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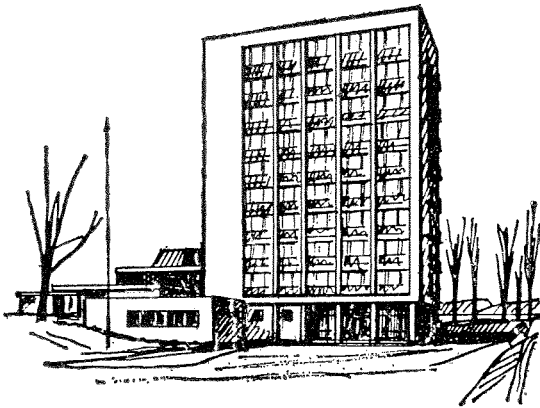
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SOVIET TAGGING OF HARP AND HOODED SEALS IN THE NORTH ATLANTIC

By

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ABSTRACT

Popov, L. A. 1970. Soviet tagging of harp and hooded seals in the North Atlantic. *FiskDir. Skr. Ser. HavUnders., 16*: 1—9.

In 1960—1968, 2 705 harp seal pups and 55 adult female harp seals were tagged in the White Sea. At Newfoundland 79 harp seal pups were tagged in 1963, and in the Jan Mayen area of the Greenland Sea 50 hooded seal pups were tagged in 1966. Monel metal clip tags were used in two seasons, but coloured plastic tail tags have been in use since 1965.

Early recaptures have shown that the northward drift of the pack ice brings the pups from the White Sea to the southern part of the Barents Sea. In some years, however, adverse conditions may change this drift pattern. Recaptures after one and two years indicate that immature harp seals spend the winter in coastal waters of the southern Barents Sea and the northern White Sea.

Two pups tagged off Newfoundland have been recaptured in West Greenland during their first summer.

INTRODUCTION

As part of an extensive Soviet research program, harp seals, *Pagophilus groenlandicus* (Erxleben, 1777) and hooded seals, *Cystophora cristata* (Erxleben 1777) have been tagged in the White Sea since 1960, in the Jan Mayen area of the Greenland Sea in 1964 and 1966 and off Newfoundland—Labrador in 1963. The taggings have been carried out by scientists from VNIRO Moscow, PINRO Murmansk and Sev-PINRO Arkhangelsk in accordance with programs approved by the Sealing Commission for the Northeast Atlantic.

The taggings by Soviet scientists supplement Canadian taggings at Newfoundland (Sergeant 1965) and Norwegian taggings at Newfoundland, in the Greenland Sea and in the Barents Sea (Rasmussen and Øritsland 1964). This paper summarizes data on Soviet taggings from 1960 to 1968 and reports the recoveries of tagged seals up to April 1969.

Table 1. Soviet seal pup taggings in 1960—1968 and recoveries up to April 1969.

Year of tagging	Series	Number tagged	Recoveries	
			Same Year	1—2 years later
Harp seals, White Sea.				
1960—1962....................	BM	45	0	0
1963..........................	A	495	0	1
1964..........................	A	105	0	0
1965..........................	B	410	8	1
1966..........................	B6	598	21	1
1967..........................	B7	389	3	1
1968..........................	B7	718*	14	0
Sum		2 760**	46	4
Harp seals, Newfoundland.				
1963..........................	N	79	4	0
Hooded seals, Greenland Sea.				
1964..........................	—	10	2	0
1966..........................	G6	50	4	0
Sum		60	6	0
Total		2 899	56	4

* 168 pups tagged by «Chistopol» not included.
** 55 adult females included.

TAGGINGS AND TAGGING METHODS

The number of seals tagged in the different areas are listed by year in Table 1. The greatest number, 2 760 harp seals, has been tagged in the White Sea. In 1960—1964, 645 harp seal pups were tagged in areas where the sealers were operating, but in 1965—1968 when sealing from vessels was prohibited in the White Sea and only coastal dwellers were allowed to hunt, the taggings were made outside the hunting areas. In 1965, 410 pups were tagged from a research vessel. In 1966, 1967 and 1968, 1 650 pups and 55 adult females were tagged from the «Toros» stations on the drifting pack ice. The first two years thin 20 mm wide plastic tags (series BM) were attached to the tails with a wire. These tags were fragile and the attachment was not good enough so they were substituted by other types. Clip tags of monel metal (fur seal type, Fig. 1A) were used in 1963 and 1964. These tags were applied to the web of a hind flipper by special pliers. Because of their colour the metal
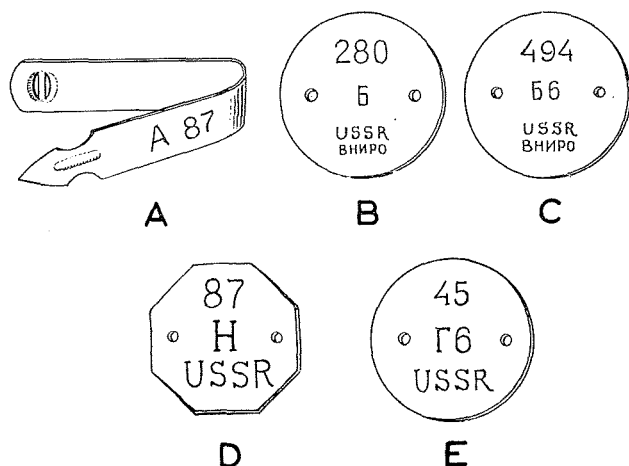
Fig. 1. Tag types used in Soviet taggings in: A, B and C) The White Sea, D) the Newfoundland area, E) the Jan Mayen area of the Greenland Sea.

tags are not easily discovered on harp seals, and may be overlooked by hunters. They also may cause inflammation with subsequent shedding of the tags. The use of the clip tags therefore was discontinued. In the following years (1965—1968) circular tags of red plastic, 2.5—3.0 mm thick and 32 mm wide, have been used (series B, B6 and B7 — USSR VNIRO, Fig. 1, B and C). These tags are attached to the tails of the seals with stainless wire, treated with a penicillin ointment, by piercing the tail with special needles.

In the Front area off Newfoundland—Labrador, 79 harp seal pups were tagged by an experimental Soviet sealing expedition in March 1963. Orange octahedral tail tags, 2.0 mm thick and 30 mm wide, were used (series N — USSR, Fig. 1D).

Except for a small number tagged with metal clips in 1964 (not included in Table 1), harp seals have not been tagged in the Greenland Sea. In 1966, however, scientists onboard the research vessel «Chistopol» succeeded in tagging 50 hooded seal pups in this area using tail tags of red plastic (series G6 — USSR, Fig. 1E).

RECOVERIES

All recovered tags are listed in the appended Table I, and the recaptures from the White Sea taggings are shown in Fig. 2. No early recoveries were reported from the taggings in 1960—1964. In 1965 Soviet vessels did not hunt in this area, and recoveries in that season were reported only by Norwegian vessels hunting in the Barents Sea.

The recaptures, 2.0°/₀ of the tagged pups, were all made during the second half of April in the area north and west of Cape Kanin Nos.

In 1966 strong winds kept the pup patches drifting in the White Sea basin throughout March and April. In May and June pups were observed along the southern and western parts of the White Sea shores. All early recoveries, 3.5%, were made among pups which had perished from exhaustion or had been caught in fish nets in these areas in May and June. The northward migration of pups to the Barents Sea did not start until the mouth of the White Sea was free from ice in June and July.

In 1967 only three of 389 tagged pups were recaptured. Southerly
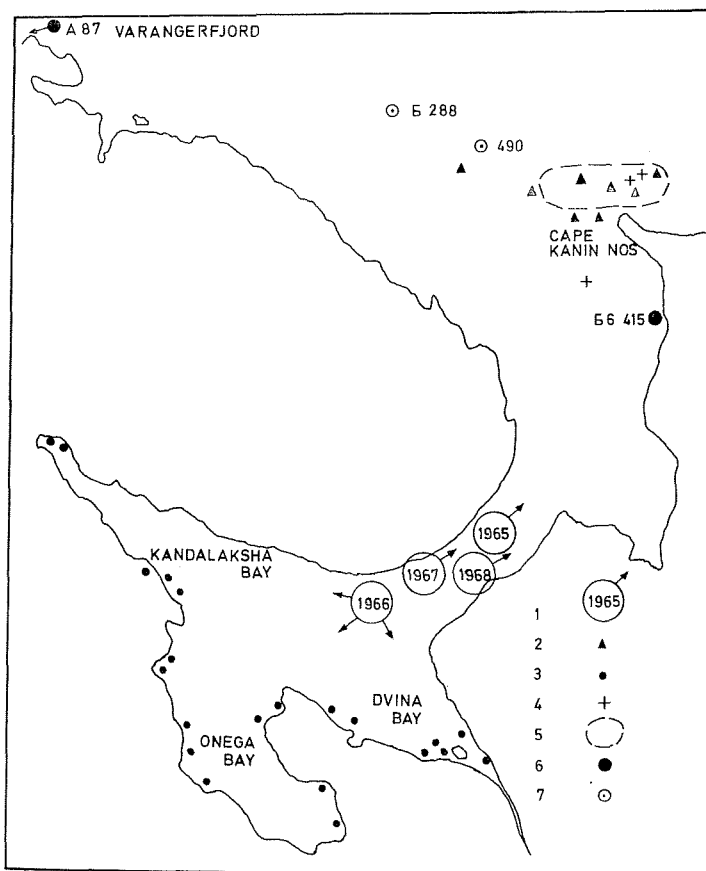

Fig. 2. Recoveries of harp seal tags from the White Sea. 1) Tagging locality and direction of passive migration, 2) recoveries in the tagging season 1965, 3) recoveries in the tagging season 1966, 4) recoveries in the tagging season 1967, 5) recoveries in the tagging season 1968, 6) recoveries in winter after 1—2 years, 7) recoveries in spring after 1—2 years.

winds kept the ice and the breeding lairs drifting northwards, and the tagged pups were found near Cape Kanin Nos by the research vessel «Chistopol» in early April, some 25 days after the tagging. No tags were returned from Norwegian sealers in 1967.

In 1968, 718 pups were tagged. Again the prevailing winds and currents sent the pups drifting to the north. After 30—35 days the pups were in international waters where the Norwegian vessels were hunting. Norwegian sealers reported 14 recaptures, 1.9%, outside Cape Kanin Nos during the first ten days of April.

Four harp seals tagged as pups in the White Sea, have been recaptured one or two years after the tagging (Fig. 2). Two of these (Nos. 490 and B288) were caught in the spring among moulting immature seals in the Barents Sea. The other two were caught in coastal waters in January 1968: a one-year-old (A67) in the Varangerfjord, Norway, and a two-year-old (B6 415) on the west coast of the Kanin Nos Peninsula.

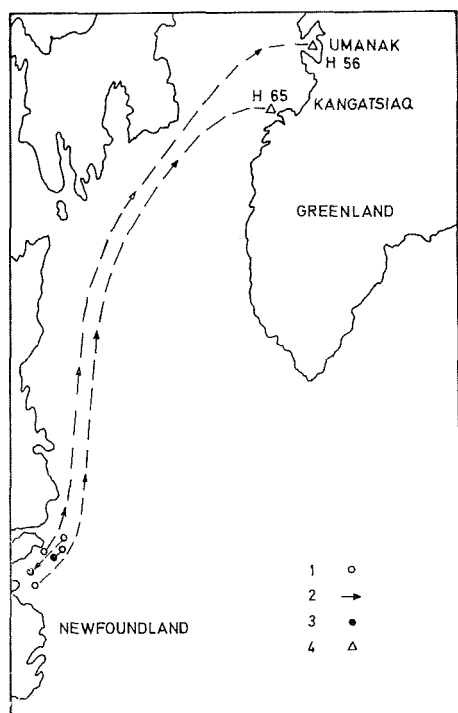Of the 79 harp seal pups tagged off Newfoundland in 1963, only

Fig. 3. Recoveries of harp seal tags from the Newfoundland area. 1) Tagging localities, April 1963, 2) assumed migrations, 3) early recoveries, 4) recoveries in July and August.

4 (5.1%) have been recaptured. Tagging localities and recoveries are shown in Fig. 3. Two tags were recovered by Canadian sealers in the same area 7 and 17 days after the tagging, and two were found on the West Greenland coast in July and August the same year.

In the Jan Mayen area of the Greenland Sea only four (8.0%) of a total of 50 hooded seal pups have been recaptured. They were all caught in the same area the same month.

DISCUSSION

The recoveries of harp seals tagged in the White Sea show that pups move passively with the drifting pack ice during the lactation period and for some time after weaning. This drift which is influenced by currents and winds in the area, usually has a northward direction and brings the pups out to the Barents Sea during April. In some years, however, constant and strong northerly winds in March and April may move the pack ice southwards, bringing the pups to the southern shores of the White Sea (e.g. 1966).

The duration of the passive northward migration of pups from the southern part of the White Sea estuary where they are born, to the Kanin Nos area depends upon the velocity of the ice drift in March. Constant and strong winds may move the pup concentrations past Cape Kanin Nos in 20—25 days, whereas the drift may take 40—50 days in years with variable winds. The passive migration to the Barents Sea brings the pups to areas with a rich food supply at the time when they are ready to start independent feeding. However, in years with a southward ice drift the pups are brought to areas of the White Sea which are poor in suitable food organisms. This will seriously impair the condition of the animals and may eventually lead to a heavy mortality among the pups as observed in 1966.

The recaptures of immature seals off the Kanin Nos Peninsula and in the Varangerfjord in January indicate that immature harp seals spend the winter i coastal waters of the Barents Sea and the northern White Sea. Independent observations show that they are feeding intensively on polar cod, *Boreogadus saida* (Lepechin, 1773), at this time of the year. Also adult seals are found feeding in coastal waters near Cape Kanin Nos during winter. In February the adult seals move towards the southern parts of the White Sea where they continue to feed until the breeding season.

The immature seals which were recaptured in the Barents Sea in April—May, were found in patches of moulting seals in the area where the White Sea harp seals usually stay during their moult.

The recaptures of harp seal pups in the Northwest Atlantic in 1963 support results of Canadian and Norwegian taggings off Newfoundland (SERGEANT 1965, RASMUSSEN and ØRITSLAND 1964). During lactation and for some time after weaning the pups move passively with the drift of the ice. Later they migrate northwards to their summer range in West Greenland (SERGEANT 1965).

Recoveries of tags from hooded seal pups in the Greenland Sea in 1966 illustrate the early dispersal of pups in that area (RASMUSSEN and ØRITSLAND 1964). The pups had moved in directions between north-north-west and southwest and were recaptured from 7 to 17 days after the tagging and from about 50 to about 110 nautical miles from the tagging localities.

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Table I. Seal tags recovered up to April 1969 from Soviet taggings in the White Sea, off Newfoundland and in the Greenland Sea 1960—1968.

Tag No.	Tagging		Recovery	
	Date	Locality	Date	Locality

Harp seals, White Sea and Barents Sea.

Tag No.	Date	Locality	Date	Locality
490........	17 March 63	65°41'N 39°22'E	3May 65	68°55'N 41°00'E
BM 33........	11 » 65	66°44'N 39°58'E	17 April 65	69°10'N 44°10'E
B 83........	13 » 65	66°25'N 41°11'E	23 » 65	Kanin Nos area
B 158........	»	»	26 April 65	69°00'N 42°38'E
B 183........	»	»	22 April 65	68°51'N 41°48'E
B 193........	»	»	April 65	Kanin Nos Area
B 211........	»	»	» »	» » »
B 269........	»	»	23 April 65	» » »
B 280........	»	»	25 April 65	69°06'N 39°53'E
B 288........	»	»	19 April 66	70°10'N 37°15'E
B6 494........	3 March 66	65°40'N 38°00'E	15 May 66	66°34'E 34°00'E
B6 511........	»	»	23 May 66	64°05'N 38°00'E
B6 313........	»	»	5 June 66	Kandalaksha
B6 339........	»	»	7 June 65	Dvina River delta
B6 380........	»	»	June 66	Kandalaksha
B6 558........	»	»	»	64°45'N 34°45'E
B6 4........	13 March 66	65°20'N 38°05'E	27 June 66	64°56'N 36°20'E
B6 190........	»	»	»	65°22'N 34°20'E
B6 387........	»	»	June 66	65°00'N 36°40'E
B6 415........	»	»	10 Jan. 68	67°42'N 44°00'E
B6 483........	»	»	June 66	65°55'N 34°45'E
B6 595........	»	»	4 June 66	64°15'N 34°30'E
B6 ?	?	?	June 66	64°40'N 35°00'E
B6 421........	18 March 66	65°10'N 37°50'E	»	65°55'N 34°45'E
B6 168........	»	»	15 June 66	?
B6 129........	»	»	1 June 66	Dvina River delta
B6 179........	24 March 66	65°10'N 37°50'E	June 66	65°22'N 34°30'E
B6 389........	»	»	23 May 66	Dvina River delta
B6 547........	»	»	6 June 66	» » »
B6 533........	»	»	16 June 66	64°22'N 37°35'E
B6 ?	?	?	June 66	65°00'N 37°45'E
B6 ?	?	?	»	64°26'N 35°20'E
A67	March 67	White Sea	16 Jan. 68	Varangerfj., Norw.
B7 136........	7 March 67	66°15'N 39°40'E	3 April 67	69°06'N 44°09'E
B7 145........	»	»	»	69°06'N 44°10'E
?	?	?	»	68°17'N 43°02'E
B7 427........	4 March 68	66°10'N 41°00'E	7 April 68	69°—69°15'N 42°—44°E
B7 465........	»	»	11 April 68	»
B7 490........	5 March 68	66°15'N 41°50'E	»	»
B7 500........	4 March 68	66°10'N 41°00'E	»	»
B7 503........	»	»	»	»

Table I (contd.) Seal tags recovered up to April 1969 from Soviet taggings in the White Sea, off Newfoundland and in the Greenland Sea 1960—1968.

Tag No.	Tagging		Recovery	
	Date	Locality	Date	Locality
B7 504........	4 March 68	66°10′N 41°00′E	10 April 68	69°—69 15′N 42°—44°E
B7 513........	»	»	7 April 78	»
B7 518........	»	»	»	»
B7 547........	»	»	»	»
B7 625........	5 March 68	66°15′N 41°50′E	»	»
B7 699........	»	»	?	»
B7 985........	10 March 68	66°45′N 42°20′E	10 April 68	»
B7 1101........	11 March 68	66°30′N 42°10′E	»	»
B7 ?	?	?	»	»

Harp seals, Northwest Atlantic.

N 6........	10 March 63	52°00′N 54°42′W	20 April 63	White Bay, Newfoundland
N 56........	22 March 63	51°20′N 53°06′W	10 Aug. 63	70°50′N 52°00′W
N 60........	»	51°23′N 53°06′W	March 63	Same area.
N 65........	19 March 63	50°20′N 55°04′W	July 63	approx. 68°21′N 53°20′W

Hooded seals, Greenland Sea.

G6 07........	2 April 66	70°00′N 11°05′W	19 April 66	69°50′N 16°00′W
G6 13........	»	»	9 April 66	70°45′N 14°20′W
G6 33........	3 April 66	70°12′N 11°05′W	19 April 66	69° N 15° W
G6 45........	»	»	»	70°54′N 12°10′W

INVESTIGATIONS ON EUPHAUSIIDS IN SOME FJORDS ON THE WEST COAST OF NORWAY IN 1966 — 1969

By

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ABSTRACT

WIBORG, KR. FR. 1970. Investigations on euphausiids in some fjords on the west coast of Norway in 1966—1969. *FiskDir. Skr. Ser. HavUnders., 16* : 10—35.

In 1966—1969 euphausiids (krill) were sampled in some fjords in Western Norway. Drained volumes of krill constituted 13—82 ml, exceptionally 100—167 ml per 1 000 m³. *Meganyctiphanes norvegica, Thysanoessa inermis* and *T. raschii* dominated in the order mentioned. During the day, *Thysanoessa spp.* kept at higher levels than *M. norvegica* ; during the night *T. raschii* and part of the stock of *M. norvegica* accumulated close to the surface. *M. norvegica* had densities of 0.1—1 specimens per m³, but higher concentrations were induced in spring with electric light. Vertical layering was observed with large specimens at deeper levels. *M. norvegica* spawned in March—June one year old. Part of the stock survived a second spawning, a few lived for nearly three years. One year olds measured 22—31 mm (average 27 mm), two year olds 32—41 mm (average 37 mm) and three year olds 43—47 mm.

In *T. inermis* a maximum of 1—4 specimens per m³ occurred in the upper 10—50 m during the night in January—February and October—November, at other times only 0.05—0.3 specimens per m³. *T. inermis* is annual in the area, spawning in March—June, with maximum in April. Length of one year olds was 17—20 mm, single second year survivors 26 mm. The two-spined form was observed in 1—3 % of the stock.

T. raschii had maximum densities of 3.5 and 5.0 specimens per m³ in the upper 10 m in February and November respectively, at other times figures were very low. *T. raschii* is annual; spawning occurs in April—June, starting somewhat later than in *T. inermis*. Growth and length distributions are as a rule similar to those of *T. inermis*.

INTRODUCTION

During the later years attention has been focused on euphausiids or krill as a source of marine protein that may be exploited commercially. In Norway a small-scale fishery started in 1965, the krill mainly being used in fish farming. The biology of krill in fjords of Western Norway has been studied since 1965 (WIBORG 1966, 1968).

MATERIAL AND METHODS

In the period 21 November 1966—29 January 1969 samples of krill were collected from the R/V «Peder Rønnestad». A three-foot

Isaacs—Kidd midwater trawl (IKMT), mesh size three mm, was towed at four knots for 10—25 minutes at different levels between the surface and 260 m in some fjords on the west coast of Norway (Fig. 1). The Byfjord near Bergen was visited most regularly, with monthly samples in the period January—June. The depths fished were checked occasionally with a Benthos depth recorder. Most hauls were made during the night. Figures have been adjusted to 1 000 m^3 filtered. Additional hauls were made with Clarke-Bumpus plankton samplers (CB), mesh size 0.5 mm, speed 2—3 knots, in the upper 40 m, and some
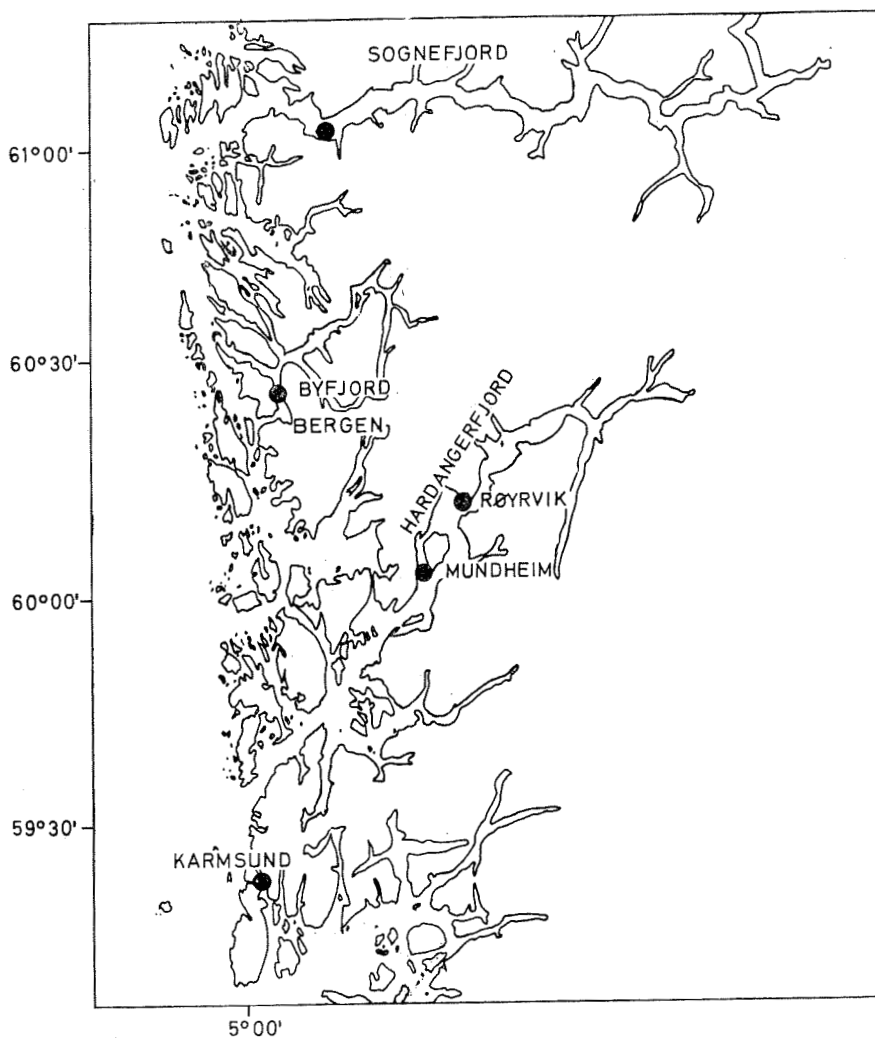

Fig. 1. Localities of krill investigations in Western Norway 1966—1969.

vertical hauls with a 40 cm Juday net, mesh size 0.2 mm, from bottom to surface. A few samples were also taken with light and ketcher in the Hardanger fjord. During the cruises bathythermograph casts were made to 260 m, and salinity and temperature were measured in the upper 60 m with a portable «salinity-temperature bridge».

In 1969 additional material was collected in the Byfjord during monthly cruises in day hauls with IKMT and a low-speed midwater trawl designed by BEYER (in preparation). The samples were preserved in 5—10 percent formalin and examined a few days after the catch. The krill and mysids were sorted out and their displacement volume measured together, then investigated under a stereoscopic microscope, and finally the total length was measured under a 2 X magnifying lens (WIBORG 1966). When the sex could be determined from external characters, males and females were measured separately.

TOPOGRAPHY AND HYDROGRAPHY OF THE BYFJORD AND THE HARDANGERFJORD

The Byfjord (Fig. 2) is part of a fjord system; in the southwestern part with a sill depth of 140 m towards the Hjeltefjord; in the north with connection to the Salhusfjord and Herdlefjord, the latter in the northwest ending in shallow sounds less than 10 m deep. The Byfjord has a central trough, 317—383 m deep. According to LINDE (1970) the temperature below 100 m is usually 7.0—8.2 C, the salinity 33.34—34.90$^0/_{00}$. Below 200 m the water is renewed each year, as a rule in November—February.

In 1966—1968 the temperature of the upper 10 m reached 15 C in June, the 10 C isotherm descending to 50 m in November 1966 and October 1967. At the surface the extreme temperatures were 3.6 C in January 1967 and 15.1 C in June 1967.

Below 10 m the salinity was usually 30 $^0/_{00}$ or more. At 5 m the lowest figure was about 22 $^0/_{00}$ in October 1967, otherwise close to 30$^0/_{00}$. At the surface, there were records of about 10 $^0/_{00}$ and 18 $^0/_{00}$ respectively in June and October 1967.

The topography and hydrography of the Hardangerfjord (Fig. 1) has been described by SÆLEN (1962, 1967). There is a sill of 150 m in the outer part, and maximun depths of more than 900 m are found in the middle fjord. At the surface the water is sometimes very brackish, especially in the inner fjord during summer and autumn. Below 20 m the salinity is above 30 $^0/_{00}$ all the year, in the deeper layers 34.4—35.5 $^0/_{00}$. Temperature below 100 m is 6.5—8.0 C all the year, at the surface 2.5—15.7 C.
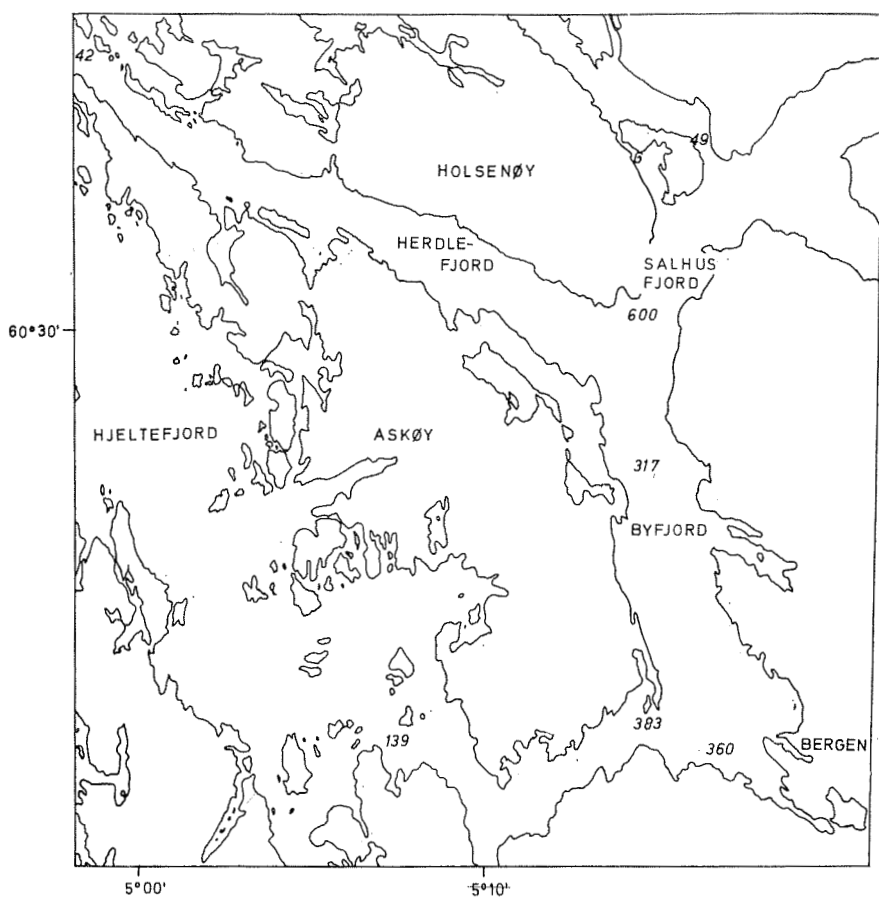
Fig. 2. The Byfjord and adjacent areas. Depths in m.

During the present investigation the extreme temperatures at the surface in the middle of the fjord were 4.9 and 16.6 C in March and June respectively, with the corresponding salinities of 30.4 $^o/_{oo}$ and 12.2 $^o/_{oo}$.

VARIATIONS IN THE VOLUMES OF KRILL AND MYSIDS IN 1967—1969

With a mesh size of three mm in the net of the IKMT some of the smaller krill will probably pass through the meshes. As the hauls were taken without any closing, the conclusions as to the vertical distribution must be taken with some precaution. However, the time of hauling in of the net was usually short as compared to the fishing time, and it

Table 1. Volumes of krill and mysids in ml per 1 000 m³ in the Byfjord near Bergen 1967—1969. 3' IKMT, mesh size 3 mm, trawling speed 4 knots. Night hauls, day hauls in italics.

Depth m	Jan.	Febr.	March	April	May	June	Oct.	Nov.
5.........	3	—	—	29	25	—	14	36
10.........	14	28	—	32	37	6	—	—
15.........	—	—	—	16	28	—	—	—
25.........	24	37	14	—	—	5	—	16
	—	*—*	*—*	*—*	*—*	*—*	*—*	*—*
50.........	82	6	13	6	13	13	12	22
	9	*3*		*1*			*2*	
100.........	39	38	—			13	6	
	—	*15*	*—*	*2*	*3*	*—*	*17*	
130.........	15	31	15	—	—	—	—	—
	17	*41*	*—*	*20*	*—*	*—*	*—*	*—*
180.........	38	38	—	—	—	13	14	—
	—	*29*	*—*	*11*	*8*	*—*	*15*	*—*
230.........	34	13	—	—	13	7	9	—
		41	*—*	*10*	*26*	*11*	*7*	*—*

is inferred that the figures give some information on the relative abundance of krill. In the Byfjord (Table 1) the volumes per 1 000 m³ varied between 13 and 41 ml, with one single figure of 82 ml in January. In a CB haul at 3 m level during the night of 19 November 1968 the volume was about 100 ml/1 000 m³.

Some IKMT hauls were made at varying times of day and night (Table 2). In January 1967 maximum in volume was observed at 50 m during the afternoon and evening, but after midnight the krill were evenly dispersed below 50 m. In February no krill were taken at 50 m or above during the day, the volume increasing from 100 m to 230 m. At dusk krill were taken from 25 m, increasing to a maximum volume in 150—200 m. In October the maximum was found in 100—200 m during the day, but at 10 m during the night. In February 1968 maximum was again below 200 m during the day, and at 10 m during the night, but in 50—230 m the krill were rather evenly distributed.

In the Hardangerfjord the volumes of krill in IKMT night hauls in 10—50 m usually were 7—30 ml/1 000 m³, but in April 1968, 83—104 ml/1 000 m³ were taken at 5 m level. In the Karmsund (Fig. 1) 167 ml/1 000 m³ were taken in a night haul at 5 m in November 1968.

None of the quantities taken indicate densities comparable with those induced by artificial light (WIBORG 1966).

Table 2. Volumes of krill and mysids in ml per 1 000 m³ in the Byfjord 1967 and 1968.

Year	Date	Hour	Depth, m							
			5	10	25	50	100	150	200	230
1967............	6—7 Jan.	1630—1700	—	—	24	45	18	17	17	33
		2000—2100	—	—	13	82	27	—	31	34
		0020—0150	—	—	16	36	39	—	38	38
1967............	6 Febr.	1306—1430	—	—	0	0	14	—	29	41
		1630—1835	—	—	11	6	26	31	38	13
1967............	16 Oct.	1020—1230	—		—	2	17	—	15	7
		2115—2330	14		—	11	6	—	13	9
1968............	5 Febr.	1020—1200	—	0.4	—	0.4	2.0	—	20	30
		2050—2330	7	37	—	18	23	—	25	21

RELATIVE COMPOSITION OF KRILL AND MYSIDS IN THE IKMT CATCHES

Nine species of krill have been identified in the catches, viz. *Meganyctiphanes norvegica* (M. Sars), *Thysanoessa inermis* (Krøyer), *T. raschii* (M. Sars), *T. longicaudata* (Krøyer), *Nyctiphanes couchii* (Bell), *Thysanopoda acutifrons* (Holt and Tattersall), *Nematoscelis megalops* (G. O. Sars), *Euphausia krohnii* (Brandt) and *Stylocheiron maximum* (Hansen). The last four species have been dealt with earlier (WIBORG 1968). In this paper the main emphasis will be laid on *M. norvegica*, *T. inermis* and *T. raschii*, both in number and volume dominating the catches.

The mysids, *Boreomysis arctica* (Krøyer), *B. megalops* (G. O. Sars), *Siriella norvegica* (G. O. Sars) and *Lophogaster typicus* (M. Sars) have been included in the counts used in Fig. 3, but otherwise not dealt with.

According to JERDE (1967) krill below a size of 13 mm are not caught quantitatively in a net with a mesh size of four mm. As will be shown later, this also seems to be the case with the three mm net used in the present investigation. Reservations must also be taken that the deeper hauls contain krill taken at upper levels. The composition of the samples may nevertheless indicate the relative abundance of the different species, especially during winter and spring when the smaller species have reached their adult size. In Fig. 3 are shown the relative numerical abundance of *T. raschii*, *T. inermis*, *M. norvegica*, and the group other krill and mysids (mainly *B. arctica* and *L. typicus*, in the Byfjord in 1967—1968.
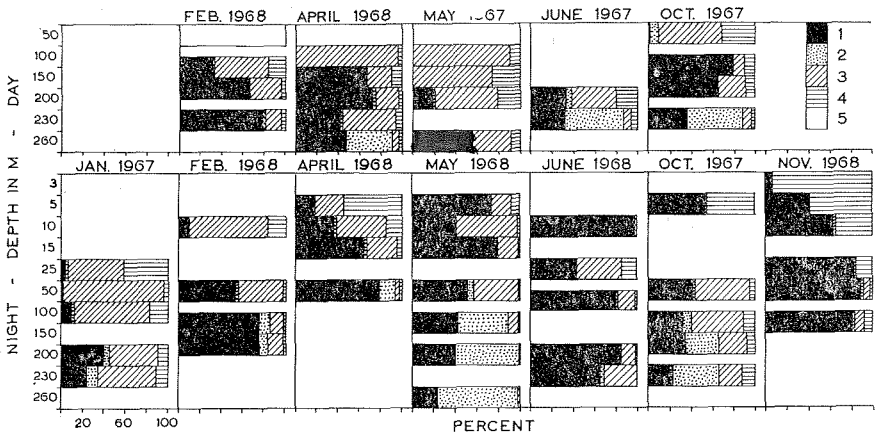
Fig. 3. Relative numerical importance of the most abundant species of krill and mysids in Isaacs-Kidd 3' pelagic trawl in the Byfjord in 1967—1969. 1) *Meganyctiphanes norvegica,* 2) Mysids, 3) *Thysanoessa inermis,* 4) *Thysanoessa raschii,* 5) hauls with no catch.

During the day, *T. inermis* and *T. raschii* dominate the uppermost hauls, in May also in 200 m. During the night conditions vary, sometimes with *T. raschii* dominating in the upper 5—10 m and *T. inermis* second, but *M. norvegica* dominates at 10—15 m in April—May, and at 5—10 m in May—June and October. In September 1967 (not figured), October 1967 and November 1968 only *T. raschii* and *M. norvegica* were taken in the upper 10 m during the night, *T. inermis* appearing at 25—50 m. This feature is in accordance with the observations of Lacroix (1961) in Canadian waters.

M. norvegica as a rule dominates below 150—200 m during the day. Mysids, mainly *B. norvegica,* sometimes also *L. typicus,* are occasionally rather numerous below 100—200 m, especially during the night, sometimes ascending to 10 m (April 1968).

In volume *M. norvegica* will nearly always dominate the samples because it is 10—15 times as big as *T. inermis* and *T. raschii.* More details about the vertical distribution will be given later in this paper.

THE KRILL SPECIES

MEGANYCTIPHANES NORVEGICA
Abundance
As the sampling did not include the entire water column from bottom to surface, the material is not very well suited to give information on the variation of the stock as a whole.
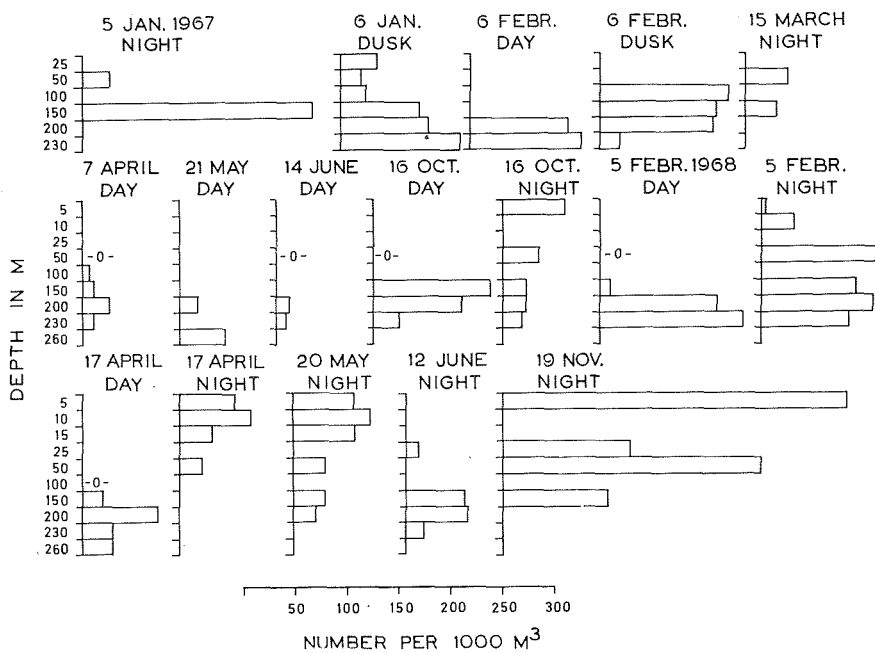
Fig. 4. Numbers of *Meganyctiphanes norvegica* per 1 000 m³ at different levels in the Byfjord in 1967—1968. —0—) no catch.

In Fig. 4 are given numbers per 1 000 m at various levels during day and night in the Byfjord in the period from January 1967 to November 1968. The figures were fairly high in January—February 1967, 125—220 specimens/1 000 m³ in the deeper hauls. In March—June numbers were low, 42 or less. In February 1968 the stock seemed to be of the same size as in February 1967, but with less reduction to April—June than in the year before. In June 1968 the new generation appeared as furciliae in the upper 10 m. In November the stock was possibly more abundant than in November 1967.

During January—June 1967 night hauls in the Hardangerfjord in 10—50 m yielded 20—55 specimens/1 000 m³. A day haul at 200 m in February 1967 at Røyrvik yielded 190 specimens/1 000 m³; in Karmsund a night haul at 4 m in November 1968 yielded 1 370 specimens/ 1 000 m³.

Vertical distribution and migration

As is evident from Fig. 3 and 4, *M. norvegica* in the Byfjord as a rule keeps below 100—150 m during the day, but may ascend to the surface at night. According to EINARSSON (1945) and MAUCHLINE (1960) larger

individuals as a rule stay deeper than the smaller ones. This was also observed in the Byfjord (Fig. 5). In February 1967 small individuals (less than 28 mm) during the day dominated at 200 m and 230 m. In the evening a few larger specimens appeared at 100 m. In 150—230 m large specimens constituted more than half the stock. In February 1968 distribution was similar, most of the larger individuals evidently staying below 200 m during the day. During the night a few large specimens were taken at 10 m, the proportion increasing to a maximum in 175—210 m. In April 1968 larger individuals (I-group) during the day were very scarce at 150 m and 220 m, but relatively abundant at 260 m. During the night this group was well represented even at 15 m. In October specimens larger than 30 mm appeared in increasing percentage from 100—150 m and downwards during the day. During the night only small *Meganyctiphanes* were taken at 5 m, but the proportion of those above 30 mm increased from 6 % in 25—75 m to 54 % in 220—260 m.

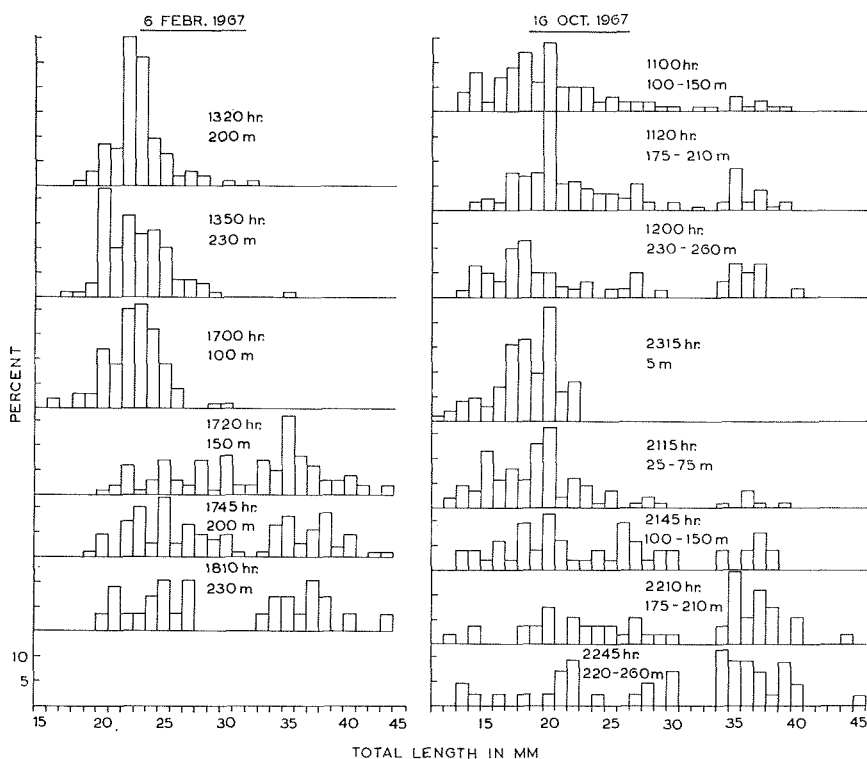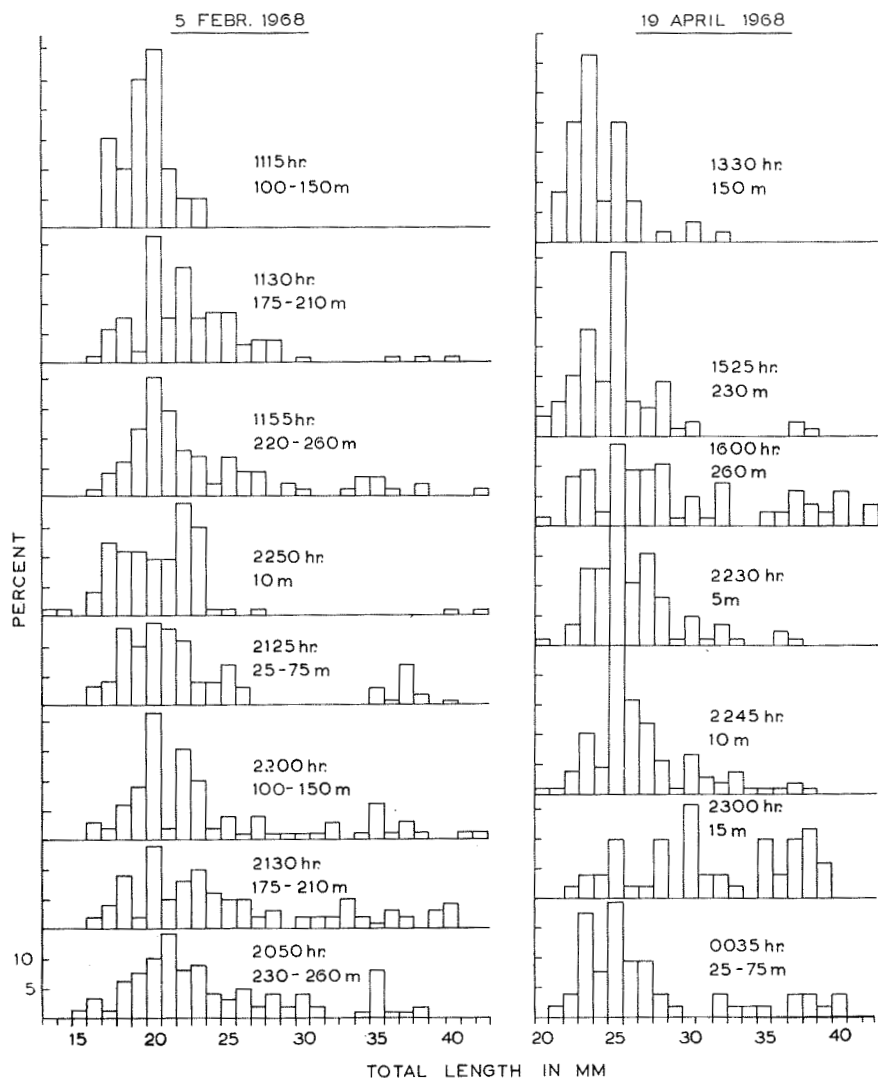During February—June adult males stayed somewhat deeper than

Fig. 5. Size distributions of *Meganyctiphanes norvegica* at different levels during day and night in the Byfjord in February and October 1967, and in February and April 1968.

Fig. 5. continued.

5 FEBR. 1968   19 APRIL 1968

TOTAL LENGTH IN MM

the females as indicated by the increase in the proportion of males with increasing depth (Table 4).

In samples taken with light and dipnet from a pier in the Hardangerfjord in November 1965 and January 1966 (Table 3) the proportion of larger individuals in November increased from midnight to a maximum in early morning. In January large individuals appeared already in the evening.

Table 3. Percentages of the various size groups of *Meganyctiphanes norvegica* taken with light and ketcher in the Hardangerfjord area in 1965—1966.

Year	Date	Hour	26 mm	27—30 mm	33—40 mm	25 mm	26—36 mm
1965........	25 Nov.	2100	100	0	0		
		2300	98	2	0		
	26 Nov.	0300	92	8	0		
		0500	66	24	10		
		0745	58	20	20		
1966........	14 Jan.	1830				97	3
		2300				90	10
	15 Jan.	0400				73	27

Growth

In the Byfjord (Fig. 6) two size groups were generally found, the O-group and I-group and I-group. In November 1966 the O-group measured 14—27 mm, mean 19 mm. A few I-group specimens measured 29—34 mm. In January 1967 the O-group ranged from 19 mm to 30 mm, mean 24 mm, increasing in June to 28—33 mm. The I-group had
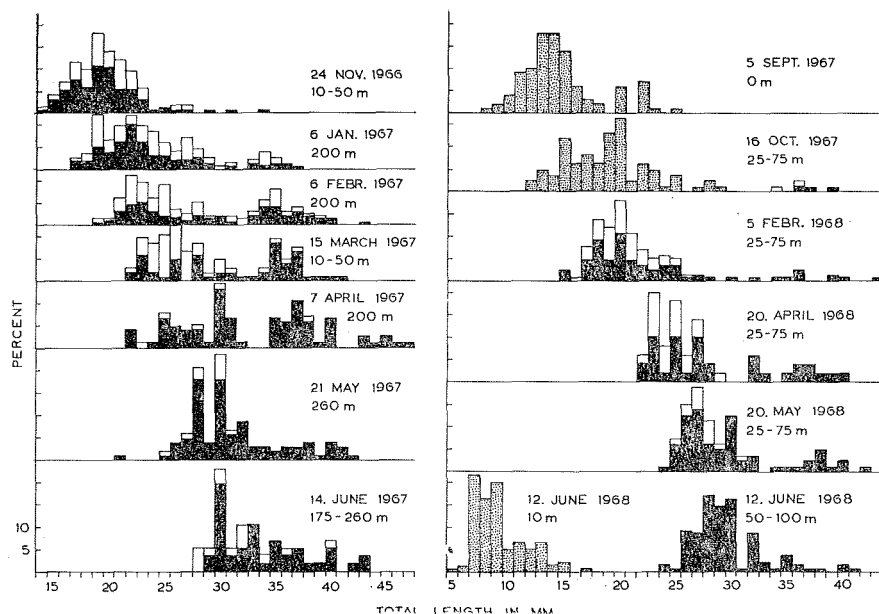

Fig. 6. Size distributions of *Meganyctiphanes norvegica* in the Byfjord (selected hauls) in 1967—1968. Black) females, white) males.

a less pronounced increase, with the peak moving from 34 mm in
January to 38—39 mm in June. Individuals probably belonging to the
II-group, 43—47 mm, appeared in February and April 1967.

In September 1967 the new 0-group measured 8—25 mm with a
peak at 13—14 mm. From October 1967 to June 1968 the development
was similar to that of the preceeding season, but in February the 0-group
individuals were smaller than the 0-group one year before. In June
1968 the brood of the year appeared as furciliae and adolescents, mea-
suring 5—15 mm.

In the Hardangerfjord (Fig. 7) the variations in size distribution
from November 1966 to June 1967 were similar to those in the Byfjord,
but the 0-group individuals were slightly larger. This may be due to
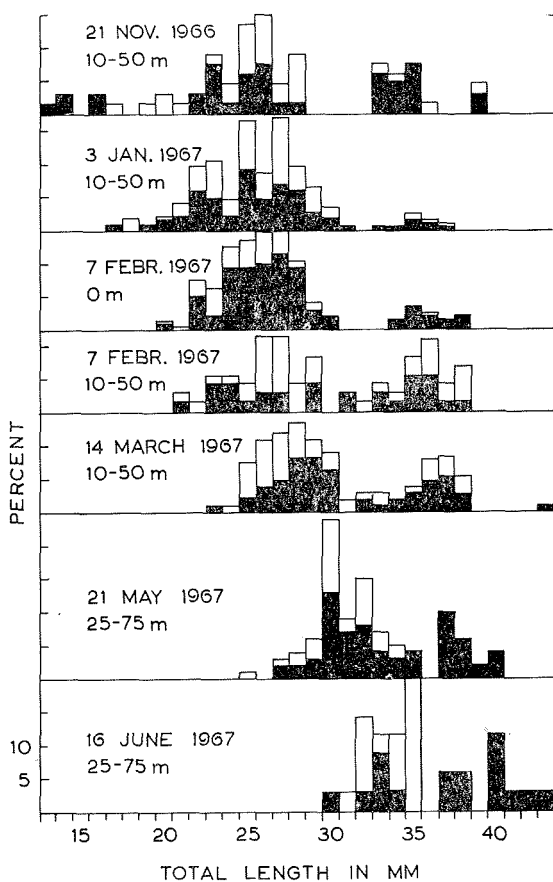local growth conditions which may vary from year to year.

Fig. 7. Size distributions of *Meganyctiphanes norvegica* in the Hardangerfjord in 1967.
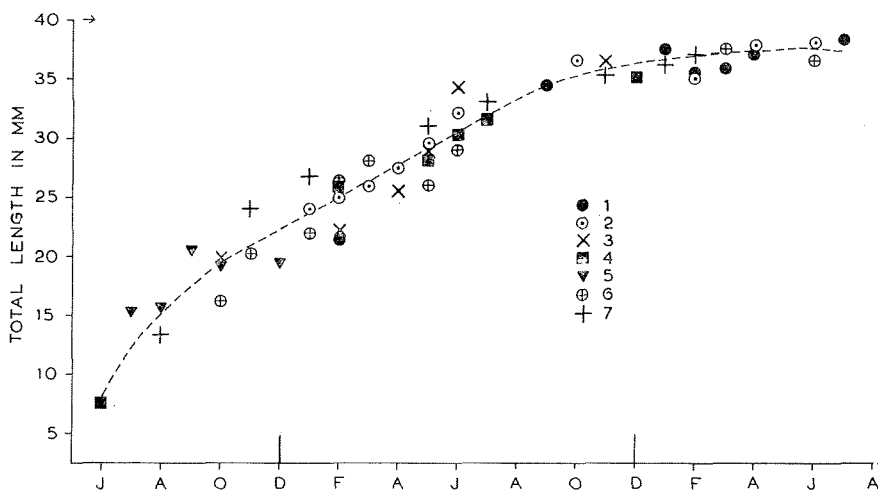Black) females, white) males.

Fig. 8. Mean length of various year classes of *Meganyctiphanes norvegica* as 0-group and I-group in the Byfjord (1—5) and in the Hardangerfjord (6—7) in various months of the year. 1 and 6) 1965, 2 and 7) 1966, 3) 1967, 4) 1968, 5) 1969.

In Fig. 8 the mean length of the 1965—1969 year classes of *M. nor-vegica* has been plotted, using all the data available for the Hardanger-fjord including data from WIBORG (1966). Variations in growth are most evident during the first year. The length increases from 7.5 mm in June to about 22 mm in December, further to 27 mm in April, and to 30—34 mm in June. During the second year of life the growth rate seems to decrease, the *Meganyctiphanes* reaching a mean length of 37—38 mm two years old. Individuals, 43—47 mm in length, taken in April 1967 (Fig. 6) are possibly nearly three years old.

It is difficult to find retardation of growth during the autumn and winter as was stated by MAUCHLINE (1960). This may be due to a long spawning period. The growth rate is similar to that found by PAULSEN (1926) for *M. norvegica* in the Skagerrak.

Maturity, sex proportions and spawning

Males have been characterized as mature when spermatophores could be clearly seen in the spermatheca and females when the thelycum could be distinguished. Percentages of mature individuals, of males, and of females with spermatozoa in the thelycum (fertilized) in the Byfjord in 1967—1968 are given in Table 4.

Table 4. *Meganyctiphanes norvegica.* Percentages of: 1) mature individuals in the samples, 2) males of the mature animals, 3) females with attached spermatophores of all the females in the Byfjord in January—June 1967 and February—June 1968. IKMT hauls.

Year	Date	Day or night	Depth m	1. mature %	2. males %	3. females with spmtf. %
1967..........	6 Jan.	night	25	0		0
		»	50	45	about 50	0
		»	100	60		0
		»	200	33		0
		»	230	52		0
	6 Febr.	night	100	56		11
		»	150	92	about 50	55
		»	200	90		47
	15 March	night	10— 50	100	47	95
		»	150	100	73	100
	7 April	night	100	100	0	100
		»	150	100	6	86
		»	200	100	7	85
		»	230	100	9	86
	21 May	day	200	100	10	40
		»	230	100	10	73
	14 June	night	175—210	100	25	16
1968..........	5 Febr.	night	10	31	—	0
		»	25— 75	40	42	(33)
		»	100—150	50	53	(33)
		»	230—260	55	49	(31)
	19 April	night	4	100	5	91
		»	10	100	12	99
		»	15	100	0	100
		»	25— 75	84	30	78
	20 May	night	4	100	1	100
		»	10	100	0	100
		»	15	100	0	100
		»	25— 75	100	21	100
		»	100—150	100	50	100
		»	200	100	63	100
		»	260	100	79	100
	12 June	night*)	10	100	0	100
		»	25	100	0	100
		»	50—100	100	0	100
		»	200	100	33	97
		»	230	100	33	100

*) The new 0-group excluded.

No mature individuals were found in November 1966, probably because no deep hauls were taken. In January the percentage of mature individuals increased from 0 at 25 m to 33—60 below 50 m, in February to 56—90 and fertilized females were observed. In March the whole stock was mature, and nearly all females were fertilized. In April the proportion of fertilized females was still high, but decreased throughout May to a low level in June.

Males and females were nearly equal in number from November 1966 to the middle of March 1967. In April the percentage of males decreased to below 10, remaining low in May and June. In 1968 the proportions of mature individuals and of fertilized females were lower in February than one year before, but had increased considerably until April. The percentages of fertilized females remained high in May and June. Males decreased very much in percentage from February to April and were scarce in the upper hauls in May, but the percentage increased to 79 at 260 m. In samples taken in 1969 the percentage of fertilized females

Table 5. *Meganyctiphanes norvegica*. Percentages of: 1) mature individuals in the samples, 2) males of the mature animals, 3) females with attached spermatophores of all the females in the Hardangerfjord, January—June 1967 and February—April 1968. IKMT night hauls. Italics: Catches with light and ketcher.

Year	Date	Depth m	1. mature %	2. males %	3. females with spmtf. %
1967........	3 Jan.	10— 50	70	42	7
		20	67	61	0
	4 Jan.	40	80	65	25
		60	80	72	13
	7 Febr.	0	90	26	46
		10— 50	85	56	42
		150	98	33	58
	14 March	10— 50	100	46	100
		150	100	39	100
	21 May	25— 75	100	32	100
	16 June	25— 50	100	50	100
		75—100	100	89	100
1968........	12 Febr.	10	74	47	46
		25— 75	91	68	43
		100—150	(93)	(20)	(33)
	23 Febr.	*0*	*100*	*34*	*100*
	27 March	*0*	*100*	*14*	*100*
	18 April	*0*	*100*	*0*	*100*
		4— 15	100	18	100

was 60—80 in June and dropped to 20 in the middle of July. As was found earlier (WIBORG 1966), larger females were fertilized before the smaller ones. In February 1967, 70 % of the females above 31 mm were fertilized, of those below 31 mm only 30 %. In February 1968 the corresponding figures were 75 % and 24 %.

In the Hardangerfjord (Table 5) 67—80 % of the individuals were mature in January 1967, increasing to 85—90 % in February and to 100 % from the middle of March. The proportion of males was relatively high in January—June 1967; minimum 26 % in a sample taken with ketcher and light in February. Fertilized females appeared in January, the percentage increasing with increasing depth. In February about half of the females, in March all, were fertilized.

In 1968 nearly all individuals were mature in the middle of February and half of the females fertilized. On February 23 individuals lured with light were all mature, the females fertilized. In March—April the percentage of males was reduced to 0—18. In 1967 the females fertilized in January measured 34—42 mm (I- and II-group), in February 87 % were above 31 mm.

Mortality

As already mentioned, the stock as a whole is considerably reduced from February to March, and the proportion of males decreased from March to April both in the Byfjord and the Hardangerfjord. It is also expected that older individuals (I- and II-group) would die at a higher rate during spring than the 0-group. The proportion of I-group to 0-group males and females in the Byfjord in 1967—1968 is shown in Table 6.

During February—June old males were less frequent than old females, in some samples entirely absent. In 1967 the percentage of old females in January was about 25, of males 20. In February old females were mainly taken below 150 m during the night. In March these females were relatively frequent at higher levels, males at 150 m. In April—June old males were scarce or absent, and the percentage of old females was also reduced.

In October the 0-group dominated during the day and above 175 m during the night. At and below 175 m the I-group constituted more than 50 %.

In 1968 old males were poorly represented, only taken in deep hauls in February. Old females were also generally scarce, indicating a poorer survival than in the spring of 1967. In the Hardangerfjord (Table 7) conditions in 1967 varied very much in the different parts of

Table 6. *Meganyctiphanes norvegica :* Proportions of I-and II-group to 0-group of males and females in the Byfjord, January 1967 to May 1968. IKMT-hauls. ÷) no males present.

Year	Date	Day or night	Depth m	I-II gr. 0-gr. males %	I-II gr. 0-gr. females %
1967..............	5 Jan.	night	10— 50	7	20
		»	150	14	26
	6 Jan.	»	100	6	24
		»	200	20	24
		»	230	32	32
	6 Febr.	day	240	0	2
		»	100	÷	0
		»	150	38	77
		»	200	26	43
	15 March	night	10— 50	8	53
		»	150	33	55
	7 April	day	150	0	18
		»	200	20	49
		»	230	0	60
	21 May	day	200	0	0
		»	230	0	19
	14 June	»	175—210	7	26
	16 Oct.	»	100—150		13
		»	175—210		21
		»	230—260		25
		night	5		0
		»	25— 75		8
		»	100—150		27
		»	175—210		54
		»	230—260		61
1968..............	5 Febr.	day	175—210	0	3
		»	230—260	9	9
		night	10	0	8
		»	25— 75	0	28
		»	175—210	14	38
		»	230—260	28	34
	17 April	day	150	÷	0
		»	200	0	2
		»	230	0	4
		»	260	0	36
	19 April	night	4	0	4
		»	10	0	5
		»	15	0	40
		»	25— 75	0	27
	20 May	night	4	÷	6
		»	10	÷	3
		»	15	÷	15
		»	25— 75	÷	17

Table 6(cont.). *Meganyctiphanes norvegica:* Proportions of I-and II-group to 0-group of males and females in the Byfjord, January 1967 to May 1968. IKMT-hauls. ÷) no males present.

Year	Date	Day or night	Depth m	I-II gr. / 0-gr. males %	I-II gr. / 0-gr. females %
1968	10 May	»	100—150	0	24
		»	200	0	67
	12 June	night	10	÷	0
		»	25	÷	10
		»	50—100	÷	4
		»	200	0	9
		»	230	0	0

the fjord, but the proportion of old males generally decreased considerably after March. The impression is also that the stock as a whole was heavily reduced after spawning. Occasionally old females dominate catches taken with dip net and light, in February 1968 constituting up to 95%. Similar observations have been made earlier (WIBORG 1966).

Table 7. *Meganyctiphanes norvegica:* Proportions of I- and II-group to 0-group of males and females in the Hardangerfjord January 1967 — April 1968. IKMT night hauls. At 0 m, catches with light and ketcher. ÷) no males present.

Year	Date	Depth m	I-II gr. / 0-gr. males %	I-II gr. / 0-gr. females %
1967	3 Jan.	10— 50	55	57
	7 Febr.	0	1	15
		10— 50	37	42
		150	44	55
	14 March	10— 50	39	41
		10— 50	27	38
	21 May	25— 75	0	40
	16 June	150	8	27
1968	12 Febr.	10	0	31
		25— 75	50	50
	18 Febr.	0	0	95
	23 Febr.	0	23	69
	27 March	0	21	33
		0	8	21
	18 April	0	÷	10
		4— 15	0	20

Conclusions

In the investigated area *M. norvegica* was seldom taken in densities higher than 150 specimens/1 000 m³, with a single exception of 1 170 specimens/1 000 m³. However, dense agregations at the surface have been induced with artificial light.

During the day *M. norvegica* keeps below 150 m with maximum concentration at 200—260 m or deeper. During the night the population migrates towards the upper layers, sometimes close to the surface. A certain layering was observed, 0-group individuals in the top layer, older individuals successively deeper. Some of the I-group males stay in deeper water both during day and night. This pattern of vertical migration is similar to that described by EINARSSON (1945) and MAUCH-LINE (1960, 1969). Occasionally older individuals arrived at the surface later in the night or early morning. Surface swarms of *M. norvegica*, attracted by artificial light in February—March, sometimes consisted mainly of 0-group females. A similar segregation of I-group individuals was observed by AITKEN (1960, quoted by MAUCHLINE 1969).

The growth of *M. norvegica* was comparable with that in the Skagerrak (PAULSEN 1926). Hatched in April—May, the 0-group attains a length of 22 mm in December, 27 mm in April, and 30—34 mm as I-group in May—June. During the second year the growth decreases, the animals in May—June measuring about 38 mm. Individuals surviving for one more year measure 43—47 mm next April.

Maturing and copulation starts in January, the I-group females being fertilized first. All individuals are usually mature and all females fertilized in the middle of March. Spawning starts in March—April, sometimes continuing throughout June.

As was found by MAUCHLINE (1960), there is a high mortality in the males during and after the transference of spermatophores in March—April and also a higher mortality in the I-group than in the 0-group in March—May. Because of the vertical segregation of the different size groups in the water mass, it is difficult to give exact figures of the mortality. In the Byfjord the survival of the I-group in the spring was definitely better in 1967 than in 1968.

THYSANOESSA INERMIS

Abundance and vertical distribution

In night hauls in the Byfjord 395 specimens/1 000 m³ were taken in November 1966, 1 500—3 600 specimens/1 000 m³ at 40—50 m level in January—February 1967 (Table 8). During April—June and in October

Table 8. *Thysanoessa inermis.* Number per 1 000 m³ in hauls with 3' IKMT and
Clarke—Bumpus plankton sampler (CB) in the Byfjord in 1967—1968.

Year	Date	Day or night	Depth m	Number of T.inermis	Number of T.inermis at other levels
1966.........	24 Nov.	night	10— 50	395	
1967.........	5 Jan.	»	10— 50	580	
	6 Jan.	»	50	3 600	52—215
	6 Febr.	day	100	290	4—125
	9 Febr.	night	10— 50	94	
	9 Febr.	»	10 (CB)	350	
	9 Febr.	»	40 (CB)	1 560	
	15 March	»	10— 50	63	
	7 April	day	150	19	5— 9
	21 May	»	260	63	54
	14 June	»	175—210	63	10
	16 Oct.	night	25— 75	38	5— 25
1968.........	5 Febr.	»	5	27	
	5 Febr.	»	10	1 500	
	5 Febr.	»	10 (CB)	4 000	22—112
	17 April	»	10	32	7— 30
	20 May	»	25— 75	26	3— 21
	12 June	»	100	9	1— 7
	19 Nov.	»	50	35	0— 7

figures were low. High figures, 4 000 specimens/1 000 m³, were again
obtained at 10 m level in February 1968.

In the Hardangerfjord *T. inermis* was taken in low numbers, maximum
125/1 000 m³.

In Karmsund an IKMT haul at 5 m in November 1968 yielded
about 1 100 specimens/1 000 m³.

The irregular variation in abundance indicates an extensive degree
of shoaling. Large numbers were only taken in night hauls and even
then, only at one single level. The greater number usually taken in
CB sampler as compared with the IKMT hauls, indicates that the smaller
specimens pass through the meshes of the IKMT. There seems to have
been a general decrease in the stock after February, both in 1967 and
1968. During the day *T. inermis* was usually most abundant at 100—200
m, during the night at 10—50 m.

Size distribution

In the Byfjord there was a major peak in the size distribution of
T. inermis at 15 mm from November 1966 to the middle of March 1967
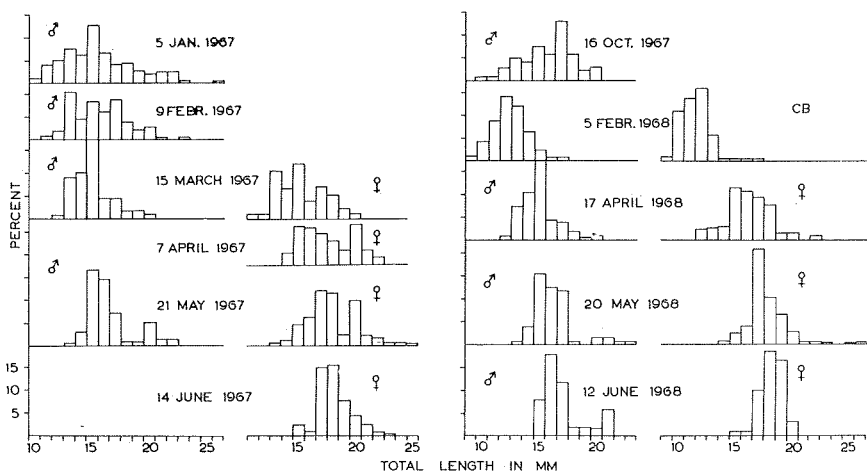
Fig. 9. Size distributions of *Thysanoessa inermis* in the Byfjord in 1967—1968. CB) from samples taken with Clarke—Bumpus plankton sampler.

(Fig. 9). In the March—June samples males and females were measured separately. Females were somewhat larger than the males with the peaks in May at 17 mm and 15 mm respectively. In both sexes there is a second peak at 20 mm, also observed in the females in April. In June the females were slightly larger than in May. In all samples taken in October 1967 there was a peak at 17 mm, in February 1968 at 12 mm. Comparing samples taken at the same level with IKMT and CB, it is evident that more small individuals are caught in the CB indicating escapement of the smaller sizes through the meshes of the IKMT.

In May 1968 the females passed the males in size, with peaks in June at 18 mm and 16 mm respectively.

T. inermis seems to be mainly annual in the Byfjord as was also found for the Hardangerfjord (WIBORG 1966). Individuals, 24—26 mm, taken in January—February 1967 may belong to the I-group.

Spawning and mortality

In the middle of March 1967 males constituted 35—40 % of the stock. Of the males 11 % carried spermatophores. At the beginning of April males were reduced to 7—8 %, indicating a heavy mortality, whereas all females carried spermatophores. In May males were again relatively more frequent, 4—48 %, possibly related to an increased mortality in females after spawning (MAUCHLINE 1966). In June 58 % of the females carried spermatophores, and the males constituted 17—20 %, but the stock was very small. Eggs and nauplii of *Thysanoessa*

sp. were found in vertical Juday net hauls from the middle of March. Maximum of spawning probably occurred in early April. In 1968 males constituted 18—24 % in April, 34 % in May. Nearly all the females carried spermatophores both in April and May except from hauls at 200—230 m where 19 % were not fertilized.

In the Hardangerfjord the samples were too scarce to give sufficient information of the spawning.

Occurrence of the two-spined form of T. inermis

According to HANSEN (1911, 1916, quoted by JONES, FORSYTH and COOPER 1967) *T. inermis* from the Pacific Ocean has two dorsal spines, on respectively the fifth and sixth abdominal sediment; in the Atlantic generally only one, on the sixth segment. Recently, JONES *et al.* (1967) found the two-spined form in the North Sea occurring in about three percent of the individuals investigated.

During the present investigation the two-spined form has also been found in the Hardangerfjord, in the Byfjord and in the Sognefjord (Fig. 1). The frequency was from 1 to 3 percent, the size of the individuals 11—20 mm.

One specimen has also been recorded in samples taken at station M at 66°N, 02°E.

The finding of the two-spined form in the coastal areas of Western Norway links very well with the occurrence in the North Sea.

THYSANOESSA RASCHII

According to MAUCHLINE (1969) *T. raschii* is a neritic species widely distributed in the northern oceans and also found along the coast of Norway. EINARSSON (1945) states that it prefers sheltered fjords, but occurs also in coastal areas.

Abundance and vertical distribution

During the present investigation *T. raschii* was taken regularly in the Byfjord (Table 9), but in numbers second to *T. inermis* except in February 1967 and November 1968. In 1967 maximum numbers were taken in January and February (3 500 specimens/1 000 m³), in 1968 in February and November. Figures then amounted up to 700 and 5 000 specimens/ 1 000 m³ respectively. In the Hardangerfjord *T. raschii* was always very scarce, maximum 2—3 specimens/1 000 m³. In Karmsund (Fig. 1) 85 and 230 specimens/1 000 m³ were taken in May and November 1968 respectively.

Table 9. *Thysanoessa raschii*. Number per 1 000 m³ in hauls with 3' IKMT and Clarke—Bumpus plankton sampler (CB) in the Byfjord in 1967—1968.

Year	Date	Day or night	Depth m	Number of *T.raschii*	Number of *T.raschii* at other levels
1966.........	24 Nov.	night	10— 50	230	
1967.........	5 Jan.	»	10— 50	440	
	6 Jan.	»	25	163	
			50	150	1—40
	6 Febr.	day	100	147	6—26
	9 Febr.	night	10— 50	68	
			10 (CB)	3 500	
			40 (CB)	100	
	15 March	night	10— 50	2	1
	7 April	day	150	9	1— 7
	21 May	»	200	19	6
	14 June	»	175—210	19	3
	16 Oct.	night	5	100	3— 9
1968.........	5 Febr.	»	5	165	
			10	315	3— 7
	6 Febr.	night	10 (CB)	720	
	17 April	»	5	125	0— 3
	20 May	»	5	9	1— 6
	12 June	»	25	4	0— 1
	19 Nov.	»	5	365	10—22
			25	22	
			3 (CB)	5 000	
			8 (CB)	730	

During the night *T. raschii* was nearly always most abundant in the upper 5—10 m, and in November 1968 it was more numerous at 3 m than at 8 m. During the day maximum number was usually taken at 100—150 m.

Size distribution

Size distributions (Fig. 10) are similar to those of *T. inermis*, but there are some differences. From November 1966 to February 1967 there were peaks at 13 mm and 15 mm. Few individuals were caught in March. In April males and females had peaks at 15 mm; in May the females were larger (18 mm) than the males (15—16 mm). In June the peaks were at 17 mm and 20 mm respectively. From September 1967 to February 1968 the peak was mainly at 12—13 mm. Figures from catches with IKMT and CB samplers 1968 are compared, showing the escapement of smaller individuals through the meshes of the IKMT.
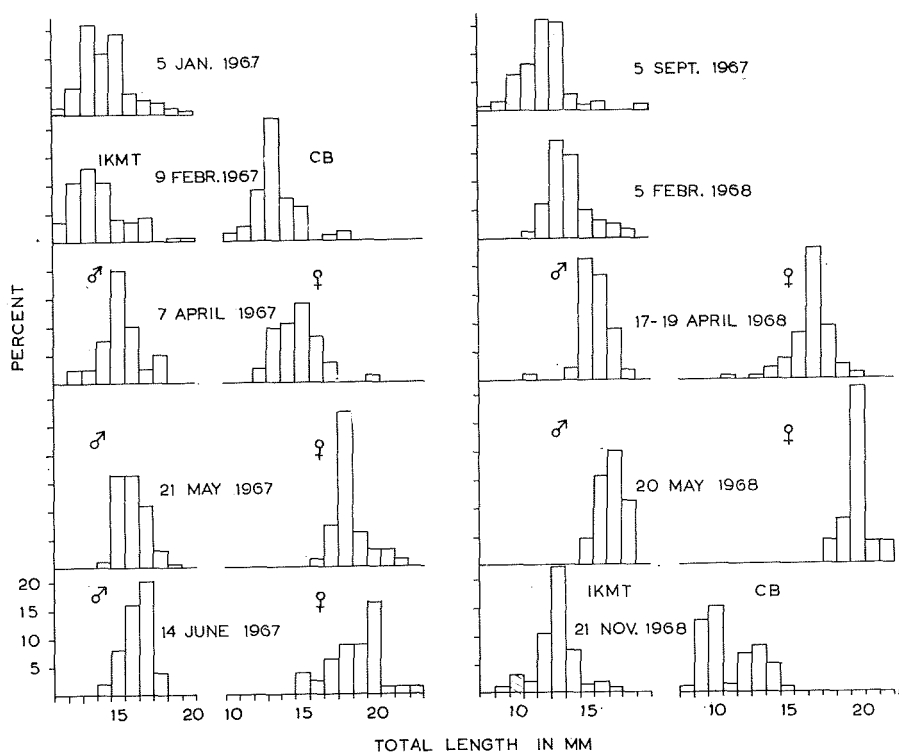
Fig. 10. Size distributions of *Thysanoessa raschii* in the Byfjord in 1967—1968. CB) from samples taken with Clarke—Bumpus plankton sampler.

T. raschii was slightly larger in April and May 1968 than in the same months the year before. In November two peaks are indicated, at 10 mm and 13 mm, and escapement of smaller individuals from the IKMT hauls is again apparent.

Spawning

In March 1967 the few individuals taken were immature. At the beginning of April 76 % of the females carried spermatophores. Males constituted 20 % of the stock. In May males were more numerous than females, (70 %), probably indicating a high mortality in the females after spawning as was found by MAUCHLINE (1960, 1969) for *M. norvegica*. In June 58 % of the females carried spermatophores, and the percentage of males had increased to 40.

In 1968 all females were fertilized in the middle of April and the male percentage was 33, increasing to 63 in May.

In Karmsund the same picture was observed in May 1968, most of the females fertilized and males dominating.

Conclusion

The preference of *T. raschii* for the upper 5—10 m layer during the night has already been mentioned. This fact in addition to the mesh size of the trawl may possibly lead to an underestimate of the numerical importance of this species. This is clearly evident in the figures for 9 February 1967 (Table 9). The size distributions are on the whole more uniform than in *T. inermis,* usually with one main peak. In May and June the mean lengths are greater than those of *T. inermis,* but the survival of individuals beyond one year seems to be insignificant, indicated by a few individuals of 22—23 mm in May—June.

Spawning occurs from April to June with maximum in the middle of April and, to judge from lack of mature individuals in March, somewhat later than in *T. inermis.* The same difference was also observed in the Barents Sea (ZELIKMAN 1958). The two peaks in the size distributions in January—February 1967 and in November 1968 may indicate a spawning period with two maxima for the years 1966 and 1968 while there seems to have been only one main period in 1967. Similar year to year differences are reported by MAUCHLINE (1966).

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ON ACOUSTIC IDENTIFICATION, SIZING AND ABUNDANCE ESTIMATION OF FISH

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ABSTRACT

Midttun, L. and Nakken, O. 1971. On acoustic identification, sizing and abundance estimation of fish. *FiskDir. Skr. Ser. HavUnders., 16* : 36—48.

A method using the fish angle (i.e. the change in target strength with fish aspect) for identification purposes is described. Significant differences in fish angle between cod and coalfish have been observed at sea. The effect of fish angle on the sampling volume of an echosounder is discussed, and it is shown that the sampling volume decreases with decreasing fish angle. A method for abundance estimation applying an echo integrator is described and discussed.

INTRODUCTION

When fish targets are recorded with an echo sounder, three main questions arise:

What kind of fish is it?

What is the size of the fish?

What is the fish density, i.e. number of fish per unit volume water or per unit area?

Fish recordings have so far been idenfified by capture or underwater photography (Parrish and Craig 1969) and also, to some extent, by recognition of typical traces on the recording paper. While the two first methods are time consuming, the third depends on the experience and skill of the observer, and there are no general rules which can be applied for an acoustic identification.

Information on the size of the recorded fish can be obtained from knowledge of target strenght which may be found by an analysis of the received echo signals (Cushing 1968, Craig and Forbes 1969).

The problem concerning the fish density can be regarded as consisting of two parts. Firstly, there is the question of counting or measuring the numbers of fish detected, and secondly, that of finding the sampling volume.

The present paper aims at a technique of direct acoustic identification and sizing of the recorded fish. Further it describes a method for abundance estimation by the application of an echo integrator.

IDENTIFICATION AND SIZING

THE DETECTION SECTOR ANGLE, φ

When the sounding ship passes over an individual target, the sector angle, φ, within which the target is detected, can be determined by the number of echoes received from it during successive transmissions (Fig. 1).

$$\varphi = 2 \ arctg \ \frac{v \ (n+1)}{2 \ D \cdot p} \tag{1}$$

v is the speed of the ship in cm/sec., n is the number of echoes received from the target, D is the depth of the target in cm and p is the repetition rate of the sounder in number of transmissions per sec.

If the target is a sphere and is passed through a circular beam a number of times at different distances from the acoustic axis, the frequency distribution of φ will be as shown in Fig. 4 D. The maximum value of φ, (φ_{max}), occurs when the target passes through the beam center. The value of φ_{max} depends on the directivity of the transducer and the target strength.

Fish targets however, do not reflect sound as does a sphere. The target strength of a fish varies with its orientation relative to the acoustic axis (MIDTTUN and HOFF 1962, HASLETT 1962 and 1965, LOVE 1969). The dorsal-lateral aspect target strength may be as much as 20 db higher than the head-tail aspect target strength. Therefore the target strength of an «ideal» fish can schematically be presented in a three-dimensional diagram as shown in Fig. 2.

Below, an attempt has been made to determine the frequency distribution of the detection sector angle φ when the «ideal» fish passes through a circular beam with different horizontal orientations and at different distances from the acoustic axis. The maximum target strength of the fish is assumed to be equal to that of the above mentioned sphere.
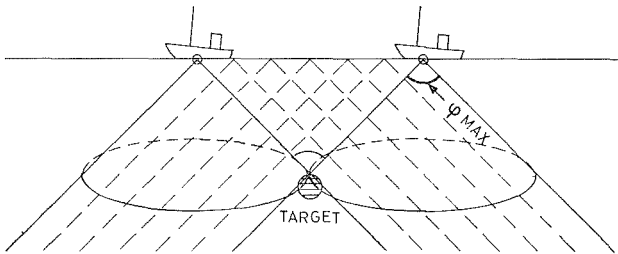

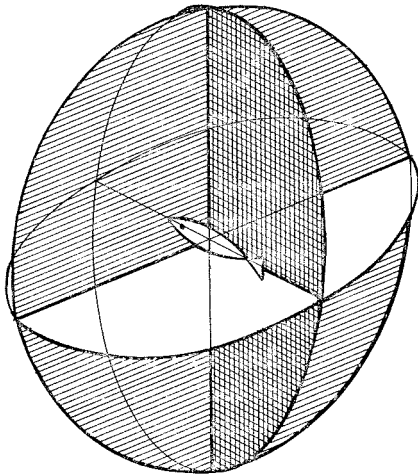Fig. 1. Schematic picture of a transducer passing a target.

Fig. 2. Target strength pattern for an «ideal» fish target.

The maximum angle, φ_{max}, will occur when the fish passes through the center of the beam and is orientated with its long axis at a right angle to the course line. Then φ_{max} is equal to that of the sphere above.

The angle φ of a fish passing through the beam center with its long axis parallel to the course line will be smaller due to the rapid decrease in target strength (Fig. 2). This value of φ is called the fish angle, φ_f.

Thus, the area within which the vertically «looking» circular transducer can «see» the «ideal» fish, is formed approximately as an ellipse (Fig. 3), of which the axes are given by

$$a = 2 \, D \, tg \, \frac{\varphi_{max}}{2} \text{ and } b = 2 \, D \, tg \, \frac{\varphi_f}{2} \tag{2}$$

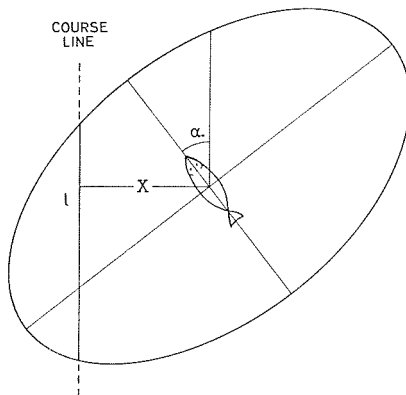Fig. 3. Schematic presentation of the detection area of an «ideal» fish.

The detection sector angle φ can be written

$$l = 2 D \ tg \ \frac{\varphi}{2} \tag{3}$$

where l is the length of an arbitrarily chord of the ellipse. In order to eliminate the depth D, l is expressed in parts of the long axis, a.

$$\frac{l}{a} = \frac{tg \ \dfrac{\varphi}{2}}{tg \ \dfrac{\varphi_{max}}{2}} \tag{4}$$

For practical applications (2) and (4) can be written

$$\frac{b}{a} = \frac{\varphi_f}{\varphi_{max}} \quad \text{and} \quad \frac{l}{a} = \frac{\varphi}{\varphi_{max}} \tag{5}$$

The frequency distribution of φ can be expressed in terms of φ/φ_{max} or l/a. l is a function of a and X, where a is the angle between the long axis of the fish and the course line, and X is the horizontal component of the distance from the course line to the fish (Fig. 3). If the transducer is considered origin and the course line the y — axis, the following equation for the ellipse is obtained:

$$\frac{((x-X) \cos a - y \sin a)^2}{a^2} + \frac{(y \cos a + (x-X) \sin a)^2}{b^2} = 1$$

and

$$l = y_1 - y_2 \text{ for } x = 0 \tag{6}$$

This gives

$$\frac{l}{a} = \frac{\left(1 + \left(\dfrac{b^2}{a^2} - 1\right) \sin^2 a - \dfrac{X^2}{a^2}\right)^{1/2}}{\dfrac{a}{b} \cos^2 a + \dfrac{b}{a} \sin^2 a} \tag{7}$$

Table 1. l/a as a function of $\dfrac{X}{a}$ and α for $b/a = 1/8$, $b/a = 1/4$ and $b/a = 1/2$.

$$\frac{b}{a} = \frac{1}{8}$$

α	$\dfrac{X}{a}$								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.......	0.124	0.122	0.119	0.115	0.108	0.100	0.089	0.075	0.054
10.......	0.126	0.124	0.121	0.116	0.109	0.101	0.089	0.074	0.052
20.......	0.132	0.130	0.126	0.120	0.113	0.102	0.089	0.070	0.039
30.......	0.143	0.140	0.135	0.128	0.118	0.104	0.085	0.056	
40.......	0.161	0.157	0.149	0.139	0.123	0.102	0.068		
50.......	0.190	0.183	0.171	0.152	0.123	0.074			
60.......	0.240	0.225	0.198	0.152	0.052				
70.......	0.332	0.288	0.193						
80.......	0.518	0.201							
90.......	0.600								

$$\frac{b}{a} = \frac{1}{4}$$

α	$\dfrac{X}{a}$								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.......	0.249	0.245	0.238	0.229	0.217	0.200	0.179	0.150	0.109
10.......	0.252	0.248	0.242	0.232	0.219	0.201	0.179	0.148	0.103
20.......	0.263	0.259	0.251	0.240	0.225	0.204	0.178	0.140	0.080
30.......	0.284	0.278	0.268	0.254	0.234	0.208	0.171	0.116	
40.......	0.317	0.309	0.295	0.275	0.246	0.205	0.143		
50.......	0.369	0.356	0.333	0.299	0.248	0.167			
60.......	0.451	0.427	0.383	0.312	0.182				
70.......	0.585	0.528	0.416	0.160					
80.......	0.783	0.621	0.076						
90.......	0.917	0.600							

$$\frac{b}{a} = \frac{1}{2}$$

α	$\dfrac{X}{a}$								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.......	0.497	0.490	0.477	0.458	0.433	0.400	0.357	0.300	0.218
10.......	0.503	0.495	0.482	0.463	0.436	0.402	0.357	0.297	0.209
20.......	0.521	0.512	0.497	0.475	0.446	0.407	0.356	0.286	0.175
30.......	0.551	0.541	0.523	0.497	0.462	0.414	0.349	0.256	0.031
40.......	0.598	0.584	0.561	0.528	0.481	0.416	0.324	0.162	
50.......	0.662	0.644	0.612	0.565	0.497	0.399	0.236		
60.......	0.747	0.721	0.674	0.602	0.495	0.318			
70.......	0.848	0.808	0.737	0.624	0.439				
80.......	0.940	0.885	0.784	0.615	0.276				
90.......	0.980	0.917	0.800	0.600	0.000				

Table 1 shows l/a as a function of a and $\dfrac{X}{a}$ for three values of b/a.
Frequency distributions of l/a are obtained from these tables and shown in Fig. 4. The distributions have marked peaks when l equals b or φ equals φ_f. Consequently, the fish angle, φ_f, can be found when φ_{max} is known. In Table 2 are listed frequency distributions of φ/φ_{max} for different values of φ_f/φ_{max}.

When all the fish recorded have the same fish angle, φ_f, and are distributed at random in horizontal orientation and distance from the acoustic axis, the distribution of φ/φ_{max} will be one of the horizontal distributions of Table 2. If however, there is a variation in fish angle, then the distribution of φ/φ_{max} can be considered as a sum of horizontal distributions in Table 2. Let n_1 be the number of observed φ_1 values, n_2 the number of observed φ_2 values and so on, and let further x_1 be the number of fish with $\varphi_f = \varphi_2$, x_1 the number of fish with $\varphi_f = \varphi_1$ and so on, then, the following set of equations is deduced

$$
\begin{aligned}
a_{11}\,x_1 + a_{12}x_2 + a_{13}x_3 + \ldots\ldots\ldots\ldots + a_{110}\,x_{10} &= n_1 \\
a_{21}\,x_1 + a_{22}x_2 + a_{23}x_3 + \ldots\ldots\ldots\ldots + a_{210}\,x_{10} &= n_2 \\
\cdot \qquad \cdot \qquad \cdot \qquad\qquad\qquad \cdot \qquad \cdot & \\
\cdot \qquad \cdot \qquad \cdot \qquad\qquad\qquad \cdot \qquad \cdot & \\
\cdot \qquad \cdot \qquad \cdot \qquad\qquad\qquad \cdot \qquad \cdot & \\
a_{101}x_1 + a_{102}x_2 + a_{103}x_3 + \ldots\ldots\ldots\ldots + a_{1010}x_{10} &= n_{10}
\end{aligned}
\tag{8}
$$

The coefficient a_{11} to a_{1010} are taken from Table 2, and the frequency distribution of φ_f is found.
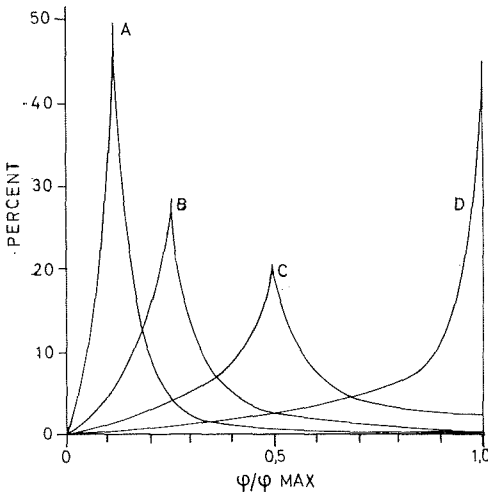

Fig. 4. Distribution in percent of φ/φ_{max} for φ_f/φ_{max} equal to A) 1/8, B) 1/4, C) 1/2 and D) 1.

Table 2. Frequency distribution in percent of φ/φ_{max} for different ratios of φ_f/φ_{max}. The fish is distributed and orientated at random with its long axis horizontally.

φ_f/φ_{max}	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	Detectability in %
0	93	7	0	0	0	0	0	0	0	0		63
0.1	15	63	13	4	2	1	1	0	0	0		66
0.2	5	20	45	15	6	3	3	1	1	1		69
0.3	1	9	20	38	13	8	4	3	3	2		71
0.4	1	6	9	17	33	14	8	5	4	4		75
0.5	1	3	7	11	16	29	14	8	6	5		80
0.6	1	2	5	8	9	17	27	15	9	7		85
0.7	1	2	4	6	7	10	17	26	16	11		90
0.8	1	1	4	5	6	8	11	17	29	18		95
0.9	1	1	2	4	5	7	10	14	22	36		100
1.0												

RESULTS OF OBSERVATIONS

Observations of φ for cod and coalfish are shown in Fig. 5 A. Fig. 5 B presents corresponding distributions of φ_f as calculated from equation (8).

The target strength and length distributions from the same observations are presented in Fig. 6. The technique of observation is described by MIDTTUN (1966). The target strengt is calculated by a method similar to that described by CRAIG and FORBES (1969). However, only the maximum signal strength from each fish has been used, and it is assumed that this maximum occured when the fish passed the transverse axis of the beam. During all the observations the zero signal strength corresponded to a target strength of —40db.

In Fig. 7 the results of the analysis are shown in a φ_f — TS diagram. The two points are the mean values, and the rectangular areas are limited by the standard deviations of the observations.

Fig. 6 and 7 show that no significant difference was observed between the two species with regard to the target strength. This is not surprising as the lengths were approximately the same. The target strength values appeared to be rather low.

Regarding φ_f, however, a considerable difference between the two species was observed, and this might in future be used for identification purposes.
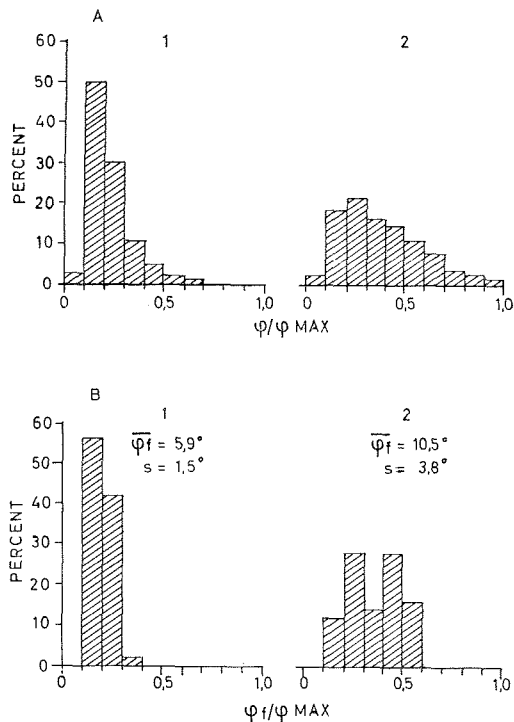
Fig. 5. Distribution in percent of $A)$ φ/φ_{max} and B) φ_f/φ_{max} for 1) coalfish and 2) cod.

DISCUSSION

The observed φ_f (Fig. 5) were lower than those calculated from the measurements of MIDTTUN and HOFF (1962). The mean lengths of the fish were, however, larger in the present experiments and therefore smaller fish angles may be expected.

Also the observed mean target strength were low as compared to the maximum values reported by MIDTTUN and HOFF (1962) even though the fish were larger. This difference is probably caused by the fish under observation being more or less inclined from the horizontal. Most underwater pictures show that fishes are usually inclined relative to each other, and consequently they are also inclined relative to the horizontal plane. From this follows that field measurements of target strengths will always be low compared to the maximum values measured in laboratories.

If a mean inclination of 5° to the horizontal plane is introduced to the data of MIDTTUN and HOFF (1962), the target strength of cod will
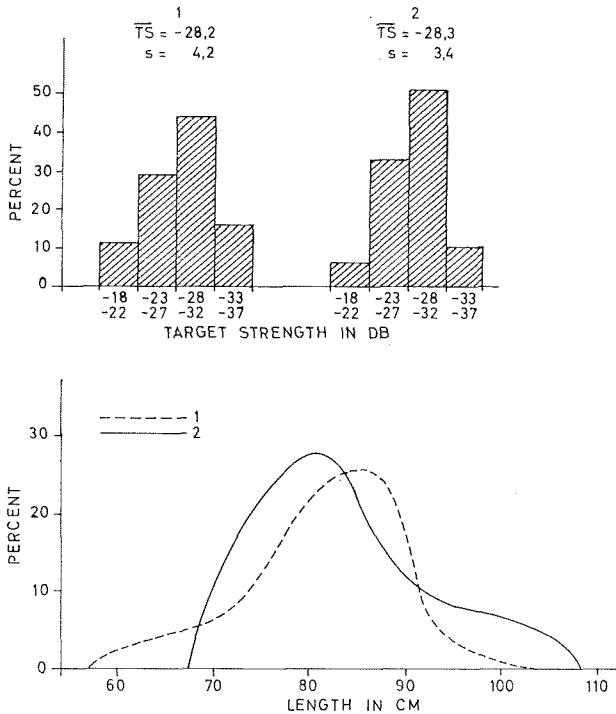
Fig. 6. Distribution in percent of target strength. 1) coalfish and 2) cod. Corresponding length distributions are shown below.

be reduced with a mean value of 5.5 db or, if the maximum dorsal aspect target strength of an 85 cm cod is taken to be — 20db, then the average inclination of the cod in our field observations is between 7 and 10°.

The detection sector angle, and consequently the fish angle as defined by us, will be influenced by the settings of the sounder. The difference obtained between cod and coalfish however, is not influenced by this since all the observations were made with the same sounder at the same settings. Another factor which will alter the detection angle, is the roll and pitch of the vessel (Fig. 4 SUOMALA 1970). As no measurements of pitch and roll angles were carried out, we were not able to analyse its influence on the results.

We assume the fish to be orientated at random but with the long axis in the horizontal plane. The first assumption was probably partly fulfilled by the pattern of different courses used during the observations. The second was, as already mentioned, not fulfilled. Considering the target strength measurements it is, however, not probable that the difference in fish angles between cod and coalfish should be caused by a
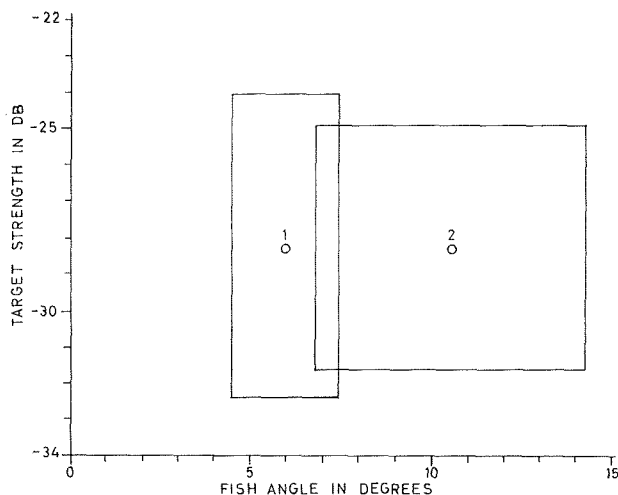
Fig. 7. Fish angle — target strength diagram showing mean values (circles) and standard deviations of observations (straight lines). 1) coalfish and 2) cod.

systematic difference in inclination between the two species during the observations.

The reason for this difference in fish angles is more likely to be found in the size and form of the swimbladders as pointed out by MIDTTUN and HOFF (1962).

More experimental work should be carried out on a number of species and for different fish sizes in order to find out more conclusively whether the fish angle can be of general value as a tool in distinguishing between fish species as it would appears from our results on cod and coalfish. In future observations should be carried out with stabilized transducers in order to eliminate errors caused by the rolling of the ship.

ABUNDANCE ESTIMATION
METHOD

Methods of abundance estimation are described in PARRISH (1969) and ANON. (1969). In the following the application of an echo integrator for the purpose of measuring fish density is explained.

The integrator was introduced by DRAGESUND and OLSEN (1965) and has recently been modified (BODHOLT 1969). The signal voltage is now squared before integration, and the output of the integrator is therefore proportional to number of fish both when multiple and individual fish targets are recorded.

Following MIDTTUN and NAKKEN (1968) we write

$$M = C_1 \cdot N \tag{9}$$

where M is the reading of the integrator, N is the number of fish giving this reading, and C_1 is the mean contribution to M from one fish.

When at constant fish density, ϱ (number per unit volum water) applying a TVG (time varied gain) proportional to the fourth power of the depth, the number of recorded fish will increase proportional to the square of the depth, D. For an integration over a given depth interval equation (9) can be written

$$M_{D^4} = C_2 \cdot \varrho \cdot D^2 \tag{10}$$

where M_D4 is the integrator reading when the TVG is set proportional to the fourth power of the depth (40 log D), and D is the mean depth of the observed depth interval.

From (10) we get

$$\frac{M_D{}^4}{D^2} = C_2 \cdot \varrho \tag{11}$$

The expression on the left side is proportional to the integrator reading when the TVG is proportional to the second power of the depth (20 log D). Consequently, when a TVG proportional to the second power of the depth is used, the integrator reading will be proportional to fish density

$$\varrho = C_3 \cdot M_D{}^2 \tag{12}$$

The constant C_3 is now independent of depth, but dependent of target strength and φ_f and the characteristics of the sounder. If target strength and φ_f of the recorded fish are known, C_3 can be found. The most convenient way to find C_3, however, is to count single fish traces, say 30, on the paper record, calculate ϱ, and divide it with the corresponding $M_D{}^2$. The obtained value of C_3 can be used in equation (12) as long as the fish species and size remain unchanged.

DISCUSSION

It is important to determine if equation (12) is also valid for schools of fish. In other words, will one fish contribute to the integrator reading with the same value when member of a school as it does when recorded as an individual?

The sampling volume will increase with increasing school density which means that C_3 should be larger for fish as school members compared to single fish. The increment in C_3, however, will be small, and we consider it negligible.

In order to determine C_3, the sampling volume must be known. This can be found from the distribution of maximum target strength

of the fish and from the directivity pattern of the transducer. Due to the directivity of fish this procedure will give too low estimates of fish density as seen from Table 2. A transducer at the surface cannot detect fish with large values of a and X within the estimated angle, φ_{max}. The detectability decreases with decreasing φ_f. Probably, the fish is also inclined relative to the horizontal, and then the detectability in Table 2 will be further reduced. Therefore, for wide beam transducers the sampling volume should be calculated from the observed values of φ instead of from the directivity diagram of the transducer.

Equation (12) is not valid for large fish densities. From echo records we know that below dense fish schools the strength of the bottom echo is considerably reduced due to attenuation of sound within the school. In such cases values of ϱ calculated from equation (12) will be too low. However, at the front of the reflected signal from a school the attenuation might be neglected, and during the raise time of the echo the squared voltage should be proportional to the number of reflectors within one half pulsevolume. This then makes it possible to find the fish density in the uppermost part of the school.

The response of fish to the ship noise might cause a lower fish density within the field sampled with an echosounder. OLSEN (1969) showed that a typical response of herring to an acoustic stimulus was to turn away from the sound source and swim towards the area of less sound intensity. It is not known, however, whether the fish will react in this way to the noise of a ship.

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