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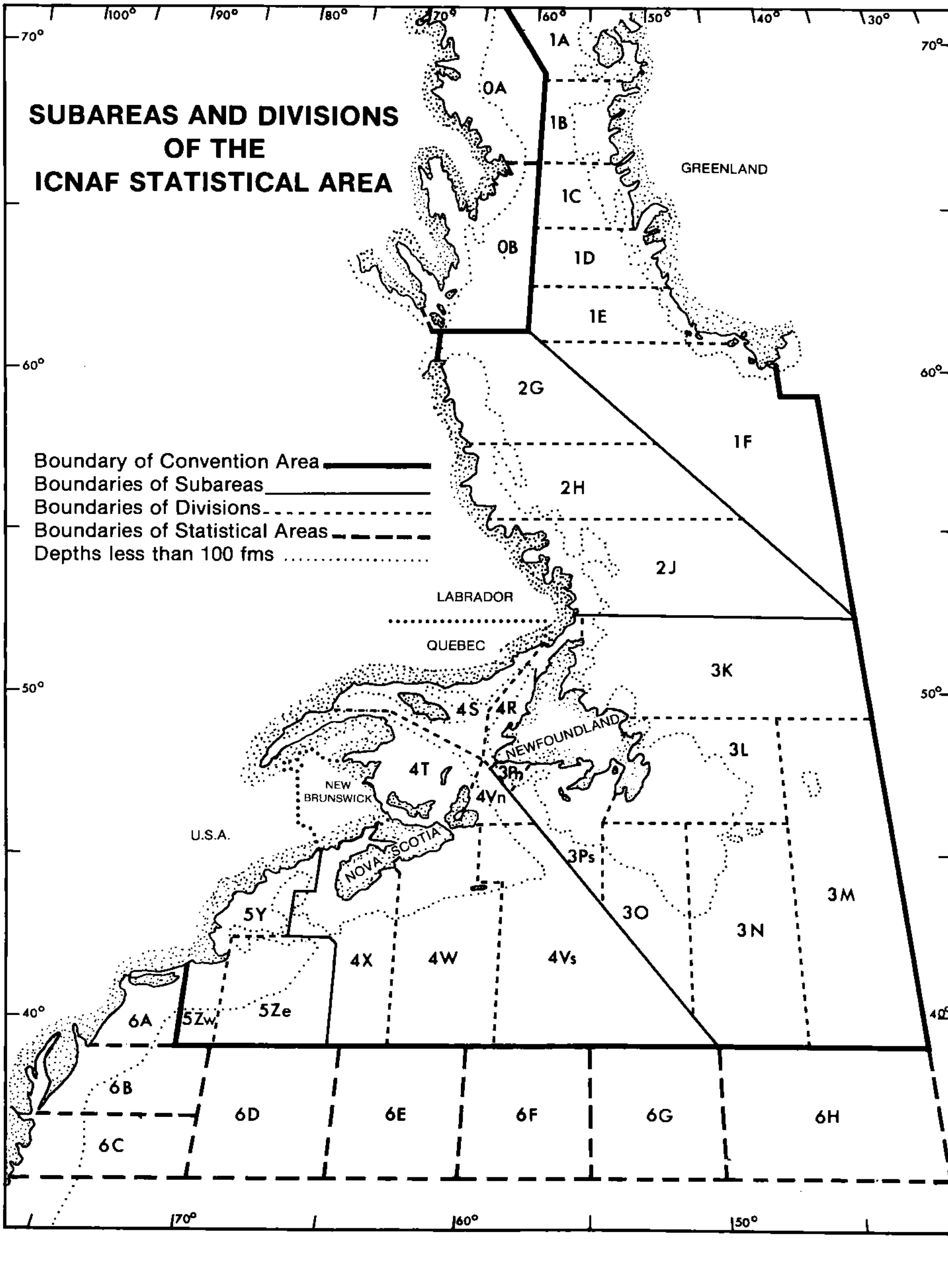
Foreword

This issue of Selected Papers is the fourth in the new series published annually or more frequently, depending on the number of contributions. During the period from 1958 to 1973, selected papers from ICNAF Meetings were published in the Redbook series.

Papers for publication in this new series are selected, subject to the approval of the authors, by the Steering and Publications Subcommittee of STACRES (Standing Committee on Research and Statistics) from papers presented to scientific meetings of ICNAF. In general, the papers selected contain information which is considered worthy of wider circulation than is normal for meeting documents but not of the standard required for publication in the Research Bulletin series. Each author is supplied with 50 reprints of his or her contribution.

This special issue contains eleven papers on shrimp (*Pandalus borealis*) selected from contributions to STACRES Meetings in June and December 1976 and in November 1977.



SUBAREAS AND DIVISIONS
OF THE
ICNAF STATISTICAL AREA
Boundary of Convention Area
Boundaries of Subareas
Boundaries of Divisions
Boundaries of Statistical Areas
Depths less than 100 fms
GREENLAND
LABRADOR
QUEBEC
NEWFOUNDLAND
NEW BRUNSWICK
NOVA SCOTIA
U.S.A.
0A
0B
1A
1B
1C
1D
1E
1F
2G
2H
2J
3K
3L
3M
3N
3O
3Pn
3Ps
4R
4S
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4Vs
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6A
6B
6C
6D
6E
6F
6G
6H
100°
90°
80°
70°
60°
50°
40°
30°

Contents

Shrimp, *Pandalus borealis* Krøyer, Stocks off Greenland: Biology, Exploitation and Possible Protective Measures[1]

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Abstract

The recent explosive development of the offshore fisheries for the deep sea shrimp, *Pandalus borealis* Krøyer, off the west coast of Greenland indicates the need for immediate measures to protect the shrimp resources. This paper reviews present knowledge of the shrimp stocks in Greenland waters and describes the development of the fisheries. Measures to protect the shrimp resources are considered. A method to estimate a precautionary total allowable catch for the offshore fisheries off Greenland is described and discussed. An annual total allowable catch (TAC) of 38,000 metric tons is proposed for the offshore grounds.

Introduction

After the rapid decrease in the West Greenland cod stock (formerly the most important fishery resource of the Greenlanders) and after the salmon fishery was restricted by international agreement, the shrimp stocks became the most important resource for the Greenland fishery.

Research on shrimp has been carried out since 1946. For many years, attention was paid to studying the general biology and distribution of shrimp, including the mapping of the actual fishing grounds. Up to the early 1960's, the research was carried out in inshore waters. However, after 1963 the research has concentrated mainly on the mapping of the offshore shrimp grounds, and a reasonably good picture of the distribution of shrimp and of the actual fishing grounds now exists for West Greenland (ICNAF Subarea 1). Research is now directed mainly to assessment of the stocks.

This paper summarizes the general biology of *P. borealis* in Greenland waters, describes the development of the fishery, and outlines protective measures for maintaining the yield under rational conditions of exploitation. The general locations of the offshore fishing grounds are shown in Fig. 1.

General Biology of *P. borealis* Stocks in Greenland

P. borealis is distributed along most of the West Greenland coast and in the southern part of East Greenland. It lives mainly at depths of 100–600 m in all fjords and offshore waters with positive temperatures (1° to 4° C) but is also found in small quantities in fjords with colder bottom water.

The fundamental biological characteristics of *P. borealis* in Greenland waters have been described by Horsted and Smidt (1956, 1965), Horsted (MS 1969) and Smidt (1969), who have shown that at West Greenland, as in other known stocks, it is a protandric hermaphrodite. The males mature at age 3 and the females at ages 4 or 5. Spawning takes place in July–August, and the females are ovigerous until hatching occurs in April–May of the following year. The period of sexual development is the same as at Spitzbergen and Jan Mayen, while development is more rapid in more southerly and warmer waters, as in the Skagerrak (Rasmussen, 1953) (Fig. 2).

Larval drift by surface currents is assumed to be essential for the recruitment to certain stocks. The Disko Bay area is believed to receive larvae from the rich offshore stocks of shrimp in the deep areas to the north of Store Hellefiske Bank. Furthermore, a wider distribution of larvae explains why the species occurs as far north as the Upernavik district. A sample from experimental trawling there in 1957 (71°53'N, 55°26'W) contained 2-, 3- and 5-year-old shrimp, while age 4 was not represented. This stock is presumably recruited from more southerly areas, and it is assumed that the conditions for drift and/or larval survival were unfavourable in 1953.

Fluctuations in stock density have often been noticed, and in some cases variation in bottom water temperature has been shown to be the cause. More or less regular variation in stock density, correlated with temperature variation, was observed in some fjords in the Julianehaab district of West Greenland. The inflow

[1] Submitted to the June 1976 Annual Meeting as ICNAF Res. Doc. 76/VI/16.

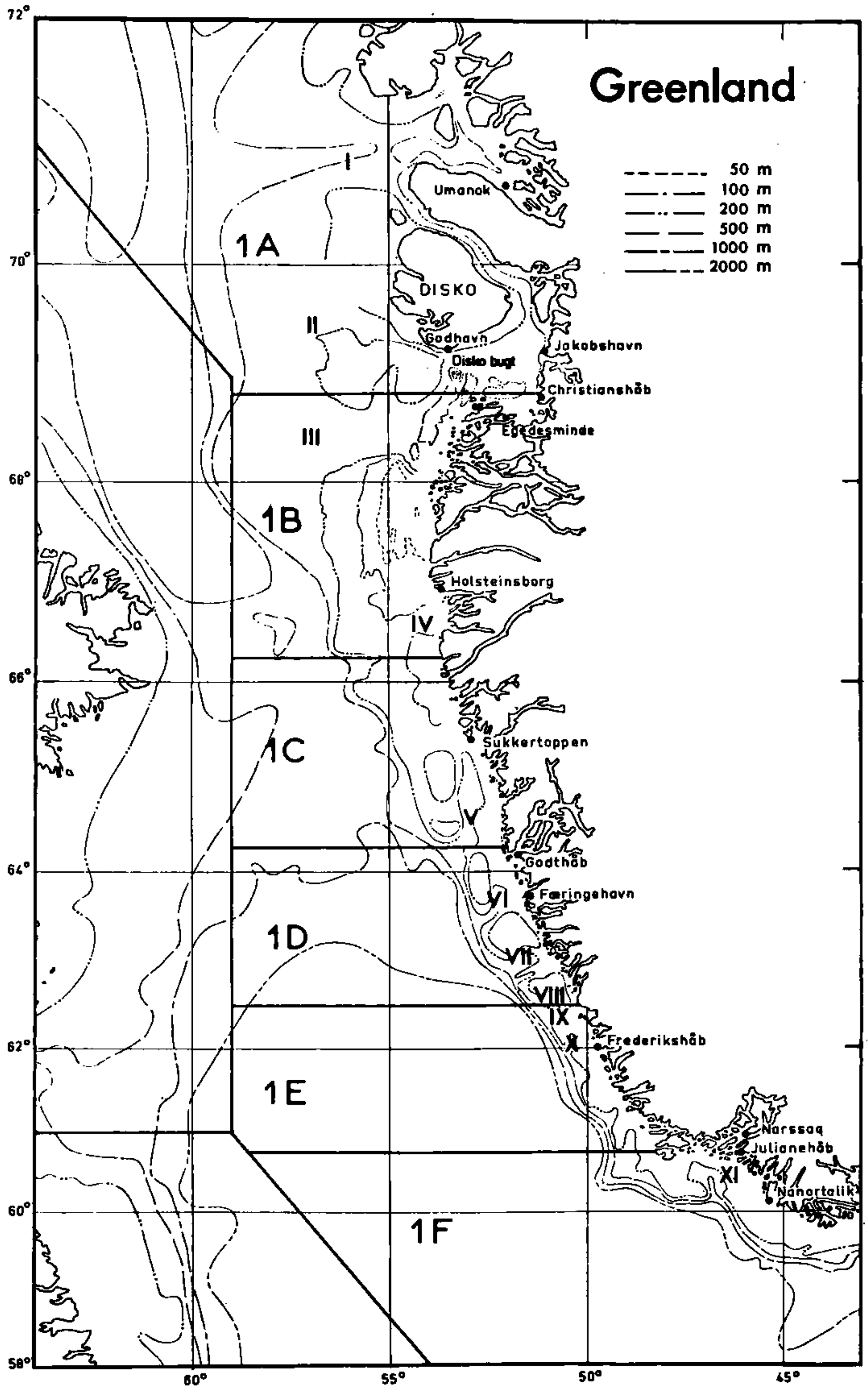

Fig. 1. West coast of Greenland showing the general location of offshore shrimp fishing grounds.

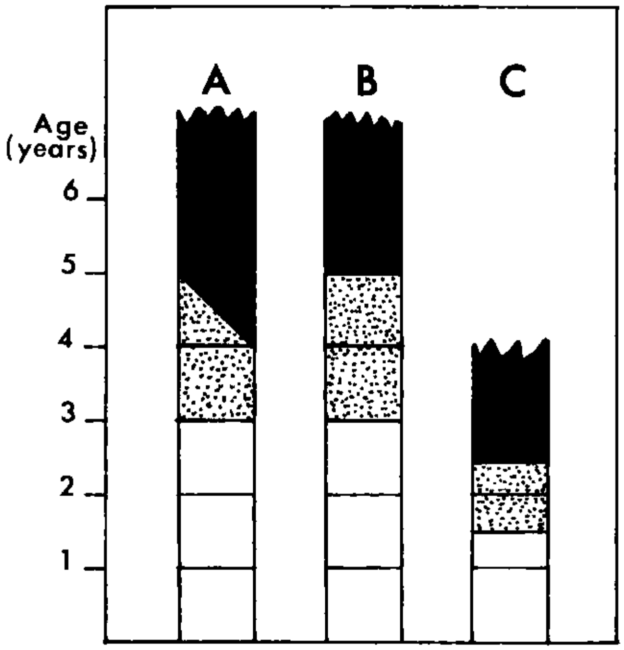

Fig. 2. Development time of *Pandalus borealis* at Greenland (A), compared with Spitzbergen (B) and Skagerrak (C) areas. Sections of columns indicate juveniles (unshaded), males (dotted) and females (black).

TABLE 1. Trend in annual landings (tons) of *P. borealis* by Greenlanders since 1950.

Year	Landings	Year	Landings
1950	175	1971	8,941
1955	566	1972	7,368
1960	1,789	1973	8,135
1965	5,051	1974	10,244
1970	8,429	1975	9,893

TABLE 2. Nominal catches (tons) of *P. borealis* by all countries fishing at Greenland, 1970–75.

Country	1970	1971	1972	1973	1974	1975
Denmark (G)	8,429	8,941	7,368	8,135	10,244	9,789
Denmark (F)	130	496	755	1,371	2,023	5,300
Denmark (M)	—	—	—	196	308	1,142
Norway	—	—	1,409	2,940	5,917	8,678
Spain	—	—	—	—	—	6,948
USSR	—	—	—	—	3,517	6,033
Total	8,559	9,437	9,532	12,642	22,009	37,890

of warm bottom water from Davis Strait at the end of the year was followed by increased catches (higher catch-per-unit-effort) in the commercial trawl fishery for shrimp. The migration of shrimp was confirmed by tagging experiments.

The rich extensive shrimp grounds north of Store Hellefiske Bank are regarded as an important recruitment reserve for the Disko Bay area. In July 1964, the R/V *Dana* caught an average of 180 kg of large shrimp per hour trawling in depths of 400–500 m, but, in 1966, only 90 kg per hour trawling were caught on the same ground. On the other hand, the commercial fishing vessels obtained unusually large catches of big shrimp in Disko Bay in 1966, when the bottom water temperatures were unusually high in Davis Strait, Disko Bay and several fjords. It is therefore likely that in 1966 large quantities of big shrimp were transported into the Disko Bay area from Davis Strait with the intruding warm bottom water. The offshore stocks are therefore regarded as important to the inshore fishing ground not only because of larval drift in the upper water layers but also because of the possible intrusion of adults in the deep water layers.

Development of the *P. borealis* Fishery at Greenland

The Greenland shrimp fishery began on a small scale in 1935 at Holsteinsborg but was interrupted during World War II. After 1950, the inshore fishery expanded rapidly as new shrimp fishing grounds were found, the richest being in the Disko Bay area at depths of 300–500 m, where by far the largest catches by Greenlanders were obtained before the offshore fishery started in Davis Strait about 1970.

About 130 boats are now engaged in the inshore shrimp fishery either on a full-time basis or during part of the year. Most of the vessels are small side trawlers ranging in size from 15 to 25 GRT, although several of them are as large as 50 GRT. The trend in shrimp landings by Greenlanders since 1950 is shown in Table 1, the average being about 9,000 tons annually since 1971. The Disko Bay area yielded 79% of the Greenlanders' catches in 1974 and 70% in 1975.

The development of the offshore fishery in Davis Strait began on a large scale in 1972 and by 1975 the total catch by all countries had increased to 38,000 tons (Table 2), of which about 29,000 tons were taken on the offshore grounds. In recent years, some large stern trawlers of the Royal Greenland Trade Department (KGH) have occasionally been used in this fishery.

The Shrimp Fishery at Greenland Compared with Other *Pandalus* Fisheries

Fisheries have developed rapidly on all North Atlantic stocks of *P. borealis* since World War II. Smidt

TABLE 3. Nominal catches (tons) of *P. borealis* in various ICNAF and ICES subareas of the North Atlantic, 1970-74.

Region	Subarea	Location	1970	1971	1972	1973	1974
ICNAF	1	West Greenland	8,559	9,437	9,532	12,642	22,009
	4	Gulf of St. Lawrence	2,026	1,780	1,353	2,172	3,609
	5	Gulf of Maine	10,615	11,127	11,016	9,339	7,964
ICES	I	Barents Sea	2,115	2,278	2,984	1,647	1,347
	IIa	Norwegian Sea	3,103	2,548	2,719	2,818	4,531
	IIb	Spitzbergen & Bear I.	290	316	1,069	2,460	3,122
	III, IV	Skagerrak & North Sea	9,160	10,440	8,776	6,572	5,250
	Va	Iceland	4,510	6,326	5,291	7,286	6,515

(1971) has described the fisheries of various member countries of the International Council for the Exploration of the Sea (ICES) up to 1970, and Table 3 shows the nominal catches in various ICNAF and ICES subareas for 1970-74. Of special interest is the development of the USA fishery for *P. borealis* in the Gulf of Maine (Table 4). A rapid increase in annual landings in the 1960's was followed by a decline in the 1970's. Wigley (MS 1975) reported that assessments conducted in 1974 indicated that the population declined about 50% from 1972 to 1975, recruitment has steadily declined since 1969, and fishing mortality (F) has probably been in excess of 1.5 since 1970. Such a development is of special concern with regard to the future of the shrimp fishery at Greenland.

A significant shrimp fishery (mainly *P. borealis*) has been developed by USA (Alaska) in the northeastern Pacific since the early 1960's (Gulland, 1970; FAO, 1974), and very large catches have been taken in recent years (Table 4) from the area which is much larger than ICNAF Subarea 1. Information from the Alaska Department of Fish and Game indicate that the average annual catch in 1973-75 was about 46,000 tons. It is likely therefore that the reported catch of 65,000 tons in 1973 (Table 4) represented a peak in the fishery and that annual catches have since declined.

TABLE 4. Annual USA landings (tons) of shrimp (mainly *P. borealis*) from the Gulf of Maine in 1960-74 and from the Northeastern Pacific in 1965-73.

Year	Landings	Year	Landings	Year	Landings
Gulf of Maine					
1960	40	1965	949	1970	10,615
1961	30	1966	1,748	1971	11,127
1962	176	1967	3,151	1972	11,008
1963	254	1968	6,567	1973	9,706
1964	422	1969	12,766	1974	7,964
Northeastern Pacific					
1965	8,800	1968	25,000	1971	48,000
1966	15,300	1969	27,800	1972	47,500
1967	24,500	1970	40,900	1973	65,100

Protective Measures for the Shrimp Stocks at Greenland

Mesh size regulation

Fishing experiments with trawl codends of different mesh sizes were carried out in 1964 on three different fishing grounds in Disko Bay. A codend mesh size of 20 mm (knot to knot) was used in six hauls, 24 mm in three hauls and 28 mm in five hauls (1 hour each). For each 100 kg of shrimp caught with the 20 mm mesh codend, 67 kg were taken with the 24 mm mesh and only 29 kg with the 28 mm mesh. The selectivity of shrimp by the different mesh sizes in terms of the percentage by weight retained is as follows:

Size group (g)	Mesh size (mm, knot to knot) 20	24	28
<3	6%	5%	1%
3-6	26%	20%	10%
>6	68%	75%	89%

Mesh selection experiments with a shrimp trawl using a covered codend were carried out by R/V *Dana* in the North Sea in 1973. A mesh size of 14 mm (knot to knot) in the codend gave a 50% retention length of 16 mm carapace length (Munch-Petersen, MS 1973). Based on the selection factor from this experiment, estimates of the 50% retention length (carapace) are 20.6 mm for 18 mm mesh, 22.9 mm for 20 mm mesh and 25.2 mm for 22 mm mesh. Mesh selection experiments on shrimp in Norwegian waters, using the alternate haul and covered codend methods (Thomassen and Ulltang, MS 1975), indicate 50% retention lengths (carapace) of 19-21 mm for codends with 40 mm mesh (stretched).

These results indicate that codend mesh sizes of 20 to 22 mm (knot to knot) are appropriate for the shrimp fishery in Greenland waters. This is in accord with selection studies carried out in the Gulf of Maine.

Wigley (MS 1975) writes: "Mesh selection studies in 1974 resulted in the establishment of mesh regulation. The basic provision of this regulation stipulates that the mesh size, in both the body and codend, of nets used for catching shrimp must be 1¾ inches (stretched mesh) or larger. Major purpose of this regulation is to reduce the mortality of small shrimps." This mesh size is equivalent to 44 mm stretched mesh or 22 mm from knot to knot.

Protection of nursery grounds

There is normally some difference in distribution of old and young shrimp. Catches from deep water areas generally have more large shrimp than catches from shallower areas (Horsted and Smidt, 1956). Many small shrimp are discarded from catches taken in the shallower areas. A possible protective measure could be the closure of such nursery areas to commercial fishing.

The local Greenland shrimp fishery regulates itself to some extent due to the price differential. The higher prices for large shrimp encourage the fishermen to avoid grounds where small shrimp are abundant. However, the nursery grounds in the offshore areas are not as well known, but it is reported that shrimp trawlers operating there tend to avoid grounds where small shrimp are prevalent.

Total allowable catch regulation

The offshore fishery for shrimp in Subarea 1 is one of recent origin and only few catch-per-unit-effort data are available. Therefore, the methods normally used in stock assessments cannot be applied at present to the Greenland fishery. To arrive at a precautionary TAC for the shrimp resource, a method based on the catch per unit area in Disko Bay has been used. The basic assumption underlying the method is that a precautionary TAC for the offshore shrimp fishing grounds should allow an annual catch per unit area not exceeding that obtained in Disko Bay in recent years. However, such a catch per unit area should only be allowed if there exists around the offshore fishing grounds large unexploited areas of shrimp concentrations, so that there is a supply of shrimp from non-exploited areas of at least the same magnitude as is supposed to occur in Disko Bay.

The landings of shrimp to the industries of the Royal Greenland Trade Department in Disko Bay are shown in Fig. 3. The 15% decrease in landings from 1974 to 1975 is partly due to bad weather conditions in the early part of 1975 compared with favourable conditions in the same period of 1974. However, a general decline in catch per unit effort has been reported. It is therefore the general impression that

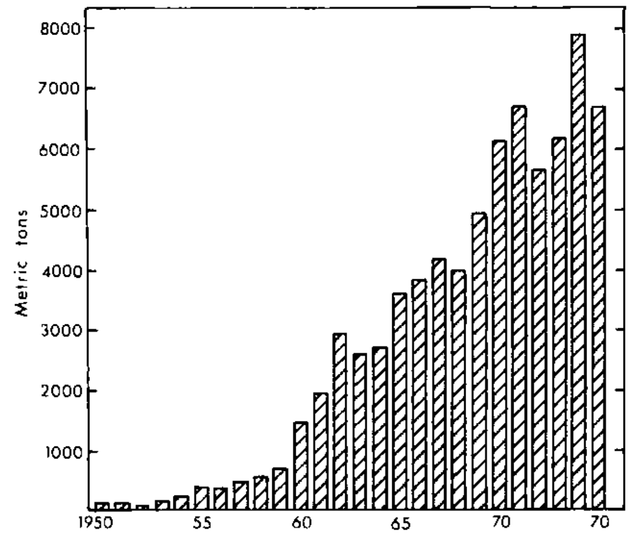

Fig. 3. Annual landings of shrimp to the shrimp-processing plants of the Royal Greenland Trade Department in Disko Bay, 1950–75.

exploitation in Disko Bay is close to the level of maximum sustainable yield (MSY) for this area. This view is supported by interviews with fishermen from Disko Bay in 1975 and 1976, although some fishermen thought that the present catch rate in Disko Bay is higher than that corresponding to the long-term MSY. Therefore, the annual catch per km^2 in 1974 has been chosen as a reasonable precautious maximum allowable catch per km^2 on the offshore fishing grounds.

In Disko Bay, the fishing grounds exploited in 1974 covered about 2,000 km^2. It is known, however, that shrimp occur everywhere in the Bay at suitable depths, and the continued heavy fishing in the area depends mainly on a supply of shrimp from the surrounding areas. This is confirmed by a decline in catch per unit effort on some fishing grounds during intense fishing, forcing the vessels to move to other areas, but when they returned to the grounds at some later time higher catch rates are again obtained.

The areas supplying the fishing grounds in Disko Bay are estimated to total about 6,000 km^2. The adjacent offshore shrimp fishing grounds (see areas II and III in Fig. 4) are thought to be of great significance for the shrimp resources in Disko Bay, supplying shrimp larvae and possibly adult shrimp, but are not included in the 6,000 km^2 supplying areas noted above. The figure does, however, include the Vaigat (north-east of Disko Island), an area with some minor shrimp concentrations that are not of significance for the shrimp resources within Disko Bay proper since the currents generally flow in a northwest direction.

With a shrimp fishing ground area of 2,000 km^2 and a supplying area of 6,000 km^2, the ratio of fishing ground to supplying area is 1:3 in the Disko area. Using the 1974 annual landings in the Disko Bay area (8,000 tons), the yield per unit area is 4 tons per km^2 of fishing ground or 1 ton per km^2 of the total area over which the exploited shrimp stock is distributed. These yield per unit area figures are used to calculate total allowable catches on the offshore fishing grounds. When an offshore ground is surrounded by a supplying area, considered to be in a geographical position to allow a reasonable migration of shrimp to the fishing ground, the proposed annual TAC is based on 4 tons of shrimp per km^2 of fishing ground. When there is no supplying area or it is considered not to be in a geographical position to allow a reasonable migration of shrimp to the fishing ground, the proposed annual TAC is based on 1 ton per km^2 of fishing ground. In either case, the proposed TAC can be expressed as 1 ton of shrimp per km^2 of the total distribution area of the exploited stock.

The known distribution of individual shrimp fishing grounds off West Greenland are shown in Fig. 4 and 5, based partly on experience gained during experimental fishing or by echo-sounding surveys of research vessels, and partly on information from trawlers fishing these areas in 1974-76. The areas include some grounds not suitable for trawling. This is especially true for the western part of fishing ground No. IV where large-scale fishing on local concentrations of shrimp occurred in 1974, the specific locations of which are unknown to the authors. The fishing grounds shown in Fig. 4 and 5 are not intended to include all possible trawling areas for shrimp along the west coast of Greenland, as shrimp have been reported to occur all along the slope of the continental shelf in depths of 200-600 m. Some of these areas may

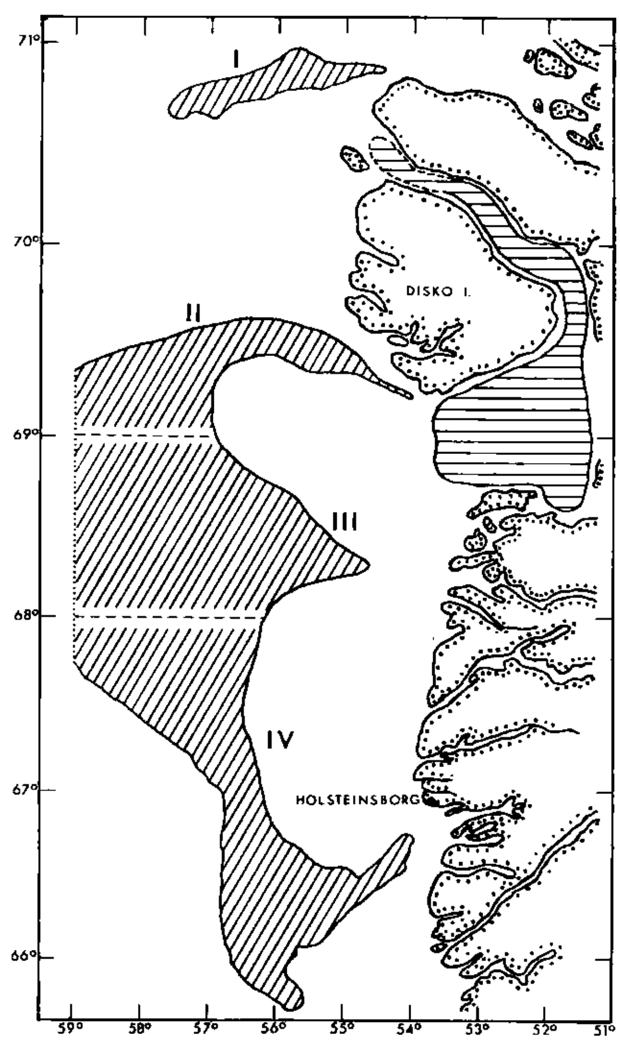

Fig. 4. Offshore shrimp fishing grounds I, II, III and IV (see Table 5 for names), and the total distribution area of exploited shrimp resources in Disko Bay as used in the calculations.

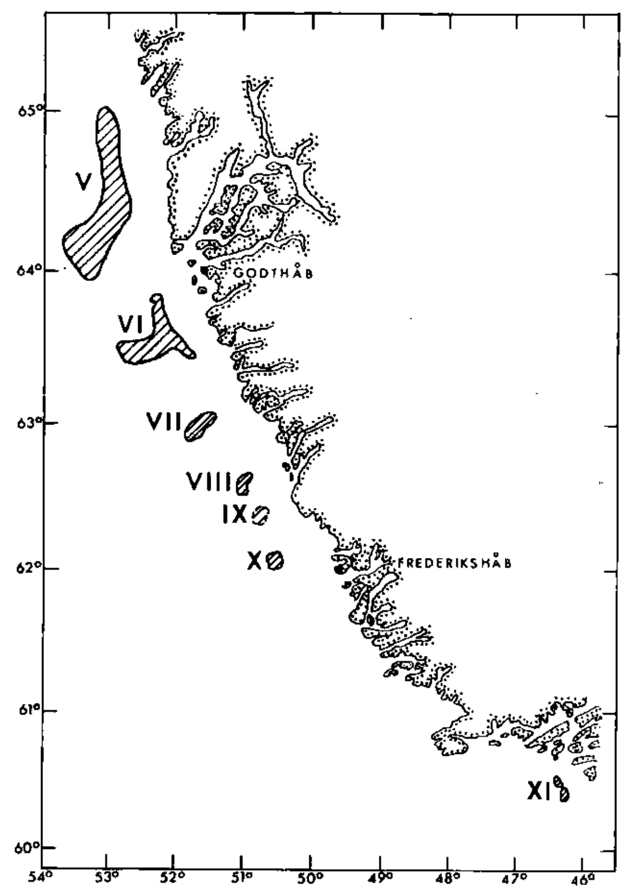

Fig. 5. Offshore shrimp fishing grounds V, VI, VII, VIII, IX, X and XI (see Table 5 for names).

TABLE 5. Estimated areas of known offshore fishing grounds off West Greenland and allowable catches based on proposed catch rates per unit area of the grounds (see Fig. 4 and 5).

Fishing grounds		Area	TAC per km²	TAC by area
No.	Locality	(km^2)	(tons)	(tons)
I	Nordostbugten (Mermaid Ground)	1,500	4.0	6,000
II	West of Blaafjeld	6,300	0.5	3,150
III	North of Store Hellefiske Bank	14,300	0.5	7,150
IV	West of Store Hellefiske Bank and Holsteinsborg Dyb	17,000	1.0	17,000
V	Sukkertoppen Dyb	2,300	1.0	2,300
VI	Godthaab Dyb	900	1.0	900
VII	Fiskenaes Dyb	180	4.0	720
VIII	Danas Dyb	80	4.0	320
IX	Ravns Dyb	—	—	—
X	Frederikshaab Dyb	125	4.0	500
XI	Julianehaabsbugten	60	4.0	240
Annual TAC for all fishing grounds (tons)				38,280

be supplying areas to the fishing grounds, but they have not been included in the areas for which TAC calculations are made, because the bottom may be too rough for trawling or fishing conditions are unknown.

Fishing grounds I, VII, VIII, X and XI (Fig. 4 and 5) are all considered to be surrounded by sufficient supplying areas to allow an annual catch of 4 tons per km^2. However, in the case of fishing grounds II, III, IV, V and VI, the supplying areas are not considered to be sufficiently large or in a geographical position to allow the migration of significant quantities of shrimp to the fishing grounds, and lower annual catch per km^2 values were used in the calculations. A catch of 1 ton per km^2 was applied to Areas IV, V and VI. However, Areas II and III, which actually include the supplying areas, are considered to be of great significance to the shrimp resource in the Disko Bay area by supplying it with shrimp larvae and sometimes adult shrimp. Therefore, the proposed total allowable catch for these two grounds is based on an annual catch of 0.5 tons of km^2. Fishing ground IX (Ravns Dyb) has been excluded from the calculations, as the bottom is too rough for trawling with the gear now used. Table 5 shows the proposed allowable catches for the various fishing grounds, based on estimated areas of the grounds and suggested annual catch rates per km^2. The proposed TAC for the offshore shrimp fisheries along the west coast of Greenland is about 38,000 tons.

Discussion

The explosive development in the offshore shrimp fishery off West Greenland points to the need for regulations to protect the shrimp resources from overexploitation. Three different types of protective measures are considered in this paper. Mesh size regulation and the closing of nursery grounds to fishing would be of value in protecting the shrimp resources. However, they are not considered to be sufficient in the present situation, not only because the present knowledge of the location of nursery grounds for the offshore stocks is limited, but also because, in this rapidly expanding fishery, there is little information on which to estimate the maximum sustainable yield. Until further information is available, a precautionary TAC is considered to be essential.

The method used in this paper to estimate a precautionary TAC for the offshore fishery is based on a number of assumptions, some of which may be questionable. The fishing grounds in the Disko Bay area are fairly well known and the 1974 figure used for the catch per km^2 is considered reliable. However, the extent of supplying areas is not well known, and for the Disko Bay area a larger supplying area than that estimated may be necessary. Bearing in mind the very likely supply of shrimp larvae from the offshore grounds to Disko Bay, if the estimated demands of supplying areas for the offshore fishing grounds are too small, the potential long-term yield may be estimated as too large. It must be noted that the very large offshore catches of recent years were taken in previously unexploited areas where the stocks consisted of an accumulation of several year-classes. Another weak point of the method is that the Disko Bay catches are used to estimate the potential yield of all of the offshore grounds, although differences between the northern and southern grounds are likely.

The sizes of the offshore fishing grounds, used as the basis for calculating the TACs, are based on present knowledge and these may be changed significantly in future years, depending on the development of fishing gear especially for fishing in rough bottom areas. The proposed TACs are strictly associated with individual fishing grounds and extensions of the exploited areas should not lead to higher allowable catches until evidence is provided that the extensions will not interfere with the supplying areas. For example, Faroese fishermen on fishing grounds VII, VIII and X (Fig. 5) are exploiting areas about four times the size of those used in the calculations (Hoydal, 1978), but these extensions correspond very closely to the areas assumed to be supplying areas for the fishing grounds, and they therefore should not influence the proposed TACs.

The catch figures for the Disko Bay fishery are based on landings, that are reasonably close to the actual catches, as practically the entire catches are landed with discarding taking place at the shrim-processing plants. In the offshore fisheries, the reported landings are minimum estimates of the actual catches, as up to 80% of the catches are known to be discarded, depending on the size of shrimp and the processing facilities on the vessels. Consequently, the proposed TACs, calculated on the basis of Disko Bay catches, should at least be representative of total catches (including discards) in the offshore fisheries.

The proposed TACs, based on the Disko Bay fishery in 1974, are considered valid for the near future only. It is therefore hoped that better data will soon make possible the assessment of the stocks on a firmer basis. Also, the very likely connection between the decline of the cod stocks at West Greenland (cod being a significant predator of shrimp) and the present size of the shrimp resources in the same area should be kept in mind. Significant changes in the stocks of cod and other predators on shrimp should therefore be followed closely, as they may influence the calculation of future TACs.

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Biological Data on the Northern Deepwater Prawn, *Pandalus borealis*, off Baffin Island[1]

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Abstract

In the autumn of 1977, significant catches of the northern deepwater prawn, *Pandalus borealis*, were taken in a groundfish trawl survey by the research vessel *Cryos* in Statistical Area 0. A minimum estimate of the biomass based on the area swept with the groundfish trawl, which is inefficient for shrimp, is about 4,000 metric tons. Modes of 12.9, 17.9, 23.1 and 29.5 mm in the length frequencies are considered to represent age-groups 2, 3, 4 and 5+, Greenland halibut, *Reinhardtius hippoglossoides*, and redfish, *Sebastes marinus mentella*, dominated the by-catches.

Introduction

A groundfish survey was carried out on board the R/V *Cryos* from 16 September to 23 October 1977 in the Baffin Island area (ICNAF Statistical Area 0) and numerous data were collected on the northern deepwater prawn, *Pandalus borealis*. Information on distribution, abundance, by-catches, length and age compositions and biometrical relationships is presented, and a minimum estimate of the stock biomass in the area is derived by the "swept area" method.

Materials and Methods

The material used in this study was obtained during a groundfish survey using the stratification scheme illustrated in Fig. 1, the details of which are given in Table 1. Strata 24 and 25 were not sampled due to depth and rough bottom respectively.

The standard gear used was a Lofoten groundfish bottom trawl with the following specifications: 31.2 m headline, 17.7 m footrope, 140 mm mesh in the wings and body, and 50 mm mesh in the codend. A total of 64 stations were occupied with this trawl during the survey, each tow being 30 min duration. Three 30-min tows were made on shrimp concentrations using a research shrimp trawl with 33.1 m headline, 37.8 foot-rope, 30 mm mesh in the wings and body and 25 mm mesh in the codend.

A minimum estimate of the shrimp biomass in the strata where significant quantities were caught was

TABLE 1. Details of stratification scheme for ICNAF Statistical Area 0 used on groundfish survey by *Cryos*, September-October 1977. The areas of strata are given in square nautical miles.

Depth range	Stratum No.	Number of sets	Area of stratum	Total area
<100 fm (183 m)	11	1	630	630
100-150 fm (183-274 m)	01	2	536	
	02	1	1,282	
	12	4	1,914	6,314
	13	2	1,390	
	19	2	1,192	
150-200 fm (274-366 m)	03	3	1,136	
	07	1	1,336	
	08	4	1,666	
	09	3	1,524	7,728
	14	2	560	
	20	2	1,114	
	25	—	392	
200-300 fm (366-549 m)	04	2	742	
	06	3	1,252	
	10	2	660	7,648
	15	2	824	
	21	5	2,270	
	26	3	1,900	
300-500 fm (549-914 m)	05	2	450	
	16	3	1,106	
	17	3	1,208	5,930
	22	2	818	
	27	5	2,348	
500-700 fm (914-1,280 m)	18	2	1,430	2,054
	23	3	624	
700-900 fm (1,280-1,646 m)	24	—	1,712	1,712
Totals	27	64	32,016	32,016

[1] Submitted to the November 1977 Special STACRES Meeting as ICNAF Res. Doc. 77/XI/70.

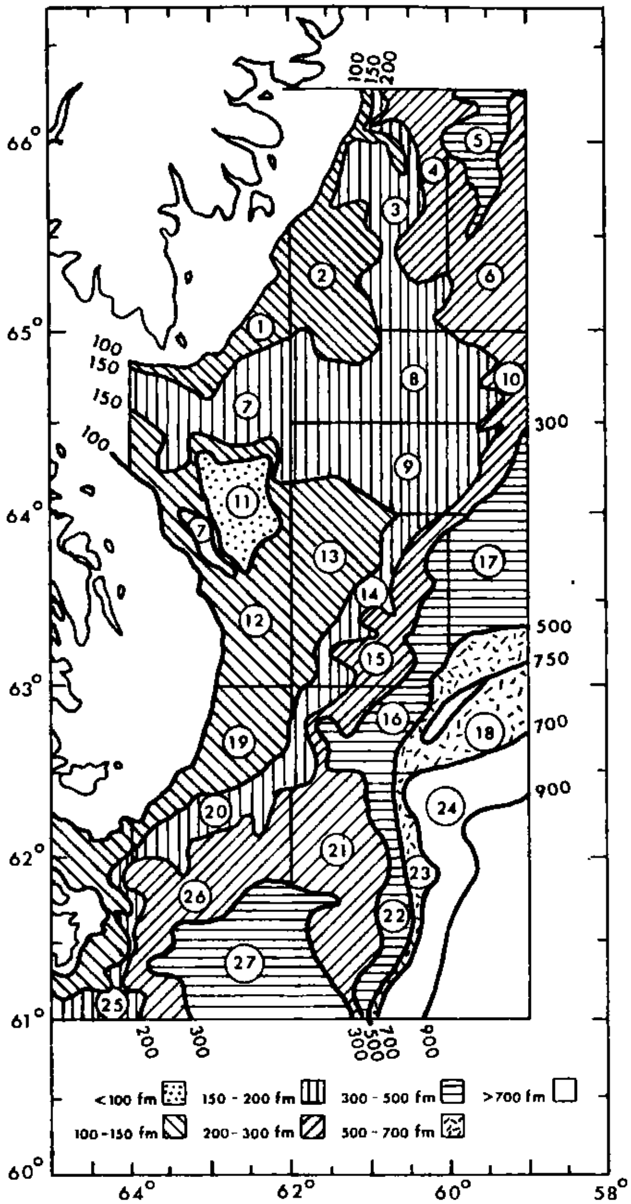

Fig. 1. Stratification scheme used for the groundfish survey in Statistical Area 0 by research vessel *Cryos* in September-October 1977. [Depth contours (fm) based on Canadian Chart No. 7011.]

calculated using the swept area method, in which the biomass (B) is given by

$$B = \Sigma B_i = \frac{\Sigma(\bar{Y}_i A_i)}{b}$$

where B_i = biomass in stratum i,
Y_i = mean yield in stratum i,
A_i = surface area of stratum i, and
b = mean area swept per tow (0.015 square nautical mile).

The size measurements of shrimp (total catches or random samples from large catches) were made to the nearest millimeter on berried and non-berried specimens separately, using the carapace length from the eye lobe to the dorsal posterior edge. The length frequencies of the groundfish trawl catches were grouped by strata. Those of the three shrimp trawl catches were combined to reflect the size composition of shrimp in the area of greatest concentration.

Cassie's (1954) method was applied to the size frequency distributions in an attempt to separate the different modal length groups and thus distinguish the age groups present in the catches.

Data for determining the relationship between total length and carapace length were obtained from the measurement (nearest mm) of 956 specimens. Data for the relationship between carapace length (mm) and the whole weight (hundredth of a gram) were obtained for 245 specimens.

Results

Distribution and abundance

Shrimp were taken in 25 sets of the groundfish trawl in 12 strata at depths of 243-519 m where the bottom temperature ranged from 0.5° to 3.0°C (Table 2) and the sediment consisted mainly of rough sand and pebble. The largest catches were obtained in strata 03, 06, 08 and 09, with average yield of 14.3, 5.5, 17.0 and 2.2 kg per 30-min set, in the depth range of 300-420 m (165-230 fm). The best catches were obtained in the northern strata between 64°10'N and 65°40'N (Fig. 2) but it was impossible to explore the same depth range in the northern part of stratum 03 due to compact ice conditions. Shrimp were absent or very scarce at the same depth range in the southern part of Statistical Area 0.

In the areas of large shrimp concentrations (strata 03 and 08), three sets were made with a research shrimp trawl with yields of 81, 27 and 49 kg per 30-min set in depths of 296-310 m (162-170 fm) with bottom temperatures from 0.6 to 0.8°C. In the strata where both trawls were used, the catches with the shrimp trawl were, on the average, 3.5 times the catches with the groundfish trawl.

Estimate of trawlable biomass

In allstrata where shrimp were taken, estimates of the biomass were calculated by the "swept area" method (Table 3). From these results, a minimum estimate of the shrimp biomass in the strata surveyed is about 4,000 tons. This estimate is very much a minimum estimate because a groundfish trawl was

TABLE 2. Basic data on catches of shrimp in groundfish survey off Baffin Island, September-October 1977.

Stratum No.	Mean position Lat.	Mean position Long.	Date	Mean time	Depth (m)	Bottom temp. (°C)	Catch/30 min N	Catch/30 min W (kg)
				Bottom trawl (50-mm codend mesh)				
01	65°00′	62°03′	23 Sep	16:50	300–306	1.3	9	0.2
03	65°17′	60°52′	24 Sep	07:29	300–305	0.7	2,167	23.0
	65°13′	60°01′	2 Oct	09:27	375–385	0.8	672	10.0
	65°01′	60°11′	2 Oct	13:02	330	0.6	442	10.0
04	65°39′	60°02′	30 Sep	14:51	512-519	1.2	26	0.5
	66°04′	60°01′	1 Oct	10:41	505-510	1.0	6	0.2
06	65°32′	59°15′	30 Sep	17:44	465–470	2.0	53	1.0
	65°09′	59°53′	2 Oct	07:28	405–420	1.2	942	10.0
07	64°51′	62°22′	23 Sep	10:36	415	—	28	0.5
08	64°43′	61°29′	25 Sep	07:28	325	2.0	1,647	27.0
	64°39′	61°00′	25 Sep	10:30	350–360	1.6	336	7.0
	64°42′	60°20′	25 Sep	15:08	373–360	1.1	1,918	29.0
	64°31′	60°24′	25 Sep	17:17	385–388	2.5	324	5.0
09	64°17′	59°36′	26 Sep	11:20	350–360	2.2	433	6.0
	64°09′	60°10′	4 Oct	07:32	344–356	2.5	34	0.5
	64°03′	60°22′	4 Oct	17:14	342-347	2.8	12	0.2
10	64°42′	59°05′	26 Sep	07:36	460–490	2.1	4	<0.1
	64°17′	59°22′	26 Sep	14:10	425	1.9	25	0.5
13	63°02′	61°57′	22 Sep	16:00	277	2.6	265	4.0
	63°58′	61°20′	3 Oct	07:32	243–245	1.9	13	0.2
14	63°03′	61°25′	22 Sep	18:14	340–350	3.0	10	0.2
	63°53′	60°28′	4 Oct	11:23	325–345	1.7	19	0.5
15	63°30′	60°32′	5 Oct	11:05	380	2.5	10	0.5
	63°13′	61°06′	15 Oct	08:05	430	2.4	2	<0.1
19	62°42′	62°26′	14 Oct	16:41	250–255	0.5	6	0.2
				Shrimp trawl (25-mm codend mesh)				
	65°03′	60°39′	24 Sep	14:15	306-307	0.6	6,360	81.0
	65°11′	60°50′	24 Sep	16:18	296-306	0.8	1,843	27.0
	64°57′	60°33′	2 Oct	17:07	305-310	0.7	5,128	49.0

TABLE 3. Biomass estimates for strata in which shrimp were caught in groundfish survey, September-October 1977.

Stratum No.	Area of stratum[1]	Number of sets	Biomass (tons)
01	536	2	4
03	1,136	3	1,085
04	742	2	17
06	1,252	3	306
07	1,336	1	45
08	1,666	4	1,888
09	1,524	3	227
10	660	2	13
13	1,390	2	195
14	560	2	13
15	824	2	16
19	1,192	2	8
		28[2]	3,817

[1] Square nautical miles.

[2] No shrimp taken in 3 sets (strata 01, 06, 19).

used with a 50-mm mesh codend which is considerably larger than 40-mm mesh codends commonly used in commercial shrimp trawls. As indicated by the larger catches in just three sets of the shrimp trawl, it is certain that a larger estimate of the biomass would have been obtained if the shrimp trawl had been used for the entire survey.

Composition of by-catches

The by-catches of commercial fish species taken with shrimp in the strata where the largest shrimp catches were made are given in Table 4. Among the 11 species caught, Greenland halibut, *Reinhardtius hippoglossoides*, and redfish, *Sebastes marinus mentella*, were the most significant. The length compositions of the by-catches of Greenland halibut and redfish in the groundfish and shrimp trawls are shown in Fig. 3. The Greenland halibut length

TABLE 4. By-catches in numbers (N) and weight in kg (W) of commercial fishes taken with shrimp by bottom and shrimp trawls during groundfish survey off Baffin Island, September-October 1977.

	Bottom trawl (50-mm codend mesh)								Shrimp trawl (25-mm mesh)	
	03		06		08		09			
Species	N	W	N	W	N	W	N	W	N	W
Pandalus borealis	1,094	14	332	4	1,056	17	160	2	4,468	52
Gadus morhua	—	—	—	—	—	—	—	—	—	—
Boreogadus saida	—	—	—	—	1	0	—	—	13	0
Macrourus berglax	1	1	3	1	—	—	9	3	—	—
Anarhichas minor	1	1	—	—	1	1	1	3	—	—
Anarhichas denticulatus	—	—	—	—	1	4	—	—	1	2
Lycodas sp.	5	1	2	0	1	0	1	0	5	1
Sebastes marinus mentella	35	1	91	7	243	12	34	2	186	2
Hippoglossoides platessoides	7	2	1	0	1	1	1	0	31	8
Reinhardtius hippoglossoides	175	21	141	44	250	31	93	30	218	18
Raja radiata	1	1	—	—	3	0	—	—	1	0
Raja spinicauda	1	0	1	0	—	—	1	0	3	0

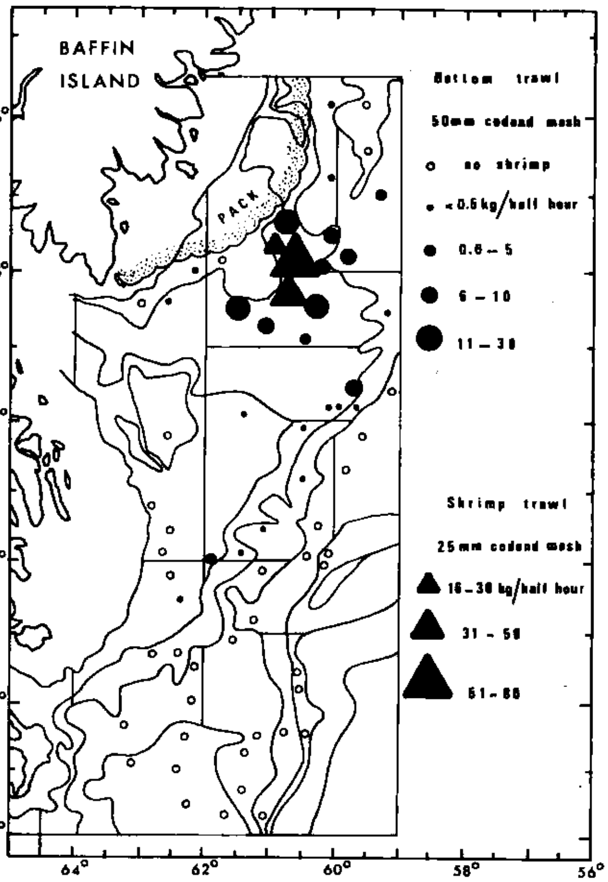

Fig. 2. Positions of stations occupied by the *Cryos* during a groundfish survey in Statistical Area 0 in September-October 1977, and the catches of shrimp in relation to the gear used.

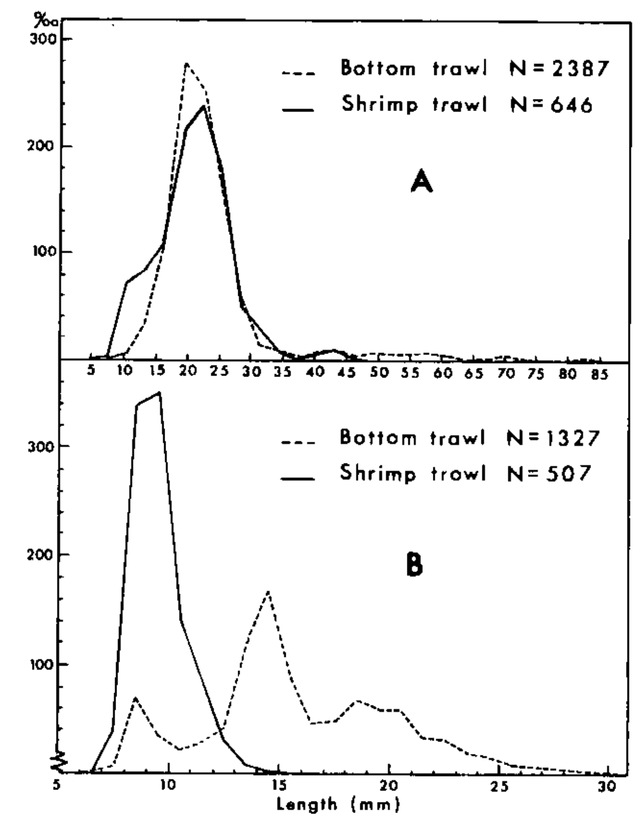

Fig. 3. Length frequencies of Greenland halibut (A) and redfish (B) taken as by-catches with shrimp in areas of shrimp concentrations in Statistical Area 0, September-October 1977.

frequencies are very similar for both gears, except that more larger specimens were caught in the bottom trawl. For redfish, on the other hand, the length frequencies are very different; specimens taken in the shrimp trawl were 7–15 cm with a modal size of 9 cm, whereas those in the groundfish trawl catches ranged in size from 6 to 30 cm with the main mode at 14 cm, representing a year-class not evident in the shrimp trawl catches.

Length composition of shrimp catches

The length frequencies of shrimp taken with the groundfish and shrimp trawls (Fig. 4) are very similar with modes at 17-18, 23 and 30 cm. An indication of a modal group at 13 cm in the groundfish trawl frequency is not evident in that of the shrimp trawl. However, the proportion of ovigerous females in the groundfish trawl samples (37%) was considerably higher than that for the shrimp trawl (17%).

The length distributions of shrimp from the groundfish trawl catches in the four strata (03, 06, 08 and 09) where shrimp were concentrated (Fig. 5) reveal the same four modes in one or more strata, their relative importance varying by strata. The proportions of ovigerous females by strata were as follows: 35% in 03, 45% in 06, 34% in 08 and 58% in 09.

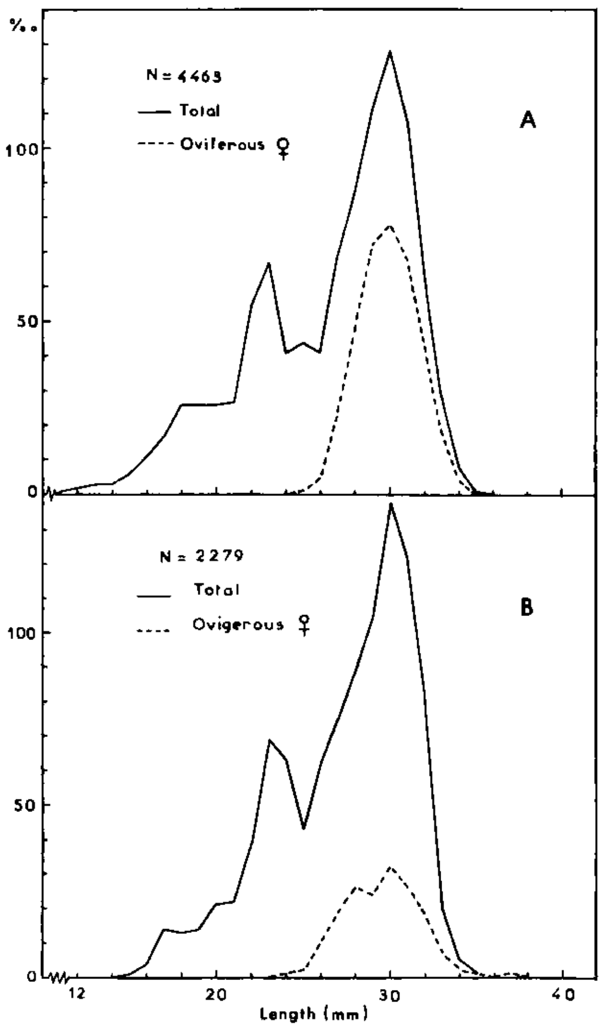

Fig. 4. Length frequencies of shrimp caught with groundfish trawl (A) and shrimp trawl (B) during the groundfish survey in Statistical Area 0, September-October 1977.

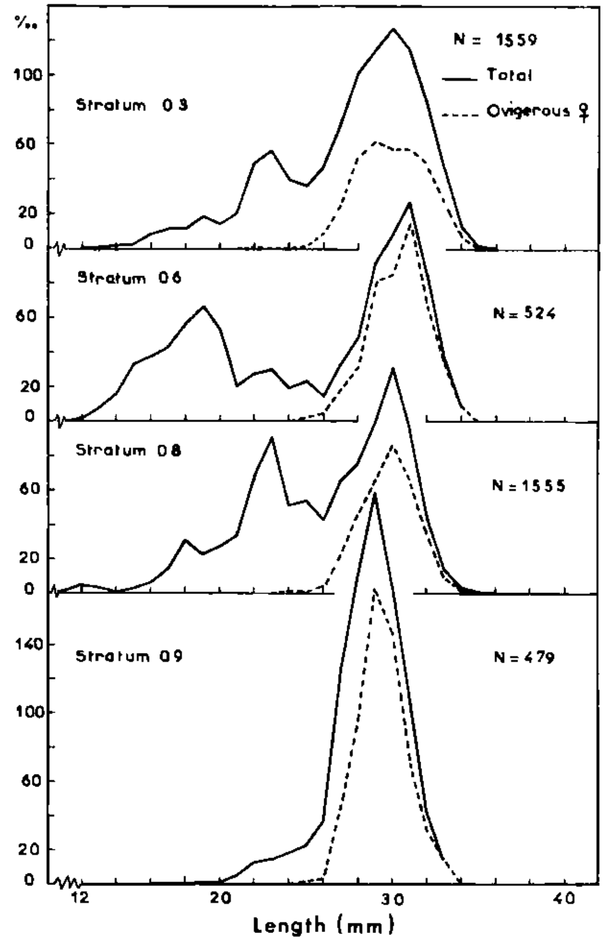

Fig. 5. Length frequencies of shrimp caught with the groundfish trawl in four strata of Statistical Area 0, September-October 1977.

Identification of age-groups

The application of Cassie's (1954) method to the length frequencies of Fig. 5 gives the following percentages of shrimp in the modal length groups for each stratum:

Modal length group (mm)	Strata 03	06	08	09
12	1	0	1	0
18-19	6	36	10	1
23	19	9	37	8
29-31	74	55	52	91

An analysis of the combined frequency for all strata in which shrimp were caught (Fig. 4A) indicates mean carapace lengths of the four modal groups at 12.9, 17.9, 23.1 and 29.5 mm with standard deviations of 1.05, 1.40, 1.10 and 1.83 respectively.

The last group (mean length at 29.5 mm) is composed entirely of females, the greater part of which is ovigerous. It is likely that this group represents an accumulation of several year-classes (Horsted, 1978). However, if the natural mortality after 5 years of age is very high, as occurs at West Greenland (Smidt, 1965), this group is likely to be composed mainly of 5-year-old shrimp.

In the group with mean length of 23.1 mm, a small number of ovigerous females were noted, mainly in stratum 03, indicating the beginning of the transitional stage from males to females. Since it is known that some individuals become ovigerous at age 4 (Carlsson and Smidt, 1978), this group presumably consists of 4-year-old shrimp. Therefore, the group with a mean length of 17.9 mm is mainly constituted of 3-year-old males and the group at 12.9 mm of immature individuals.

Length-weight relationship

The relationship between carapace length (L_c) and whole weight (W) of 245 shrimp, ranging in length between 14 and 35 mm (Fig. 6), was determined by the least squares regression of the natural logarithms of the pairs measurements. The logarithmic and exponential relationships are as follows:

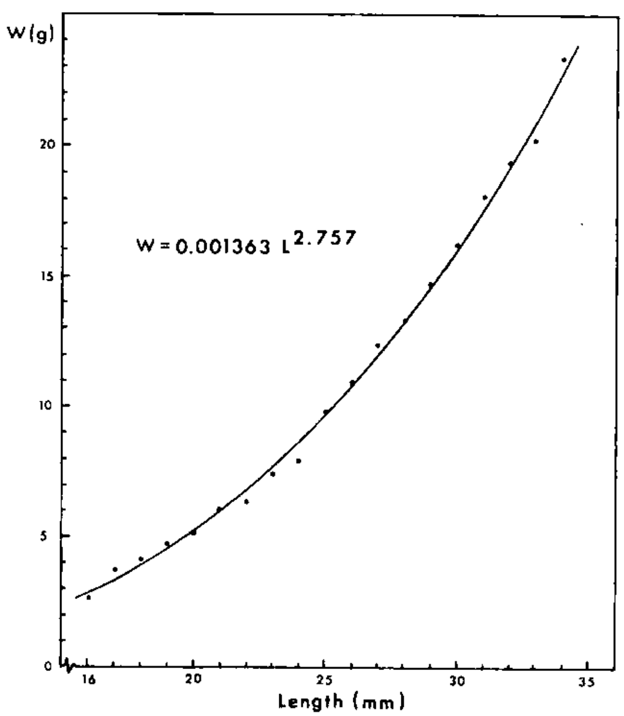

Fig. 6. Length-weight relationship for shrimp caught in Statistical Area 0, September-October 1977.

$$ln(W) = 2.757\ ln(L_c) - 6.598$$

$$W = 0.001363\ L_c^{2.757}$$

The correlation coefficient (r) for the log-log regression is 0.99.

Total length *versus* carapace length

Biometric observations on 956 specimens to determine the relationship between the total length (L_t) and the carapace length (L_c) in shrimp resulted in the linear equation:

$$L_c = 0.273\ L_t - 1.958$$

with a correlation coefficient (r) of 0.99.

Conclusions

From the results of a groundfish survey by the research vessel *Cryos* in Statistical Area 0 in the autumn of 1977, significant concentrations of shrimp were found and the following conclusions were made:

1. Shrimp are concentrated mainly in the northern part of Statistical Area 0 at depths of 300–420 m. The largest catches were taken in four strata between latitudes 64°10′ and 65°40′N, with smaller catches as far south as 63°00′N. It is possible that the shrimp off Baffin Island represent the southwestern extension of a stock which may extend over a horseshoe-shaped area to the north of Statistical Area 0 and across the Davis Strait ridge to West Greenland.

2. On the basis of the catch rates of shrimp with groundfish trawl, a minimum estimate of the biomass in the area is about 4,000 tons. This estimate is very much a minimum estimate due to the use of a groundfish trawl with a codend mesh of 50 mm, which is about 10 mm larger than the codend mesh size of commercial shrimp trawls.

3. The catches of shrimp were composed of four modal length groups with mean lengths at 12.9, 17.9, 23.1 and 29.5 mm, corresponding to age-groups 2, 3, 4 and 5+ respectively.

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A Trawl Survey of the Offshore Shrimp Grounds in ICNAF Division 1B and an Estimate of the Shrimp Biomass[1]

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Abstract

A stratified trawl survey of the offshore shrimp grounds off West Greenland between 66° and 69° N lat was made in July 1976. On the basis of data from 44 trawling stations, the fishable biomass of shrimp, *Pandalus borealis*, in the area surveyed was estimated by the "swept area" method to be about 55,000 tons. Although corrections were made for diurnal variation, the estimate is probably a minimum one due to the assumption that all shrimp of fishable size above the swept area are retained by the trawl.

Introduction

Research surveys of the offshore shrimp grounds at West Greenland have shown that the most extensive grounds are found in ICNAF Divisions 1A and 1B (Carlsson and Smidt, 1978). Catch statistics and other available information (Hoydal, 1978; Fuertes and Lopez-Veiga, MS 1976; Berenboim *et al*., MS 1976) clearly show that the greatest fishing effort was applied in Div. 1B in 1975. Consequently, the research work of 1976 was concentrated in this important area.

A part of the research effort involved a trawl survey in July 1976 by the stern trawler *Sisimiut*, kindly placed at the disposal of the Greenland Fisheries Research Laboratory by the Royal Greenland Trade Department. Since this trawler fished shrimp commercially for some months in 1976, the vessel was equipped with shrimp fishing gear and the captain and crew were experienced in shrimp fishing. The author and one technician participated in the survey.

Material and Methods

The area covered by the survey extended from 66° to 69° N lat and as far west as the 600 m contour line although fishing to the west of 59° W long was impossible on account of drift ice (Fig. 1). The positions of 50 trawling stations were selected before the start of the survey, based on a map with 10 m contours supplied by the Geological Survey of Greenland. The distribution of stations was made to cover various depths and latitudes, and in all cases the actual depths at the pre-selected positions corresponded extremely well with the expected depths. The commercial gear used made trawling possible at most stations. Only in a few cases was the bottom, as recorded by echo-sounder, considered too rough for trawling. Some desired stations west of 59° W long between 68 ° and 69° N lat could not be occupied because of drift ice.

The gear used was the "Fjortoft Sputnik" otter trawl with 43 m headline and 51 m footrope. One trawl haul, normally of 1 hour's duration and at a speed of 3 knots, was made at each station. After each haul, the catch was sorted and handled by the crew in the normal commercial way, and the relevant information recorded in the fishing logbook. The catch of shrimp was recorded in units of boxes, each containing about 30 kg. A sample of about 2 kg was taken from each haul and frozen for later analysis. The by-catches of fish by species and of invertebrates other than *Pandalus borealis* were estimated by the observers, and, in most cases, samples for length frequencies were taken of redfish and Greenland halibut. Analysis of the by-catch data has not yet been completed.

Of the pre-selected stations, 44 were occupied during the survey. Furthermore, 2 days were set aside for the vessel to fish commercially at a place chosen by the captain. Eight commercial hauls were made in the vicinity of 67°15'N, 56°45'W, where about 25 larger trawlers of various nationalities were fishing for shrimp at the time.

On the basis of the map mentioned above and observations from the survey, a preliminary stratification of the surveyed grounds was designed and the area of each stratum estimated. For the purpose of estimating the shrimp biomass in each stratum, the catches from all hauls were converted to catch per hour fishing (most hauls were actually 1

[1] Submitted to the November 1976 Special Meeting as ICNAF Res. Doc. 76/XII/150.

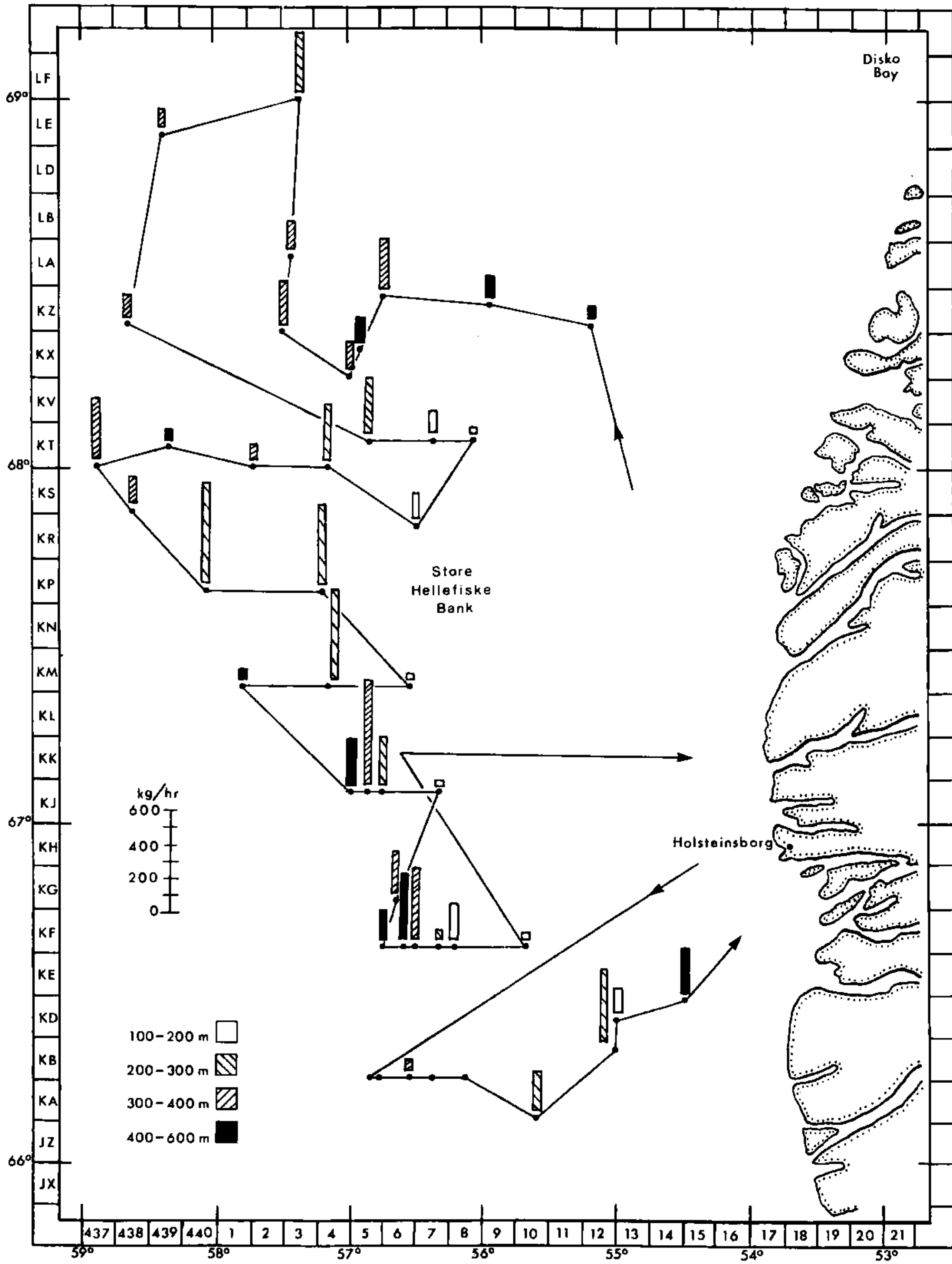

Fig. 1. Cruise track of *Sisimiut* survey off West Greenland in July 1976, showing positions of stations and catches per hour trawling by depth zones.

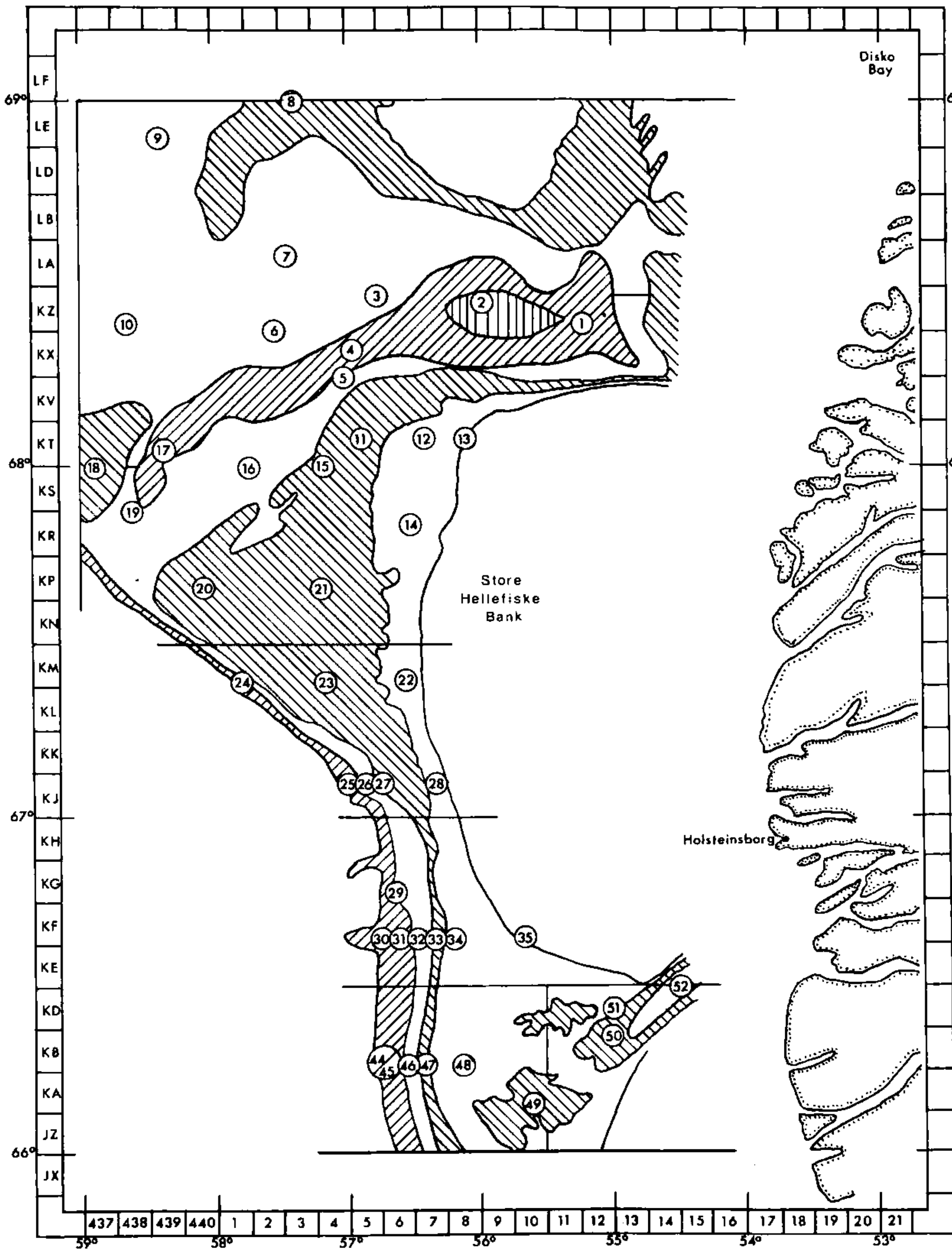

Fig. 2. Preliminary stratification of shrimp grounds covered by *Sisimiut* survey off West Greenland in July 1976. (Positions of stations are indicated by numbers which correspond to the haul numbers listed in Table I.)

TABLE 1. Catches of shrimp per hour trawling by *Sisimiut* in July 1976 corrected for diurnal variation, arranged to give the mean catch per hour, depth range, approximate area and estimate of the shrimp biomass in each stratum. (Positions of trawling stations are shown in Fig. 1 and the various strata in Fig. 2.)

Stat. No.	Date in July	Time of hauling	Depth (m)	Catch per hr (kg)	Diurnal variation factor	Adjusted catch/hr (kg)	Average catch/hr (kg)	Depth of strata (m)	Area of strata (km^2)	Biomass estimate (tons)
8	14	2135-2235	265	315	1.66	523	523	200-300	2,475	7,751
3	14	0715-0815	380	280	1.19	333	215	300-400	7,705	9,920
6	14	1545-1645	330	240	1.04	250				
7	14	1815-1915	350-380	150	1.21	182				
9	15	0135-0235	330	100	1.63	163				
10	15	0540-0640	320	120	1.25	150				
1	14	0015-0115	450	80	1.80	108	115	400-500	3,000	2,066
4	14	0950-1110	475	135	1.08	146				
17	16	0205-0305	435	60	1.50	90				
2	14	0240-0340	530	150	1.50	225	225	500-550	355	478
5	14	1305-1405	350	150	1.02	153	166	300-400	2,930	2,912
16	16	2345-0045	350-360	90	1.80	162				
19	16	0630-0730	340-370	150	1.21	182				
18	16	0405-0500	300-310	360	1.33	479	479	250-300	515	1,477
11	15	1210-1310	225	300	1.02	306	489	200-300	3,665	10,731
15	15	2110-2210	265	330	1.53	505				
20	16	0940-1040	280-290	600	1.09	654				
21	16	1215-1315	220	480	1.02	490				
12	15	1400-1500	160	120	1.00	120	151	150-200	1,615	1,460
14	15	1845-1945	185-195	150	1.21	182				
13	15	1600-1700	140-160	35	1.05	37	37	Borderline		
22	16	1510-1610	160-170	30	1.01	30	27	150-200	450	73
28	17	0700-0800	170	20	1.21	24				
23	16	1740-1840	230	540	1.16	626	497	200-300	1,565	4,658
27	17	0500-0610	265	280	1.31	367				
24	16	2115-2215	475	55	1.55	85	268	400-600	300	513
25	17	0015-0115	450-460	270	1.80	486				
26	17	0215-0315	350	630	1.50	945	945	300-400	450	2,546
30	17	1220-1320	550	180	1.02	183	287	400-600	520	894
31	17	1410-1510	450	390	1.00	390				
29	17	0905-1105	390-400	270	1.10	297	369	300-400	520	1,149
32	17	1555-1655	340-350	420	1.05	441				
33	17	1735-1835	255	80	1.14	68	68	200-300	300	122
34	17	1910-2010	170-190	210	1.25	263	263	150-200	1,270	2,000
35	17	2100-2200	128-135	35	1.47	51	51	Borderline		
44	20	1500-1600	550	0	1.00	0	0.5	400-600	615	2
45	20	1650-1750	450	0.5	1.05	0.5				
46	20	1830-1945	350	48	1.21	58	58	300-400	230	80
47	20	2020-2125	225	4	1.47	8	6	200-300	310	11
48	20	2200-2330	170	3	1.80	5	5	150-200	2,470	74
49	21	0045-0145	205-210	240	1.80	432	511	250-300	1,155	3,534
50	21	0350-0500	245-250	437	1.35	590				
51	21	0545-0645	168-195	150	1.24	186	186	150-200	1,545	1,720
52	21	0750-0855	420	250	1.15	288	288	300-500	230	397
Total area/biomass									34,190	54,568

hour's duration) and conversion factors applied to take account of diurnal variation. As indicated by Hoydal (1978), the trawl was assumed to sweep a sector 30 m wide, and therefore the area swept at a speed of 3 knots is estimated to be 0.167 km^2 per hour trawling. Fishermen and gear manufacturers consider this estimate to be a reasonable one.

Survey observations

Figure 1 shows the cruise track of the *Sisimiut* during 14-21 July 1976, including the positions of the stations fished and the unadjusted catches per hour trawling at various depth ranges. The best catches were generally obtained at depths between 200 and 400 m. Catches were small in depths less than 200 m and greater than 400 m except for three hauls over 400 m in the southern part of the area surveyed. Relevant information on the catches, arranged according to the preliminary stratification of the area (Fig. 2), are given in the first five columns of Table 1.

Diurnal variation

It was quite obvious from the results of the survey that the variation in catch per hour by depth and station was considerable and that this variation made in unrealistic to use the material for analysis of diurnal variation in catches. Consequently, the information derived from the eight commercial hauls during this survey and from other commercial fishing by the vessel in the same division and month before and after the survey were used (Smidt, 1978). These data are illustrated in Fig. 3. The highest density (or availability) of shrimp on the bottom occurred in early afternoon with lower catch rates at night. Although

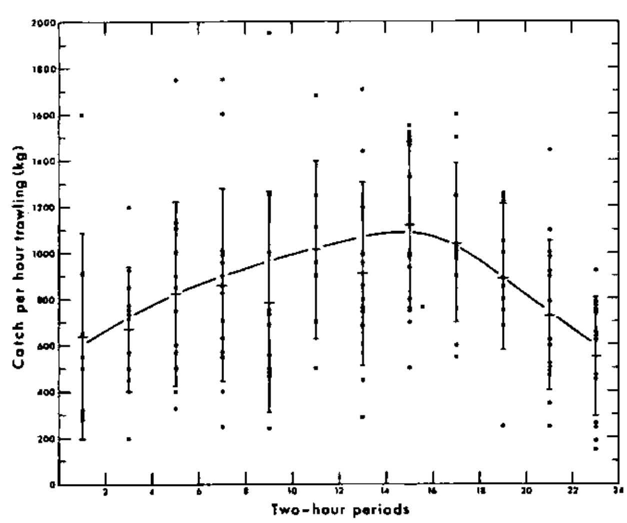

Fig. 3. Catches per hour trawling in commercial fishing by *Sisimiut* in Div. 1B in July 1976. (Each dot represents a haul; the mean and standard deviation for each 2-hour period are indicated by vertical lines.)

TABLE 2. Conversion factors for dirunal variation of shrimp catches, July 1976.

Time of day (hr)	Catch/hr (kg)	Conversion factor
0-2	600	1.80
2-4	720	1.50
4-6	815	1.33
6-8	890	1.21
8-10	950	1.14
10-12	1,010	1.07
12-14	1,060	1.02
14-16	1,080	1.00
16-18	1,030	1.05
18-20	890	1.21
20-22	735	1.47
22-24	600	1.80

there is considerable variation within each 2-hour period, it is clear that the results of the survey would be biased if diurnal variation is neglected. The factors used to account for diurnal variation in catches are given in Table 2. In applying these conversion factors to the survey results, if a haul overlapped two of the 2-hour periods, a weighted mean conversion factor was calculated from the hauling time within each of the standard periods. Diurnal variation factors applied to the survey catch rates are listed in Table 1.

Estimation of shrimp biomass

Under the assumption that the trawl swept an area of 0.167 km^2 per hour, and using the average catch rates and sizes of strata listed in Table 1, estimates of the shrimp biomass in the various strata were calculated, the estimate for the area as a whole being 55,000 tons. It is important to note that the biomass estimates are based on the assumption that the average catch rate for the stations within a stratum would be expected in all parts of the stratum. Furthermore, these estimates represent the exploitable biomass only, with no adjustments for the selective action of the gear used.

Commercial fishing in 1976

The time set aside for commercial fishing during the survey by *Sisimiut* resulted in eight hauls being made on 18 July at approximately 67° 15'N, 56° 45'W where about 25 large trawlers were fishing for shrimp (Table 3). The average adjusted catch per hour trawling commercially (882 kg) was somewhat higher than the average (600 kg) of three hauls (no. 25, 26 and 27) made in the general area during the survey.

During several months in 1976 both before and after the survey, the *Sisimiut* fished shrimp commercially (Table 4). For all months in which significant fishing took place, the average catch rate remained relatively stable, the highest being recorded

TABLE 3. Commercial shrimp fishing by *Sisimiut* on 18 July 1976 in the general vicinity of 67°15'N, 56°45'W.

Trawling time	Actual catch (kg)	Catch per hr (kg)	Diurnal variation factor	Adjusted catch/hr (kg)
0045–0150	400	369	1.80	664
0230–0435	2,500	1,200	1.45	1,740
0505–0710	1,800	864	1.26	1,089
0745–0945	960	480	1.15	552
1045–1245	900	450	1.05	473
1320–1520	1,000	500	1.01	505
1605–1805	1,800	900	1.06	954
1830–1945	1,000	800	1.21	968
Weighted average		773		882

in September. An interesting feature of the fishing activity in 1976 was the gradual northward shift from about 66°N lat in January to about 68°N in October.

Discussion

The method used to estimate the biomass excludes those shrimp which are too small to be retained by the trawl, and no correction for selectivity has been made. This in itself would tend to give an underestimate of the biomass. The method further assumes that all shrimp (of trawlable sizes) found within or above the sector swept by the trawl are actually caught. However, some shrimp may be so far off the bottom that they escape the trawl, but the correction for diurnal variation does, at least to some extent, take this into account. Also, it is not known to what extent shrimp may actively escape from the target area just before the trawl gets there or to what extent the large bobbins on the footrope allow some shrimp to escape below the net.

The fishing fleet is often concentrated in a very small area, and, if all shrimp in the paths of the trawls were retained, a very rapid decline in catches would be expected within a short period. For example, an area of about 1,500 km^2 may often be fished for about 9,000 trawling hours, corresponding roughly to the fishing activity of 20–25 trawlers in a month and also corresponding roughly to a total swept area of about 1,500 km^2. Although the reduction in the initial stock size due to fishing may to some extent be compensated for by immigration from adjacent areas, the lack of an abrupt decline in catch rates possibly demonstrates that not all of the shrimp in or above the swept area are retained in a haul. This points to the likelihood that the biomass estimate is a minimum estimate of the stock size.

Berenboim *et al.* (MS 1976) consider that vertical distribution is a major factor in the estimation of biomass. However, although it is clear that diurnal variation in catches occurs (Fig. 3), it cannot be taken for granted that all echo-scatterers observed above the bottom on the shrimp fishing grounds are due to shrimp. The R/V *Adolf Jensen* in June 1976 made two hauls by pelagic trawl in areas where two different types of echo-scatterers were observed (Kanneworff, MS 1976). A 30-min haul on 17 June in Div. 1B at 180–190 m in the shrimp fishing area contained a pure catch of small redfish (620 kg or 26,000 specimens).

TABLE 4. Catch per haul (kg) in the commercial shrimp fishery of the *Sisimiut* during 1976. (Number of hauls in parentheses; duration of each haul approximately 2 hours; latitude is given by rectangle code of Fig. 2.)

Lat.	Jan	Feb	May	June	July	Aug	Sep	Oct
KS	—	—	—	—	—	—	—	1,100 (17)
KR	—	—	—	—	—	—	—	825 (24)
KP	—	—	—	—	—	—	1,430 (23)	836 (42)
KN	—	—	—	—	—	—	1,048 (40)	850 (36)
KM	—	—	—	1,305 (20)	—	903 (244)	1,502 (60)	780 (10)
KL	—	—	—	1,032 (53)	1,525 (36)	790 (49)	1,559 (51)	225 (4)
KK	—	—	—	1,061 (66)	847 (47)	100 (2)	200 (1)	320 (5)
KJ	—	—	—	1,189 (45)	805 (142)	383 (6)	200 (1)	967 (3)
KH	—	—	—	688 (8)	629 (51)	725 (4)	—	—
KG	175 (4)	—	—	722 (9)	—	—	—	—
KF	300 (5)	—	550 (6)	687 (15)	—	—	—	—
KE	—	—	—	460 (45)[1]	—	—	—	—
KD	100 (1)	—	—	789 (18)	—	—	—	—
KB	907 (15)	—	—	691 (11)	—	—	—	—
KA	947 (17)	200 (2)	—	—	—	—	—	—
JZ	1,316 (92)	786 (21)	—	—	—	—	—	—
JX	—	—	—	—	—	—	—	—
JV	100 (1)	—	—	—	—	—	—	—
Avg.	1,135 (135)	735 (23)	550 (6)	928 (290)	874 (276)	867 (305)	1,391 (176)	833 (141)

[1] Inner part of Holsteinsborg Deep.

The second haul on 18 June in Div. 1C at 180–190 m contained several liters of euphausids only. Since by far the majority of the euphausids would have escaped through the meshes of the trawl, it is considered that the echo-scatterer was a dense concentration of euphausids. Therefore, further information on echo-scatterers and vertical distribution of shrimp are necessary before this factor can be properly taken into account.

Catch rates in the commercial fishery of the *Sisimiut* throughout 1976 were generally higher than those in the survey. This is, of course, primarily due to the fact that fishermen choose the best places for their fishing, but could to some extent also be due to a difference in the duration of the haul. Nearly all survey hauls were 1-hour hauls, reckoned from the minute when the easing of the trawl was stopped to the minute when hauling started. No consideration has been given to the possible lag time between the minute when the winch was stopped to the time when the trawl was actually on bottom and fishing. Each minute of lag time per hour would add about 1,000 tons to the biomass estimate, but the lag time in any haul is not supposed to be more than 5 min. No information exists as to whether the trawl gradually fishes better or worse as the catch accumulates with time.

Probably the most remarkable feature of the survey is the nearly complete absence of shrimp at some of the fishing stations (Fig. 1), at or near which the *Sisimiut* had rather good catches earlier in the year (Table 4). The average catch rate during the day of commercial fishing on 18 July, in the area where 25 large trawlers were concentrated, was well above the level of most of the survey hauls although not so much higher than those survey hauls near the area of commercial fishing. As indicated by the distribution of fishing activity by the *Sisimiut* in 1976 (Table 4) and other observations, there was a gradual northward movement of the commercial fleets during the 1976 fishing season.

In 1971, the R/V *Adolf Jensen* surveyed a part of the area covered by the 1976 *Sisimiut* survey, six hauls having been made at various depths between 66° and 68° N lat (Table 5). Only one of these hauls produced a reasonably good catch. Although the depths fished at that time were generally greater than those fished by the commercial fleets, the results of both surveys indicate that great variation in shrimp abundance occurs between years, within years and between grounds. The same situation was experienced by the R/V *Dana* in the deep north of Store Hellefiskebanke where catches were good in 1964, but where an attempt to introduce the ground to Greenland fishermen in 1966 failed because of poor catches.

TABLE 5. Shrimp catches in trawl hauls of R/V *Adolf Jensen* west of Store Hellefiskebanke, 1971.

Date	Rectangle (Fig. 1)	Depth (m)	Trawling time	Catch/hr (kg)
24 Jul	JZ 5	670	1525–1628	7 spec.
4 Aug	KB 6	480	1522–1622	6 spec.
5 Aug	KG 6	530	0951–1015	4.8
6 Aug	KK 6	300–340	1607–1707	38.0
10 Aug	KP 438	350	1336–1436	112.0
11 Aug	KL 3	500–570	1630–1730	2.5

The experience in 1964 and 1966 is probably explained through hydrographical observations. The hydrographic situation off West Greenland in 1966 was characterized by unusually warm water to the west of the banks, and this warm current extended into Disko Bay where bottom temperatures were about 1.5°C above the normal of about 2°C (Hansen, 1967a). Hansen (1967b) stated that the shrimp catches in Disko Bay were unusually high in 1966 and indicated, as a likely explanation, that warm bottom currents transported great quantities of shrimp from the Davis Strait grounds to Disko Bay. Hermann (1967) reported that this warm current along the West Greenland coast could be followed from 1963 to 1966, when it culminated in Div. 1B and in Disko Bay.

It is possible that currents of suitable temperatures keep the shrimp concentrations in constant movement, sometimes distributed widely over the fishing grounds and sometimes concentrated on more specific parts of the grounds. In any case, the fishermen are likely to find the best concentrations for fishing, and the use of commercial data, if extrapolated to cover large areas outside the limited areas in which fishing occurs in any short period of time, would lead to overestimation of the biomass (and hence the potential yield) in the area as a whole.

Considering the methods used and the reasons given above, it must be stressed that the biomass estimate for the area surveyed is likely to be an underestimate of the stock and that the estimate applies only to the situation in July 1976. There is no guarantee that the estimate represents the standing crop in the area.

Acknowledgements

My sincere thanks are due to the captain and crew of the *Sisimiut* for their great help and good cooperation during the survey, and to the Royal Greenland Trade Department for making it possible to use the vessel for this survey. Mr K. P. Nielsen was a most effective technician on board during the survey, and my colleagues at the Institute have been of great help in preparing and discussing the material for this paper.

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An Assessment of the Deep Sea Shrimp, *Pandalus borealis*, Stock off West Greenland[1]

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Abstract

The catch per unit effort in the Faroese fishery off West Greenland in 1975 is based on the analysis of 5,828 hauls of shrimp trawlers. Estimates of the area swept by the trawl in 1 hour and of the sizes of the shrimp fishing grounds were used to estimate the biomass of shrimp on the offshore fishing grounds. The resultant biomass estimate of 86,000 tons is considered to be a minimum for several reasons given.

Introduction

The commercial fishery on deep sea shrimp off West Greenland was initiated by Faroes trawlers in 1969. Norwegian vessels entered the fishery in 1972, and Spanish and USSR vessels began fishing there in 1974. Consequently, the total nominal catch of shrimp on the offshore grounds increased rapidly from 2,000 metric tons in 1972 to 42,000 tons in 1976.

Knowledge of the shrimp fishery has increased considerably in the most recent years due to the introduction of larger and more efficient vessels, and the fishing grounds have been extended due to the ability of vessels to trawl on rougher bottom than in the early years of the fishery. By the end of 1975, 11 Faroese trawlers were participating in the fishery. Research on shrimp at the Faroes Fisheries Laboratory began in 1976 with the placing of observers on board of commercial vessels and the sampling of catches. Catch data on a haul-by-haul basis exist since 1973. Trawler captains are required to send a copy of their fishing logsheets to the Fisheries Laboratory, where the data are processed and stored in the data bank of the local FISKHAG ADP-system.

Materials and Methods

The total nominal catch of shrimp by Faroese vessels off West Greenland in 1975 was 5,300 tons, of which catch and effort data for about 3,500 tons have been processed and form the data base for this study. The catches are reported on the logsheets by small statistical areas of 0.5° latitude and 1° longitude. To define precisely the grounds fished by Faroese vessels, two of the most experienced skippers outlined the limits of these grounds on a chart. The sizes of the grounds are given in Table 1. On the basis of logbook returns, the catch per hour trawling (CPUE) by month and division was computed. The average CPUE for each division was obtained by weighting the monthly CPUE's by the corresponding catches.

The larger Faroese shrimp trawlers use a 1800-mesh "Sputnik" trawl with a groundrope of 51 m. Information from the manufacturers indicate that the average width of the sector swept by the trawl is about

TABLE 1. Estimated size of grounds with commercial concentration of shrimp fished by Faroese vessels in Subarea 1.

ICNAF Div.	Name of grounds	Size of area, km^2
1B	Northern edge Store Hellefiske Bank	2,200
	West of Store Hellefiske Bank	3,700
	Holsteinsborg Deep	1,700
	Small area at 68° N, 58° W	600
	West of Lille Hellefiske Bank	800
	Total (Div. 1B)	9,000
1C	Sukkertoppen Deep	2,300
1D+1E	Frederikshåb Deep	500
	Godthåb	1,000
	Dana Deep	300
	Fiskenas Deep	800
	Off Qingigtuarssuk	300
	Edge of Frederikshåb	300
	Total (Div. 1D+1E)	3,200

[1] Submitted to the June 1976 Annual Meeting as ICNAF Res. Doc. 76/VI/15.

30 m. The towing speed is usually about 3 miles per hour. Therefore, the area swept by the trawl in one hour is estimated to be 0.167 km². The fishable stock size is estimated by the expression:

$$\frac{\text{Size of fishing grounds} \times \text{CPUE}}{\text{Area swept by trawl per hour.}}$$

Results

The basic catch per unit effort data used in the calculations are given in Table 2. The results of the calculations are as follows:

Parameter	Divisions 1B	1C	1D+1E
Weighted average CPUE (tons/hr)	0.721	0.368	0.263
Size of fishing grounds (km²)	9,000	2,300	3,200
Estimate of standing stock (tons)	39,000	5,000	5,000

It is estimated that the stock biomass in the areas fished by Faroese trawlers in 1975 was 49,000 tons. To obtain an estimate of the total biomass of shrimp on the offshore fishing grounds, it was necessary to include the size of certain grounds not fished by Faroese vessels. These grounds represent about 17,000 km², according to Carlsson and Smidt (1978). Using the intermediate value of 0.368 tons per hour (Div. 1C), the additional stock biomass is estimated at 37,000 tons. Thus, the total stock biomass on the grounds fished by Faroese vessels and outside these grounds is estimated at 86,000 tons.

Discussion

The estimate of the stock size of shrimp exploited off West Greenland, based on data for 1975, must be considered a minimum estimate for the following reasons:

a) The estimate is based on the assumption that the trawl effectively catches every shrimp in the area swept.

b) The model does not take into account the vertical distribution of shrimp which may exceed the height of the trawl headline.

c) The CPUE estimates are based on 11 vessels with very different performances. If the data for the most efficient two or three vessels were used, the CPUE's would be higher with a consequent increase in the stock size estimate.

d) Faroese skippers tend to underestimate their catches, as evidenced by an analysis of logbook records in which the estimates are about 10% lower than actual landings in the cod fishery and 15% lower in the industrial fishery.

e) The value used for the area swept is critical, as an underestimate of this parameter would result in overestimation of the stock size. To minimize this risk, the area swept was based on the trawl used by the largest vessels.

The minimum estimate of the stock in the order of 80,000–90,000 tons is rather a crude estimate considering the assumptions involved. With more detailed information on the fishery and on the distribution of shrimp it would be possible to develop a more complex model which takes into account such factors as variation in trawl size, speed of tow, weather conditions, vertical and seasonal distribution of shrimp, etc. However, a more serious problem is

TABLE 2. Catch (metric tons) and catch per hour fishing (CPUE) by month and ICNAF division for 11 Faroese trawlers off West Greenland, 1975. (Average CPUE's are weighted by the monthly catches.)

Month	1B Catch	1B CPUE	1C Catch	1C CPUE	1D Catch	1D CPUE	1E Catch	1E CPUE	1 (NK) Catch	1 (NK) CPUE	Total catch
Jan	231	0.585	4	0.240	106	0.152	<1	0.045	1	0.110	342
Feb	273	0.814	28	1.003	100	0.232	—	—	—	—	401
Mar	—	—	1	0.105	60	0.186	—	—	—	—	61
Apr	—	—	—	—	—	—	—	—	—	—	—
May	164	1.067	8	0.341	—	—	—	—	—	—	172
Jun	312	0.614	4	0.080	39	0.182	—	—	25	0.771	380
Jul	656	0.975	129	0.338	220	0.292	163	0.408	19	0.304	1,187
Aug	—	—	—	—	—	—	—	—	18	0.260	18
Sep	—	—	—	—	—	—	—	—	—	—	—
Oct	183	0.372	50	0.165	135	0.252	98	0.332	—	—	466
Nov	274	0.677	—	—	—	—	—	—	—	—	274
Dec	269	0.320	6	0.098	61	0.147	44	0.145	—	—	380
Total	2,362	(0.721)	230	(0.368)	721	(0.229)	305	(0.345)	63	(0.474)	3,681

determining how the current estimate of the stock size relates to the true situation under conditions of a rapidly developing fishery. The offshore fishery began in 1969 but not many vessels participated before 1974. The problem then is whether the current estimate of stock size should be considered as an estimate of the virgin stock, the accumulated biomass which is being fished, or an estimate of a stock in the kind of equilibrium that would be expected under fishing pressure.

Furthermore, few data are available to permit the calculation of realistic fishing mortality rates, and the lack of information on natural mortality and stock-recruitment relationships, together with the ageing problem, makes it difficult to carry out a proper assessment of the stock for the purpose of predicting future yields.

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CARLSSON, D. M., and E. SMIDT. 1978. Shrimp, *Pandalus borealis* Krøyer, stocks off Greenland: biology, exploitation and possible protective measures. *ICNAF Sel. Pap.*, this volume, p. 7 – 14.

Norwegian Investigations on the Deep Sea Shrimp, *Pandalus borealis*, in West Greenland Waters[1]

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Abstract

Investigations on the shrimp fishing grounds off West Greenland in July-August 1976 showed that the Norwegian catches consisted mainly of large shrimp, mostly fully mature females. Most of the shrimp were 20-28 mm carapace length with a maximum frequency at 26 mm. Total weight of discarded shrimp was about 9% of the reported shrimp catches. Small redfish (10-20 cm) dominated in the by-catches with small quantities of cod and Greenland halibut, but the by-catches were small compared with those of other areas. Estimates of the fishable stock size of shrimp on the offshore grounds, by the swept area method using Norwegian catch and effort data for the commercial fishery ranged from 79,000 to 102,000 metric tons in 1975 and from 93,000 to 120,000 tons in 1976. These are considered to be minimum estimates various reasons discussed.

Introduction

Norwegian vessels started fishing for shrimp off West Greenland in 1971. The initial fishery was successful and by 1975 there were 22 vessels participating. Many of the vessels and their crews had been involved in the cod fishery off Greenland before 1969. The largest vessels (15 in all) operated from the Møre district in Norway and the remainder from the Troms area, the latter group having experience in the shrimp fishery of the Barents Sea. The fishing conditions in the West Greenland area are quite different from those experienced in Norwegian waters, the Spitzbergen area and the Barents Sea. In these latter areas, the bottom is sandy or muddy and the trawl can be used safely almost anywhere in areas where the depths are suitable for shrimp, whereas off West Greenland the bottom is much rougher and the areas where it is possible to trawl for shrimp are much smaller. Although the loss or destruction of fishing gear off Greenland is much greater than in the Northeast Atlantic, the high density of shrimp in Greenland waters attracted Norwegian fishermen to fish there.

The Norwegian vessels that fish off West Greenland are all refrigerated with a capacity of 70-300 tons of frozen shrimp, most being in the range of 80-120 tons capacity. The fishing gear used is essentially the same as that used in the Barents Sea: Sputnik trawls of 1600-1800 meshes with a 41 or 51 m groundrope and the mesh size from 35 to 43 mm (stretched), the average being about 40 mm.

In 1976, 26 Norwegian vessels participated in the fishery. The main fishing grounds are shown in Fig. 1. Most of the catches were taken along the western slope of Store Hellefiske Bank.

Field Investigations in 1976

From 13 July to 5 August 1976, one of the authors was an observer on board of the stern trawler M/V *Pero*, which is the largest of the Norwegian trawlers fishing for shrimp in Greenland waters (575 gross registered tons and length of 47 m). Two types of trawl were used: a 2200-mesh Wing trawl with a groundrope of 62 m, and a 1800-mesh Sputnik trawl with a groundrope of 51 m. The Sputnik trawl has a much higher opening than the Wing trawl, but there seemed to be no significant difference in the fishing effectiveness between the two types. The mesh size used in both trawls was 43 mm.

When the catch was taken on board, it was dumped into a tank of running seawater with a capacity of 3 tons of shrimp. A grill on the top of the tank prevented the larger fish from entering the tank and a hatch was used to float out the small redfish and other floating fish that went through the grill. The shrimp were then washed from the tank through a hatch onto a conveyor belt which carried them to the sorting machines where they were sorted in "large", "small" and "discard" categories. After boiling and drying, the shrimp were packed and frozen for 16 hours at -36° C and then stored at -20° C. The observer never saw the production stop for lack of shrimp, but delays often occurred because of insufficient freezing capacity which on the *Pero* was about 8 tons of shrimp per day.

Information on trawl catches during the period of observation is given in Table 1. The quantities of

[1] Submitted to the December 1976 Special Meeting as ICNAF Res. Doc. 76/XII/155.

TABLE 1. Catches of shrimp and by-catches of fish in some trawl hauls by M/V *Pero* off West Greenland in July–August 1976.

			Position			Shrimp catch (kg)				By-catches (numbers)			
Tow No.	Date	Time	N. lat.	W. long.	Towing time (hr)	Small	Large	Total	Discard	Redfish	Cod	Gre. hal.	Other fish
1	13 Jul	1815	66°57′	56°21′	2.33	.....	.....	750	—	1,000	—	200	Few
2	14 Jul	0505	66°48′	56°20′	2.33	264	1,144	1,408	132	770	110	265	103
4	14 Jul	1130	66°48′	56°20′	2.33	132	1,360	1,492	176	803	36	168	50
5	14 Jul	1520	66°46′	56°20′	2.50	.....	.....	1,600	—	660	13	155	42
6	15 Jul	0815	66°44′	56°15′	2.50	.....	.....	900	—	610	16	142	131
7	15 Jul	1115	66°44′	56°15′	2.33	132	748	880	100	—	—	112	76
9	15 Jul	1815	66°44′	56°15′	0.83	.....	.....	10	—	Much	—	—	1
10	16 Jul	0615	67°16′	56°40′	2.00	88	880	748	60	1,500	18	44	43
11	16 Jul	0915	67°16′	56°40′	2.25	.....	.....	1,000	—	2,500	16	53	58
12	16 Jul	1245	67°16′	56°40′	2.50	.....	.....	1,200	—	7,100	7	91	46
13	16 Jul	1650	67°06′	56°45′	2.25	.....	.....	1,650	—	300	—	944	64
14	17 Jul	0905	67°11′	56°20′	2.00	418	1,210	1,628	176	1,150	6	21	23
15	17 Jul	1150	67°11′	56°20′	2.50	280	864	1,144	—	1,000	7	24	13
16	17 Jul	1525	67°03′	56°15′	2.50	.....	.....	3,000	—	700	5	30	18
17	18 Jul	0700	67°11′	56°20′	2.00	.....	.....	800	—	400	20	18	21
18	16 Jul	1000	67°11′	56°20′	2.00	362	1,024	1,386	—	3,000	9	47	46
19	18 Jul	1325	67°11′	58°20′	2.56	.....	.....	650	—	1,000	2	12	23
20	18 Jul	1640	67°11′	56°35′	1.67	440	1,364	1,804	—	800	—	39	19
21	19 Jul	0810	67°11′	56°35′	2.00	.....	.....	2,000	—	2,500	2	50	55
22	19 Jul	1100	67°11′	56°35′	2.08	.....	.....	1,870	—	2,400	—	48	24
23	19 Jul	1430	67°11′	56°35′	2.00	500	1,700	2,200	200	2,000	6	59	39
24	20 Jul	0755	67°11′	56°35′	2.00	176	748	924	—	3,000	4	50	32
25	20 Jul	1115	67°11′	56°40′	2.00	220	902	1,122	—	2,000	6	82	22
26	20 Jul	1420	67°11′	56°40′	2.33	352	1,474	1,826	—	2,000	3	258	48
27	20 Jul	1805	67°12′	56°15′	2.00	.....	.....	1,350	—	2,000	5	124	13
26	21 Jul	0740	67°12′	56°50′	1.67	308	1,276	1,584	—	2,000	5	152	18
29	21 Jul	1045	67°12′	56°43′	2.00	506	1,760	2,266	—	1,000	9	210	33
30	21 Jul	1340	67°12′	56°43′	2.33	506	1,870	2,376	—	3,000	17	222	27
31	21 Jul	1710	67°12′	56°15′	1.00	.....	.....	600	—	700	3	81	24
32	22 Jul	0830	67°11′	56°40′	2.50	286	1,122	1,408	—	2,000	23	94	24
33	22 Jul	0955	67°11′	56°40′	2.67	440	1,606	2,046	—	2,500	56	116	16
34	22 Jul	1400	67°11′	56°40′	2.50	289	1,011	1,300	72	3,500	24	79	12
36	23 Jul	0720	67°11′	56°40′	2.25	.....	.....	1,900	—	3,200	2	39	44
37	23 Jul	1110	67°11′	56°40′	2.25	330	1,122	1,452	—	4,600	—	82	26
38	23 Jul	1445	67°11′	56°40′	1.00	178	528	704	—	.....	.....	.....	.....
40	24 Jul	0640	67°15′	58°42′	2.50	308	1,012	1,320	88	3,000	—	78	2
41	24 Jul	0935	67°15′	56°42′	2.17	220	836	1,056	—	6,500	3	48	10
42	24 Jul	1250	67°13′	57°01′	2.50	260	1,256	1,518	—	2,040	—	75	39
43	24 Jul	1640	67°13′	57°01′	2.25	.....	.....	1,200	—	3,000	3	111	50
44	25 Jul	0555	67°02′	56°35′	2.17	176	770	946	—	5,000	—	364	2
45	25 Jul	1000	67°02′	56°38′	2.25	44	220	264	—	10,000	—	34	26
46	25 Jul	1340	67°02′	56°38′	2.33	88	572	660	—	5,000	1	26	14
47	25 Jul	1700	67°02′	56°38′	2.50	.....	.....	800	—	3,000	—	38	21
48	26 Jul	0800	67°03′	56°45′	2.00	.....	.....	1,340	—	1,200	—	320	5
49	26 Jul	1200	67°03′	56°45′	2.50	264	1,848	2,112	—	300	—	240	18
50	26 Jul	1520	67°03′	56°45′	2.25	.....	.....	1,750	—	200	—	153	9
51	27 Jul	0555	67°06′	57°00′	2.50	396	2,376	2,772	—	150	—	136	2
52	27 Jul	0940	87°06′	57°00′	2.50	220	1,672	1,892	—	200	—	173	—
53	27 Jul	1350	67°06′	57°00′	2.00	132	1,452	1,584	—	150	—	172	1
54	27 Jul	1710	67°06′	57°00′	2.25	.....	.....	1,380	—	150	—	322	5
55	26 Jul	1025	67°08′	57°00′	2.25	176	1,674	1,650	—	100	—	81	3
56	28 Jul	1420	67°06′	57°00′	2.58	.....	.....	1,474	—	300	—	141	5
57	29 Jul	0755	67°04′	57°00′	2.50	88	2,166	2,254	—	3,000	1	34	9
56	29 Jul	1415	67°04′	57°00′	2.00	54	474	528	—	500	—	26	—
59	29 Jul	1730	67°04′	57°00′	2.33	.....	.....	1,000	—	200	—	148	—
60	30 Jul	0650	67°06′	57°00′	1.83	40	796	836	—	310	—	61	7
61	30 Jul	0935	67°08′	57°00′	1.42	40	840	880	—	300	—	18	5
62	30 Jul	1145	67°08′	57°00′	2.00	110	506	616	—	.....	.....	.....	.....
63	30 Jul	1505	67°08′	57°00′	1.50	88	1,232	1,320	—	800	—	46	14
64	30 Jul	1730	67°06′	57°00′	1.00	.....	.....	528	—	300	—	43	13
65	31 Jul	0710	67°05′	56°58′	2.00	.....	.....	792	—	100	—	98	1
66	31 Jul	1025	67°05′	56°58′	2.50	.....	.....	1,000	—	150	—	66	—
67	31 Jul	1405	67°05′	56°58′	2.17	176	880	1,056	—	500	—	90	1
68	31 Jul	1715	67°05′	56°58′	2.00	.....	.....	900	—	100	—	139	14
69	1 Aug	0640	67°09′	56°58′	1.00	88	528	616	—	3,000	—	1	1
70	1 Aug	0910	67°09′	56°58′	2.00	121	1,507	1,628	—	5,000	—	11	1
71	1 Aug	1215	67°09′	56°58′	2.00	66	880	946	—	7,000	—	8	5
72	1 Aug	1525	67°09′	56°58′	2.00	44	858	902	—	5,000	—	35	3
73	2 Aug	0640	67°09′	56°58′	1.67	.....	.....	4,500	—	4,000	—	1	—
74	2 Aug	1120	67°09′	56°56′	1.25	.....	.....	4,500	—	8,000	—	—	—
75	2 Aug	1840	87°09′	56°58′	1.00	.....	.....	2,400	—	7,000	—	1	1
76	3 Aug	0940	67°48′	58°13′	0.56	.....	.....	130	—	3,000	—	3[1]	11
77	3 Aug	1135	67°48′	58°13′	1.50	198	856	1,056	—	.....	—	1[1]	1
79	3 Aug	1915	67°32′	58°22′	1.50	.....	.....	2,700	—	4,000	—	1[1]	—
80	4 Aug	1200	67°32′	56°19′	0.67	66	634	700	—	6,000	—	—	—

[1] A total of 120 fry were also taken in these three tows.

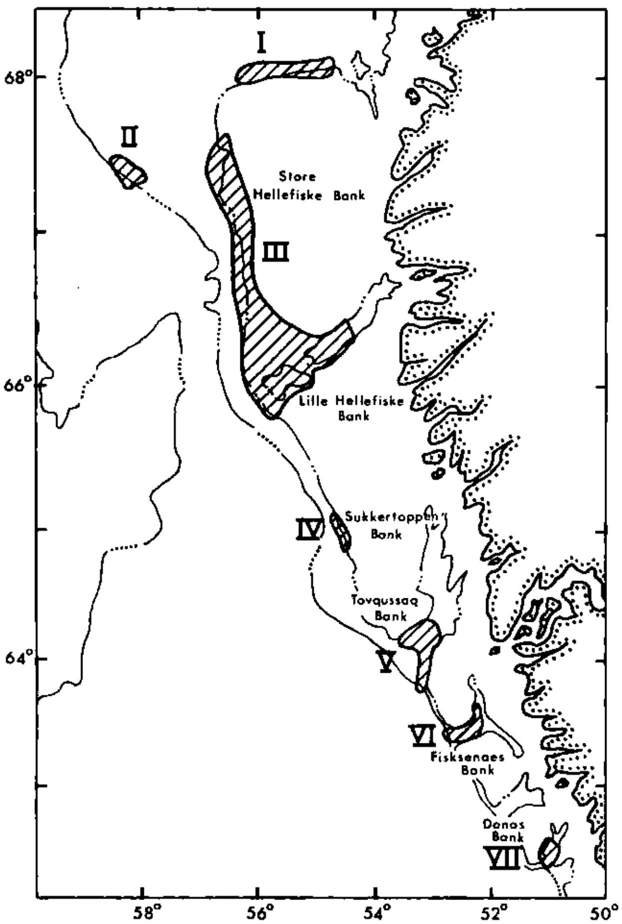

Fig. 1. The main areas fished by Norwegian trawlers off West Greenland: southeast of Disko Bugt (I), slopes of Store Hellefiske Bank and Holsteinborg Dyb (II and III), slope of Sukkertoppen Bank (IV), Sukkertop Dyb (V), Godthåb Dyb (VI), and Danas Dyb (VII).

"small", "large" and discarded shrimp are given only for those cases where it was certain that there was no mixing of different hauls in the tank. The total production for the 44 hauls in which shrimp were sorted into "small" and "large" was 59,010 kg, of which 84% were large. For the eight hauls, from which quantities of discarded shrimp were recorded, the production (10,976 kg) consisted of 81% large and 19% small shrimp. Discarded shrimp from these hauls constituted 8% of the total shrimp catch of 11,980 kg.

Size Composition of Shrimp

Thomassen and Ulltang (MS 1975) have shown the effects of 30-mm and 35-mm mesh codends on the size composition of shrimp caught in Norwegian waters, and it was predicted that the 43-mm mesh codend used on the *Pero* would catch mainly the very large shrimp. Table 2 gives the length composition of random samples from some shrimp catches by *Pero* off West Greenland, together with available frequencies for the "small" and "large" categories and for discards. The difference between the length composition (random samples) of shrimp taken with a 43-mm mesh codend by *Pero* off West Greenland in 1976 and that for shrimp caught in the northern Barents Sea with a 35-mm mesh codend is remarkable (Fig. 2A), the modes being at 26 and 19 mm respectively. According to length-at-age data reported by Horsted and Smidt (1956), the bulk of the shrimp caught by *Pero* were ages 4 and 5, most of which were fully mature females.

The difference in length composition between "small" and "large" shrimp are shown in Fig. 2B, with modes at 21 and 27 mm respectively. The "small"

TABLE 2. Length composition of shrimp caught by M/V *Pero* off West Greenland in July–August 1976. (Numbers in heading refer to tow numbers in first column of Table 1.)

Carapace length (mm)	Random samples from individual catches											"Large" shrimp				"Small" shrimp	Discards
	1	2	9	10	13	15	20	26	34	72	Total	15	49	72	Total	15	1
11	—	—	—	—	—	—	—	1	—	—	1	—	—	—	—	—	—
14	—	—	—	—	—	—	—	1	—	—	1	—	—	—	—	—	—
15	—	—	—	1	—	—	—	1	—	1	3	—	—	—	—	—	—
16	—	—	—	2	—	—	4	—	—	—	6	—	—	—	—	—	1
17	2	4	—	3	1	4	2	—	2	—	18	—	—	—	—	—	1
18	2	5	10	2	6	12	7	2	3	2	51	—	—	—	—	1	8
19	9	15	14	9	8	12	4	10	5	5	91	2	—	1	3	12	11
20	15	32	23	13	8	14	13	9	6	7	140	1	1	—	2	21	28
21	33	53	51	18	13	32	24	18	14	11	267	3	3	—	6	37	43
22	27	49	45	16	23	18	22	27	18	7	252	5	8	4	17	43	42
23	16	26	21	12	11	10	11	13	11	8	139	6	8	1	15	12	24
24	15	22	19	18	12	25	28	14	15	7	175	10	17	3	30	5	9
25	43	54	34	43	42	24	40	45	34	25	384	23	36	11	70	10	4
26	44	36	25	62	56	49	36	54	58	49	469	41	61	37	139	5	4
27	31	25	32	45	60	23	31	27	31	46	351	35	60	52	147	1	—
28	22	9	9	8	22	6	12	11	14	42	155	8	36	33	77	—	—
29	1	4	—	1	6	1	3	1	—	7	24	1	11	8	20	—	—
30	—	—	—	1	1	—	1	—	—	1	4	—	3	1	4	—	—
31	—	—	—	—	—	—	—	—	—	1	1	—	—	1	1	—	—
Totals	260	334	283	254	269	230	238	234	211	219	2,532	135	244	152	531	147	175

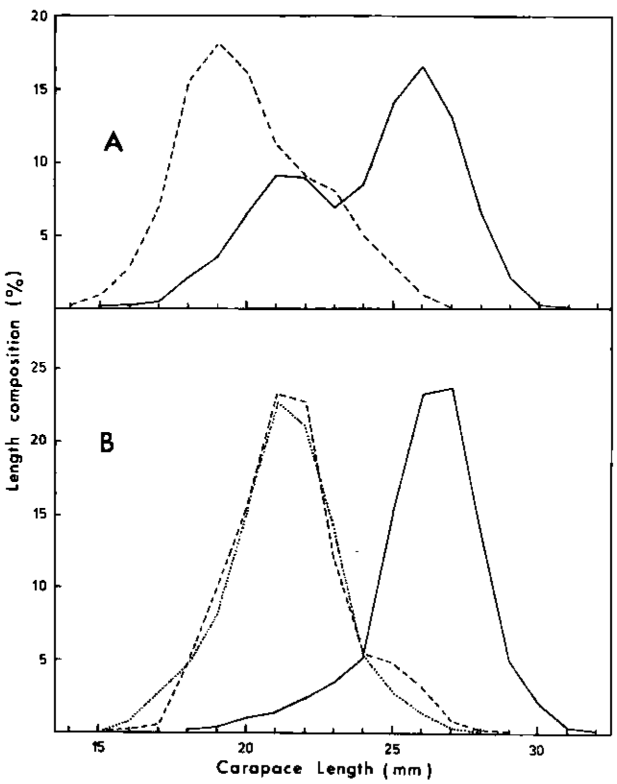

Fig. 2. (A) Length composition of shrimp caught by M/V *Pero* off West Greenland in July-August 1976 using 43-mm mesh codend (solid line, 3-point moving average), and a typical length composition of shrimp from the Barents Sea using a 35-mm mesh codend (broken line).

(B) Length composition of "large" (solid line), "small" (broken line) and discarded (dotted line) shrimp caught by M/V *Pero* off West Greenland in July-August 1976 (3-point moving averages).

shrimp taken off West Greenland are on the average larger than the shrimp caught in the Barents Sea. The length composition of discards is very similar to that of "small" shrimp. Most of the discarded shrimp are soft-shelled and crushed, the quantities discarded varying with the shell condition.

By-catches in the Shrimp Fishery

When trawling for shrimp with small-mesh trawls, the by-catch of fish species is usually a problem. Table 1 gives the by-catches (in numbers) for some trawl hauls by *Pero* in July-August 1976. The fish were counted individually except for redfish which were estimated in hundreds or thousands. None of the fish species were kept except those consumed on board during the trip.

Redfish were by far the most numerous in the by-catches, up to 10,000 being taken in a single haul. All of the redfish were very small, being 10-20 cm long (Fig. 3). They present a problem in trawling for shrimp at high northern latitudes, as Rasmussen and Øynes (1970) described trawl hauls of 3 hours' duration containing up to 69,000 redfish in the Barents Sea. More than 7,000 Greenland halibut were taken off West Greenland as by-catch with 104.5 tons of shrimp, but most were less than the minimum length (55 cm) generally accepted for consumption in Norway. Only 577 cod (35-50 cm long) were caught, representing a very small by-catch, in contrast to the average of one cod per kg of shrimp reported by Rasmussen and Øynes (1974) in 22 hauls off Spitzbergen and in the Barents Sea. Other fish in the by-catches (Table 1) were small numbers of American plaice, blue whiting, catfish and Atlantic halibut. Thus, by-catches of fish in the shrimp fishery off West Greenland are small compared with catches off the Norwegian coast and in the Barents Sea.

Catch and Catch per Unit of Effort

The catches per hour trawling (CPUE) for 1975 and 1976 by month and division (Table 3) were weighted by the corresponding monthly catches to provide the average catch per hour trawling in each division for each year. Although the monthly fishing effort may be a better weighting factor than monthly catch, the difference between the results using the two methods was relatively small and the latter method was used so that the results would be comparable with those of Hoydal (1978).

Most of the fishing activity in 1975 and 1976 took place in Div. 1B (Table 3) where the highest catch rates (CPUE) were achieved, particularly in April and May, although there was considerable variation between

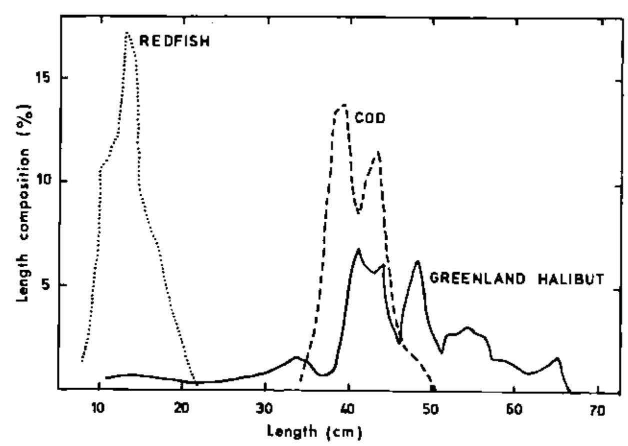

Fig. 3. Length composition of the by-catches of redfish, cod and Greenland halibut caught by M/V *Pero* off West Greenland in July-August 1976.

months. The weighted average CPUE increased from 1975 to 1976 by 6.5% in Div. 1B and by 32.3% in Div. 1C, whereas it remained at about the same level for both years in Div. 1D. It is not possible to determine whether these increases reflect an increase in abundance of shrimp or higher efficiency due to better knowledge of the area. The latter could, for example, result in better seasonal distribution of the fishery and fewer hauls with damaged gear or no catch (all hauls are included in the calculations). Although the annual average CPUE increased from 1975 to 1976 in Div. 1B, the average weighted CPUE for the last 3 months of the year in this area decreased from 0.58 to 0.26.

The figures given in Table 3 include all reported catch and effort data. Although most of the vessels use the same type of trawl, there is some variation in vessel size and towing speed which may influence the catch per hour trawling. The monthly catch and catch per hour trawling for the largest trawler (M/V *Pero*) in 1975

TABLE 3. Catch (metric tons) and catch per hour trawling (CPUE) by month and division, 1975 and 1976. (1976 data are preliminary; CPUE values in parentheses are weighted averages.)

		1A		1B		1C		1D		1E		
Year	Month	Catch	CPUE	Catch	CPUE	Catch	CPUE	Catch	CPUE	Catch	CPUE	Total catch
1975	Jan	—	—	—	—	4	0.200	32	0.221	—	—	36
	Feb	—	—	21	0.206	140	0.237	126	0.257	—	—	287
	Mar	—	—	43	0.297	143	0.194	86	0.208	2	0.200	274
	Apr	—	—	717	0.869	3	0.250	4	0.308	—	—	724
	May	—	—	461	1.110	24	1.200	—	—	—	—	485
	Jun	—	—	217	0.371	136	0.255	232	0.237	—	—	585
	Jul	—	—	1,485	0.504	116	0.208	86	0.396	—	—	1,687
	Aug	—	—	792	0.438	—	—	23	0.169	2	0.167	817
	Sep	58	0.319	373	0.237	26	0.184	85	0.243	—	—	542
	Oct	17	0.378	1,425	0.657	10	0.156	82	0.225	—	—	1,534
	Nov	—	—	579	0.431	—	—	5	0.128	—	—	584
	Dec	—	—	221	0.442	—	—	—	—	—	—	221
	NK	—	—	—	—	—	—	—	—	—	—	902
	Total	75	(0.332)	6,334	(0.584)	602	(0.260)	761	(0.251)	4	(0.184)	8,676
1976	Jan	—	—	180	0.621	78	0.438	73	0.257	—	—	340
	Feb	—	—	516	0.822	31	0.254	52	0.274	—	—	651
	Mar	—	—	29	1.160	110	0.245	178	0.272	—	—	375
	Apr	—	—	662	1.033	156	0.398	125	0.179	—	—	999
	May	—	—	1,684	1.328	—	—	—	—	—	—	1,771
	Jun	—	—	1,032	0.603	—	—	1	0.167	—	—	1,179
	Jul	—	—	1,269	0.471	14	0.259	8	0.421	—	—	1,291
	Aug	—	—	1,573	0.376	2	0.200	2	0.200	—	—	1,577
	Sep	—	—	899	0.386	—	—	5	0.357	—	—	937
	Oct	—	—	677	0.247	—	—	39	0.271	1	1.000	838
	Nov	28	0.412	1,190	0.265	1	0.111	—	—	—	—	1,405
	Dec	—	—	184	0.246	—	—	4	0.250	—	—	242
	Total	28	(0.412)	9,895	(0.622)	392	(0.345)	487	(0.249)	1	(1.000)	11,605
CPUE 76/75					1.070		1.330		0.990			

TABLE 4. Catch (metric tons) and catch per hour trawling (CPUE) by M/V *Pero* off West Greenland in 1975 and 1976. (Figures in parentheses are weighted averages.)

	1975						1976			
	1B		1C		1D		1B		1D	
Month	Catch	CPUE	Catch	CPUE	Catch	CPUE	Catch	CPUE	Catch	CPUE
Jan	—	—	—	—	—	—	32	1.032	—	—
Feb	3	0.094	—	—	41	0.279	108	0.900	—	—
Mar	11	0.367	3	0.231	10	0.250	—	—	29	0.248
Apr	—	—	—	—	—	—	15	1.154	—	—
May	—	—	—	—	—	—	310	1.582	—	—
June	—	—	20	0.606	4	0.267	—	—	—	—
Jul	148	0.488	6	0.353	—	—	211	0.616	—	—
Aug	79	0.449	—	—	—	—	79	0.712	—	—
Sep	9	0.243	—	—	—	—	—	—	—	—
Oct	223	1.057	—	—	—	—	—	—	—	—
Nov	65	0.392	—	—	—	—	—	—	—	—
Total	538	(0.698)	29	(0.515)	55	(0.273)	755	(1.092)	29	(0.248)

and 1976 are given in Table 4. This vessel tows at a constant speed of 3 nautical miles per hour and the catch rates are, on the average, appreciably higher than those in Table 3. A comparison between 1975 and 1976 data (Table 4) can be made only for July and August in Div. 1B, for which the average catch rate increased (36%) from 0.47 in 1975 to 0.64 in 1976. Data for the same months and division from Table 3 indicate that the average catch rate decreased (12%) from 0.48 in 1975 to 0.42 in 1976.

The catch and effort data for *Pero* during a trip in April–May 1976 were examined in detail. Figure 4 shows the catch per hour for each haul made (excluding hauls with damaged gear) off West Greenland during 29 April–25 May. The high CPUE value for May (1.58) in Table 4 is mainly due to the extremely high catches during 1–10 May (Fig. 4), the average catch per hour trawling for 62 consecutive hauls (between the vertical broken lines in Fig. 4) being 5.29 tons with a standard error of 0.48 tons. During this period the *Pero* fished at various locations southwest of Store Hellefiske Bank and at Holsteinborg Dyb, the frequent shifts in location being probably due to ice conditions.

The catch per unit of effort in the shrimp fishery off Greenland is considerably higher than in other areas of the North Atlantic. For example, Strøm and Rasmussen (1970) and Rasmussen and Øynes (1974) reported catches per hour trawling in the Barents Sea of 50–200 kg.

Stock Size Estimates from Catch per Unit Effort

Hoydal (1978) estimated the total stock of shrimp of fishable size on the offshore grounds to be 86,000 tons, by calculating the area swept during 1 hour of trawling and utilizing catch per unit of effort data for Faroese vessels in 1975. If it is assumed that the trawl effectively catches every shrimp in the area swept, the stock size is estimated by

$$\frac{\text{area of shrimp fishing grounds} \times \text{CPUE}}{\text{area swept by the trawl}}$$

The areas of the various fishing grounds assumed

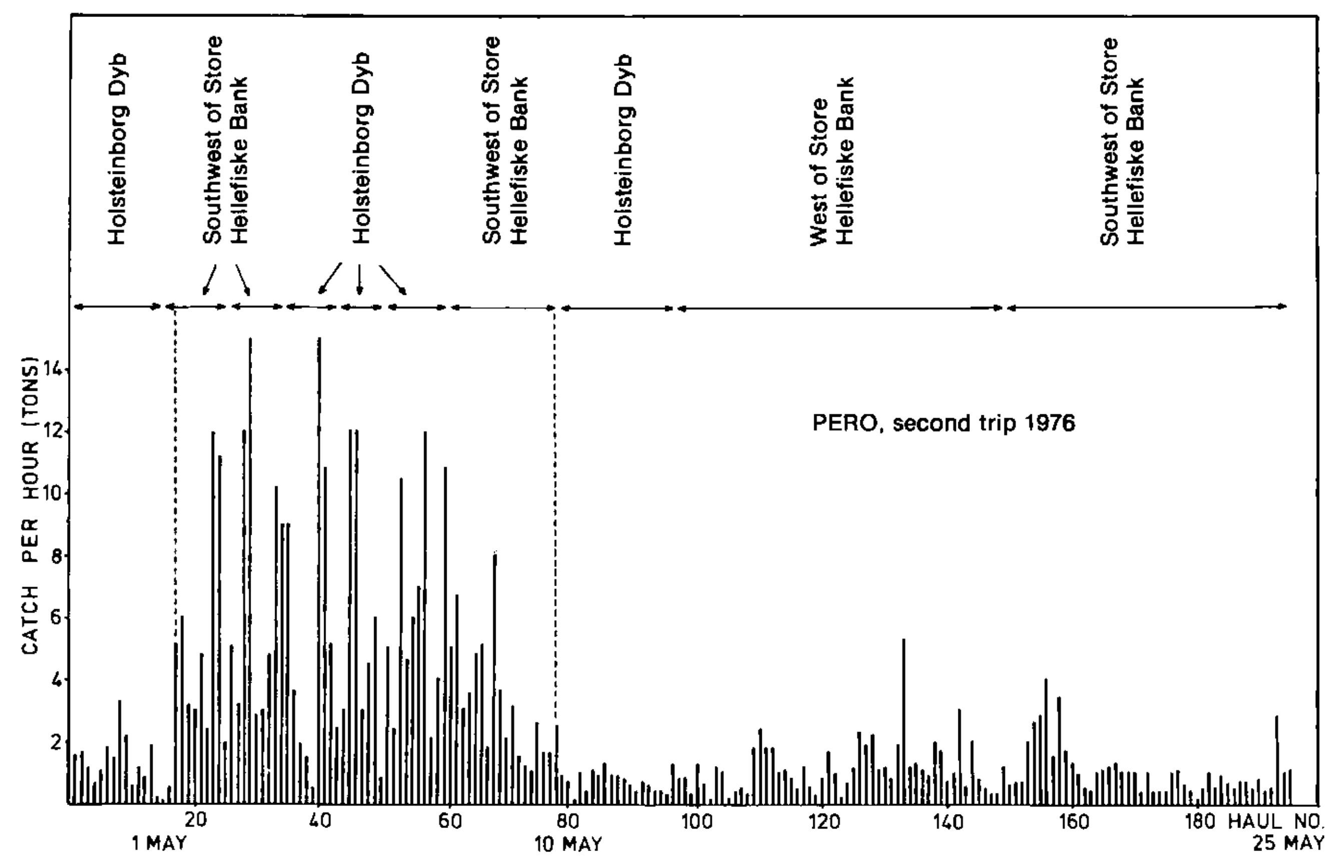

Fig. 4. Catch per hour trawling in each haul by M/V *Pero* during its second trip to West Greenland in May 1976. Hauls within the ranges designated by arrows were made in approximately tha same position.

by Hoydal (1978) were applied to the Norwegian data (9,000 km^2 in Div. 1B, 2,300 km^2 in Div. 1C and 2,900 km^2 in Div. 1D and 1E, and an additional area of 17,000 km^2 for which the CPUE in Div. 1C was assumed). The area swept per hour by an 1800-mesh Sputnik trawl (51 m groundrope), assuming that the trawl sweeps a 30-m wide sector at 2.5 nautical miles per hour, is calculated to be 0.139 km^2, which was used to estimate the stock size in 1975 and 1976, based on the average CPUE values in Table 3. The mean area swept per hour is probably slightly overestimated as some Norwegian vessels use a smaller trawl. Since the *Pero's* towing speed was 3.0 miles per hour, the area swept per hour trawling (noted above) was increased by 20% for use with the 1975 CPUE data of Table 4. No estimate of stock size was made from *Pero's* 1976 data due to inadequate coverage of the divisions and months. Therefore, using the swept area method, as applied by Hoydal (1978), estimates of the shrimp biomass off West Greenland were obtained as follows:

a) Stock sizes of 79,000 tons in 1975 and 93,000 tons in 1976, estimated from Norwegian CPUE data given in Table 3; and

b) Stock size of 102,000 tons in 1975, estimated from *Pero* CPUE data given in Table 4, with a projected stock size of 120,000 tons in 1976 using the ratio of stock sizes in (a).

Discussion

Hoydal (1978) gives several reasons why estimates of stock size based on the swept area method must be considered as minimum estimates. Of the factors listed, the following are perhaps the most critical: (i) every shrimp in the area swept by the trawl is assumed to be caught; and (ii) the vertical distribution of shrimp may exceed the height of the headline of the trawl. Experienced fishermen have reported that catches made after sunset are low and that the best fishing usually occurs just after sunrise. This may be due to diurnal vertical migration of shrimp. It may be argued, however, that in some cases the method may provide overestimates of the stock size, since it is assumed that the fleet is distributed on the fishing ground randomly with respect to shrimp density. If there are small local areas within the fishing grounds with especially high densities of shrimp and the fleet concentrates on these areas, the method could give an overestimate of the stock size. In the fishery off West Greenland, one or more vessels may fish for several days in a very small area towing back and forth along the same track. The observer on board the *Pero* counted 26 trawlers fishing for more than a week along essentially the same track in an area west of Store Hellefiske Bank. These concentrations of fishing activity may be due to the difficulty of fishing in neighbouring areas because of rough bottom and have no connection with variations in shrimp density. Since the factors contributing to underestimation of stock size are likely to have a much greater effect on the estimate than those contributing to overestimation, the authors agree with Hoydal (1978) that estimates based on the swept area method must be considered as minimum estimates.

The increase in CPUE from 1975 to 1976 does not necessarily mean that the stock size has increased by a corresponding proportion, because there may have been some increase in efficiency. However, this does not imply that the stock size will be overestimated by using 1976 CPUE data. If the increase in CPUE indicates that a given density of shrimp is more effectively fished in 1976 by, for example, avoiding rough bottom, the relative size of the 1976 stock compared to the size of the 1975 stock will be overestimated. The stock size, in absolute numbers, however, will still be underestimated because of 100% catching efficiency is assumed for the shrimp present in the area swept. If the increase in CPUE reflects the greater ability of the fishermen to find the highest concentrations of shrimp, there could be a danger of overestimating the stock size by using the 1976 data. The possibility that the fleets concentrate on local high concentrations of shrimp has already been mentioned above.

The above discussion also covers the question whether stock size estimates should be based on the CPUE of the most efficient vessels or all vessels. Under one set of assumptions it may be argued that both types of estimates are biased downward, which implies that estimates based on the CPUE of the most efficient vessels are "best" (in our case, the estimates based on *Pero's* CPUE). Under the other set of assumptions, however, the use of CPUE data for the most efficient vessels may lead to an overestimate of stock size.

A critical assumption of the swept area method concerns the size of the areas containing shrimp concentrations. The estimates of stock size given in this paper are based on areas of known shrimp concentrations. If substantial quantities of shrimp exist on grounds not covered by the areas used in this paper, the stock size estimates are likely to be minimum values. If all areas with suitable depths for shrimp were included in the calculations, the estimates of stock size would increase substantially.

The size of concentrations fished by *Pero* in early May 1976 (Fig. 4) may be estimated by applying the average catch per hour during the 10-day period (5.3 tons) to the area of the fishing grounds southwest of Store Hellefiske Bank and at Holsteinborg Dyb (roughly estimated to be 3,900 km^2). The resultant estimate of the size of these concentrations by the swept area method is about 124,000 tons. This estimate supports the conclusion that Hoydal's (1978) biomass estimate and those given earlier in this paper are underestimates, because shrimp may probably also occue in substantial quantities outside the limited area covered by *Pero* in May.

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A Method for Determining the Total Allowable Catch of Deep Sea Shrimp, *Pandalus borealis*, off West Greenland[1]

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Abstract

A method is outlined for calculating the total allowable catch of deep sea shrimp off West Greenland from an estimate of the mean annual stock size and a constraint on the reduction of the spawning stock compared to the virgin stock.

Introduction

To estimate the total annual catch which can be safely removed from a stock, both the exploitable stock biomass and the minimum spawning stock biomass required to maintain future recruitment have to be known. For the stock of deep sea shrimp off West Greenland, only very rough estimates of the present stock size exist. No historical data are available to indicate the minimum stock size required to maintain future recruitment. Decisions about the appropriate catch level must therefore be based on more or less theoretical considerations. In this paper the effect of fishing on the stock is described in terms of a few parameters and the problem of estimating the total allowable catch (TAC) is reduced to consideration of one or two key parameters.

Methods

With the present codend mesh size of about 40 mm (stretched), as used by most vessels fishing for shrimp off West Greenland, an unlimited fishing effort would not be harmful from the viewpoint of yield per recruit. Most of the shrimp in the catches are 4 years old or older (Ulltang and Øynes, 1978), and at these ages the shrimp probably suffer a high natural mortality rate, especially after the females have produced their first larvae. The important questions for management purposes are therefore how much the reproductive potential is reduced by fishing, and how much this potential can be reduced without causing a substantial decrease in recruitment.

Assuming that recruitment to the fishery is knife-edged at an age of r years and that shrimp produce larvae for the first time at an age of r+t (time of hatching) and continue to do so each year thereafter, and assuming further that the natural mortality is equal to M before age r+t and M_1 afterwards, the mean annual fishable stock (in numbers) (Beverton and Holt, 1957) will be

$$\bar{P}_N = \frac{R}{F+M}\left\{1 - e^{-(F+M)t}\right\} + \frac{Re^{-(F+M)t}}{F+M_1} \qquad (1)$$

where R is the recruitment at age r, and F is the instantaneous fishing mortality. The annual catch (in numbers) is given by

$$C = F\bar{P}_N = \frac{FR}{F+M}\left\{1 - e^{-(F+M)t}\right\} + \frac{FRe^{-(F+M)t}}{F+M_1} \qquad (2)$$

The stock size (in numbers) producing recruits will be

$$S = Re^{-(F+M)t}\left\{1 + e^{-(F+M_1)} + e^{-2(F+M_1)} + \ldots\right\}$$

$$= \frac{Re^{-(F+M)t}}{1-e^{-(F+M_1)}}$$

and

$$S/S_0 = \left\{\frac{Re^{-(F+M)t}}{1-e^{-(F+M_1)}}\right\}\left\{\frac{1-e^{-M_1}}{Re^{-Mt}}\right\}$$

$$= \frac{e^{-Ft}(1-e^{-M_1})}{1-e^{-(F+M_1)}} \qquad (3)$$

[1] Submitted to the December 1976 Special Meeting as ICNAF Res. Doc. 76/XII/172.

TABLE 1. Ratio of spawning (hatching) stock size (numbers) to virgin spawning (hatching) stock size (S/S_0) for various values of fishing mortality (F), natural mortality after first spawning (hatching) (M_1), and time (t) between recruitment to the fishery and first spawning (hatching).

	t = 1.0			t = 1.5			t = 2.0		
F	M_1 =0.75	M_1 =1.00	M_1 =1.50	M_1 =0.75	M_1 =1.00	M_1 =1.50	M_1 =0.75	M_1 =1.00	M_1 =1.50
0.1	0.834	0.857	0.881	0.793	0.816	0.838	0.754	0.776	0.797
0.2	0.704	0.741	0.778	0.637	0.670	0.704	0.577	0.606	0.637
0.3	0.601	0.644	0.689	0.518	0.554	0.593	0.445	0.477	0.511
0.4	0.518	0.562	0.612	0.424	0.460	0.501	0.347	0.377	0.410
0.5	0.449	0.494	0.545	0.349	0.384	0.424	0.272	0.299	0.331
0.6	0.391	0.435	0.486	0.290	0.322	0.360	0.215	0.239	0.267
0.7	0.342	0.384	0.434	0.241	0.271	0.306	0.170	0.191	0.215
0.8	0.301	0.340	0.388	0.202	0.228	0.260	0.135	0.153	0.174
0.9	0.266	0.302	0.347	0.169	0.193	0.221	0.108	0.123	0.141
1.0	0.235	0.269	0.311	0.142	0.163	0.189	0.086	0.099	0.115
1.2	0.185	0.214	0.251	0.102	0.118	0.138	0.056	0.064	0.076

where S_0 is the "virgin" stock, i.e. the stock producing recruits when there is no fishing, still assuming recruitment R at age r. Ratios of spawning stock to "virgin" stock (S/S_0) for various values of F, M_1 and t are given in Table 1. An estimate of t may be obtained from general biological information on the shrimp stock and data on age composition of the catches, its value being dependent on the mesh size used. M_1 is more difficult to estimate. However, for high values of M_1 relative to F, moderate changes in M_1 will not significantly alter S/S_0 (Table 1), and a minimum value of S/S_0 is obtained by setting a minimum value of M_1 into equation (3).

The upper limit for F can be found from equation (3), if the lowest level that S/S_0 should be allowed to reach could be determined by some criteria. If a direct estimate of the mean annual stock size is available, the TAC may then be calculated from equation (2). It should, however, be noted that $\bar{P}_N$ in equations (1) and (2) is the equilibrium mean annual stock corresponding to the assumed value of F. The variation in $\bar{P}_N$ with F may be studied by the use of equation (1). Before calculating C from equation (2), an approximate correction should be made to the observed mean annual stock size if the F corresponding to the TAC is significantly different from the mean F during the most recent years. If F is small compared with M and M_1, moderate changes in F will not significantly alter $\bar{P}_N$.

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Diurnal Variation in Shrimp Catches on the Offshore Grounds in ICNAF Divisions 1B and 1C[1]

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Introduction

The stern trawler *Sisimiut*, owned by the Royal Greenland Trade Department, fished for shrimp on the offshore grounds off West Greenland for several months during 1975 and 1976. Information on positions, duration of hauls and catches (in 100 kg units) were obtained from the fishing logbook and the catches per hour trawling calculated. Most of the trawl hauls had a duration of about 2 hours, but all hauls of 1 to 3 hours were used.

Results

The results of the study, based on 1,381 hauls covering the periods October 1975–January 1976 and June–December 1976, are given in Table 1 by 2-hour periods of the day. The average catches per hour trawling are shown in Fig. 1 by 2-hour period and month, with the exception of data for October 1975, November 1976 and December 1976, in which the number of hauls was too few in most time periods to provide reliable averages. The detailed material and a smoothed curve for July 1976 is presented by Horsted (1978). Despite the great variation in individual catches, the unsmoothed curves of Fig. 1 clearly show diurnal variation in catches, the smallest being taken at night. Furthermore, the greatest occurred in the autumn when the change in light intensity is maximal, while the smallest variation occurred in December and June–July when the variation in light intensity is minimal. It is therefore reasonable to believe that diurnal variation in light intensity causes diurnal vertical migration of shrimp, some of which move off the bottom at night.

These observed day and night variations in shrimp catches are in good agreement with information from interviews with Greenland fishermen in the Disko Bay

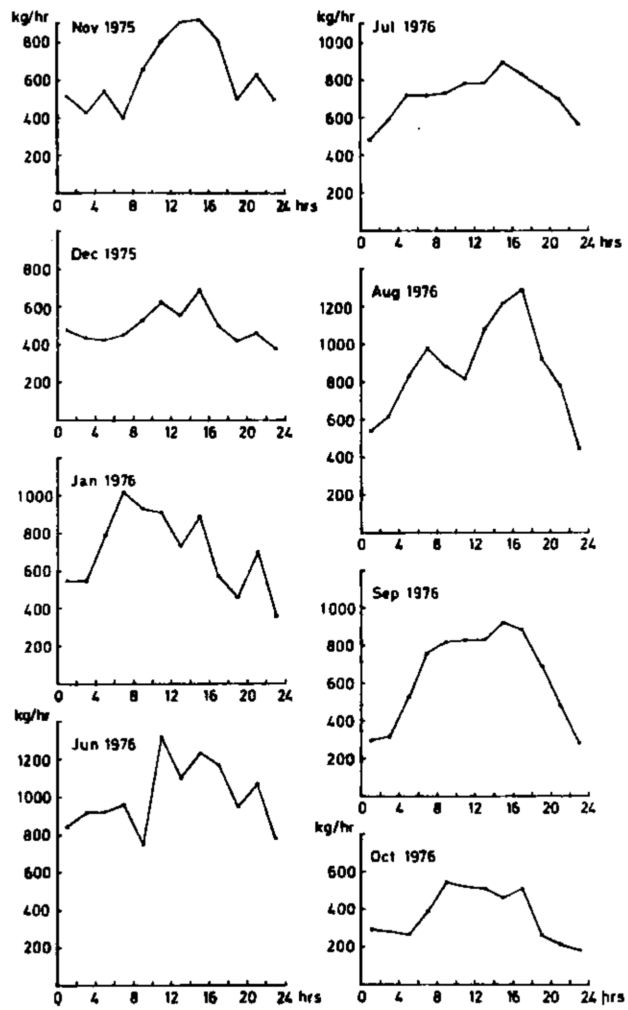

Fig. 1. Diurnal variation in average catch (kg) per hour trawling by *Sisimiut* in various months from November 1975 to December 1976.

[1] Submitted to the December 1976 Special Meeting as ICNAF Res.Doc. 76/XII/149.

TABLE 1. Diurnal variation in shrimp catches in Div. 1B and 1C by 2-hour period and month.

		Two-hour intervals											
		0–2	2–4	4–6	6–8	8–10	10–12	12–14	14–16	16–18	18–20	20–22	22–24
						1975							
Oct	Kg per hour	68	68	67	145	902	655	519	490	1,050	400	337	321
	No. of hauls	2	2	1	3	3	2	3	2	4	1	4	3
	Stand. dev.	45	46	—	177	644	771	376	14	597	—	199	106
Nov	Kg per hour	512	434	540	404	656	805	914	922	810	500	632	504
	No. of hauls	15	14	17	17	18	17	21	22	17	23	15	15
	Stand. dev.	405	205	296	265	306	500	477	690	493	294	379	424
Dec	Kg per hour	481	436	426	451	533	625	560	685	497	417	461	381
	No. of hauls	6	5	8	5	6	5	5	6	6	7	6	6
	Stand. dev.	104	129	146	135	186	327	309	320	242	208	282	173
						1976							
Jan	Kg per hour	545	548	790	1,008	931	913	734	891	566	461	697	362
	No. of hauls	8	9	11	9	7	11	9	12	9	12	5	6
	Stand. dev.	870	303	806	683	519	642	376	405	295	403	473	389
Jun	Kg per hour	845	922	924	963	752	1,321	1,099	1,231	1,172	952	1,071	778
	No. of hauls	8	12	11	13	11	12	12	12	11	14	14	13
	Stand. dev.	482	401	207	357	537	954	745	558	626	419	612	449
Jul	Kg per hour	475	589	722	726	732	776	777	891	830	760	700	569
	No. of hauls	13	14	14	20	12	11	15	19	11	16	16	15
	Stand. dev.	407	321	416	436	453	456	446	512	437	434	328	256
Aug	Kg per hour	535	622	835	976	880	814	1,083	1,216	1,287	911	775	435
	No. of hauls	10	9	16	13	8	15	14	10	15	17	13	8
	Stand. dev.	553	319	486	399	435	433	410	456	999	574	538	310
Sep	Kg per hour	304	324	533	760	819	832	829	916	878	689	478	279
	No. of hauls	13	12	16	20	14	16	14	21	21	13	15	15
	Stand. dev.	292	252	251	383	503	401	264	521	490	314	385	178
Oct	Kg per hour	287	283	267	386	535	522	511	459	511	258	207	184
	No. of hauls	9	12	23	20	17	22	22	23	26	19	15	12
	Stand. dev.	137	238	137	131	193	243	261	261	283	119	135	120
Nov	Kg per hour	234	392	138	425	89	1,014	520	606	447	271	500	326
	No. of hauls	5	3	5	6	1	4	8	4	5	6	1	3
	Stand. dev.	290	350	84	313	—	431	497	422	296	255	—	242
Dec	Kg per hour	573	167	396	330	133	291	67	808	301	378	83	275
	No. of hauls	2	3	3	5	2	3	1	3	4	2	1	4
	Stand. dev.	132	150	273	200	54	209	—	100	302	13	—	118

area. They have indicated that catches are smaller at night than during the day in summer and especially in the autumn, as shrimp move up from the bottom at night, but the difference in day and night catches is not very great in the winter. Some fishermen have observed shrimp swimming close to the surface at night (Smidt, MS 1976).

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USSR Investigations on Shrimp in the West Greenland Area, 1976[1]

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Abstract

The general biology and distribution of shrimp on the offshore grounds in ICNAF Division 1B is considered on the basis of investigations carried out on board of USSR scientific scouting vessels in 1976. Mean densities of shrimp were calculated from information obtained by trawling and underwater observations, and the total biomass of shrimp in the near bottom and upper water layers estimated.

Introduction

Soviet investigations on distribution, biology and behaviour of shrimp, *Pandalus borealis*, off West Greenland were continued in 1976. In July to October, the scientific scouting vessels *Medvezhy*, *Persey III* and *Kronstadt* explored the bank slopes and deeps in the area between 66° and 71°N latitudes. As in 1975 (Berenboim *et al.*, MS 1976), dense concentrations of shrimp were found in Holsteinsborg Deep and on the western and northern slopes of Store Hellefiske Bank. On the basis of data collected, an assessment of the shrimp stock in ICNAF Div. 1B was made.

Materials and Methods

Shrimp fishing was carried out with bottom trawls fitted with an escape valve for fish, which significantly reduced the by-catches of young fish species. The average mesh size of the codend was 18 mm (knot to knot). In the area of investigation, the work carried out involved 697 trawl hauls, 22 shrimp samples for biological analysis, 13 hydro-biological stations, 20 hydrological stations, 105 water temperature measurements, 10 submersions of the hydrostat *Sever-1* and 16 settings of the *Triton* camera.

Measurements of shrimp and the determination of sex and maturity stages of the gonads were carried out according to the methods of Rasmussen (1953) and Allen (1959). The larvae stages were classified according to Lebour (1940). The sizes of the shrimp concentrations were assessed by instrumental trawl surveys and underwater observations.

Biology and Distribution

In 1976, commercial concentrations of shrimp were found on the western and northern slopes of Store Hellefiskebanke and in the Holsteinsborg Deep (Fig. 1). The highest catch rates were obtained at depths between 220 and 300 m on the western slope of Store Hellefiske Bank, where the interaction of the West Greenland and Baffin Island currents have been observed. As in 1974 and 1975, the near-bottom temperatures in the areas of shrimp concentrations ranged from 1.6° to 2.5°C, but relatively colder water was observed in the 50–150 m layer (Fig. 2). The stability of the polar hydrological frontal zone and cold water incursions determined to a considerable degree the distribution and density of shrimp concentrations. In contrast to the situation in 1975, temperature-related variation in catches occurred more often in 1976.

Observations from the hydrostat *Sever-1* and the near-bottom camera showed that the density of shrimp in the 10 m layer near bottom was considerably higher during the day than at night. Shrimp in the transitional stage migrated to 150 m or more above the bottom during the night, where they constituted 92.5% of pelagic trawl catches, the remainder being females. Bottom trawl catches consisted of 42% transitionals and 58% females.

In 1976, the spawning of shrimp on Store Hellefiske Bank started in late August, and the relative numbers of transitionals and females in different maturity stages were similar to those of the shrimp concentrations in 1975 (Fig. 3). As usual, transitionals

[1] Submitted to the December 1976 Special Meeting as ICNAF Res. Doc. 76/XII/156.

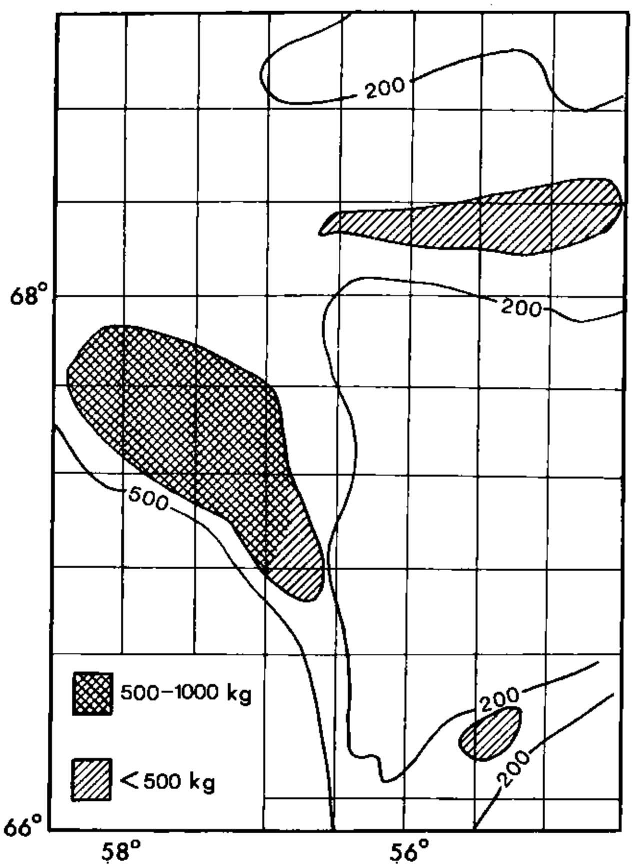

Fig. 1. Distribution of shrimp concentrations in the offshore waters of Div. 1B, based on catch rates of the USSR fleet in 1976.

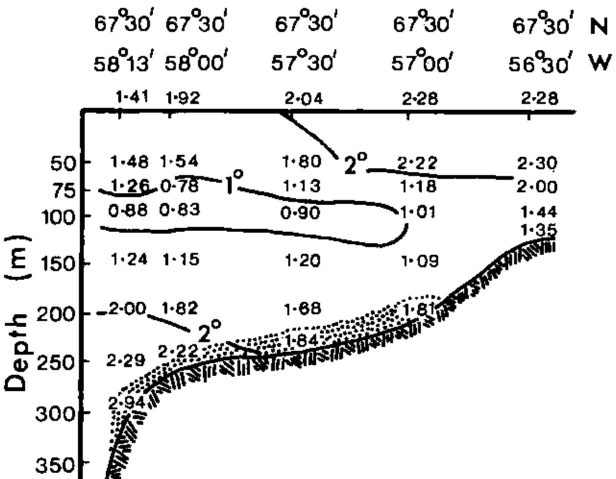

Fig. 2. Vertical temperature distribution in the area of shrimp concentrations (dotted area) on the western slope of Store Hellefiske Bank in 1976.

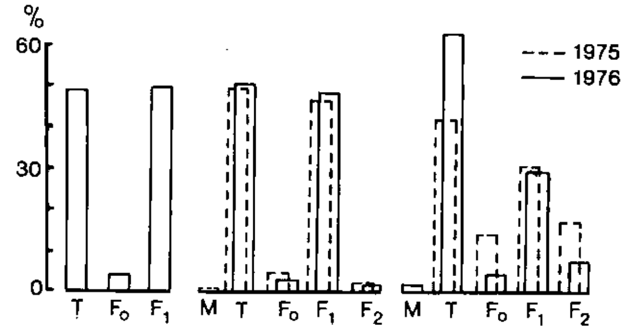

Fig. 3. Sexual maturity groups in the shrimp concentrations on the western slope of Store Hellefiske Bank in August-September 1975 and July-September 1976. (M = male, T = transitional, F_0 = females not spawning, F_1 = females with developed ovocytes in gonads, and F_2 = females with eggs on pleopods.)

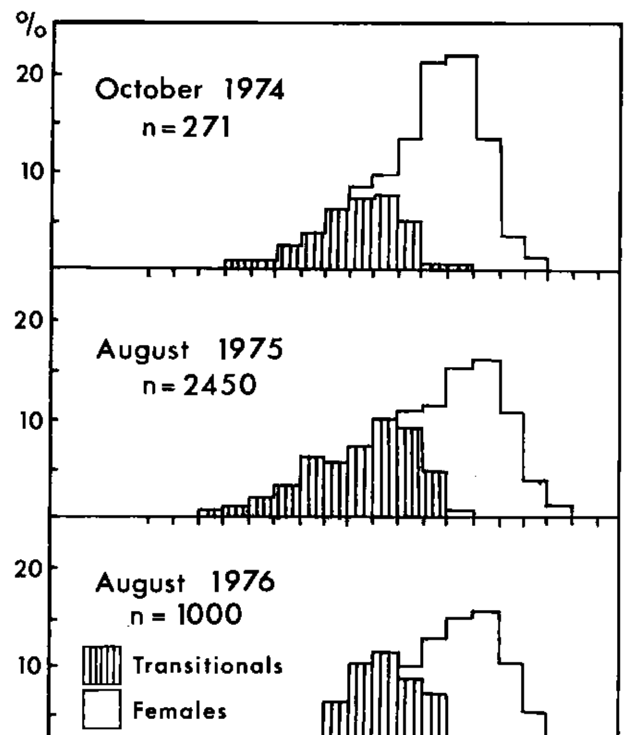

Fig. 4. Size composition of shrimp concentrations on the western slope of Store Hellefiske Bank, 1974-76.

and females made up the bulk of the commercial catches (Fig. 4), with no significant changes in size composition from 1974 to 1976. The modal carapace length was 22-23 mm for transitionals and 26-27 mm for females. The average weight of shrimp caught was

9.2 g, and the quantity of small shrimp weighing less than 3 g each constituted less than 1% of the catches.

In August and September, large numbers of shrimp larvae (stages 4 to 6) were caught in the near-botttom layers in the Store Hellefiske Bank area with a plankton net (opening diameter 50 cm). Considering the well-known circulation in the Davis Strait area (Kiilerick, 1943), the occurrence of shrimp larvae in the near bottom layers is confirmation of the hypothesis of Berenboim *et al.* (MS 1976) concerning the drift of shrimp larvae with the West Greenland Current (Fig. 5). Carlsson and Smidt (1978), on the basis of long-term investigations, similarly concluded that the existence of and recruitment to the shrimp concentrations in the Upernavik District was due to the wide spread distribution of larvae and their northerly drift. Therefore, the large shrimp concentrations on the offshore grounds in the Store Hellefiske Bank area are likely to be as much dependent upon the intensity and direction

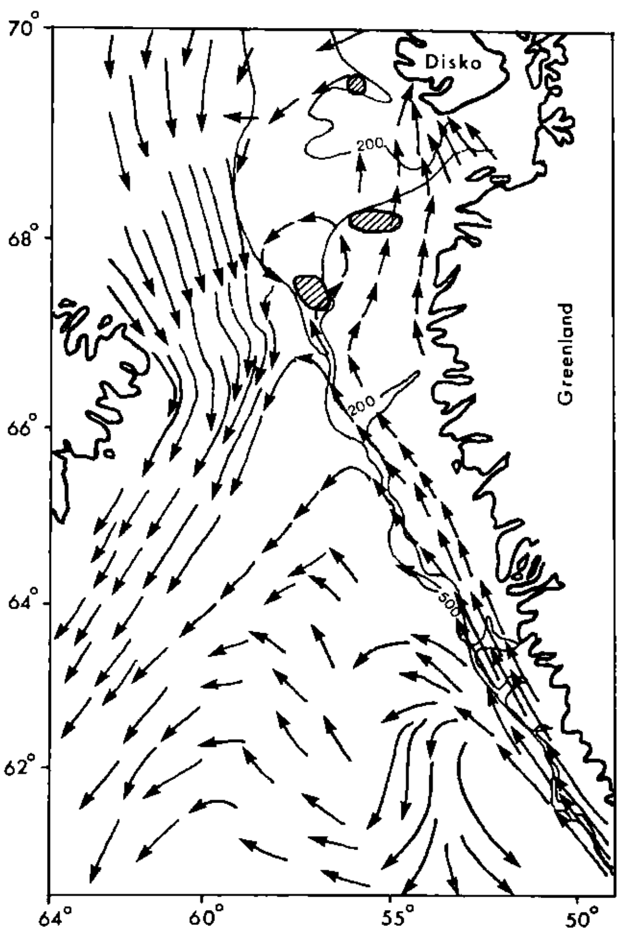

Fig. 5. The areas of shrimp larvae occurrence off West Greenland (shaded areas) and a scheme of the Davis Strait currents (from Kiilerich, 1943).

of larval drift from more southerly areas as on their own reproductive capacity.

Biomass Estimate

The estimate of the total biomass of shrimp on the offshore grounds of Div. 1B was made by the method described by Berenboim *et al.* (MS 1976), using the most recent data on the area, density and vertical distribution of shrimp. From observation by hydrostat *Sever-1* and underwater photography, the average density of shrimp in the 1 m layer above the bottom was estimated to be 0.619 per m^3, which is 23 times higher than that found in the 150 m layer. Shrimp were observed up to 150 m above the bottom in the day-time and from the bottom to the surface at night. The shrimp concentrations were estimated to cover an area of 1,250 square nautical miles. Biomass estimates were therefore made for the near-bottom layer (1 m) and for the 150 m layer immediately above, using average day-time shrimp densities of 0.619 and 0.027 respectively, and a mean shrimp weight of 9.2 g, as follows:

$$B_1 = 3.43 \cdot 10^6 \cdot 1250 \cdot 0.619 \cdot 9.2 \cdot 10^{-6} = 24,416 \text{ tons}$$

$$B_{150} = 3.43 \cdot 10^6 \cdot 1250 \cdot 150 \cdot 0.027 \cdot 9.2 \cdot 10^{-6} = 159,752 \text{ tons}$$

The total biomass of the shrimp concentrations on the western slope of the Store Hellefiske Bank is estimated to be about 184,000 tons.

Conclusions

Survey results and other data indicate that the shrimp stock on the offshore grounds in Div. 1B is in a good state despite rather intensive fishing. Catch rates of Soviet vessels, fishing for shrimp over an area of about 1,600 square nautical miles, were about the same in 1976 as in 1975 (i.e. 500 to 1,000 kg per hour trawling). Similarly, there were no noticeable differences in length and age composition (modal lengths of 23 and 26–27 for age-groups 4 and 5+) of shrimp caught by trawls with codend mesh size of 18 mm (knot to knot) during 1974–76, these age-groups constituting about 80% of the catches.

From an instrumental trawl survey and underwater observations, the total biomass of shrimp in the offshore waters of Div. 1B was estimated to be 184,000 tons. This estimate must be considered approximate for the following reasons: (a) the available data were inadequate to evaluate seasonal and annual fluctuations in abundance, the strength of year-classes and the characteristics of larval drift; (b) the effects of hydrological and meteorological conditions on the distribution and behaviour of shrimp are at present not well known; and (c) the determination of the average density and the vertical distribution of the concentrations were based only on large shrimp, the average weight of which was calculated from samples of the commercial catches.

To assess the total biomass of shrimp in the West Greenland area as the basis for the rational exploitation of the resource and the establishment of yield quotas, international shrimp investigations should be conducted along the following lines: (a) determination of genetic relationships between populations in different parts of the West Greenland area; (b) development of methods for shrimp stock assessment, including the application of instrumental methods (e.g. underwater observations); (c) determination of the influence of hydrometeorological conditions on the distribution and behaviour of shrimp; and (d) continuation of work on the selectivity of shrimp trawl meshes.

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The Life Cycle of Shrimp, *Pandalus borealis* Kr., in Greenland Waters in Relation to the Potential Yield[1]

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Abstract

The commercial fishery for shrimp in Greenland waters exploits mainly the larger individuals. *Pandalus borealis* is a protandric hermaphrodite and the individuals are fully exploitable before any eggs and larvae are produced. Some length frequencies and the maturity stages of transitionals and females in samples from various inshore and offshore grounds are analyzed. The duration of the berried period is approximately 8 months. Since ecdysis cannot occur in berried females and since most of the previously berried females rapidly develop new eggs, annual growth after the time of first spawning must therefore be very slow. This leads to an accumulation of age-groups around a prominent mode near the maximum size of the length frequency. However, the transitionals, which are rather easily recognized in the samples during the early part of the year, are often as numerous as the group of females to which they recruit in June–July, thus implying that mortality in the female group must be very high. It is suggested that the transitionals could be used as a measure of each year's recruitment to the exploited part of the stock.

Introduction

Sampling of shrimp in Greenland waters has been an important part of the research program of the Greenland Fisheries Investigations since 1946. Analyses of the samples have led to a fairly good knowledge of the general biology of the species, especially in regard to the life cycle, including sexual development, spawning and hatching (Horsted and Smidt, 1956). However, the analyses have not normally been considered in relation to the yield from the stocks. Some of the information that may be useful as background for discussion of potential yields is brought forward in this paper.

Materials and Methods

In the initial phase of the research on shrimp in Greenland waters, the samples were normally sorted into four categories: juveniles, males, transitionals (*Pandalus borealis* is a protandric hermaphrodite), and females. Furthermore, the transitionals and the females were broken down into groups according to the development of the gonads and eggs: individuals without roe, those with head roe, berried (ovigerous) females, and those in which the eggs had recently hatched or were lost (setae on pleopods) (Berkeley, 1930). All four groups pertain to females, but only the first two apply to transitionals. The information available on transitionals and females is less detailed than that used by Rasmussen (1953) in his analysis of shrimp in Norwegian waters.

After several years of study from 1946 to the late 1950's, the general biology of shrimp seemed to be so well described that the detailed analysis of the samples was discontinued, and recent work has been confined to the measurement of large numbers of individuals and the sorting of the samples into just three categories: without roe, with head roe, and berried females. It is unfortunate that the more detailed breakdown of the samples was discontinued, as some of the analyses in this paper require the use of detail found only in the earlier material.

An important category in gonad development, called "berried and with head roe", was never considered in the previous analyses, although it was noticed (Horsted and Smidt, 1956, p. 76). Sometimes a footnote on the sampling data sheets indicated that berried females and those which had recently hatched also had head roe, but generally the presence of head roe was recorded only when no eggs or setae occurred on the pleopods. Horsted and Smidt (1956) classified head roe in the earlier samples as soon as the green color of the gonad was clearly visible through the carapace, whereas various persons who sorted the

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more recent samples recorded head roe when the green color of the gonad extended close to the posterior part of the carapace. Head roe would therefore appear to have occurred later and be relatively less abundant in the more recent material than in the earlier samples. The material used by Horsted and Smidt (1956) was generally preserved in formalin before being examined, whereas the recent samples were frozen and head roe development in individuals was not as easily recognized in the early stage.

Another difference in the analysis of the earlier and the more recent material was in the measurement of the carapace length. Shrimp in the earlier samples were measured in mm (below) from the eye lobe to the lateral posterior edge of the carapace, whereas shrimp in the more recent samples were measured to the nearest 0.5 mm from the eye lobe to the dorsal posterior edge of the carapace. Rasmussen (1953) also measured his specimens by the latter method but in millimeters. Horsted and Smidt (1956, p. 73) give a comparison between Rasmussen's and their method of measuring.

In the time available to prepare material for the assessment of the Subarea 1 shrimp stocks at the December 1976 Special Meeting, only a small amount of the available material could be considered. This study has therefore been confined to series of inshore samples taken over several years in Tunugdliarfik Fjord and Disko Bay and to offshore material from Godthaab Deep and Sukkertoppen Deep which covers the months important for this analysis (Appendix Tables 1 to 5).

Results

The Tunugdliarfik Fjord material

The duration of the berried (ovigerous) period in shrimp varies with area (Rasmussen, 1953; Horsted and Smidt, 1956). In Greenland waters, the period is a relatively long one, extending from August to April-May. The best material to illustrate the annual cycle is from Tunugdliarfik Fjord between Narssaq and Narssarssuaq in southern Greenland. The stock has been exploited since the early 1950's with annual catches of 200–300 tons in the early years of the fishery and rather less since about 1960.

Shrimp were sampled in detail throughout most of the 1950's (Appendix Table 1), but only the portions of the samples consisting of transitionals and females are considered here. Combination of the samples by month results in a reasonably good picture of the

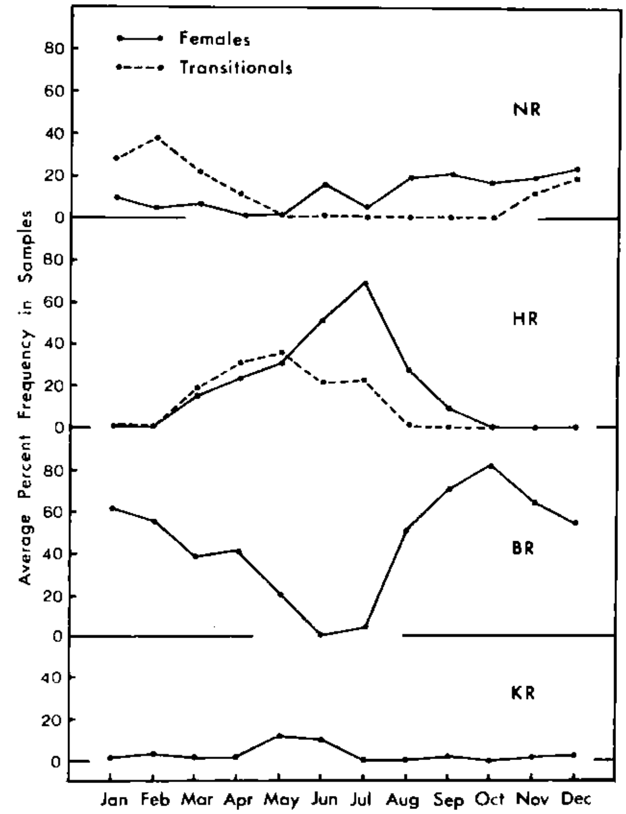

Fig. 1. Average monthly frequency of the various maturity stages of transitionals and females in samples from Tunugdliarfik Fjord, 1947–58. (NR = no roe, HR = head roe, BR = berried females, and KR = lost or newly hatched roe.)

annual cycle for the various categories of gonad development (Fig. 1). In September-October, when spawning has finished, most of the shrimp considered consist of berried females [70–80% when averaged over years on a monthly basis but with annual peaks of more than 80% (App. Table 1)]. There are also some individuals without roe, a few of which have setae on the pleopods, indicating that they have recently spawned but are not becoming berried. This corresponds with observations by Rasmussen (1953) on shrimp in Norwegian waters. Throughout the winter, the proportions of berried females fluctuate somewhat, but the general trend is downward. This decline is partly due to some individuals losing their eggs but mainly due to the recruitment of transitionals. The number of transitionals without head roe (NR) increases from November to February. Head roe in transitionals (and females) is not visible until late February after which the number in this group (HR) increases considerably during March to May. Their relative number subsequently declines because they gradually change and get classified as females with head roe. The number of females with head roe continues to increase during June and July, mainly because of the influx of females whose eggs were hatched in April–May and which, after a short period with setae on the pleopods, get classified as females with head roe. Immediately before spawning starts in late July, the number of shrimp with head roe reaches a peak (about 90% of all transitionals and females). However, some females, in which the eggs were recently hatched, do not develop roe in the same year but remain as females without roe (KR). The numbers in this category seem to be relatively low in the Tunugdliarfik stock, but, when these are combined with other females in which spawning was unsuccessful, the numbers of non-roe females may reach a level of 20–30% in the autumn. In February–March of the following year, most of these individuals develop head roe and are distinguished from the transitionals with head roe only by the character of the endopodite of the first pair of pleopods (Berkeley, 1930; Rasmussen, 1953).

Length frequency diagrams of samples show that transitionals and females have a common mode and that there may sometimes be a small group of larger (older) females (Fig. 2). In September, the group around the mode at 25 mm consists mainly of berried females, whereas in February there are two groups: the berried females, and the transitionals which will develop head roe during March–May and recruit to the female component of the stock. Although these two groups are not two distinct year-classes in the strictest sense, they could be regarded as such for the purpose of stock assessment. The transitionals may consist of slow-growing individuals of one age-group and fast-growing individuals of the following age-group, but they could be regarded as a single cohort of recruits for assessment purposes.

The material as illustrated (Fig. 1) may lead one to judge that, even if transitionals had not been separated from females in the "head roe" group, it might still be possible to separate recruits from the older females. That part of the "head roe" group, which in March–April consists of older females, occurs in the preceding September–October as the major part of the "no roe" group of females. It might therefore be possible to judge its strength in the combined (transitionals and females) "head roe" group of March–April.

It is interesting to note that the relative strength of the recruiting cohort is close to the strength of the older age-groups to which it will eventually recruit, and that this might lead to the possibility of estimating mortality. However, for the inshore shrimp grounds of West Greenland, it has been clearly demonstrated that the length composition of the population changes with depth (Fig. 3 and 4). It is likely that many of the females emigrate (actively or by currents) from the shallower to the deeper grounds in the Tunugdliarfik area. In fact, on one deepwater ground near Narssaq, the population consists of larger and possibly older shrimp than on the shallower Tunugdliarfik ground (Fig. 4). It is therefore likely that the relative strength of the recruits in the Tunugdliarfik material is overestimated in relation to the more widely distributed population in the area.

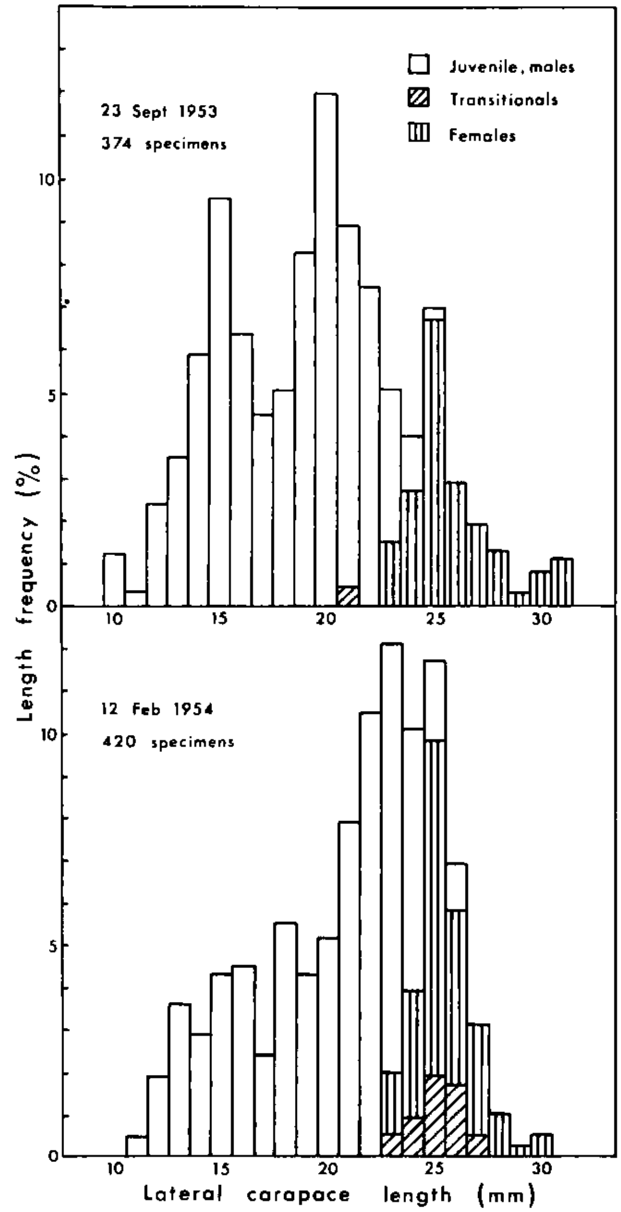

Fig. 2. Length frequencies of shrimp in samples from Tunugdliarfik Fjord, September 1953 and February 1954.

Since ecdysis cannot occur in berried females, there is no growth in carapace length during the period from early August to late April (Fig. 1). In the May–June

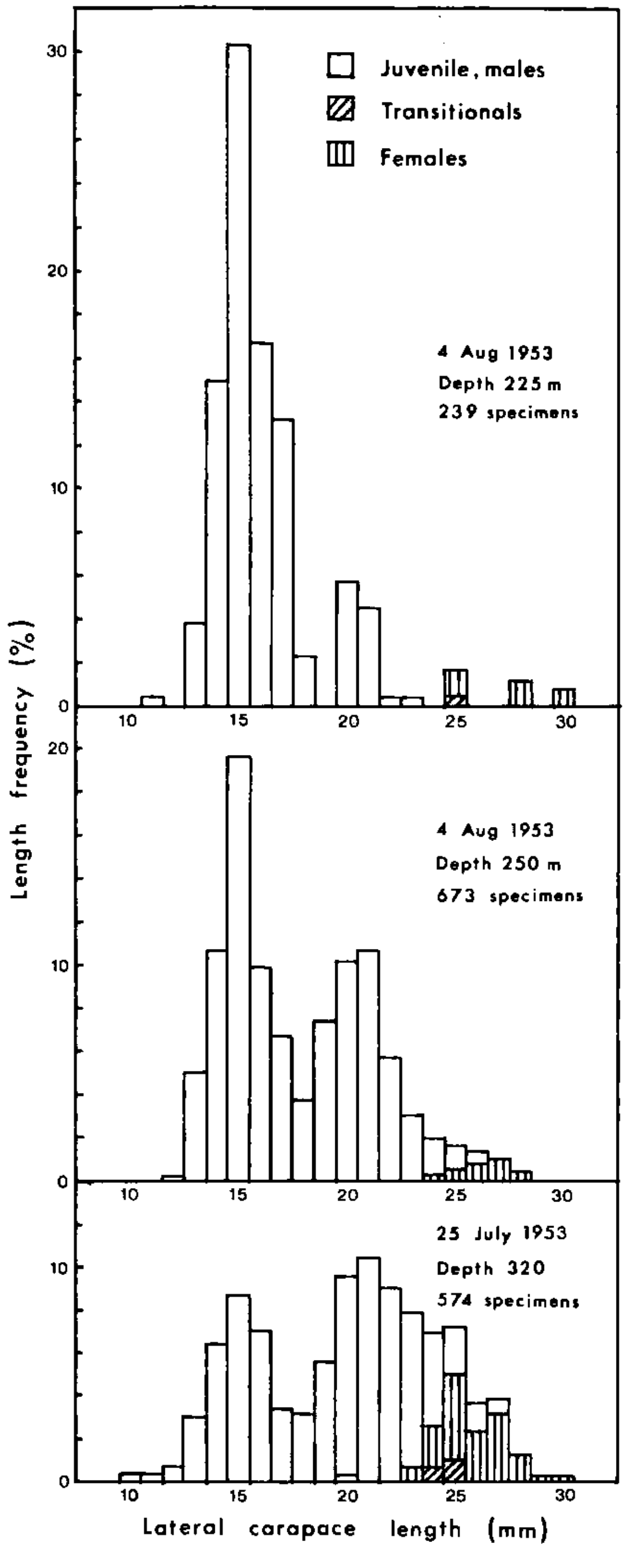

Fig. 3. Length frequencies of shrimp in samples from different depths in the Sermersoq area, southern Greenland. (From Horsted and Smidt, 1956.)

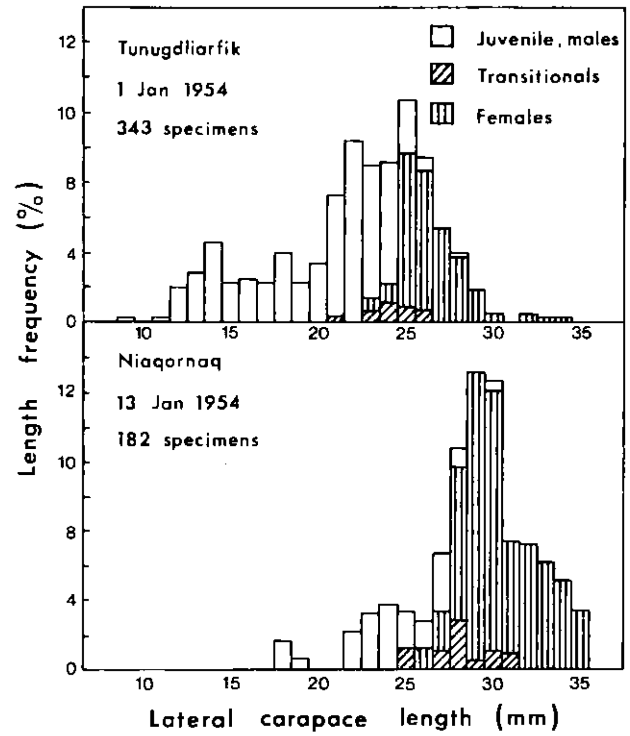

Fig. 4. Length frequencies of shrimp in samples from two grounds of different depths in the Narsaaq area of southern Greenland. (From Horsted and Smidt, 1956.)

period, most of the previously berried females rapidly develop new eggs. Therefore, from the time of first spawning, growth is so slow that one can hardly expect to find separate age-groups by the Petersen method within a frequency distribution whose range is only 5–6 mm. Only those relatively few females which take "a year of rest" from spawning seem capable of growing to any significant extent, and that group is represented in some of the length frequency diagrams around a mode at about 30 mm (Fig. 2). Therefore, any attempt to estimate mortality from the modal frequencies of the female component of the stock is very unrealistic, because several cohorts may be accumulated around the major mode and the various length groups may be unevenly distributed on the fishing grounds according to depth. Furthermore, Horsted and Smidt (1956) have demonstrated that the inflow of warm water in the deeper parts of the Tunugdliarfik Fjord results in a greater abundance of shrimp especially of the larger sizes, in the winter than in summer and autumn (Fig. 2). The catch rate in the area is highest in the winter when the warm bottom water dominates and the shrimp emigrate into the fjord from the outer part of the fjord and the adjacent offshore grounds. Such emigration of specific size groups limits the possibility of using length frequency data to estimate mortality rates.

The Disko Bay material

The available material consists of a large number of samples collected during many years from the various grounds in the Bay. However, detailed sorting has only been made for samples from the late 1940's and 1950's and for some samples taken in the 1970's, the latter being broken down in to three categories of gonad development without separation of transitionals and females (Appendix Tables 2 and 3). The collection of the material was generally limited to the summer months and therefore does not allow for detailed analysis of the annual cycle, especially during March-April when the transitionals are supposed to reach their maximum frequency. Material from two grounds was chosen for analysis: the Godhavn ground near the southeast coast of Disko Island, and the Christianshaab ground in the southeastern part of Disko Bay.

The average monthly frequencies (percentages) of the three major categories of gonad development for both grounds and for both the early and recent periods are shown in Fig. 5. The spawning period is about the same as in the Tunugdliarfik area, starting in July and ending in late August or early September, as indicated by the decline in frequency of shrimp with head roe. The extent and duration of spawning may vary considerably from year to year, and this is clearly evident from the 1948 samples which show a later-than-usual spawning, with the occurrence of many shrimp with head roe in late August and even in early September (Appendix Tables 2 and 3).

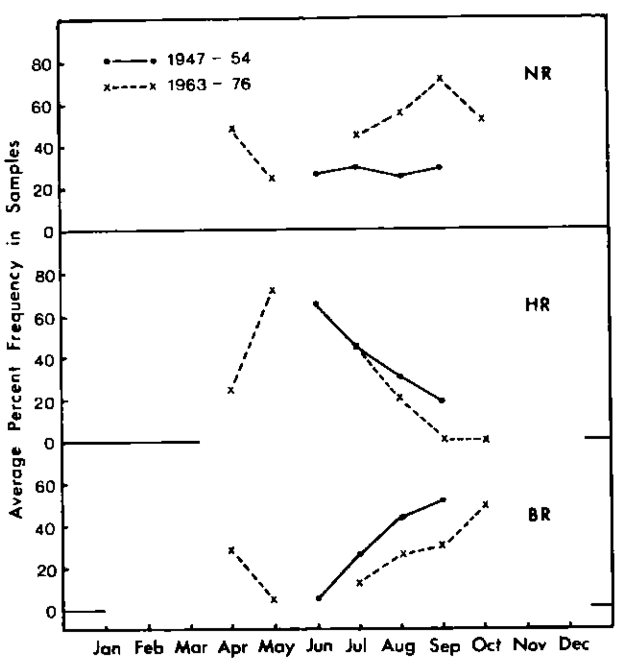

Fig. 5. Average monthly frequency of the three major stages of gonad development (transitionals and females combined) in shrimp samples from Disko Bay, 1947-54 and 1963-76. (NR = no roe, HR = head roe, and BR = berried females.)

In contrast to the Tunugdliarfik material, the Disko Bay samples indicate that a relatively greater number of females do not become berried but pass the winter months without roe. Therefore, the potential productivity per stock unit may be relatively low in the Disko Bay area, and year-class fluctuations may be significant. For example, in 1950 the June and July samples show relatively large numbers of transitionals with head roe (Appendix Tables 2 and 3), which contributed to the relatively high level of berried females later in the same year.

The most remarkable features of the Disko Bay material (Fig. 5) are that there were considerably fewer berried females and more individuals without roe in the recent period (1963-64 and 1974-76) than in the early period (1947-54). This possible reflects some influence of the fishery, which has increased substantially since the 1940's and 1950's (Carlsson and Smidt, this volume) and which may have exploited the larger shrimp more heavily than the smaller ones, due partly to mesh selection and partly to the seeking of grounds where the larger shrimp dominate. The relative increase in the frequency of shrimp with no roe is mainly due to recruitment of more smaller shrimp in recent years than formerly but also to the relative decline in the frequency of larger shrimp, since the sum of the frequencies must balance to 100% for each month. There are at present no suitable data available to clearly demonstrate absolute changes in abundance of the various size and maturity categories. Further studies, including information on the possible loss of roe at spawning and on the tendency for some females to "take a year of rest" after spawning, are needed before firmer conclusions can be made.

The Godthaab Deep and Sukkertoppen Deep material

The Godthaab Deep, located east of Fylla Bank (Div. 1D), and the Sukkertoppen Deep, between Fylla Bank and Banana Bank (Div. 1C), are two offshore grounds where trawling stations have been established in the annual survey program of the Greenland Fisheries Investigations. All of the available samples from these grounds are listed in Appendix Tables 4 and 5. All of the material are from the most recent period (1970-76), and consequently the "head roe" category in these samples is not directly comparable with the Tunugdliarfik and the early Disko Bay material because of the somewhat different criteria for determining the presence of head roe (see Materials and Methods). The samples for the two offshore grounds were combined (as was done for the Disko

Bay material) and the average percentage frequencies of the three categories of gonad development plotted by month (Fig. 6). Despite the absence of samples for September, it is evident that spawning begins somewhat later than in the inshore areas but seems to be completed by October. Berried females did not occur in the samples until mid-August, whereas in the inshore areas some females become berried in July. Hatching seems to take place over the same period as in the Tunugdliarfik area, probably ending a little earlier.

It appears that a relatively high percentage (80% or more, see Appendix Tables 4 and 5) of the spawning females become berried in the same year, but the rate of decline of berried females in the early months of the year is probably somewhat less than that indicated in Fig. 6, due to the increasing recruitment of transitionals to the "no roe" category in those months. However, since transitionals and females were not separated and since the early stages of head roe development were not classified as in the early material from Tunugdliarfik Fjord, it is difficult to interpret the fluctuations in the "no roe" category. Future samples will have to be analyzed in greater detail before firm conclusions can be drawn, but the present material indicates that spawning on these grounds was very successful in 1973 and 1975 but less so in 1974 when

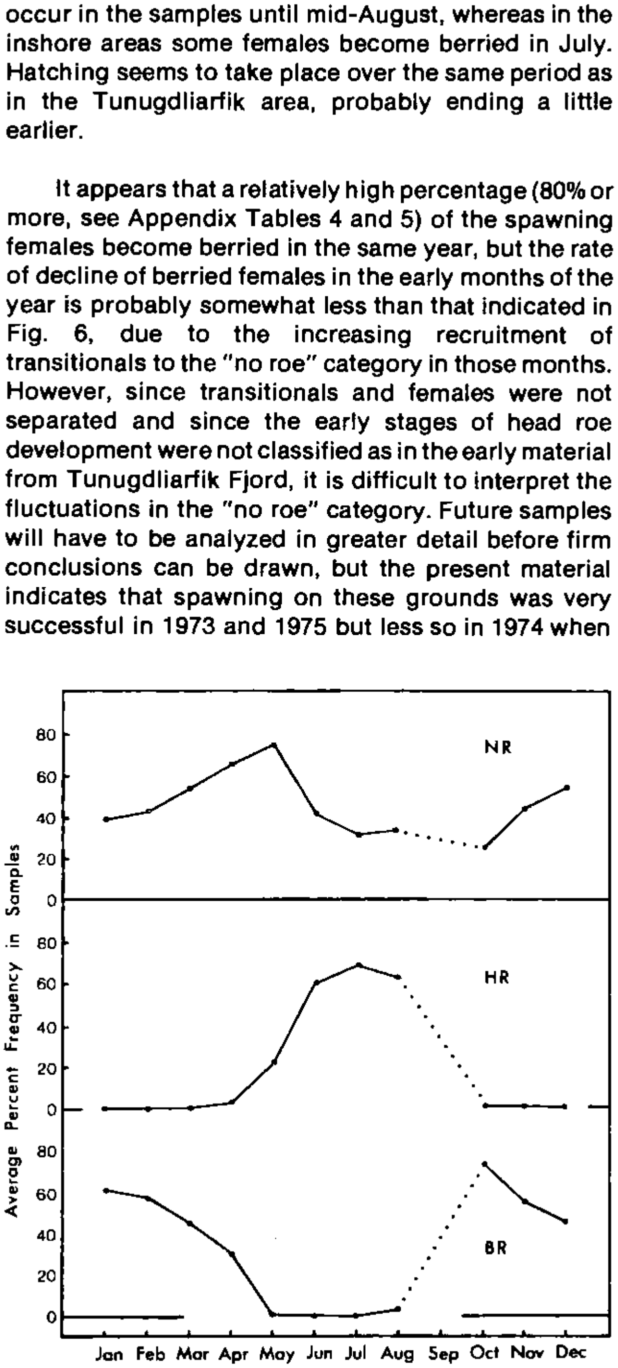

Fig. 6. Average monthly frequency of the three major stages of gonad development (transitionals and females combined) in shrimp samples from Godthaab Deep and Sukkertoppen Deep offshore grounds, 1970–76. (NR = no roe, HR = head roe, and BR = berried females.)

the relative abundance of berried females was low in November on both grounds and also in January 1975 on the Godthaab Deep ground (Appendix Tables 4 and 5). The very low percentage of berried females in the January 1976 sample from Sukkertoppen Deep is unusual. This may be due in part to the recruitment of a large number of transitionals which will develop head roe in the following months and partly to the migration of berried females from the ground. The samples do not allow any judgement about the degree to which berried females will develop roe for the next season, although most length frequencies suggest an accumulation of age-groups in the length range of 26–30 mm (lateral carapace length), corresponding to a dorsal carapace length range of 22–26 mm.

General Discussion and Conclusions

Although the duration of the berried period for shrimp in Greenland waters may vary somewhat between grounds, it is considerably longer than in some other areas of the North Atlantic where the species occurs. In general, most of the berried females develop roe for a new spawning about 4 months after the eggs are hatched. This means that the annual growth increment in carapace length is very small and thus leads to an accumulation of age-groups around a very prominent mode centered in a very narrow size range near the maximum size in the length frequency diagram. This is in contrast to the length frequencies of catches of most fish species, in which the right limb of the frequencies usually declines gradually with increasing size due to the declining abundance of age-groups as they become older and grow in size. The possibility of separating the age-groups of mature shrimp by the Petersen method is therefore not present. The problem is further complicated by the differences in length frequencies from different grounds and also by gear selection.

The commercial fishery exploits mainly the transitionals and females, but some large males are also taken (Berenboim *et al.*, MS 1976; Fuertes and Lopez-Veiga, MS 1976). The transitionals could probably be used as a measure of each year's recruitment to the exploited group. Anyway, it is important to remember that the long-term yield from the female component of the stock cannot be greater than the mean annual recruitment to the group, and a part of the recruiting group would have to be protected for spawning and hatching, the latter taking place about a year after the transitionals recruit to the fishery. The fact that *Pandalus borealis* is a protandric hermaphrodite makes the question of stock-recruitment relationship and exploitation rate very important, since spawning by females does not occur before they enter the exploited phase of their life and the females are exposed to at least a full year's fishing mortality before they produce any larvae.

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APPENDIX

TABLE 1. Samples of shrimp from Tunugdliarfik, near Narssaq (Div. 1F); percentages in various stages of development for transitional (T) and for females (F) refer to the total of numbers listed under T and F. (NR = no roe, HR = head roe, BR = berried females, and KR = lost or newly hatched roe.)

		No. in	Number		Transitionals		Females			
Date	Year	sample	T	F	NR	HR	NR	HR	BR	KR
2 Jan	1958	274	10	66	13.2	—	1.3	—	81.6	3.9
8 Jan	1953	209	24	14	63.2	—	18.4	—	18.4	—
10 Jan	1956	326	17	33	34.0	—	4.0	—	60.0	2.0
13 Jan	1954	343	13	107	10.8	—	12.5	—	75.0	1.7
25 Jan	1954	342	10	104	8.8	—	10.5	1.0	76.3	0.4
26 Jen	1957	433	18	39	31.6	—	14.0	—	54.4	—
11 Feb	1953	378	28	40	41.2	—	14.7	—	44.1	—
12 Feb	1954	420	23	87	20.9	—	3.6	1.0	73.6	—
21 Feb	1956	307	2	5	28.6	—	—	—	71.4	—
28 Feb	1957	251	9	8	52.9	—	—	—	35.2	11.8
1 Mar	1954	371	30	99	23.3	—	8.5	2.3	64.3	1.6
2 Mar	1950	216	5	38	9.3	2.3	16.3	11.6	58.1	2.3
3 Mar	1958	397	21	15	58.3	—	8.3	19.4	13.9	—
9 Mar	1953	449	63	58	—	52.1	—	12.4	34.7	1.0
16 Mar	1950	121	14	80	7.4	7.4	8.5	53.2	23.4	—
18 Mar	1954	502	39	25	—	60.9	1.6	7.8	29.7	—
18 Mar	1957	179	9	9	50.0	—	5.6	11.1	33.3	—
23 Mar	1958	688	17	21	23.7	21.0	7.9	—	44.7	2.6
6 Apr	1954	512	43	83	—	34.1	2.3	11.9	49.2	2.4
7 Apr	1953	475	59	82	—	41.8	—	14.2	42.6	1.4
10 Apr	1958	378	7	11	—	36.9	—	27.8	33.3	—
20 Apr	1954	524	20	51	5.6	22.5	4.2	2.8	64.8	—
29 Apr	1950	213	3	14	—	17.6	—	58.8	17.6	5.9
4 May	1950	185	5	6	—	45.6	—	36.4	18.2	—
7 May	1954	543	15	46	3.3	21.3	3.3	19.7	31.1	21.3
7 May	1958	484	4	3	—	57.1	—	—	42.9	—
10 May	1950	213	4	7	—	36.4	—	45.6	18.2	—
21 May	1953	562	32	43	—	42.7	4.0	16.0	4.0	33.3
21 May	1954	562	6	65	—	8.5	4.2	69.0	2.8	15.5
8 Jun	1954	572	12	59	—	16.9	1.4	78.9	—	2.8
11 Jun	1953	593	36	41	—	46.8	28.6	24.7	—	—
14 Jun	1956	338	4	8	—	33.3	41.7	—	—	25.0
21 Jun	1954	606	8	49	1.8	12.3	14.0	70.2	—	1.8
22 Jun	1953	412	16	102	—	13.6	3.4	78.8	—	4.2
30 Jun	1956	465	1	32	—	3.0	12.1	57.6	—	27.3

TABLE 1. (continued)

Date	Year	No. in sample	Number T	Number F	Transitionals NR	Transitionals HR	Females NR	Females HR	Females BR	Females KR
5 Jul	1954	513	14	93	—	13.1	3.7	81.3	1.9	—
7 Jul	1947	160	33	40	—	45.2	2.7	52.1	—	—
16 Jul	1953	243	32	56	—	36.4	4.5	53.4	5.7	—
19 Jul	1958	517	6	26	—	18.8	—	81.3	—	—
30 Jul	1958	340	0	39	—	—	12.8	76.9	10.3	—
9 Aug	1953	225	0	22	—	—	45.5	13.6	40.9	—
22 Aug	1953	446	2	57	1.7	1.7	20.3	13.6	62.7	—
22 Aug	1955	443	1	49	—	2.0	2.0	74.0	22.0	—
23 Aug	1954	766	0	13	—	—	15.4	—	84.6	—
31 Aug	1956	478	1	59	—	1.7	11.7	40.0	46.7	—
6 Sep	1951	942	0	51	—	—	37.3	27.5	35.3	—
7 Sep	1953	541	4	87	4.4	—	20.9	2.2	71.4	1.1
7 Sep	1955	462	0	42	—	—	—	31.0	69.0	—
23 Sep	1952	294	0	34	—	—	44.1	—	47.1	8.8
23 Sep	1953	374	1	72	1.4	—	26.0	2.7	69.9	—
23 Sep	1955	291	0	44	—	—	—	—	97.7	2.2
29 Sep	1956	459	0	55	—	—	16.4	1.8	81.8	—
10 Oct	1953	438	2	86	2.3	—	29.5	—	68.2	—
20 Oct	1956	233	0	25	—	—	16.0	—	84.0	—
24 Oct	1953	539	0	60	—	—	18.3	—	81.7	—
24 Oct	1955	520	0	50	—	—	4.0	—	96.0	—
10 Nov	1953	476	13	71	15.5	—	45.2	—	39.3	—
14 Nov	1955	409	0	87	—	—	1.1	—	98.9	—
15 Nov	1957	314	8	19	29.6	—	—	—	63.0	7.4
24 Nov	1953	463	8	77	9.4	—	28.2	—	62.4	—
11 Dec	1953	409	21	71	22.8	—	39.1	—	37.0	1.1
14 Dec	1955	595	6	17	26.1	—	8.7	—	52.2	8.7
28 Dec	1953	379	8	93	7.9	—	20.8	—	71.3	—

TABLE 2. Samples of shrimp from Godhavn ground near Disko Island; percentages in various stages of gonad development for transitionals (T) and for females (F) refer to the total of numbers listed under T and F. (NR = no roe, HR = head roe, BR = berried females, and KR = lost or newly hatched roe.)

Date	Year	No. in sample	Number T	Number F	Transitionals NR	Transitionals HR	Females NR	Females HR	Females BR	Females KR
					1948–54					
8 Jun	1950	341	16	13	—	55.2	—	31.0	—	13.8
1 Jul	1952	204	39	27	—	59.1	15.2	21.2	4.5	—
12 Jul	1949	320	2	27	—	6.9	44.8	48.3	—	—
18 Jul	1950	361	68	76	—	47.2	17.4	20.8	14.6	—
23 Jul	1953	273	6	24	—	20.2	16.7	16.7	46.7	—
23 Jul	1953	516	8	67	—	10.7	28.0	22.6	38.7	—
28 Jul	1952	277	15	148	0.6	8.7	38.6	4.3	45.3	4.3
1 Aug	1954	460	22	74	—	22.9	2.1	25.0	40.6	9.4
18 Aug	1953	393	7	142	4.7	—	38.3	2.7	54.4	—
21 Aug	1949	421	1	46	—	2.1	44.7	2.1	51.1	—
2 Sep	1948	172	10	84	—	10.8	—	55.3	31.9	2.1
					1963–76[1]					
29 Apr	1975	750	231		.....		39.0	27.3	33.8	.....
29 Apr	1975	673	271		.....		58.3	19.9	21.8	.....
13 May	1976	1457	228		.....		42.1	53.1	4.9	.....
16 Jul	1976	797	417		.....		41.2	48.7	10.1	.....
24 Jul	1971	205	59		.....		54.2	39.0	6.8	.....
27 Jul	1964	341	23		.....		39.1	43.5	17.4	.....

TABLE 2. (continued)

Date	Year	No. in sample	Number T	Number F	Transitionals NR	Transitionals HR	Females NR	Females HR	Females BR	Females KR
					1963–76[1]					
4 Aug	1974	347	131		.....		54.5	24.8	20.8	.....
7 Aug	1975	749	453		.....		39.7	26.5	33.8	.....
12 Aug	1963	216	65		.....		63.1	26.1	10.8	.....
31 Aug	1974	249	130		.....		66.2	13.1	20.8	.....
20 Sep	1974	232	104		.....		77.9	1.9	20.2	.....
20 Sep	1975	1379	293		.....		66.6	—	33.4	.....
23 Sep	1974	503	93		.....		75.3	—	24.7	.....
30 Sep	1974	548	175		.....		84.6	—	15.4	.....
15 Oct	1975	908	354		.....		47.2	—	52.8	.....
18 Oct	1974	476	129		.....		71.3	—	28.7	.....

[1] Samples sorted into three categories only: no roe, head roe, and berried females; percentages listed under NR and HR for females actually pertain to transitionals and females.

TABLE 3. Samples of shrimp from Christianshaab ground, Disko Bay; percentages in various stages of gonad development for transitionals (T) and for females (F) refer to the total of numbers listed under T and F. (NR = no roe, HR = head roe, BR = berried females, and KR = lost or newly hatched roe.)

Date	Year	No. in sample	Number T	Number F	Transitionals NR	Transitionals HR	Females NR	Females HR	Females BR	Females KR
					1947–54					
3 Jun	1954	114	25	55	—	31.3	52.5	16.3	—	—
26 Jun	1952	162	32	42	5.4	37.8	21.6	24.3	10.8	—
3 Jul	1953	212	11	94	5.7	4.8	53.3	16.2	18.1	1.9
8 Jul	1949	323	3	41	6.8	—	25.0	68.2	—	—
22 Jul	1950	335	32	69	3.0	28.7	10.9	27.7	28.7	1.0
22 Jul	1950	357	18	62	1.3	21.3	16.3	27.5	28.8	5.0
29 Jul	1953	544	23	61	(27.4)		31.0	9.5	32.1	—
31 Jul	1953	180	3	59	1.6	3.2	25.8	17.7	50.0	1.6
1 Aug	1950	114	3	25	3.6	7.1	21.4	10.7	57.1	—
8 Aug	1954	252	3	64	—	4.5	34.3	29.9	31.3	—
15 Aug	1950	168	1	26	3.7	—	25.9	14.8	55.6	3.7
19 Aug	1948	390	24	91	—	2.9	9.6	60.0	9.6	—
27 Aug	1948	760	11	57	—	16.2	8.8	25.0	47.1	—
27 Aug	1949	810	13	165	4.5	2.8	50.6	3.4	38.8	—
28 Aug	1948	357	11	87	—	11.1	8.1	43.4	28.3	8.1
31 Aug	1948	571	3	38	4.9	2.4	9.8	24.4	58.5	—
1 Sep	1950	161	1	32	3.0	—	12.1	6.1	72.7	6.1
10 Sep	1953	207	7	81	4.5	3.4	50.0	13.6	28.4	—
22 Sep	1953	187	4	42	8.7	—	41.3	—	50.0	—
28 Sep	1947	324	0	26	—	—	26.9	—	73.1	—
					1974–76[1]					
19 May	1976	889	313		.....		7.6	90.4	1.9	.....
23 Jul	1975	817	212		.....		40.6	44.8	14.6	.....
1 Aug	1974	501	138		.....		49.3	29.0	21.7	.....
12 Aug	1974	535	132		.....		57.8	14.4	28.0	.....
25 Aug	1976	847	251		.....		54.2	0.8	45.0	.....
17 Sep	1975	1075	216		.....		54.6	—	45.4	.....
22 Sep	1974	246	75		.....		64.0	—	36.0	.....
22 Oct	1975	1397	180		.....		40.6	—	59.4	.....
23 Oct	1975	976	290		.....		40.7	—	59.3	.....
24 Oct	1974	548	164		.....		59.8	—	40.2	.....
24 Oct	1974	591	122		.....		52.5	—	47.5	.....

[1] Samples sorted into three categories only; no roe, head roe, and berried females; percentages listed under NR and HR for females actually pertain to transitionals and females.

TABLE 4. Samples of shrimp from Godthaab Deep (Div. 1D); percentages in various stages of development for transitionals (T) and females (F) refers to the numbers listed under T + F. (NR = no roe, HR = head roe and BR = berried females.)

Date	Year	No. of sample	No. of T + F	Transitionals + females NR[1]	HR	BR	Size[1] (mm)
8 Jan	1974	170	90	16.7	—	83.3	27 L
9 Jan	1975	226	122	76.2[2]	—	23.8	23 L
17 Jan	1971	160	130	10.0	—	90.0	24 L
20 Jan	1976	541	292	10.3[2]	—	89.7	22.5 D
21 Jan	1974	177	63	27.0	—	73.0	27 L
6 Feb	1973	129	92	41.3	—	58.7	25 L
17 Apr	1973	147	95	26.3	6.3	67.4	26 L
24 Apr	1975	549	149	36.9[2]	4.0	59.1	27 L
13 May	1971	209	200	92.0[3]	—	8.0	25 L
26 May	1972	225	136	34.6	65.4	—	25 L
5 Jun	1970	403	110	68.2	31.8	—	—
8 Jun	1976	723	288	62.5	37.5	—	22 D
11 Jun	1974	275	99	19.2	90.9	—	26 L
18 Jun	1975	804	122	32.0[4]	68.0	—	22.5 D
22 Jun	1973	164	116	13.8	86.2	—	26 L
13 Jul	1972	390	201	46.3	53.7	—	25 L
13 Jul	1974	270	195	11.8	88.2	—	26 L
24 Jul	1970	250	53	35.8	64.2	—	24 L
18 Aug	1971	353	137	44.5	51.8	3.6	25 L
19 Aug	1971	317	101	42.6	53.5	4.0	25 L
19 Aug	1975	406	149	32.9[4]	63.1	4.0	22.5 D
7 Oct	1975	578	273	19.0	0.7	80.2	23.0 D
23 Oct	1973	228	92	31.5	—	68.5	26 L
10 Nov	1975	684	219	24.2	—	75.8	23.0 D
27 Nov	1974	217	92	63.0[5]	—	37.0	24 L

[1] Length frequencies were used to judge the likely numbers of shrimp without head roe (NR) which may be transitionals and females, on the basis of minimum carapace sizes indicated (L = lateral and D = dorsal measures of carapace.

[2] Likely composed mainly of transitionals which have or will develop head roe.

[3] Includes many with recently hatched eggs.

[4] May include relatively many large males.

[5] Likely to include many in the first transitional stage.

TABLE 5. Samples of shrimp from Sukkertoppen Deep (Div. 1C); percentages in various stages of development for transitionals (T) and females (F) refer to the numbers listed under T + F. (NR = no roe, HR = head roe and BR = berried females.)

Date	Year	No. in sample	No. of T + F	Transitionals + females NR[1]	HR	BR	Size[1] (mm)
14 Jan	1976	591	338	95.0[3]	—	5.0	22.0 D
13 Feb	1973	144	116	44.0	—	56.0	26 L
12 Mar	1973	121	111	54.1[3]	—	45.9	25 L
14 Apr	1972	189	125	80.8[3,4]	—	19.2	26 L
21 Apr	1975	122	86	98.8	—	1.9	26 L
30 Apr	1976	595	279	88.9[3]	1.8	9.3	22.5 D
28 May	1971	171	150	100.0[2]	—	—	25 L
1 Jun	1970	341	288	99.7	0.3	—	—
9 Jun	1976	460	335	32.8	67.2	—	23.5 D
14 Jun	1972	151	133	36.8	63.2	—	26 L
18 Jun	1974	265	208	24.0[3]	76.0	—	25 L
24 Jun	1975	478	257	10.5	89.5	—	24.0 D
28 Jun	1973	242	217	48.8	51.2	—	25 L
20 Aug	1971	226	182	17.6	82.4	—	26 L
4 Dec	1974	117	50	54.0	—	46.0	26 L

[1] Length frequencies were used to judge the likely numbers of individuals without roe (NR) which may be transitionals and females, on the basis of minimum carapace sizes indicated (L = lateral and D = dorsal measures of carapace).

[2] Most have recently hatched eggs (setae on pleopods).

[3] Likely composed mainly of transitionals which have or will develop head roe.

[4] Contains some which have recently hatched the eggs.

Estimated Density of Shrimp, *Pandalus borealis*, in Greenland Waters and Calculation of Biomass on the Offshore Grounds Based on Bottom Photography[1]

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Abstract

Bottom photography was used during 1975-77 in West Greenland waters to estimate the density of the shrimp, *Pandalus borealis*, population. Photographs were taken on eight shrimp grounds in Disko Bay during 1975 and 1976 and at 10 different stations west and north of Store Hellefiskebanke in ICNAF Divisions 1A and 1B in 1977. The densities (numbers per square meter) are given for the different localities, and an estimate of the biomass is presented, the calculation being made on the basis of the stratification scheme used for estimating the biomass from a trawl survey in 1976. A vsriance analysis model for testing tha significance of the density estimates is considered.

Introduction

The population assessment of shrimp, *Pandalus borealis*, is complicated by the lack of methods for determining directly the age of individual shrimp (Carlsson, MS 1976), and consequently some of the parameters required for use in population dynamics models are not well known. Catch and effort data have been used to assess the distribution and size of the stock by the "swept area" method (Horsted, 1978; Hoydal, 1978), and more recently a photographic technique has been introduced to obtain data on the density of shrimp (Kanneworff, MS 1976). An analysis of data obtained during 1975-77 is presented in this paper in the light of their usefulness for estimating the biomass of shrimp on the offshore grounds in Div. 1A and 1B.

Materials and Methods

The equipment used for the bottom photographic surveys and the techniques of handling are described by Kanneworff (MS 1976). In 1977, a high-speed colour film (diapositive) was used, except for a few short series with black-and-white film to check the functioning of the camera.

The various trawling grounds in Disko Bay and the photographic stations in the offshore area, together with the stratification scheme used in the biomass calculations, are shown in Fig. 1 and 2. The material considered in this paper consists of 1,476 bottom photographs in September-October 1975 from Disko Bay, 955 photographs from Disko Bay in May 1976, and 2,177 photographs from the offshore grounds in Div. 1A and 1B in July-August 1977. Due to poorer weather conditions offshore, the number of photographs per station in the 1977 material was considerably lower than that for the inshore stations in 1975 and 1976. Because of a technical problem, a long series of photographs were taken about 4-5 m above the bottom at several of the stations in 1977. This provided the opportunity to see if shrimp were swimming up to this distance above the bottom at a number of stations.

The shrimp seen on the photographs were classified into three size categories: small (less than 18-20 mm carapace length), large (greater than 26-28 mm), and medium (all others). The percentage size compositions of shrimp, as measured from the photographs, are as follows:

	Small	Medium	Large
Disko Bay 1975	27.9	69.8	2.4
Disko Bay 1976	41.3	57.4	1.3
Offshore 1977	3.1	92.2	4.7

The densities are based on counting the number of shrimp in photographs each of which covered an area of 3.39 square meters of the bottom (Kanneworff, MS 1976). The biomass estimates are based on an average

[1] Based on material submitted to the December 1976 Special Meeting as ICNAF Res. Doc. 76/XII/152 and to the November 1977 Spacial Meeting as ICNAF Res. Doc. 77/XI/65.

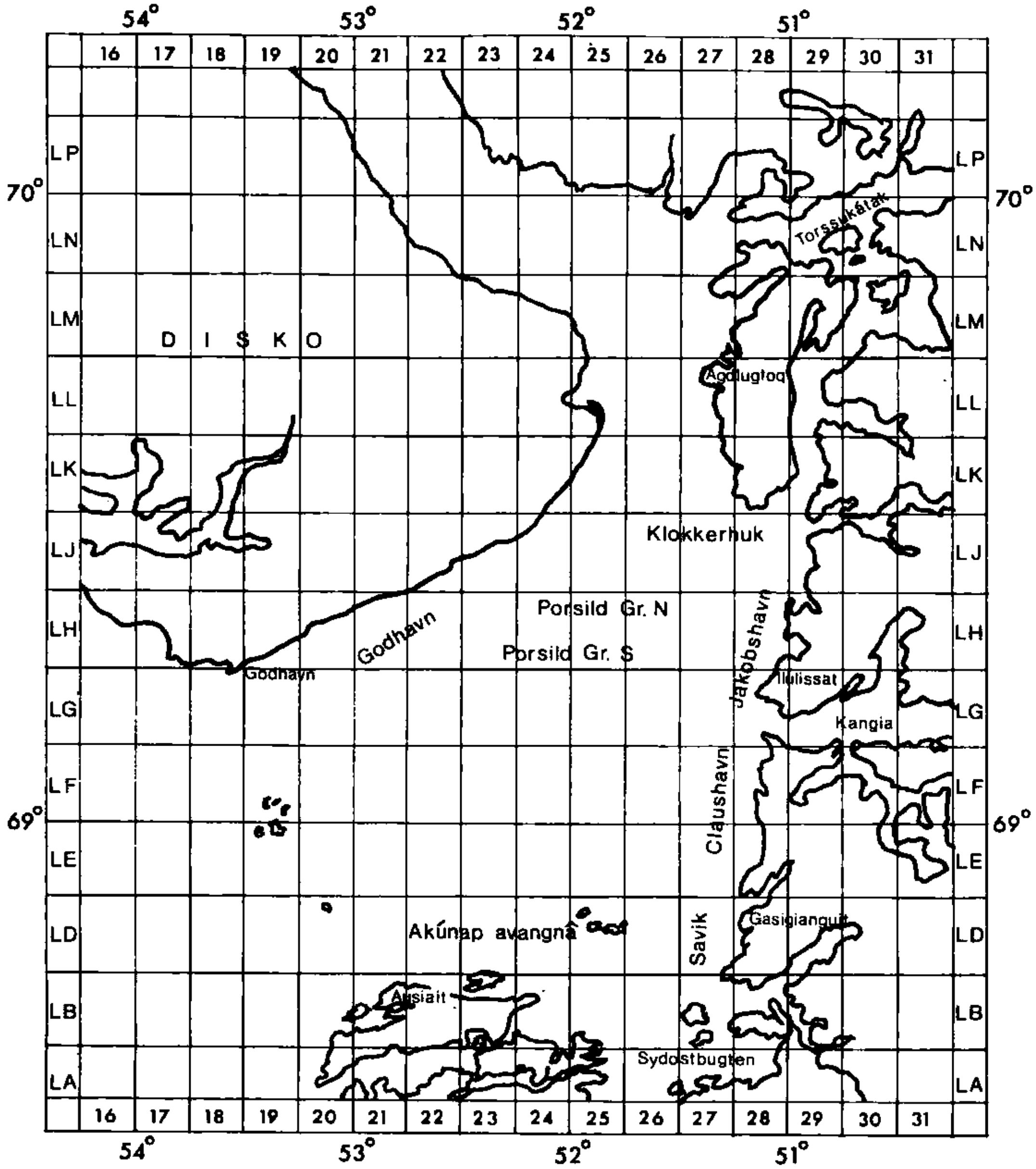

Fig. 1. Map of the shrimp grounds in Disko Bay where photographic surveys were carried out in 1975 end 1976.

shrimp weight of 7.71 g, being the average weight of 11,198 specimens in 41 samples from the 1976 trawl survey (Horsted, 1978).

Results and Discussion

The results of the photographic surveys in Disko Bay (1975 and 1976) are summarized in Table 1 and those for the offshore grounds (1977) in Table 2. The density values for shrimp in Disko Bay are on the average nearly 10 times greater than those for the offshore grounds. A comparison of the 1975 and 1976 density values for Disko Bay (Table 1) shows that the average density at the Godhavn stations in 1976 was about twice the level observed in 1975, and the increase observed at the Porsild Gr. stations was about 25%. The 1975 observations were made shortly before the fishing season ended due to ice cover and those of 1976 were made immediately after the ice broke up in May. The differences may be due to the absence of fishing in the area for about 7 months during the 1975-76 winter, giving time for the shrimp stock to recover and redistribute on the fishing grounds before the 1976 fishing season started.

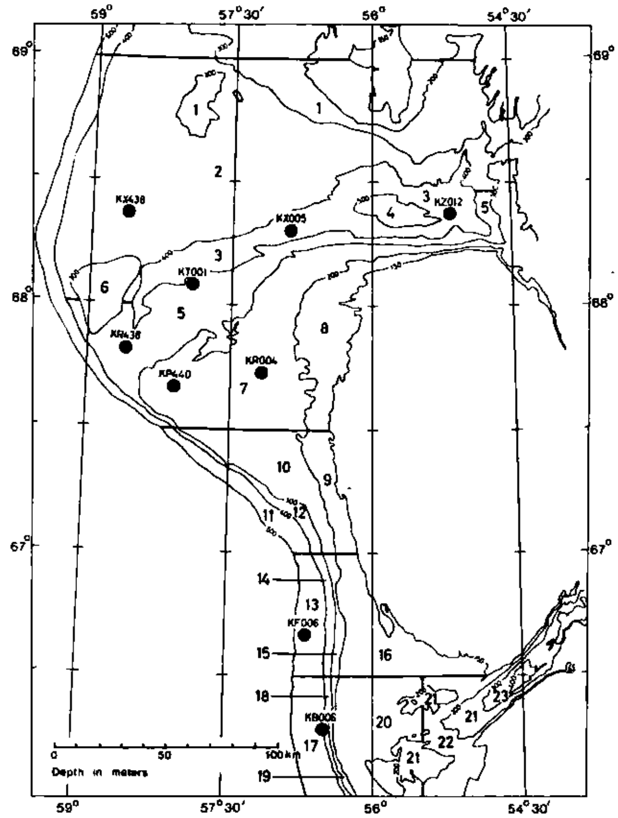

Fig. 2. Depth contour map of the survey area off West Greenland. Photo-stations (black dots) with corresponding area codes are shown, together with the stratification scheme used in the biomass calculations.

For data processing, the observations were grouped by 30-min periods in order to examine diurnal variation in shrimp density. An example of this for a station in Disko Bay is given in Table 3. The material shows considerable fluctuation in density during the different time periods of the day, but only a few of the Disko Bay stations were sampled in a way to provide the possibility of studying diurnal variation in density.

An attempt was made to use a simple mathematical model (K. P. Anderson, Danish Institute for Fisheries and Marine Research, personal communication) based on a two-way analysis of variance, taking into account both the differences between stations and those between time periods, as follows:

$$d_{ij} = D + a_i + t_j + E_{ij}$$

where d_{ij} = density at site i and time of day j,
D = overall mean density,
a_i = area dependent variable,
t_j = time dependent variable,
and E_{ij} = random variable.

The model was not adequate to satisfy the assumption of one area dependent and one time-dependent variable. The analysis showed that there must be one or more variables which are dependent on both area and time. Furthermore, contrary to expectation, the frequency of observations with 0, 1, 2, ..., *n* shrimp per observation was not consistent with

TABLE 1. List of photographic stations in Disko Bay in 1975 and 1976 with observed average densities of shrimp.

Year	Date	Area code	Area name	Depth (m)	No. of observations	Density (No./m²)	Variance
1975	17 Sep	LD027	Sevik	390	50	0.79	0.22
	17 Sep	LD027	Savik	375	12	0.47	0.15
	17 Sep	LF027	Claushavn	295	51	2.34	0.15
	18 Sep	LF027	Claushavn	290	21	2.01	0.20
	15 Oct	LH019	Godhavn	390	139	1.68	0.23
	16 Oct	LH020	Godhavn	360	178	1.52	0.24
	16 Oct	LJ026	Porsild Gr. N	330	98	0.93	0.23
	17 Oct	LJ028	Klokkerhuk	285	44	3.14	0.04
	18 Oct	LJ028	Klokkerhuk	295	196	2.93	0.04
	19 Oct	LH025	Porsild Gr. N	310	299	1.29	0.25
	20 Oct	LH025	Porsild Gr. S	430	223	0.21	0.15
	20 Oct	LH025	Porsild Gr. S	435	165	0.38	0.18
1976	12 May	LG019	Godhavn	401	175	3.79	0.70
	13 May	LG020	Godhavn	400	201	2.87	0.05
	13 May	LH025	Porsild Gr. N	305	282	1.52	0.24
	14 May	LH026	Porsild Gr. N	330	99	1.47	0.25
	14 May	LH025	Porsild Gr. S	435	173	0.35	0.17
	21 May	LD025	Akúnâp avangnâ	225	25	6.68	4.28

TABLE 2. List of photographic stations on the offshore grounds in 1977 with observed average densities of shrimp.

Date	Area code	Area name	Depth (m)	No. of observations	Density (No./m²)	Variance	No. of off-bottom observations
24 Jul	KZ012	N of Store HFB	465	35	0.19	0.15	38
24 Jul	KZ012	N of Store HFB	465	54	0.19	0.11	0
25 Jul	KT001	W of Store HFB	350	17	0.21	0.16	333
26 Jul	KP440	W of Store HFB	278	82	0.37	0.16	216
26 Jul	KR438	W of Store HFB	390	64	0.21	0.18	351
27 Jul	KR004	W of Store HFB	210	116	0.71	0.20	151
4 Aug	KB006	W of HBG Deep	470	282	0.11	0.11	10
5 Aug	KF006	W of Store HFB	572	23	0.04	0.12	1
5 Aug	KX005	N of Store HFB	410	204	0.15	0.13	5
6 Aug	KX438	N of Store HFB	344	190	0.11	0.11	5

TABLE 3. Observations from one photographic station in Disko Bay by 30-min intervals illustrating the diurnal variation of shrimp density on the bottom. (Porsild Ground South, rectangle LH025, 435 m, 14 May, from Table 1.)

Time period	No. of observations	No. of shrimp	No. per observations	Density (No./m²)	Variance
1500-1529	21	38	1.81	0.53	0.16
1530-1559	12	30	2.50	0.74	0.21
1600-1629	3	3	1.00	0.29	0.09
1630-1659	11	11	1.00	0.29	0.09
1700-1729	29	33	1.14	0.34	0.10
1730-1759	30	33	1.10	0.32	0.12
1800-1829	18	13	0.72	0.21	0.04
1830-1859	30	32	1.07	0.31	0.10
1900-1929	11	13	1.18	0.35	0.16
1930-1959	8	2	0.25	0.07	0.17

the Poisson distribution, which was one of the assumptions underlying the model. A usable model must therefore take account of a more appropriate type of distribution and include other possibilities on interaction between the parameters. Since a suitable model has not yet been developed to test statistically the differences between stations and time periods, only the trends and probable differences in the density values can be pointed out. Likewise, the biomass calculations can only be considered as very rough estimates.

On the basis of the stratification scheme for the offshore grounds used by Horsted (1978), biomass estimates were calculated for those strata which were covered by the photographic sampling, under the assumption that the mean density at each station represents the density of the stratum in which the station is located (Fig. 2). The trawl survey in 1976 (Horsted, 1978) and the photographic survey in 1977 were carried out during the same time of the year (July-August), and hence a comparison of the results is not complicated by seasonal fluctuations in abundance.

The total biomass in size strata covered by the photographic survey in 1977 was estimated to be 31,210 tons, about 17% higher than the biomass estimated for the same strata from the 1976 trawl survey (Table 4). Even if the surveys were conducted in the same year, such an increase would be expected because the estimate based on trawling excludes small shrimp which enter but are not retained by the trawl. The biomass estimate for the entire area dealt with by Horsted (1978) was 54,600 tons in the summer of 1976. This estimate would be somewhat higher if account were taken of the small shrimp not retained by the trawl but included in photographic observations. In any case, the biomass estimate is still a minimum figure, as it takes into consideration only that part of the shrimp stock which is near or on the bottom during trawling (excluding shrimp entering but not retained by the trawl) or which is on the bottom during photographic sampling.

No shrimp were shown in the 1,110 photographs which were taken by accident with the camera about 4-5 m above the bottom (Table 2). Shrimp would have been recognized in the focus interval about 130-180

TABLE 4. Comparison of biomass estimates for various strata by the photographic method in 1977 with estimates from a trawling survey for 1976 as reported by Horsted (1978).

			Biomass (tons)	
Stratum No.	Area of stratum	Shrimp density (No./m²)	Photo method (1977)	Trawling method (1976)
1	2,475	—	—	7,751
2	7,705	0.11	6,458	9,920
3	3,000	0.16	3,704	2,066
4	355	—	—	478
5	2,930	0.21	4,691	2,912
6	515	—	—	1,477
7	3,665	0.57	16,004	10,731
8	1,615	—	—	1,460
9	450	—	—	73
10	1,565	—	—	4,658
11	300	—	—	513
12	450	—	—	2,546
13	520	0.04	154	894
14	520	—	—	1,149
15	300	—	—	122
16	1,270	—	—	2,000
17	615	—	—	2
18	230	0.11	199	80
19	310	—	—	11
20	2,470	—	—	74
21	1,155	—	—	3,534
22	1,545	—	—	1,720
23	230	—	—	397
Total	34,190			54,568
Total (strata 2, 3, 5, 7, 13, 18)			31,210	26,603

cm from the camera if they had been present. Nearly all of the shrimp shown on the bottom photographs were in direct contact with the bottom. Therefore, free swimming shrimp are not considered to account for a significant portion of the stock at the time of the photographic sampling which in 1977 was carried out during daytime only. However, diurnal variation must be taken into account in any model developed to simulate the population dynamics of the stock.

Although the photographic method has a number of limitations as described by Kanneworff (MS 1976), e.g. the possible influence of the presence of the equipment on the behaviour of shrimp, it is considered to be reliable in providing absolute values of the density of that part of the stock which is actually on the bottom during the time of the sampling.

Acknowledgement

The author acknowledges the help of Mr K. P. Andersen of the Danish Institute for Fisheries and Marine Research, who developed the model and the computer program for the variance analysis.

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Danish Trawl Surveys on the Offshore West Greenland Shrimp Grounds in 1977 and Previous Years[1]

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Abstract

The fishable biomass of shrimp, *Pandalus borealis*, in part of ICNAF Division 1B in 1977 was estimated by the "swept area" method on the basis of a number of hauls by a commercial trawler and compared to estimates for 1976. Relative to 1976, the biomass in 1977 seems to have increased in the northern part of Div. 1B and decreased somewhat in the southern part. Diurnal variation in various periods of the year is analyzed and conversion factors calculated. Research vessel hauls on shrimp grounds in Div. 1C and 1D during 1968-77 showed no clear trend in catch rate up to 1975 but a decrease thereafter.

Introduction

Research surveys of the offshore shrimp grounds off West Greenland have shown that the most important of these are in Div. 1A and 1B (Carlsson and Smidt, 1978). Stations have been fished in this area as part of the annual research program of the Greenland Fisheries Investigations. These stations and others previously established in other parts of Subarea 1 are occupied as regularly as possible by the R/V *Adolf Jensen*, maintaining as far as possible a standard trawl and a standard trawling technique.

In 1976, the research work included a trawl survey by the Greenland commercial trawler *Sisimiut* which fished 44 stations in a stratified scheme covering the area between 66°N and 69°N and east of 59°W at depths between 150 and 600 m (Horsted, 1978a). Research on the offshore shrimp grounds in 1977 was concentrated in Div. 1B and was based on trawling and bottom photography. The latter is reported separately by Kanneworff (1978).

Materials and Methods

The 1977 data were obtained partly from trawling by the *Adolf Jensen* (side trawler, 167 GRT, 525 BHP) and partly by the *Sisimiut* (stern trawler, 722 GRT, 2000 BHP) which had two biologists on board as observers during two trips in June.

The *Adolf Jensen* used the so-called "Alaska balloon" trawl with groundrope (length of bobbins) of 31.9 m and codend mesh size about 36 mm. The vessel normally trawls at 2 to 2.5 knots. However, in May 1977, a new trawl of the same dimensions did not work properly unless towed at about 3 knots, and subsequent hauls were therefore made at that speed. This illustrates the difficulty of maintaining standard trawling procedures even though every effort is made to maintain a standard gear. The *Sisimiut* used a "Fjortoft Sputnik" trawl with 51 m groundrope, 43 m headline and codend mesh size about 40 mm, which was towed at a speed of 3 to 3.5 knots. During a short period in May, the two vessels trawled at the same place and time in order to compare their fishing power.

Research vessel hauls are normally of 1-hr duration, whereas those of commercial trawlers may be longer, frequently 2 hr. For analysis in this paper, all trawl catches have been converted to 1-hr hauls. The total catches of the *Adolf Jensen* are usually recorded with an accuracy of 95% or better. The catches of the *Sisimiut* may be less accurate, as they are reported to the captain in terms of boxes (each containing about 30 kg) and recorded to the nearest 100 kg.

When vessels are operating offshore beyond the radar range of the coast, the accuracy of the trawling positions is usually not very good. In some cases, the rectangles recorded in the *Sisimiut* logbook do not correspond to the depths given on nautical charts.

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[1] Submitted to the November 1977 Special STACRES Meeting as ICNAF Res. Doc. 77/XI/67.

Many hauls extended over more than one rectangle, but only one rectangle was recorded in the logbook and used in automatic data processing. No attempt has been made to adjust the rectangles recorded to charted depths, as, in general, there was reasonably good agreement.

The shrimp catches by the *Adolf Jensen* in Div. 1A, 1B and the northern part of Div. 1C in 1977 are listed by rectangle in Table 1. Catch and effort data for the *Sisimiut* in Div. 1B in June 1977 are given in Table 2. For analyses of these data, it was necessary to take diurnal variation into account, as was done by Horsted (1978a) in his analysis of 1976 data from the *Sisimiut* trawl survey.

Correction for Dirunal Variation in Catch Rate

Diurnal variation in the catch rate of shrimp in Greenland waters is well-known to fishermen and has been described by Smidt (1978) and Horsted (1978a). Smidt showed that the magnitude of diurnal variation varied with the seasons, being most pronounced when the variation in light intensity is greatest, i.e. around the equinoxes. It seems reasonable, therefore, that specific conversion factors be used when analyzing data for the following groups of months: (a) November–February, (b) June–July, (c) May and August, (d) April and September, and (e) March and October. The available data do not cover all months, but all of the suggested groups of months are represented. The data from individual hauls by *Sisimiut* from December 1975 to October 1976 (Smidt, 1978) and also in June 1977 (Table 2) are plotted in Fig. 1.

TABLE 1. Offshore bottom trawl hauls by R/V *Adolf Jensen* in Div. 1A, 1B and northern part of Div. 1C in 1977. (Data are arranged from north to south. Two or more catches are given when two or more hauls were made in the same rectangle.)

ICNAF Div.	Rectangle code (Fig. 1)	Date	Depth range (m)	Actual catch/hr (kg)	Corrected catch/hr (kg)
1A	LP440	9 Aug	347	46	46
	LK008	8 Aug	219–224	207	457
1B	KZ012	24 Jul	344	167	175
	KX005	6 Aug	403–420	210	273
	KX438	6 Aug	344	60	60
	KX012	14 May	441–473	24, 42, 97	26, 42, 102
	KT001	25 Jul	351	100	118
	KS004	22 Jul	290	93	96
	KR438	26 Jul	390	1,260	1,273
	KR006	22 Jul	169–175	4	4
	KP440	25 Jul	273–280	470	494
	KP004	27 Jul	210	360	385
	KN002	13 May	228–240	450, 580	832, 851
	KN003	12 May	240–257	260	619
	KN004	12 May	225–230	378, 1,070	835, 1,263
	KM004	27 Jul	224–229	—	—
	KL005	12 May	235	56, 100	57, 100
	KK005	12 May	260–285	45	53
	KJ007	21 Jul	167–220	1	1
	KF006	4 Aug	536–574	57	108
1C	KA011	16 May	206–225	70, 102, 120	116, 142, 285
	KA011	28 Jul	213–228	22	27

TABLE 2. Catches of shrimp per hour trawling by *Sisimiut* on the offshore grounds in Div. 1B, 15–26 June 1977. (The average catches per hour have been adjusted for diurnal variation and are arranged by the strata used for estimating biomass in 1977.)

Stratum No.	Map code (Fig. 1)	Depth (m)	Fishing effort (hauls)	Fishing effort (hours)	Catch/hour (kg) Actual	Catch/hour (kg) Adjusted
1	KZ05	302	1	1.0	50	66
2	KZ12	425	1	1.0	40	49
3	KX06	340	1	1.0	30	42
4	KV06	270	1	0.9	76	81
	KT04	264	3	6.4	343	483
	KS06	219–253	7	14.6	521	667
5	KV11	245	1	1.6	126	202
	KV12	245	1	1.7	240	300
	KT08	245	1	2.0	150	152
6	KR02	264	1	2.0	500	535
	KR03	256–302	3	5.7	618	729
	KR04	212–245	10	20.4	1,029	1,215
	KR05	250–285	3	6.9	1,142	1,197
	KP04	208–266	4	9.3	525	617
	KN03	245	1	2.2	415	456
7	KM03	255	1	1.8	171	173
	KM04	283	1	1.0	200	325
	KL04	226–237	4	8.3	576	636
	KL05	220–226	6	12.5	624	828
8	KJ06	226	1	1.0	300	423
9	KM01	491	1	1.0	60	85
10	KM01	378	1	1.0	200	300
11	KK07	189	1	1.0	500	610
—	KK08	140	1	1.0	50	56

There is obviously great haul-to-haul variation, due not only to diurnal variation but also to other factors. The variation is so great in June–July that it may seem unrealistic to postulate a diurnal variation. On the other hand, the data for December–January and especially for October clearly indicate a diurnal variation although a great deal of variation still exists within each of the 2-hr periods.

Fitting curves (by eye) to the distributions of points in Fig. 1 leads to the conversion factors given in Table 3. The factors for each period of the year were calculated by assigning a value of 1.00 to the catch rate for the 2-hr period corresponding to the highest point on the curve. These conversion factors were then used to adjust the actual catch rates listed in Tables 1 and 2. It is quite obvious that this crude procedure can be criticized, as it would be doubtful whether catch rates like the very high ones in the early morning of the December–January period (Fig. 1) should be increased, if they are to be taken as abundance indices.

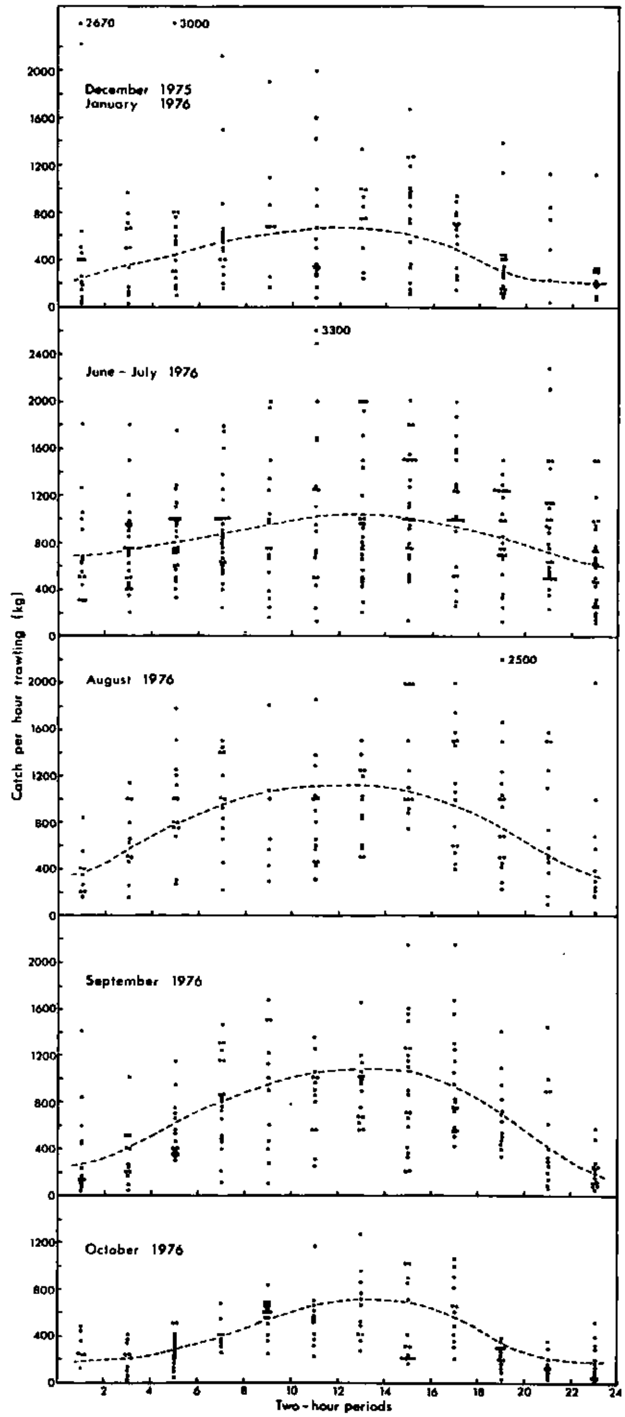

Fig. 1. Shrimp catches per hour trawling by the *Sisimiut* in Div. 1B from December 1975 to October 1976, arranged to show diurnal and seasonal variation. Each dot represents a haul plotted at the mid-point of a 2-hr period. The median lines are fitted by eye.

Catch rates during June (and possibly earlier) to September are shown as being generally higher than during other periods of the year (Fig. 1). If this is an annual tendency, conversion factors should possibly take into account not only the diurnal variation within each specific period of the year but also the variation between periods. Since fluctuations in light intensity are believed to cause the diurnal variation, it is possible that this factor could also cause variation in the catch rates from season to season. However, such variation could also be caused by the annual recruitment of shrimp to the exploited stock (Horsted, 1978b), especially if recruitment tends to be stepwise or even knife-edge rather than continuous. Variation in distribution of shrimp, resulting from active migration or hydrographic conditions, could also greatly influence the abundance of shrimp in any given area (Horsted and Smidt, 1956).

Comparison of Catch Rates Between Vessels

The catch rates of shrimp by the *Sisimiut* and the *Adolf Jensen*, when both vessels were operating at the same time and place in May 1977, are given in Table 4. The first three hauls of the *Adolf Jensen* were made at 2 to 2.5 knots, whereas the others were made at 3 to 3.5 knots, which was also the towing speed of the *Sisimiut*. There was much variation in catch rate for both vessels (no correction made for diurnal variation), but in all cases of simultaneous trawling the catch rate of *Sisimiut* was greater than that of *Adolf Jensen*, a result to be expected because of the difference in the trawls used.

The material is not sufficient to establish a reliable overall conversion factor for the difference in fishing power between the two vessels. All eight hauls give an average factor of 3.4 to convert the catch rates of *Adolf Jensen* to those of *Sisimiut*, whereas the last five hauls give a conversion factor of 2.1. As a first approximation, therefore, the fishing power of the *Sisimiut* could be taken to be twice that of *Adolf Jensen*, but no conversion factor has been applied to the *Adolf Jensen* data presented in this paper.

Long-Term Trends in Research Catch Rates

The catches of shrimp in 1-hr hauls by the *Adolf Jensen* at standard stations in Div. 1C (Sukkertoppen Deep) and Div. 1D (Godthåb Deep) during 1968–77 are shown in Fig. 2. No correction has been made for

TABLE 3. Average catch per hour (CPH) and conversion factor (CF) for diurnal variation of shrimp catches based on *Sisimiut* trawl hauls from December 1975 to October 1976. (The basic material is given by Smidt (1978) and illustrated in Fig. 1-5.)

Time of day (hr)	Nov-Feb		Jun-Jul		May, Aug		Apr, Sep		Mar, Oct	
	CPH	CF	CPH	CF	CPH	CF	CPH	CF	CPH	CF
0-2	250	2.68	690	1.51	350	3.21	260	4.08	190	3.63
2-4	350	1.91	740	1.41	540	2.08	400	2.65	200	3.45
4-6	450	1.49	810	1.28	800	1.41	610	1.74	280	2.46
6-8	540	1.24	880	1.18	950	1.18	800	1.33	400	1.73
8-10	610	1.10	970	1.07	1,050	1.07	940	1.13	540	1.28
10-12	670	1.00	1,030	1.01	1,110	1.01	1,030	1.03	650	1.06
12-14	680	1.02	1,040	1.00	1,125	1.00	1,060	1.00	690	1.00
14-16	600	1.12	990	1.05	1,070	1.05	1,050	1.01	680	1.01
16-18	500	1.34	940	1.11	950	1.18	910	1.16	560	1.23
18-20	300	2.23	850	1.22	770	1.46	700	1.51	325	2.12
20-22	230	2.91	740	1.41	510	2.21	420	2.52	200	3.45
22-24	210	3.19	640	1.63	350	3.21	200	5.30	180	3.83

TABLE 4. Comparison between simultaneous trawl catches of the *Sisimiut* and the R/V *Adolf Jensen* in Div. 1B in May 1977. (Towing speed was 3 to 3.5 knots except for the first three hauls of *Adolf Jensen* at 2 to 2.5 knots.)

Map code (Fig. 1)	Time of day	Catch per hour (kg) *Sisimiut*	Catch per hour (kg) *A. Jensen*	Ratio (SIS/AJ)
KJ005	0455	52	45	1.16
KL005	0945	457	56	8.16
KM003	1200	700	100	7.00
KN003	1610	1,333	1,070	1.25
KN003	2025	825	378	2.18
KN003	2220	1,309	280	4.68
KN003	0245	650	450	1.44
KN003	0750	629	560	1.08

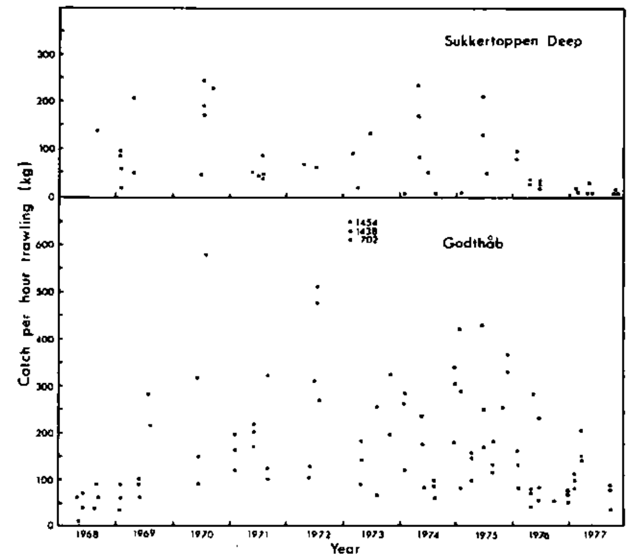

Fig. 2. Shrimp catches per hour trawling by the R/V *Adolf Jensen* in Sukkertoppen Deep (Div. 1C) and in Godthåb Deep (Div. 1D), 1968-77. Each dot represents a haul.

diurnal variation, but all hauls were made during the daytime. There was great haul-to-haul variation on days when two or more hauls were made, and it is difficult to see any clear trend over the entire period. However, it must be borne in mind that the fishing power of the vessel has not been constant. A new, more efficient type of trawl was introduced in July 1971, and skippers changed in December 1968 and in March 1974. Therefore, from the initial operation of the vessel in September 1967 to the early part of 1969 and again in 1974, the catches are likely to have been affected by the process of learning by the skippers in becoming familiar with the fishing grounds and the operation of the vessel and gear. The most stable period, in terms of fishing power, was probably that of 1975-77. Over these three years, there seems to have been a definite decline in catch rate in both the Godthåb Deep and the Sukkertoppen Deep. For the latter ground, the recent decline in catch rate has been confirmed by Greenland fishermen. The Sukkertoppen Deep was one of the most important grounds, if not the most important, in the early years of the offshore fishery by non-Greenlandic vessels.

Even if the fishing power of the research vessel were kept constant and even if exploitation had been stable over a long period, one would still expect to find fluctuations in abundance indices due to natural variation in the shrimp stocks, caused by year-class fluctuation, migration, variation in distribution on the grounds, fluctuation in predators, etc. It is extremely difficult to analyze the material for all such possible sources of variation, but their combined effect on the stocks would have to be taken into account when formulating management strategy. As indicated above, there is evidence of a decline in abundance of shrimp on the two grounds over the last 3 years.

Trends in Catch Rates of the Commercial Fishery

The monthly catch rates of Greenland trawlers in Div. 1B from October 1975 to September 1977 do not indicate any clear trend (Table 5). However, monthly averages for such a large area may not be good indices of fluctuations in the total stock of the area, since at any given time only a part of the area is covered by the fishery. Horsted (1978a) showed that the fishery in 1976 had a northward displacement, possibly due to the movement of the major concentrations of shrimp. This displacement of the fishery in 1976 is evident from Table 4, and a more pronounced displacement seems to have occurred in 1977.

Figure 3 illustrates the distribution of fishing effort, in terms of number of hauls, by Greenland trawlers in 1976 and 1977. Although a fairly large area between 67° N and 68° N was fished intensively in both years, the 1977 fishery extended northward to some areas not fished in 1976. Also, more of the deeper parts of the bank slope seem to have been fished in 1977 than in 1976.

The important question about the gradual northward displacement of the fishery from 1975 to 1977 is whether it actually reflects a movement of shrimp concentrations or whether it is due to changes in catch rates caused by the fishery itself. If the latter is the case, one would not expect to find remarkably high catch rates in some unit areas (rectangles) at one time of the year and hardly any catch at all at other times (Horsted, 1978a). It is therefore likely that some movement of the shrimp concentrations does occur. The picture is also influenced by Arctic drift ice which prevents fishing in parts of the major shrimp grounds during certain times of the year. However, the gradual northward displacement of the fishery could also be due to the movement of some vessels to new grounds where the initial abundance of shrimp is better, following the depression of catch rates on the usual fishing grounds.

Comparison of Biomass Estimates for 1977 and 1976

Horsted (1978a) gave biomass estimates for shrimp by strata in Div. 1B, based on applying the "swept area" method to catch rates of the M/V *Sisimiut* at pre-selected stations fished in July 1976. Although a specific survey similar to that of 1976 was not made in 1977, this vessel, with observers on board, made some hauls in the survey area in June 1977. It is therefore not possible to make a comparison between the 2 years for the total area covered by the 1976 survey, but biomass estimates for some of the strata (or even parts of strata) may be considered.

A comparison of the catch rates and biomass estimates available for 1976 and 1977 are given in Table 6, the 1977 figures corresponding to the data listed in Table 2. The stratification of the area and the stations fished during the 1976 survey are shown in Fig. 4. Some of the strata are broken down into smaller areas to facilitate a comparison of the areas covered both in 1976 and 1977. Sampling was so sparse in the

TABLE 5. Shrimp catches per hour fished (kg) by Greenland trawlers in Div. 1B, October 1975 to September 1977. (Areas and months with less than 10 hours' trawling are excluded.)

	1975			1976									1977								
Map code	Oct	Nov	Dec	Jan	Feb	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
KV	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	597	—	—	—	—
KS	—	—	—	—	—	—	—	—	—	531	—	—	—	—	—	—	—	915	546	407	454
KR	—	—	—	—	—	—	—	—	—	357	—	—	—	—	—	—	—	815	541	649	452
KP	—	—	—	—	—	—	—	—	572	348	—	—	169	—	—	—	—	402	735	499	434
KN	—	550	—	—	—	—	—	—	444	366	452	—	389	—	—	—	735	868	685	525	353
KM	290	518	488	—	—	1,233	—	784	643	325	495	—	1,716	—	—	—	553	606	769	451	362
KL	—	609	373	—	—	870	1,138	692	719	180	—	—	1,163	—	—	1,056	787	474	616	418	—
KK	—	—	282	—	—	885	812	—	—	249	—	—	922	—	—	702	450	—	—	270	—
KJ	—	—	—	—	—	996	673	—	—	—	—	—	—	115	—	668	360	—	—	—	—
KH	—	—	—	—	—	—	544	—	—	—	—	—	—	1,394	—	—	564	—	—	—	—
KG	—	—	—	—	—	573	—	—	—	—	—	72	—	547	—	—	—	—	—	—	—
KF	—	—	—	—	—	643	—	—	—	—	—	—	—	547	—	317	—	—	—	—	—
KE	—	—	—	—	—	—	—	—	—	—	—	—	—	933	—	395	—	—	—	—	—
KD	—	—	—	—	—	892	—	—	—	—	—	—	—	—	821	738	—	—	—	—	—
KB	—	—	—	502	—	375	—	—	—	—	—	459	—	—	767	432	—	—	—	—	—
KA	—	—	—	440	—	—	—	—	—	—	—	360	—	721	228	215	—	—	—	—	—
JZ	—	—	—	639	620	—	—	—	—	—	—	—	782	457	—	180	—	—	—	—	—
JX	—	—	—	—	—	—	—	—	—	—	—	—	474	—	—	—	—	—	—	—	—
Mean	290	545	417	620	620	867	733	769	605	350	477	333	851	684	718	578	596	684	686	496	434

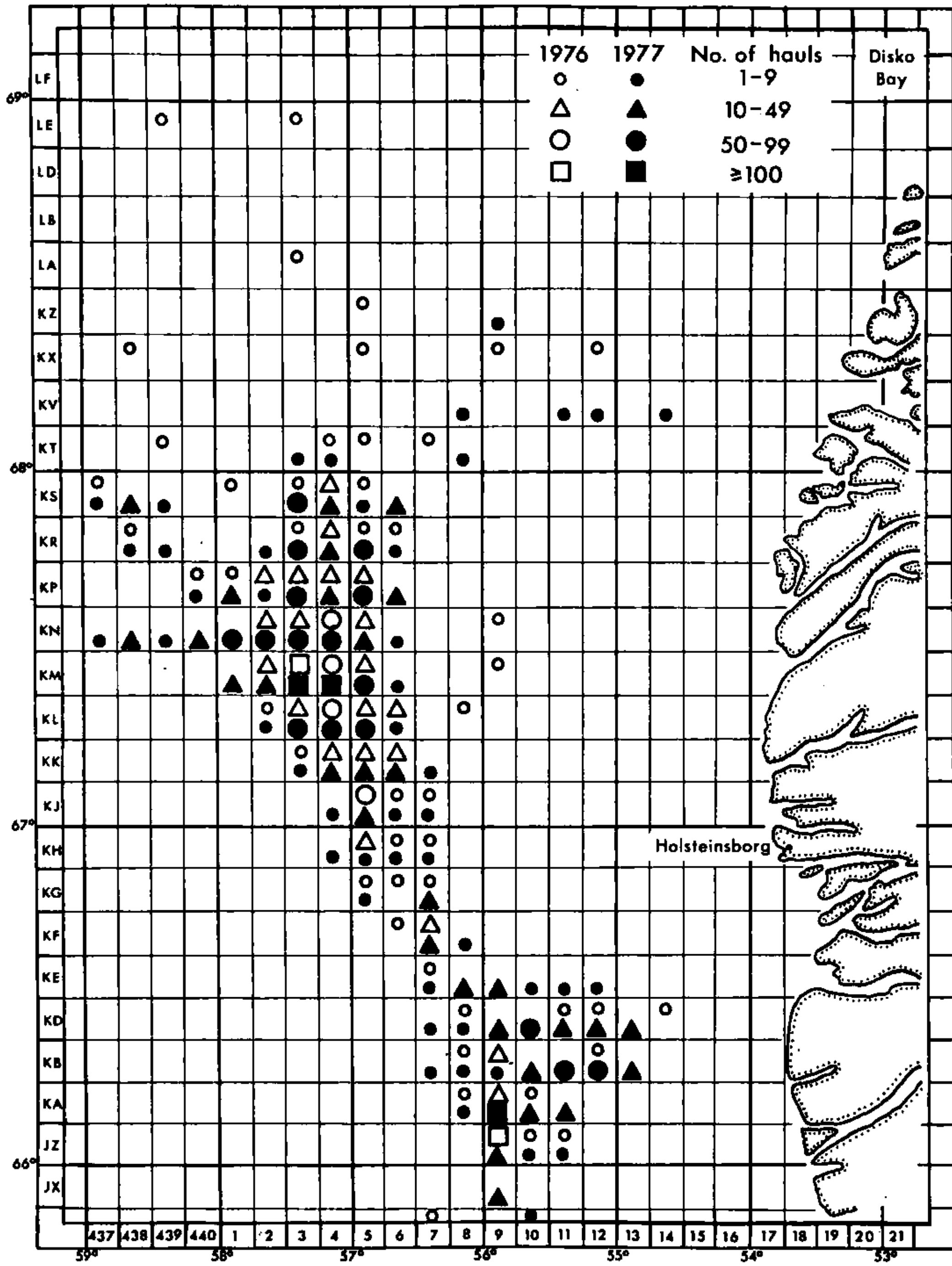

Fig. 3. Fishing effort (number of hauls) of Greenland trawlers off West Greenland in 1976 and 1977 by rectangular unit areas (15° long × 7.5° lat).

northernmost part of the survey area in 1977 that it seems impossible to extrapolate the few hauls in 1977 to the strata established for the 1976 survey. However, at all three stations sampled north of 68° 15'N in 1977, the catch per hour fished was much lower than at any of the 10 stations north of this latitude in 1976. The catches of the *Adolf Jensen* to the north of Store Hellefiske Bank (Table 1) were also very low in May 1977 (KX012) but were somewhat higher in July and August (KX005, KZ012).

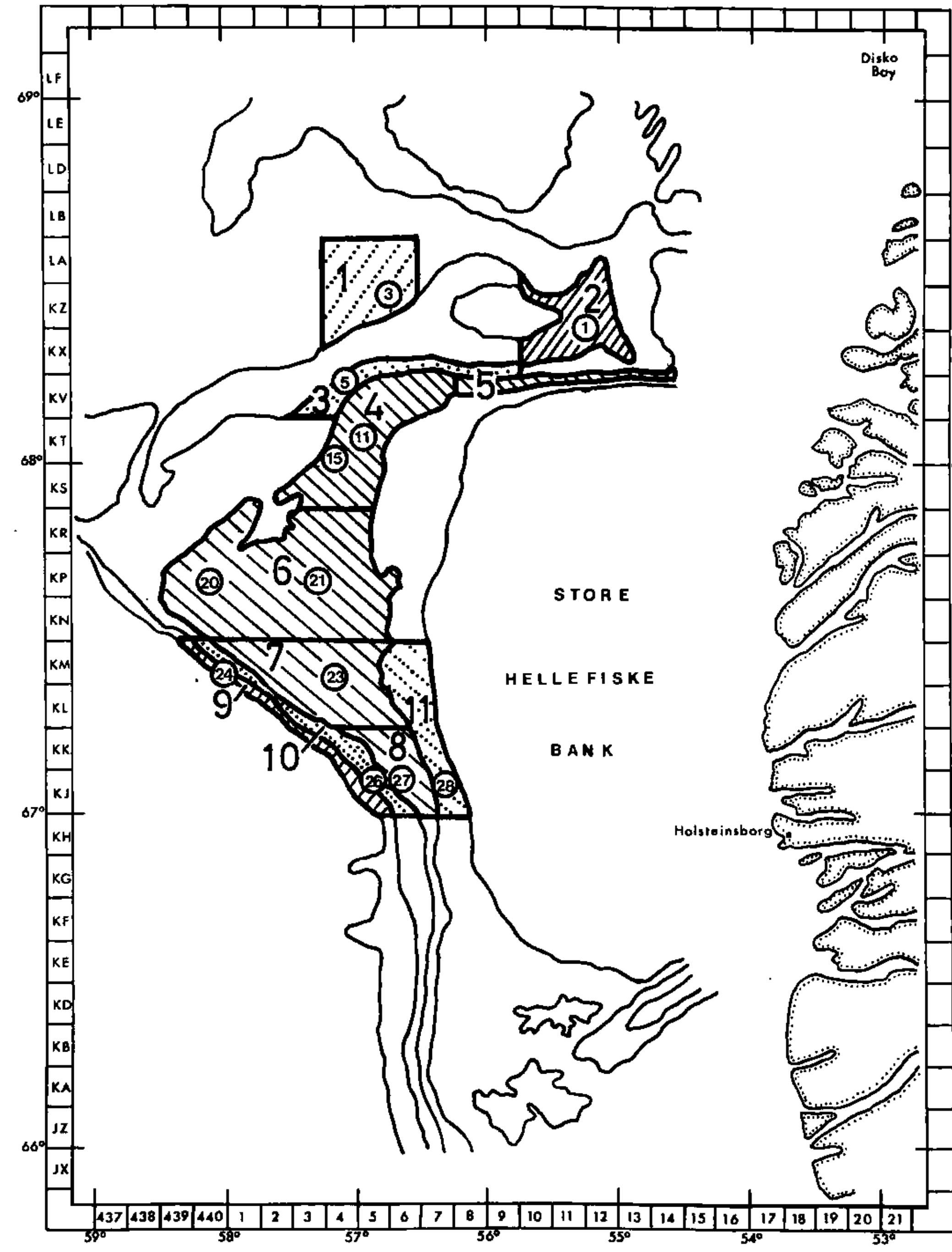

Fig. 4. Stratification and numbering of stations in the area off West Greenland surveyed by *Sisimiut* in July 1976 and in June 1977. The 1976 stations are indicated by numbered circles (see Horsted, 1978a) and the strata used for 1977 data are shown by heavy lines and numbers corresponding to strata referred to in Tables 2 and 6.

There is not much material for comparison between the 2 years for the western slope of Store Hellefiske Bank (strata 9 and 10), and the same applies to the shallower part of the bank. The two shallow-water hauls gave very different results, *viz* 610 kg per hour (corrected) at 189 m and 56 kg per hour at 140 m (Table 2). This, together with the very low catches of the *Adolf Jensen* in shallow water (Table 1, rectangles

TABLE 6. Comparison of biomass estimates in 1977 with those of 1976 applied to the strata used for 1977 data. [Strata and 1976 stations are shown in Fig. 4; details of 1977 data from Table 2 and 1976 data from Horsted (1978a).]

Station number 1976	Stratum number 1977	Area of strata (km²)	Average catch per hour (kg)		Biomass estimate (metric tons)	
			1976	1977	1976	1977
3	1	830	333	66	1,655	328
1	2	680	108	49	440	200
5	3	330	153	42	302	83
11, 15	4	720	406	404	1,750	1,740
—	5	220	(489)	218	(645)	287
20, 21	6	2,490	572	792	8,530	11,809
23	7	1,140	626	490	4,273	3,345
27	8	420	367	423	923	1,064
24	9	300	85	85	153	153
—	10	450	—	300	(2,546)	808
28	11	450	24	610	65	1,644
Total biomass					21,283	21,461

KR006 and KJ007), indicates that the 150 m contour line can be considered as the shallow-water boundary for the distribution of the stocks.

Considering the material for the 11 strata used in 1977, for which a comparison with the 1976 data can be made, the biomass estimate of 21,461 tons for 1977 is essentially the same as that for 1976 (Table 6). However, on the basis of the catch and effort data presented in Table 2, the biomass estimates for strata 4-8 are considered to be the most useful for comparison between years.

The sum of the 1977 biomass estimates for strata 4, 5 and 6 is 13,836 tons in contrast to a figure of 10,925 tons for 1976 (Table 6). For the combined area of these three strata and an area east of stratum 5 not included in he above estimates, Horsted (1978a) obtained a biomass estimate of 10,731 tons for 1976. This indicates that the biomass in June 1977 was somewhat higher in this important area than in July 1976. For strata 7 and 8, the sum of the 1977 biomass estimates is 4,409 tons whereas the corresponding figure for 1976 is 5,196 tons. Horsted (1978a) obtained a biomass estimate of 4,658 tons for 1976 by averaging the catch rates for the two strata. It seems, therefore, that there was less shrimp in strata 7 and 8 in June 1977 than in July 1976. These trends in biomass estimates for the important part of the shrimp grounds in Div. 1B also point to a northward displacement of the main shrimp concentrations between 1976 and 1977.

While it is not possible to make a comparison between the 2 years for the entire area surveyed in 1976, due to the lack of 1977 data for the strata in the large area between 68°N and 69°N, the evidence indicates that, apart from the northward displacement of the shrimp concentrations, the biomass on the grounds south of 68°N in June 1977 was about the same as in July 1976. Since the shrimp stocks off West Greenland have only been fished at a high level of exploitation during the past 2 or 3 years, and since the fishery exploits mainly females (mostly about 4 years old), it is doubtful that the possible influence of the fishery on the stocks would yet be evident.

The limitations of the "swept area" method for estimating biomass have been discussed by the ICNAF Subcommittee on Assessments (ICNAF, 1977, p. 14) and are also noted by Hoydal (1978). When used in conjunction with a random stratification scheme, it normally gives minimum biomass estimates, although the correction for diurnal variation will improve the estimates.

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a) Manuscript should be type-written, *double-spaced*, and on one side only of good quality white bond paper, size 8½ × 11 inches (220 × 280 mm).

b) Leave all margins 1 inch (25 mm) to 1½ inches (38 mm) for editorial marks and queries.

c) Prepare and submit the original and one copy of the text and two sets of illustrations.

d) Number all pages of the manuscript consecutively with Arabic numerals in the centre of the top margin space.

e) Start a new page for each of the following sections with appropriate headings and sub-headings: (1) title, name and address of author, list of contents (if applicable); (2) abstract of the paper; (3) text; (4) references to literature; (5) tables; (6) legends for figures and (7) figures.

f) Please *double-space everything* — Text, quotations, footnotes, tables end table headings, legends, references to literature, and use even greater spacing where helpful (particularly around equations and formulate).

g) Wherever practical the text should be subheaded into Abstract, Introduction, Materials and Methods, Results, Discussion and Acknowledgements. If authors wish to provide a summary of the conclusions, it should follow the Discussion.

h) All measurements, linear, weight, and time, should be given in numerals (not words) in the metric system. The Celsius scale should be used as a standard. When other units of measure are preferred, authors should include equivalents in metric units.

i) Footnotes should be avoided as far as possible, but if necessary they must be numbered consecutively in the text and typed under a horizontal line at the bottom of the page concerned.

j) Only those words to be printed in italics should be underlined.

Abstract

Each Manuscript should have an abstract not to exceed 3% of the length of the text or 200 words whichever is the smaller. For position of the abstract in the manuscript see (e) above. The abstract should summarize the contents and conclusions of the paper, point to new information in the paper and indicate the relevance of the work.

Tables

a) Tables should be carefully constructed so that the data presented may be easily understood.

b) Tables should be set out on separate sheets following the references.

c) Position of the tables in the text should be indicated clearly.

d) Each table should be provided with a descriptive heading which, together with the column headings, makes the table intelligble without reference to the text.

e) Tables should be numbered consecutively with Arabic numerals, e.g. Table 1, 2, 3, etc.

Figures

a) All illustrations, whether black-and-white drawings, graphs, photographs, or tone drawings, are to be considered as figures.

b) Each figure should be mentioned and described in the text.

c) A legend should be provided for each figure; the legends should all be typed together on a separate sheet or sheets attached to the manuscript following the tables.

d) Figures should be numbered consecutively with Arabic numerals, as Fig. 1, 2, 3, etc.

e) Figures should be set out on sheets preferably the same size as the text pages and in any case should not require a printer's reduction to less than one-third. Small figures can be arranged in groups on sheets the same size as the text pages.

f) For guidance in preparing figures, the size of the printed area of the page is 21 × 17 cm. The publications have a two-column format, each column 8 cm wide.

g) Photographs presented as figures should be high contrast, glossy prints, about 5 × 7 inches (125 × 175 mm) in size and should be shipped flat protected by stout cardboard.

h) Each illustration should be identified by marking the figure number and the author's name on the back lightly in soft pencil.

(over)

Bibliographic Style

a) References to literature in the text should be by the author-date system, for example

It was reported that (Collins, 1960) the...;
In examining the situation, Rossini (1959) felt that...

Where more than one paper by the same author(s) have eppeared in one year, reference should be given as follows:

Osborne and Mendel (1914a); Osborne and Mendal (1914b)
or Osborne and Mendel (1914a and b); (Barnet and Robinson, 1942; King end Pierce 1943a, 1954)

Reference to material not yet submitted for publication should be written into the text e.g. "Harvey, in an unpublished manuscript,..." or "Harvey, in a letter,..."

b) All references cited by the author-name system in the text should be listed alphabetically by the surname of the first *author* at the end of the paper. *Year* of publication follows the authorship. Then give the full *title* of the paper. This should be followed by the abbreviated name of the *periodical* with the *volume* and *pages* in Arabic numbers (e.g.:2: 120-136). For abbreviations of periodicals follow the "Word List of Scientific Periodicals". An issue, number supplement or other part within a volume is shown in parentheses only when paged independently (e.g.:2(4):1-56; 34 (Suppl. 2):1-26). Any special Series (Ser 3, III or C) precedes the volume number. In *book citations* after the title, there appears the edition, the publisher's name, place of publication, and the number of pages if one volume, but the number of volumes if more. Reference to material submitted but not yat published should be referred to in the list of references as "in press" or "Submitted for publication" followed by the date of submission.