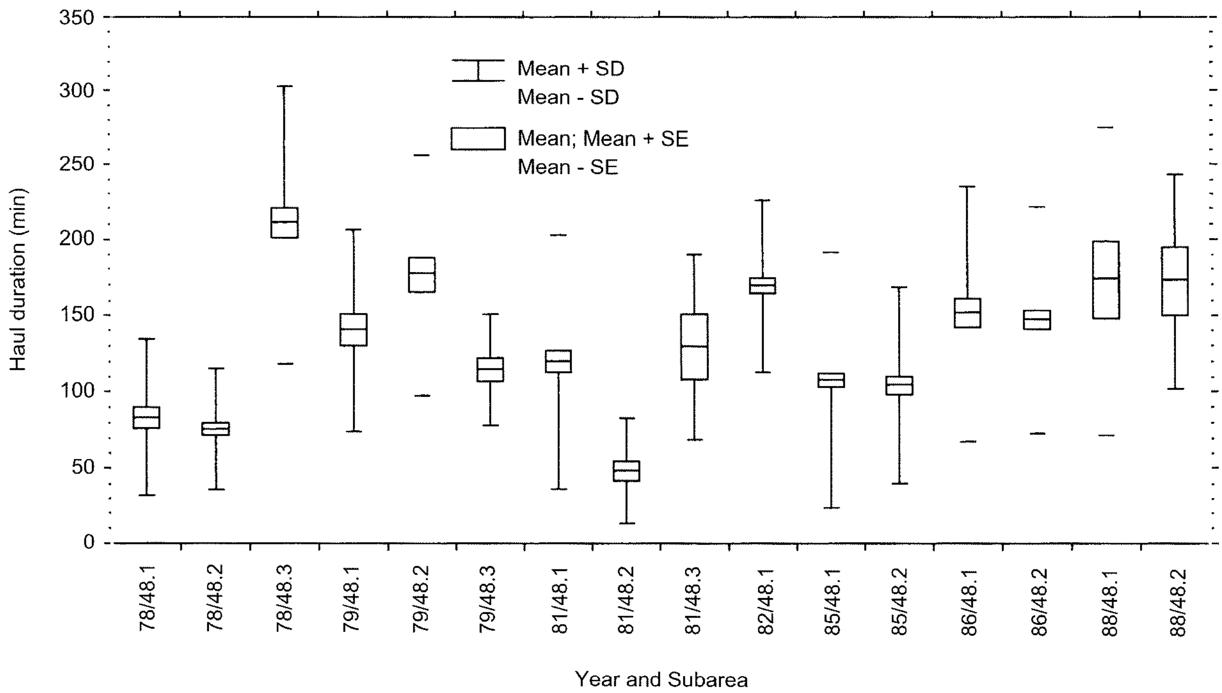


Figure 7: Trawling duration (minutes) during commercial fishing operations in different years and subareas.

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