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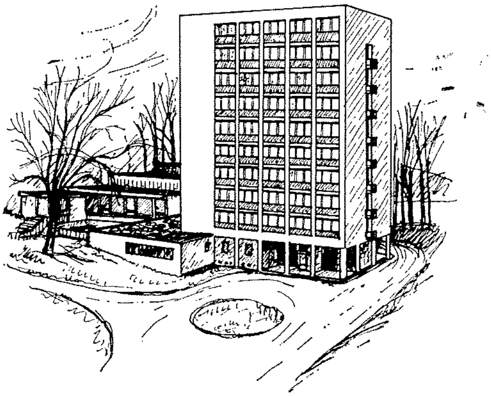

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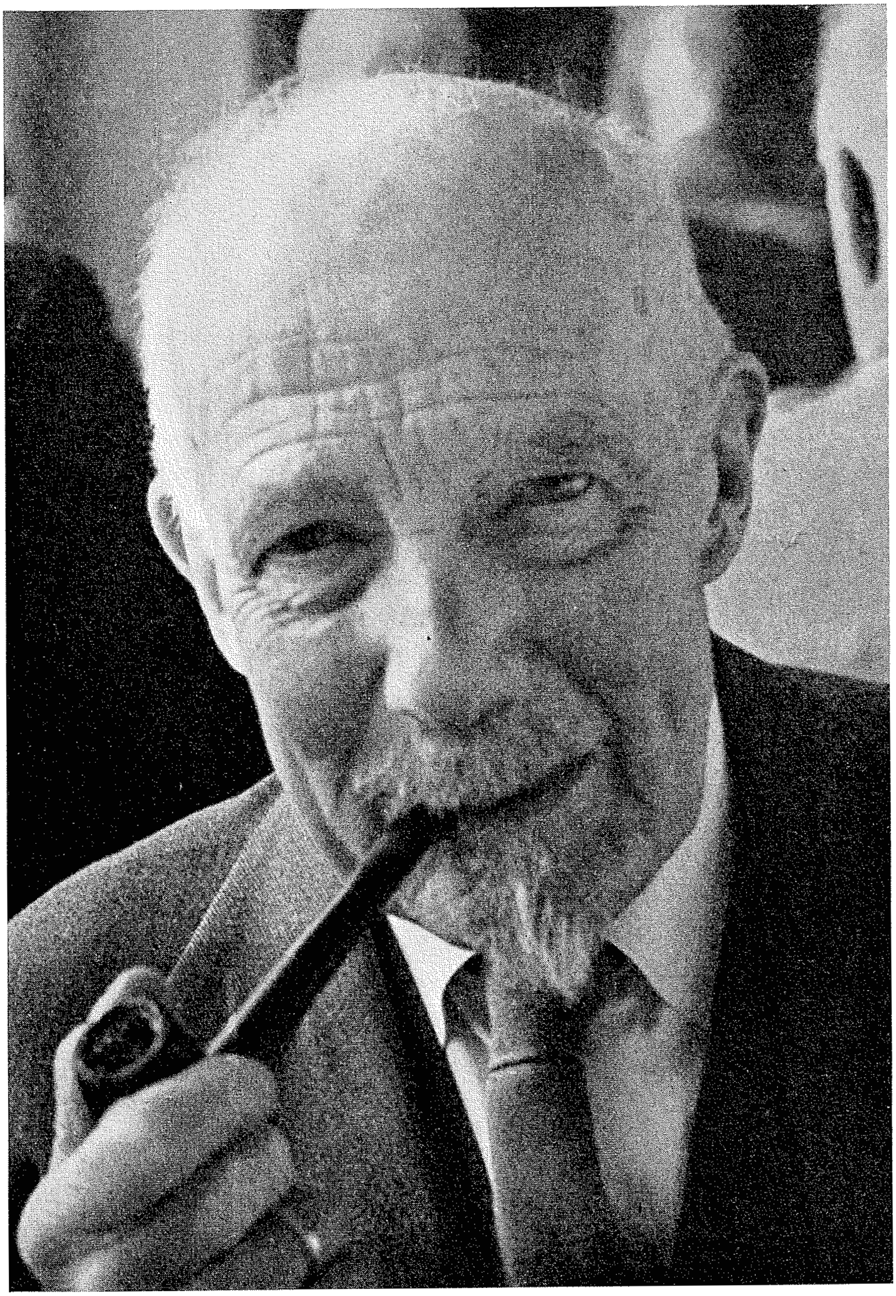

(Foto Berland)

Einar Koefoed

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We are greatly indebted to the authors of the present contributions and also to Dr. Ronald Scheline for serving as the language consultant. Valuable library and reference assistance was given by Mrs. Elsa Strand and Mr. Leif Takvam.

Bergen May 1963.
Gunnar Sundnes

Foreword

BY

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Einar Koefoed was born in Copenhagen on July 26, 1875. His parents were Rear Admiral Vilhelm Ferdinand Koefoed (1837—1930) and Emilie Koefoed (1841—1914). During the years 1887—1890 Einar Koefoed visited with his parents the small Norwegian bathing resort and fishing port of Hankø on the eastern side of Oslofjord. Many of these days at Hankø were spent with a fisherman among the skerries and islands and these fishing trips would have a decisive influence on his future career.

From 1898—1900 Koefoed worked as an assistant to Dr. C. G. Johannes Petersen at the Danish Biological Station in Fredrikshavn and at the Biological Station in Nyborg. The opportunities for a marine biologist to make a living from fisheries investigations were few, as Dr. Petersen pointed out, but Koefoed's interest in fisheries research was very strong. In 1898 he participated in the meeting of Scandinavian Naturalists in Stockholm and took this opportunity to visit Norway to see Dr. Johan Hjort at the Biological Station in Drøbak.

Koefoed was very interested in the important fishing experiments carried out in Norwegian fjords by Hjort and Dr. Knut Dahl. He spent the summer of 1898 in Larvik and here he had the chance to begin investigations of his own. He used a plankton net to study the fish eggs and larvae in Larviksfjord. On several occasions he met the Norwegian marine scientists Dahl, Ola Nordgaard and Bjørn Helland Hansen and in 1901 was invited to join Hjort's group in Bergen. He accepted this offer and in April 1902 became a new member of Hjort's famous group.

The following years were rich in work, results and warm friendship. When Hjort decided that the staff, and often the wives as well, deserved some recreation he closed the laboratory doors (which was also the kitchen in his flat) and they all went off "to the corner" for a glass of wine. Or if finances permitted, they went to the Bellevue Restaurant which was famous for its steaks as well as its bowling alley. The cooperation and relationships within the group were close and informal. Even important staff meetings were attended by the wives who often joined in the discussions, even if they could not officially vote! It was during this period (1907) that Einar Koefoed married Christiane Tandberg.

The cruises alternated with laboratory work and when Koefoed returned from the S/S "Michael Sars" cruise in 1910 he had material which became a lifetime work not only for himself but for many other specialists as well. During World War I, when research cruises were suspended, Koefoed finished his description for the demersal fish species collected on this cruise.

In 1917 Johan Hjort found it necessary to resign from his position as Director of Fisheries and went to Copenhagen. Koefoed followed him and continued his work there on the pelagic fishes collected on the "Michael Sars" cruise. But he could not easily forget Bergen and when he received an invitation to return to fisheries research there he accepted. In addition to scientific work his new duties included responsibility for the library.

Koefoed returned to Bergen in July 1921 but he found that times had changed and the golden era of Norwegian fishery investigations had passed. The efficient research vessel "Michael Sars" had been handed over to the navy and the members of the old group were scattered. There was little interest in fishery research and the problem was one of utilizing the quantities of fish caught. After four lucrative war-years the future looked bleak and the Directorate of Fisheries was more concerned with social problems such as keeping the fishermen working.

In spite of this, the marine research work slowly began, not because of any enthusiasm from the public, but because of the drive of a handful of men who had inherited the dreams, ideas and duties of those better days which had passed.

Together with the late captain Thor Iversen, Koefoed ventured northwards. They continued Hjort's exploratory work on expeditions which combined practical and scientific tasks, e. g. sounding and mapping the fishing banks. They also managed to determine the correct position of Hopen Island. We know how many cruises were carried out, how many sections were run, how many stomach contents were investigated and how much salinity and temperature data were collected because it is all neatly recorded in journals and log books. But little is said of the hard work and the narrow escapes which they had on those primitive fishing vessels during their encounters with the ice, freezing gales and darkness of the North.

These cruises provided many good stories. As captain Iversen was responsible for the safety of his crew and ship he sometimes took the drastic measure of tying Koefoed to a davit when he had to take a hydrographical station. Not only was this a lifesaving measure but it ensured that Koefoed would be onboard to take the next station.

It might appear strange that Koefoed became one of the most daring research sailors in Norway when his real place seemed to be in the laboratory bent over a microscope. But his list of research publications shows that he also found time for this. This list continues to grow and his most recent publication appeared in 1962, 60 years after he began in Norwegian fishery research.

For many years Koefoed had to remain on shore. The interuption caused by World War II and then by the illness of captain Iversen halted the cruises. In the meantime, however, he continued with his microscope studies and his library duties. Then in 1950 a new Norwegian research vessel, R/S "G. O. Sars", was put into operation and he again took part in the duties at sea. Koefoed was then 75 years old and to this new ship and its young crew he was a link to another era in Norwegian fisheries research. Everyone was honoured to have one of the famous oldtimers along with them in their new endeavours, just as we are now pleased to count him as one of us at the Institute for Marine Research.

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Einar Koefoed and his work as zoologist during the practical — scientific fishery investigations in northern waters from 1923—38

BY

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In 1920 the Directorate of Fisheries started anew the practical-scientific fishery research work in northern waters. This type of research had originally been introduced by Dr. Johan Hjort at the turn of the century, and the renewed investigations were meant to follow along the same lines.

The Norwegian fishery authorities had no ocean research vessel at their disposal at that time, but the plan was put into operation in 1923 with leased fishing vessels which were properly equipped for their special task. The scientists would necessarily lead a rather miserable life onboard a small fishing vessel, but to scientists with the proper attitude and with a burning interest this would be of secondary importance.

The collecting of scientific material on the cruises was to be performed by Einar Koefoed.

On these cruises to the far north great demands were made on the working capacity and patience of the zoologist. Being responsible for the collecting and preservation of the scientific material, Einar Koefoed had to work at all hours day and night, weekdays and Sundays, and some times perhaps several 24 — hr. days in one stretch without rest and sleep if the situation so demanded. Fishery advisor Thor Iversen, with whom Einar Koefoed cooperated, has in one of his reports commented on Koefoed's work with the following words: "When the collected material of specific scientific value has become so comprehensive I wish to emphasize that this mainly is due to the zoologist Einar Koefoed who has participated in the majority of the expeditions".

The material which Koefoed collected through a number of years on the expeditions to northern waters was subsequently sent to various scientific institutions. The biological and zoological collections were sent to the Bergen Museum, the Zoological Museum of Oslo, the Tromsø Museum and the Division for Fishery Research at the Directorate of

Fisheries. Botanical material was sent to the Bergen Museum and the Norges Svalbard og Ishavsundersøkelser. Also, geological samples collected on the cruises were sent to the latter institute, while the water samples and temperature readings from the hydrographic work were sent to the Geophysical Institute in Bergen.

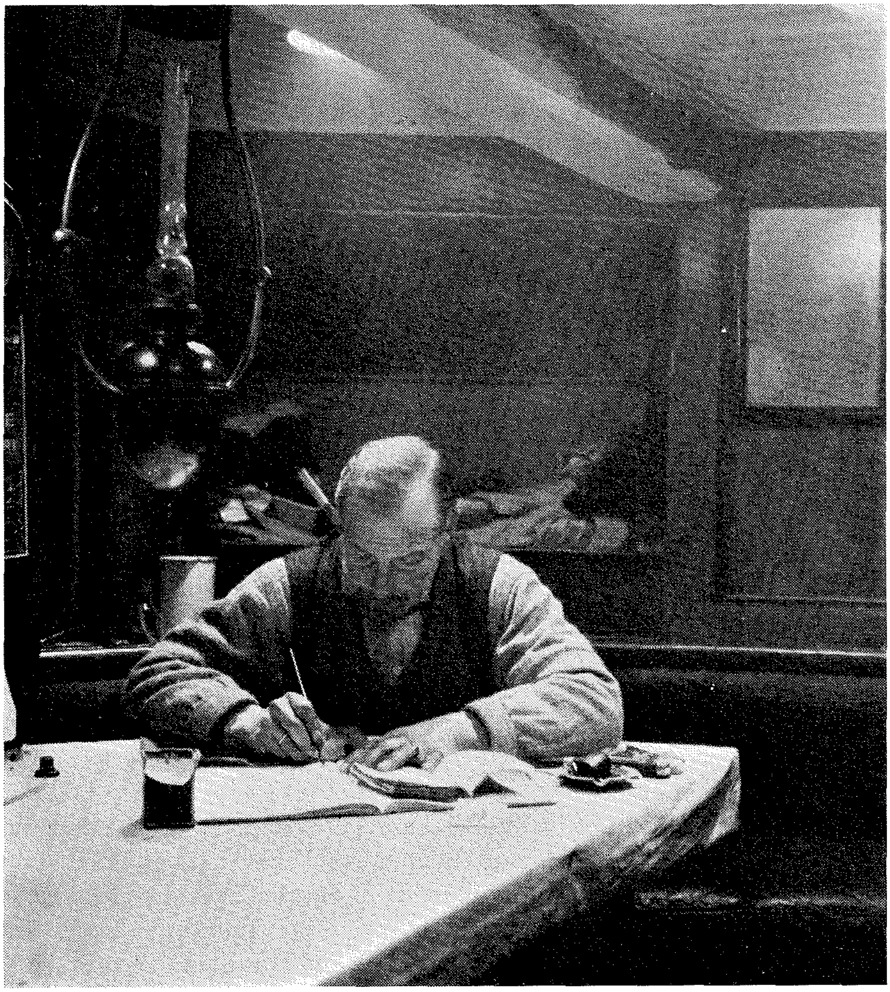
On the basis of the large scientific material collected by Einar Koefoed in the northern waters a series of papers and articles have been published by the various institutions. A list of such publications is appended at the end of this article.

The fishery investigations during the years 1923—38 covered the whole Barents Sea from the White Sea in the south to Franz Josef Land in the north, the whole of the Svalbard area including the Bear Island bank plateau as well as the Norwegian Sea, the Jan Mayen area and the sea off Southeast Greenland. During the years a large collection was made of the marine fauna in this widespread area. Also, much material was collected ashore consisting of stones, plants and animals from Southeast Greenland, Jan Mayen, Spitsbergen and Hope Island. Einar Koefoed is not only an eminent zoologist but has also excellent knowledge of botany and geology. He always made very precise notes in his diary about the various findings, he took good care of the collected samples and saw to it that they were sent to the proper interested institutions.

During the period from 1923 to 1938 Koefoed spent altogether 43 months on the exploratory fishery expeditions in northern waters. The limitation of the present article does not allow for a detailed description of Koefoed's work on all these cruises. But a few notes on the achievements performed by Koefoed on Thor Iversen's expeditions in the different years may be of interest.

Koefoed has always been a keen and accurate observer both at sea and during visits ashore, and his notes, such as those from Hope Island, are real gems. The following notes are taken from his diary dated August 25th, 1924.

"Næsset er en vidtstrakt mosdækket slette, hist og her en tue av tyndt højt, ca. 10 cm. græs uten aks; bladene var frosset brune i spissen. I mosen vokset hyppigst *Saxifrage cernua*, med den konkurrerte i hyppighed den lave hvidblomstrede *Saxifraga*, som paa grunn av sine utløbere oftest står i tætte klynger; nu og da en tue av grønarve uten blomster, av *Saxifraga cæspitosa* og *Oppositifolia*, denne nærmest skråningen. Mosen, som et enkelt sted hadde sporehuse var hist og her avbrutt av graa lavpletter. — Nævnes må også en enkelt tue av *Saxifraga* med ægformet læderagtige blade tandede i den ytre but avrundede rand, rosetstillede. Bladenes farve var mørkegrøn men randen var brunrød. Blomsterstanden var mittstillet, men den hadde kun reist sig litet over bladrosetten og



Einar Koefoed writing in his journal on the expedition with F/W "Tovik" in 1924.

blomsterne var kun svakt utviklet saa de hvitgrønne kronblade var skjult under bægerbladene og krummet ind omkring frugtstolen. — På langs gik revner i mosteppet, hvor vand var rislet ned høiere oppe fra. Tre steder sås senkninger, hvor der hadde staat vand; det ene sted var der et sølvagtigt overtræk over mosen, inntørket skum, det andet en brun skorpe over jorden, og det tredje en rød, som et rødt lag av alger eller sop. På fjellskråningen fandtes i vandsig to tuer *Ranunculus*, og på den tørre stenede skråning mange valmuer, mest gule med grønsorte pletter i randen av kronbladene, men også hvite (for en del bleges vel blomsterne efter utspringet). På sletten pilte avgaarde en dunklædt brungrå endnu ikke flyvefærdig tyvjounge, tyvjo skrikende over. Gik tilbake langs stranden og samlet sten med avtryk og med forsteninger.»

The headland of Hope Island which Koefoed investigated on this occasion was later named "Koefoed Point" (Thor Iversen 1941).

After a preliminary classification in 1924 Koefoed listed 15 species of flowering plants besides various species of mosses and lichens. Of flowering plants Koefoed collected, according to Johannes Lied (1926), 16 species of which 8 were new for Hope Island. According to E. Jørgensen (1926) the material collected by Koefoed contained 35 species of mosses. In a preliminary communication Bernt Lynge (1926) stated that the number of species of mosses collected by Koefoed in 1924 on Hope Island was 19. A list of the flowering plants, mosses and lichens found on Hope Island was given by Thor Iversen in his publication «Ishavsøya Hopen» (1941). The fossil plants brought back by the expeditions in 1924 and 1925 were treated by Ove Arboe Høeg (1926), and the fossil shells by W. Bodylewsky (1926).

As regards the bird life on Hope Island Thor Iversen (1941) cited from Koefoed's notes: "Hope Island was place of resort for such birds as the Guillemot (*Uria Lomvia*), the Glaucus Gull (*Larus hyperboreus*), the kittiwake (*Rissa tridactyla*) and Skuas (Stercorarius). Single Black Guillemots (*Uria grylle*) and flocks of Spitsbergen Eiders (*Somateria mollissima*) were also seen. On the beach the Purple Sandpiper (*Tringa maritima*) were tripping about."

In his report on the expeditions Thor Iversen (1925) said "that the collected material, and particularly that from the small isolated rock Island situated so far out in the sea east of South Cape of Spitsbergen, has awakened great interest among the specialists. The Hope Island has not previously been thoroughly investigated, and this island is considered to be very difficult of access."

The scientific material collected ashore was, however, only a byproduct of the main object of the expeditions, namely the fishery experiments and the study of the fauna of the sea. In this exploratory work various types of fishing gear were employed, such as long-lines, trawl gear and beach seine. The large quantity of bottom animals and so-called "scientific fishes" were properly taken care of and preserved by Koefoed. This valuable material was later distributed to the various scientific institutions.

In 1925 the expedition was suddenly interrupted on July 24 when the leased research vessel "Tovik" stranded on the beach in the Ice Fjord, West Spitsbergen. Another vessel which happened to be in the area came to assistance, and "Tovik" was pulled off the rocks and towed to

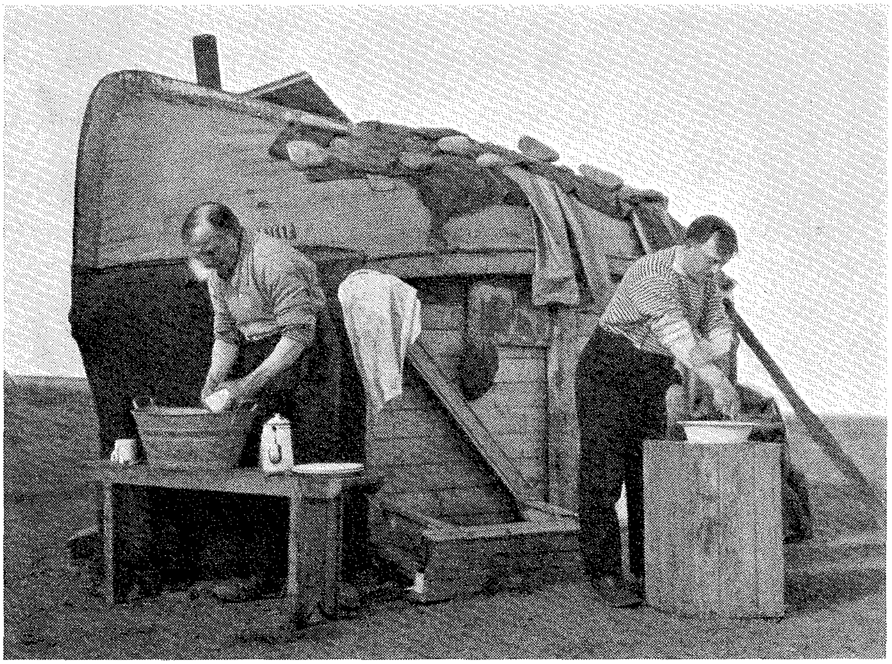
F/W "Tovik" beached after being damaged at Spitsbergen in 1925.

the bay off the Longyear coal mines. However, the vessel was so badly damaged that it was left there. Iversen and Koefoed found shelter in a so-called "pleasure house" which consisted only of an old life boat turned upside down. In this shelter the two members of the expedition spent the whole summer until September 9th. But Koefoed was not unemployed on account of the shipwreck. In his diary we find, for example, the following entry from this period: "From July 24. to 27. observed several times *Cyanea capilata* and *Limacina helicina* near the sea surface in the bay inside the Hotel Point. In a gillnet set in the Advent Bay 12 herring were caught on July 29th, 9 herring on the 30th and 20 on the 31st. The herrings are steadily caught on the outer end of the net. It is large herring, measured one at 35 cm. The herring stomach contained young sea scorpions. There was inside fat on the stomach and along the edges of the pyloric caeca. The herring was thick across the back with a rounded convex belly. Most of them, however, look like empty herring with the ribs like black crosses under the belly. The sexual organs are small."

The long stay in the turned-over lifeboat had also some bright moments. Thus the stranded expedition happened to witness an historical event in that distant part of the world. On Friday August 14th 1925 we find a short entry in the journal which says: "The flag of Norway is hoisted over Svalbard", thus denoting Norway's sovereignty of the land according to the Svalbard Treaty.

In the following years the Iversen—Koefoed team worked with the same intensity and interest in these Arctic waters, with only a few interuptions some years due to lack of funds for the expeditions. They collected a vast amount of material and observations from land and sea, a collection which at that time was of fundamental value and hardly could be equalled. Much of the material was collected under extreme conditions such as those during the winter cruise in the Barents Sea 1932—1933 with the S/S "Borgenes", a steel-hulled trawler. On Christmas eve 1932 the vessel was working in the middle of the Barents Sea in approximate position 74° N. lat, 37° E. long. The ship was moving in newly-formed ice slush with the surface temperature minus 1,5° C and the air temperature minus 8,4° C. All day a section of hydrographic stations was worked. It was not until second Christmas day that the dangerously over-iced "Borgenes" arrived at Honningsvåg, Finnmark, where the crew and the two scientists were granted a few days of belated Christmas celebration. But the course was soon set eastwards again to the banks off the White Sea. During the month of January 1933 they were engaged in mesh selection experiments using a small-meshed net over the cod-end of the trawl. It was a cold and nasty job for Koefoed to measure the thousands of small haddock and cod collected in the fine-meshed covering and likewise to examine and measure the fish in the cod-end proper (Iversen 1933). All the work was performed on the fore deck without any shelter from wind and snow. On February 2nd the cylinders of the trawl winch burst on account of the cold weather, and during the rest of the cruise to the end of February the exploratory fishing went on with long-lines.

In the summer of 1938 Koefoed went on his last ordinary cruise to the Arctic waters with Thor Iversen. Koefoed was then 63 years old, and it was perhaps the right moment for him to enjoy a deserved rest in the sun and summer in more southern latitudes. He would perhaps also get an opportunity to work up a small part of the material which he had collected through a great number of years. There were some specific fish species, such as the *Liparids* which particularly had attracted his interest, and he had many other collections which he wanted to study, record and



Einar Koefoed (left) and Thor Iversen outside their shelter on Spitsbergen.

publish before he retired. Koefoed's wish was granted, and for many years he was able to work just as industriously in his laboratory in Bergen as he did on the many fishery expeditions to the far north.

But finally, in his 86th year, he announced to the staff that the time to officially retire had arrived. But he was quick to add that he planned to continue his work, although at a more leisurely pace, and we are all pleased to see him now at the institute.

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Length and Growth of the Porbeagle *(Lamna nasus,* Bonnaterre) in the North West Atlantic

BY

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I. INTRODUCTION

The data considered in this paper were collected by the present author aboard a commercial fishing vessel operating with pelagic long lines for porbeagle in the North West Atlantic. The long lines were shot in altogether 52 localities scattered over the area with an average number of 500 hooks in a shot. The effective fishing depth was generally 10—30 m. In all, 2488 porbeagle were caught. Of these 2066 fish were sampled. Fig. 1 shows the area of operation with some of the principal fishing grounds.

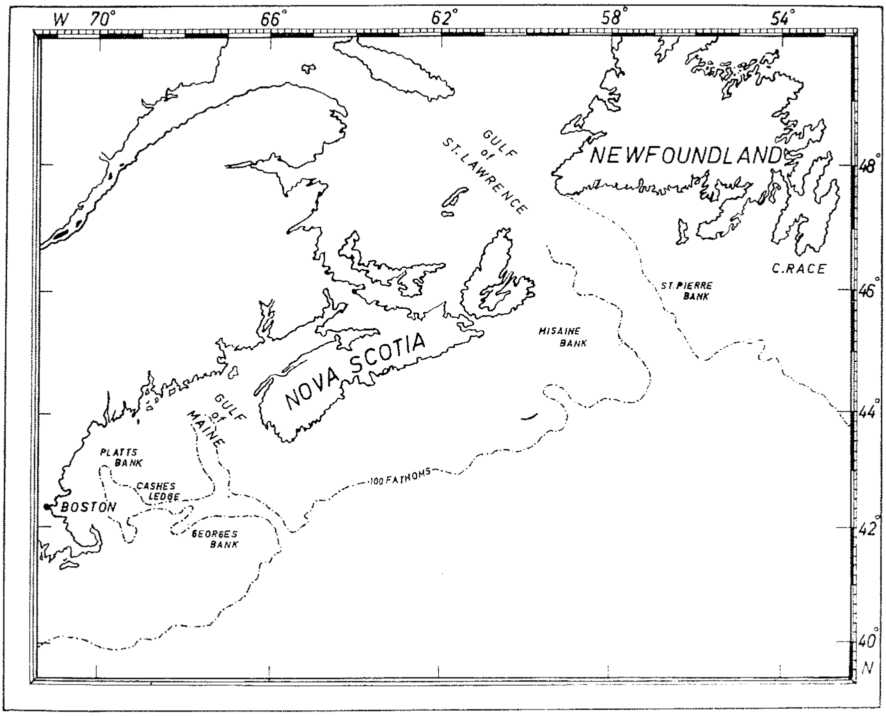

Fig. 1. The fishing area.

II. THE LENGTH

1. *Dorsal length*

It proved impractical, if not impossible, to measure the total length of any great number of fish during the fishing operations. To circumvent this difficulty, only the "dorsal length" was recorded in the majority of the measurements. This "dorsal length" was chosen because one single observer could operate both quickly and precisely without hampering the fishermen's work during the hauling of the line. A further advantage is that the measurement can be performed also after the fish is gutted, beheaded, and the fins cut off. The "dorsal length" (l) is, by definition, the length from the anterior edge of the first dorsal fin at the base to the anterior edge of the pre-caudal pit (Fig. 2).

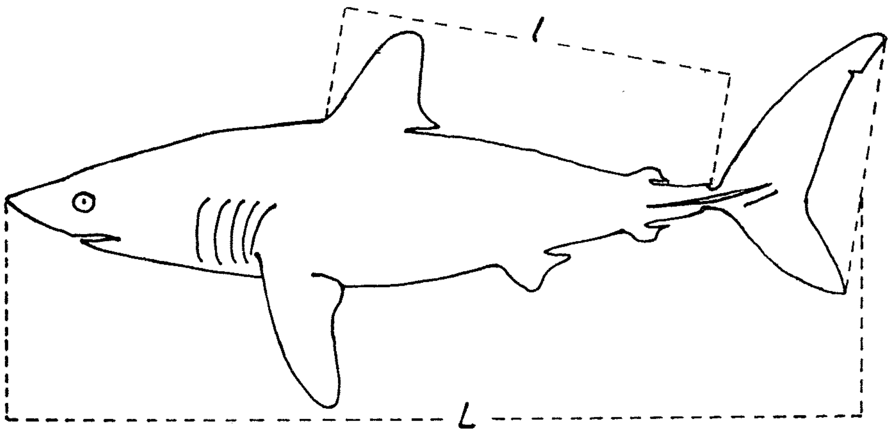

Fig. 2. Total length (L) and dorsal length (l). For further explanation see text.

Several days with good fishing elapsed before a workable routine could be established, and these catches were but poorly sampled. For the rest, however, the dorsal length was recorded for every fish going into the freezer. When arranging the material, neighbouring localities are considered as sub-areas (named after the nearest principal fishing ground) and tabulated separately. Table 1 shows the frequency distributions of l in 3 cm groups, separately for males and females. In addition to the 1810 measurements entered in Table 1, the dorsal lengths of 55 fish for which the sex was not determined, were recorded.

Table 1. *Frequency distributions of dorsal length. North West Atlantic, July—September 1961.* (*Lamna nasus*).

Date	Sub-area	Sex	3 cm groups																											*n*	Mean	σ^2
			50—52	53—55	56—58	59—61	62—64	65—67	68—70	71—73	74—76	77—79	80—82	83—85	86—88	89—91	92—94	95—97	98—100	101—103	104—106	107—109	110—112	113—115	116—118	119—121	122—124	125—127	128—130			
12—18. VII	Platts Bank 1	♀		1	1	2	7	9	4	3	8	5	8	2	5	5	3	3	4	7	2	1	1							81	80.93	206.32
		♂		5	2	2		3	5	5	4	2	7	4	4	2	1		1	2	1									50	75.90	175.68
20—29. VII 6— 7. VIII	Cashes Ledge 2	♀		1	1		3	3	6	3	7	10	8	11	16	9	13	6	11	6	7	5	5	3	2	2				138	89.41	193.77
		♂			1	2	1	7	5	4	8	6	7	13	15	20	14	19	17	15	15	20	18	6	9	4	2			228	95.18	206.14
25—31. VII 2— 8. VIII	Georges Bank 3	♀			3	1	1	4	6	16	14	14	28	29	22	27	26	19	21	13	20	14	8	8	3	6	1			304	90.68	177.90
		♂		1		1	2	2	8	6	9	14	19	29	27	25	22	19	10	17	26	18	6	10	6	1	1			279	92.17	166.98
13. VIII— 2. IX	Misaine Bank 4	♀	1	1	4	3	4	4	7	5	7	12	13	19	12	15	9	15	14	15	13	18	21	30	33	17	8	4		305	98.74	309.78
		♂	2	2	1	2	4	2	4	6	4	7	3	1	9	6	2	12	10	8	12	18	19	9	18	8	1			169	97.92	320.31
14. VIII 3—12. IX	St. Pierre Bank 5	♀				3			1	1	1	2	2	4	1	1	3	3	3	14	9	14	9	5	4	2	2			84	101.18	198.73
		♂				1				1	1	2	2		1	3	1	6	17	25	22	22	24	26	9	4	3	1	1	172	106.13	94.87
12. VII— 12. IX	Grand Total 6	♀	1	3	9	9	15	20	24	28	37	43	59	65	56	57	54	46	53	55	51	52	44	46	42	27	11	4		912	93.29	261.71
		♂	2	8	4	8	7	14	22	22	26	31	38	47	56	56	40	56	55	67	76	78	67	51	42	17	7	1	1	898	95.79	239.18

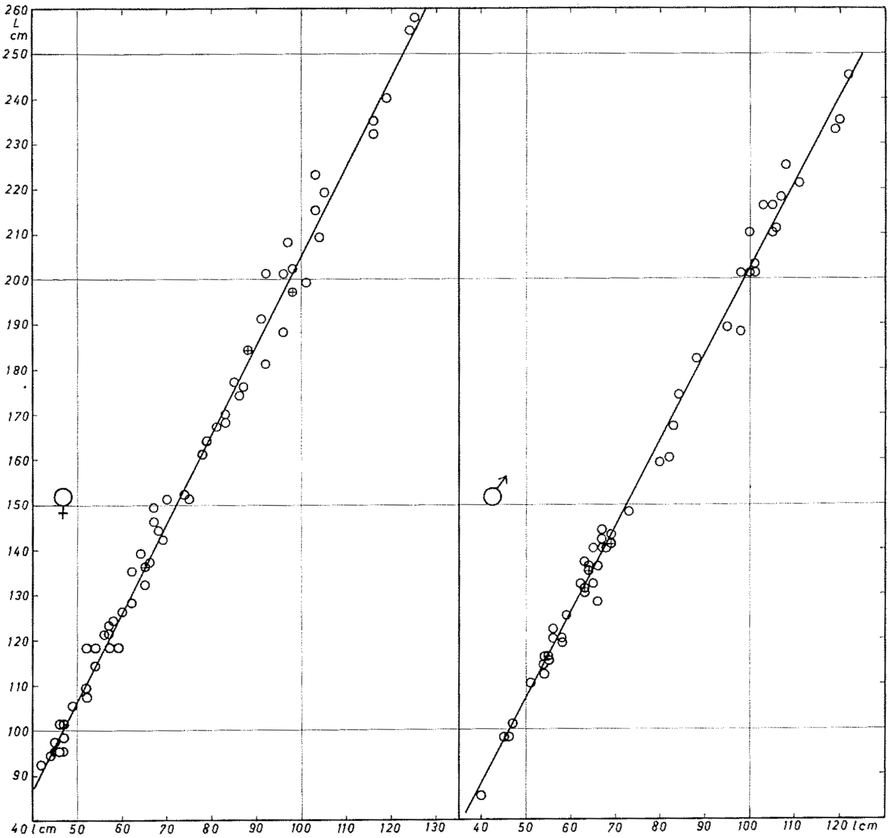

Fig. 3. The correlation of total length (L) and dorsal length (l). Circles: observation points. Circles with cross denote 2 observations in the same point.

2. *Correlation between dorsal length and total length*

In order to obtain data for calculation of the total length (L) from the dorsal length, both L and l were recorded in 122 fish (Table 2). L was measured as the length of the axis from the tip of the snout to a line drawn between the tips of the upper and lower lobe of the caudal fin (Fig. 2). Both measurements were read to the nearest cm using a steel measuring tape.

The close correlation between L and l is demonstrated in Fig. 3. Obviously, the relationship is linear. The regression is calculated from the data set forth in Table 2 where also the sums of L and l and their squares and cross products are entered separately for males and females.

Writing the regression in the form (Fisher, 1948):

$$L = a + b(l - \bar{l}) \qquad (1)$$

Table 2. *Corresponding measurements of total length (L) and dorsal length (l). North West Atlantic, July—August 1961. (Lamna nasus).*

Date	Sex	*L* cm	*l* cm	Date	Sex	*L* cm	*l* cm	Date	Sex	*L* cm	*l* cm
14 July	♀	184	88	21	♀	118	59	3	♂	148	73
14	♀	107	52	21	♂	131	63	3	♂	144	67
14	♂	159	80	21	♂	120	58	3	♂	135	64
14	♀	223	103	22	♀	139	64	3	♀	167	81
14	♀	197	98	22	♂	114	54	3	♂	132	65
15	♀	184	88	22	♂	125	59	3	♀	114	54
15	♀	201	92	22	♂	142	67	5	♀	123	57
15	♂	141	69	22	♀	126	60	5	♂	116	55
15	♂	160	82	24	♀	168	83	6	♀	132	65
15	♀	177	85	24	♂	167	83	6	♀	101	46
16	♀	95	45	24	♂	188	98	6	♀	136	65
17	♀	235	116	24	♂	210	100	6	♀	105	49
17	♂	112	54	24	♀	181	92	6	♀	124	58
17	♀	199	101	24	♂	201	98	7	♂	182	88
17	♂	189	95	24	♀	144	68	7	♀	95	46
17	♀	128	62	24	♀	170	83	7	♂	140	65
17	♀	109	52	24	♂	174	84	8	♂	116	54
18	♀	215	103	24	♀	146	67	13	♀	98	47
18	♀	208	97	24	♂	225	108	16	♀	255	124
18	♀	202	98	25	♂	216	105	16	♂	98	45
18	♀	209	104	26	♂	141	69	17	♀	191	91
18	♂	201	101	26	♂	130	63	18	♀	219	105
18	♂	115	55	26	♂	135	64	19	♀	240	119
20	♀	136	65	26	♀	188	96	19	♀	258*	125
20	♂	201	100	27	♀	151	75	19	♀	101	47
20	♀	232	116	27	♀	149	67	20	♀	197	98
20	♀	164	79	27	♀	121	57	20	♀	161	78
20	♂	216	103	27	♀	121	56	21	♀	201	96
20	♀	118	52	27	♀	118	54	21	♀	174	86
20	♀	95	47	27	♂	137	63	22	♂	203	101
21	♂	245	122	27	♂	143	69	22	♂	235	120
21	♂	210	105	27	♂	120	56	23	♀	176	87
21	♂	221	111	27	♂	136	64	25	♂	101	47
21	♂	233	119	27	♂	140	68	25	♀	92	42
21	♂	211	106	27	♂	140	67	26	♀	137	66
21	♂	218	107	30	♂	131	63	26	♀	135	62
21	♂	110	51	3 Aug.	♀	151	70	30	♂	98	46
21	♀	118	57	3	♀	152	74	30	♀	97	45
21	♀	142	69	3	♂	136	66	30	♀	94	44
21	♂	119	58	3	♂	122	56	30	♂	85	40
21	♂	128	66	3	♂	132	62	Number		122	122

$\sum$	Sex	*L* cm	*l* cm	L^2	l^2	*Ll*	*n*	Mean	
								L cm	*l* cm
	♀	10 144	4 877	1 713 370	398 999	826 440	65	156.062	75.031
	♂	8 878	4 321	1 482 570	354 925	725 059	57	155.754	75.807

* See footnote p. 33 and Plates I and II.

the value of a will be equal to the average length of L: $a = \frac{S(L)}{n}$ or $a_m = 155.754$ cm and $a_f = 156.062$ cm where the indices m and f refer to males and females respectively. The estimate of b is the ratio of the covariance to the variance of the l distribution ($n-1$ falls out) : $b = \frac{S(Ll) - n\bar{L}\bar{l}}{S(l^2) - n\bar{l}^2}$, or $b_m = 1.9020$ and $b_f = 1.9752$. The sampling variances of a and b are $V(a) = \frac{\sigma^2}{n}$ and $V(b) = \frac{\sigma^2}{S(l-\bar{l})^2}$. The value of σ^2 is estimated by summing the squares of the differences between the observed L and the calculated L_c and dividing by the degrees of freedom: $s^2 = \frac{1}{n-2} S(L-L_c)^2$. The sum of the squared deviations may also be found from the equation:

$$S(L-L_c)^2 = S(L-\bar{L})^2 - b^2 S(l-\bar{l})^2 \qquad (2)$$

The values of s^2 are found to be: $s_f^2 = 19.79$, $s_m^2 = 14.43$, and the total: $s^2 = 17.29$. From this is calculated the t of the difference between the means and of the difference between b_f and b_m: $t = \frac{a_f - a_m}{s}\sqrt{\frac{n_f \cdot n_m}{n_f + n_m}} = 0.408$,

and $t = \frac{b_f - b_m}{s}\sqrt{\frac{S_f(l-\bar{l})^2 \cdot S_m(l-\bar{l})^2}{S_f(l-\bar{l})^2 + S_m(l-\bar{l})^2}} = 2.16$.

In the first instance is found: $0.6 < P < 0.7$ and the difference between the mean total lengths is not significant. On the other hand, the difference $(b_f - b_m)$ must be judged significant since $0.02 < P < 0.05$. From this analysis two important biological facts emerge: Firstly, the average growth rate is the same for males and females, and secondly, the relative position of the first dorsal fin is different in males and females, the males having the longer average dorsal measurement. It is also seen that the variability in position of the first dorsal fin is greater for the females. This does not by any means invalidate the technique of estimating the total length by measurement of the dorsal length. The sampling variance of (1) is: $V(L) = \sigma^2 \left[\frac{1}{n} + \frac{(l-\bar{l})^2}{S(l-\bar{l})^2}\right]$. From this it is seen, that in a sample of say 100 fish with a standard deviation of 15 cm, the errors introduced by measuring the dorsal lengths and using the regression to estimate the total lengths, are for the mean L: ♂±0.38 cm and ♀±0.44 cm, while the standard errors of the mean, inherent in the sample $\left(b \frac{15}{\sqrt{n}}\right)$, are: ♂±2.35 cm and ♀±2.96 cm. The precision of the estimates for L is lessened proportionally to the square of the distance of l from $\bar{l}$. At the point $l - \bar{l} =$ twice the standard deviation (i.e. 30 cm) the errors would be: ♂±0.85 cm and ♀±1.00 cm.

These figures serve to demonstrate the practicability of the method of measuring the dorsal length and calculating the total length by means of a regression formula which is also manifest from the high value of the correlation coefficient: $r = \frac{S(Ll)}{\sqrt{S(L^2)\,S(l^2)}}$ which is found to be: $r = 0.9995$. for both males and females. The two regressions are:

$$\begin{aligned} ♂\; L &= 155.754 + 1.9020(l - 75.807) \\ ♀\; L &= 156.062 + 1.9752(l - 75.031) \end{aligned} \qquad (3)$$

or for practical purposes:

$$♂\; L = 1.90\, l + 12 \quad \text{and} \quad ♀\; L = 1.98\, l + 7$$

3. *Total length*

Owing to the fact that the smaller fish (below 150 cm, $l < 72$ cm)[1] obtain a lower price in the market, the fishermen tend to avoid grounds where small fish are caught. The smallest fish (less than 115 cm, $l < 54$ cm)[1] are not marketable and are generally thrown back into the sea. An unfortunate consequence of these circumstances is that a sample of the commercial catch will not, as a rule, give wholly reliable information about the composition of the stock. In the present case, however, it is possible to correct this bias to some extent, since all the fish not going into the freezer were given over to the fisheries biologist for dissecting and closer examination. In addition, 92 fish were tagged and liberated on various localities. For the tagged and the examined fish all total lengths were recorded (Table 3).

Returning to the measurements of the dorsal lengths, these may now be transformed into total lengths by means of (3) and the frequency distributions corrected according to Table 3. The relevant data are presented in Table 4. The calculations of n, range, and mean are straight-forward and need no explanation. The procedure of pooling two samples, with known variances and means, is given by the formula:

$$(n_1 + n_2 - 1)\sigma^2 = (n_1 - 1)\sigma_1^2 + (n_2 - 1)\sigma_2^2 + \bar{L}_1^2 n_2 + \bar{L}_2^2 n_2 - \bar{L}(\bar{L}_1 n_1 + \bar{L}_2 n_2) \quad (4)$$

where the indices 1 and 2 denote the original distributions and $\bar{L}$ the mean in the grand sample with variance σ^2. This is, in fact, equivalent to the method used in building the corresponding Analysis of Variance (Fisher, 1948). If the index 1 denotes the directly sampled fish, $\bar{L}_1$ and

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[1] These limits are actually set by the gutted weight: <25 kg and <10 kg.

σ_1^2 are obtained from Table 3. $\bar{L}_2$ is calculated from the mean dorsal length (Table 1) by means of (3) and σ_2^2 according to (2). Since σ_2^2 is calculated from a transformed distribution, (n_2-1) in (4) must be entered with (n_2-2) and (n_1+n_2-1) with (n_1+n_2-2). $\bar{L}$ is calculated as the weighted mean of $\bar{L}_1$ and $\bar{L}_2$. Each item in (4) is now easily calculable and from the estimated value of σ^2 the standard deviation and the standard error of the mean in the new distribution are found.

From the beginning of July to the beginning of August, the catches were taken in the Gulf of Maine region. On the Nova Scotian Shelf proper no porbeagle was caught, but on either side of what may be termed the "entrance" to the Gulf of St. Lawrence (Misaine Bank, St. Pierre Bank), the species was again met with in some abundance although the catches were on an average smaller than in the Gulf of Maine. The fishery in the eastern region took place from the middle of August to the beginning of September. Table 4 shows that the average length of the porbeagle increases from the West to the East within the area which is also borne out from the statistics of the commercial part of the catch (Table 1). An analysis of the variances (σ^2) in Table 4 shows significant aberrations between the means ($F=8.10$, $P<0.01$).

That the fish were concentrated in two main regions about 400 nautical miles apart does not necessarily mean that there are two separate populations, in spite of the differences between the means. In fact, a tagged fish, liberated at Platts Bank in July 1961 and recaught near Cape Race in September of the same year (Aasen, 1962) indicates a common stock with migratory habits. Later recaptures on the Nova Scotian Shelf (Halifax) and in the Gulf of St. Lawrence from the same tagging region point to the same conclusion. If this is so, the differences in the length distributions must be caused by segregation or in other words: the migration pattern for the smaller fish is different from that of the larger ones. Judged from the success of the fishery, the migration from the Gulf of Maine began in early August when the catches decreased conspicuously in that region.

The importance of these observations on the porbeagle in the North West Atlantic is augmented by the fact that this stock has virtually been a virgin one, from a fisheries point of view, until the summer of 1961. It would appear that here a unique opportunity is offered to study the effects of the fishery on a population from the beginning of its exploitation. Provided that the composition of the catch presents a reasonably accurate picture of the stock composition, the grand total in Table 4 will be an overall estimate of the length frequency distribution of the porbeagle in the North West Atlantic in the unexploited phase. The 55 fish for which the sex was not determined, are excluded from this total.

Table 3. *Frequency distributions of total length (L) for the tagged and the examined fish. North West Atlantic, July—September 1961. (Lamna nasus).*

L cm	1 Platts Bank			2 Cashes Ledge			3 Georges Bank			4 Misaine Bank			5 St. Pierre Bank			6 Grand Total		
	♀	♂	*T*	♀	♂	*T*	♀	♂	*T*	♀	♂	*T*	♀	♂	*T*	♀	♂	*T*
85— 87											1	1	1		1	1	1	2
88— 90																		
91— 93										1		1				1		1
94— 96				2		2		1	1	2		2	1		1	5	1	6
97— 99										2	3	5	1		1	3	3	6
100—102				1		1				1	1	2	1	1	2	3	2	5
103—105				1		1										1		1
106—108		1	1														1	1
109—111	1		1	2	1	3					1	1				3	2	5
112—114	1		1		1	1	2		2							3	1	4
115—117	1	1	2				1	2	3		1	1				2	4	6
118—120				3	3	6	1	1	2		1	1				4	5	9
121—123	1		1				4	1	5							5	1	6
124—126				3	2	5	1		1				1		1	5	2	7
127—129		1	1		2	2											3	3
130—132				2	1	3		4	4					1	1	2	6	8
133—135		2	2				1	2	3	1		1				2	4	6
136—138	3	1	4	1		1		3	3							4	4	8
139—141	1		1	1	2	3		3	3							2	5	7
142—144	1	1	2	2	1	3		2	2							3	4	7
145—147	1		1	1		1										2		2
148—150	2	1	3				1	1	2							3	2	5
151—153	2	1	3	3	1	4	3		3							8	2	10

154—156	2		2													2		2
157—159		1	1		1	1											2	2
160—162	2		2		2	2										2	2	4
163—165	1	1	2	1		1	1		1							3	1	4
166—168	2	1	3				1		1							3	1	4
169—171				1		1										1		1
172—174	2		2	1	1	2	1		1							4	1	5
175—177	1		1	1		1										2		2
178—180	1	1	2													1	1	2
181—183	3		3		1	1										3	1	4
184—186	1		1					1	1							1	1	2
187—189	2		2		1	1										2	1	3
190—192	1	1	2	1		1										2	1	3
193—195		1	1														1	1
196—198				1		1										1		1
199—201																		
202—204																		
205—207				1	1	2										1	1	2
208—210																		
211—213					1	1											1	1
214—216	1		1													1		1
217—219																		
220—222																		
223—225	1		1		1	1										1	1	2
Number	34	15	49	29	23	52	17	21	38	7	8	15	5	2	7	92	69	161
Mean . . .	160.91	150.20	157.63	139.69	150.30	144.38	146.29	133.86	134.95	101.86	103.25	102.60	101.00	116.00	105.29	141.92	138.83	139.40
σ^2	719.76	659.31	712.04	906.65	1111.00	1005.36	419.08	284.85	336.71	209.27	120.21	150.26	211.50	450.00	269.75	994.47	842.89	926.19

Table 4. *Characteristics of the various length distributions. For further explanation see text. North West Atlantic, July—September 1961.* (*Lamna nasus*).

Sub-area	Sex	cm				number			cm²			cm	
		Range	$\bar{L}$	$\bar{L}_1$	$\bar{L}_2$	n_1	n_2	n_1+n_2	σ_1^2	σ_2^2	σ^2	σ	$\pm\frac{\sigma}{\sqrt{n_1+n_2}}$
Platts Bank	♀	109—227	165.37	160.91	167.24	34	81	115	719.76	834.91	802.39	28.33	2.64
1	♂	106—216	154.82	150.20	156.21	15	50	65	659.31	763.22	658.44	25.66	3.18
	T	106—227	161.56	157.63	163.03	49	131	180	712.04	787.24	768.39	27.72	2.07
Cashes Ledge	♀	94—245	176.33	139.69	184.03	29	138	167	906.65	782.31	1083.38	32.91	2.55
2	♂	109—251	188.94	150.30	192.84	23	228	251	1111.00	763.47	942.95	30.71	1.94
	T	94—251	183.90	144.38	189.52	52	366	418	1005.36	784.27	1032.20	32.13	1.57
Georges	♀	112—251	184.42	146.29	186.55	17	304	321	419.08	716.28	780.94	27.95	1.56
Bank	♂	94—251	183.39	133.86	187.12	21	279	300	284.85	618.45	781.97	27.96	1.61
3	*T*	94—251	183.92	134.95	186.82	38	583	621	336.71	668.32	802.97	28.34	1.14
Misaine	♀	91—256	200.25	101.86	202.51	7	305	312	209.27	1232.36	1432.20	37.84	2.14
Bank	♂	85—251	193.77	103.25	198.05	8	169	177	120.21	1180.11	1523.23	39.03	2.93
4	*T*	85—256	197.90	102.60	200.92	15	474	489	150.26	1213.23	1468.76	38.32	1.73
St. Pierre	♀	85—251	201.37	101.00	207.34	5	84	89	211.50	804.58	1381.45	37.17	3.94
Bank	♂	100—262	212.53	116.00	213.65	2	172	174	450.00	359.65	467.69	21.63	1.64
5	*T*	85—262	208.75	105.29	211.58	7	256	263	269.75	509.30	796.68	28.23	1.74
Grand Total	♀	85—256	187.13	141.92	191.69	92	912	1004	994.47	1041.96	1243.20	35.26	1.11
6	♂	85—262	190.06	138.83	194.00	69	898	967	842.89	880.66	1079.19	32.85	1.06
	T	85—262	188.57	139.40	192.83	161	1810	1971	926.19	962.21	1174.22	34.27	0.77

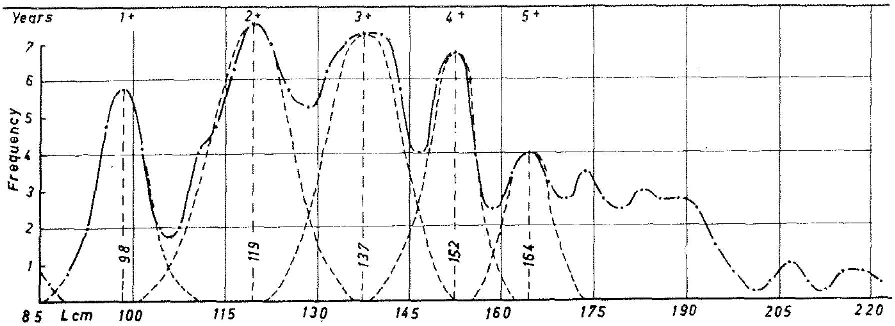

Fig. 4. Diagrammatic representation of the total length distribution for the tagged and examined fish demonstrating modes in the frequencies. For further explanation see text.

accordingly, seem to be in the Spring rather than in the Summer as stated by Bigelow and Schroeder (loc. cit.). The largest reported embryo was 66 cm and the smallest recorded fish 75 cm according to the same authors. It seems, therefore, very likely that the length at birth is somewhere around or between these figures. Working from this hypothesis it follows that the smallest measured fish (Table 3) probably belongs to the 0-group. The 1 + year old fish will consequently have an average length of 98 cm (the first mode in Fig. 4) and the mean length for the next year-group (2 +) will be 119 cm. For the 3 +, 4 +, and 5 + year-groups the modal lengths are 137 cm, 152 cm, and 164 cm respectively.

Presuming a correct interpretation of the facts, these figures may be used to construct the growth curve for the porbeagle. Employing the von Bertalanffy's growth formula (Beverton and Holt, 1957), the length at any time (L_t) is determined by:

$$L_t = L_\infty - (L_\infty - L_0)e^{-kt} \tag{5}$$

where L_∞ and k are constants. The parameter L_∞, or the asymptotic length, is found by a Walford graph (Walford, 1946) to be 280 cm. From (5) is obtained: $ln(L_\infty - L_t) = -kt + ln(L_\infty - L_0)$. If the average time interval from production until time of observation is denoted by Δt, one gets: $ln(L_\infty - L_{t+\Delta t}) = -k(t+\Delta t) + ln(L_\infty - L_0)$ or:

$$ln(L_\infty - L_{t+\Delta t}) = -kt + ln(L_\infty - L_{\Delta t}) \tag{6}$$

Putting the observed data for $L_{t+\Delta t}$ into (6), a series of values is found from which k can be calculated (Table 5). Denoting the age by t and the natural logarithms of $L_\infty - L_{t+\Delta t}$ by β, the following regression is obtained:

$$\beta = \bar{\beta} - k(t - \bar{t}) = 5.299 - 0.1107t \tag{7}$$

III. THE GROWTH

1. *Evidence from the length distributions*

An inspection of the entries in Table 1 will show that, as a rule, one or the other sex is dominating. This feature was, in fact, very striking in the individual catches. That implies that the sexes normally move in separate concentrations (no actual school was ever observed). However, Table 4 shows that in the final summation, the sexes occur in nearly equal numbers (♀ 49%; ♂ 51%), and the average lengths are also very much the same. A test of the difference between the means shows no statistical significance ($t = 1.90$; $P > 0.05$). From this fact it is inferred that males and females have the same average growth rate (see also page 25). That the mean lengths vary quite considerably from catch to catch for both ♂ and ♀, but without any indication of the mean for either sex being consistently the greater, is taken as supporting evidence. In this connexion it is worth noting that a test of the difference between the means in the grand total of Table 1 gives $t = 3.48$ and $P < 0.001$, and this is highly significant. Judging from the dorsal length only, one would be led to the conclusion that the males grow faster than the females.

The distributions entered in Table 3 are all multimodal, and the modal lengths may be interpreted as the average lengths of different year-groups. Unfortunately, only in the grand total are the entries numerous enough to present a coherent picture. The modes for males and females are seen to be roughly corresponding, but the fine grouping and relatively scanty observations obscure the issue. It will not improve matters to use a coarser grouping since in that case relevant details are lost in the process. However, when ♂ and ♀ are considered together (Table 3.6.*T*) the first five modes in the distribution are clearly discernible. In Fig. 4 this feature is shown graphically with the frequencies smoothed according to the formula $d = \frac{a+2b+c}{4}$ (solid line). In the Figure the actual length distributions of the various distinguishable year-groups are also tentatively sketched in (broken lines).

No embryo was present in any of the several hundreds of mature females examined during the months July—September of 1961. Large embryos have been found at the Flemish Cap grounds in late May according to information supplied by fishermen, and embryos have been reported from the Gulf of Maine in November and January (Bigelow and Schroeder, 1948) The record of embryos in August by Bigelow and Schroeder (loc. cit.) is in sharp contrast to the present author's observations and must be considered rather unusual. The time for propagation would,

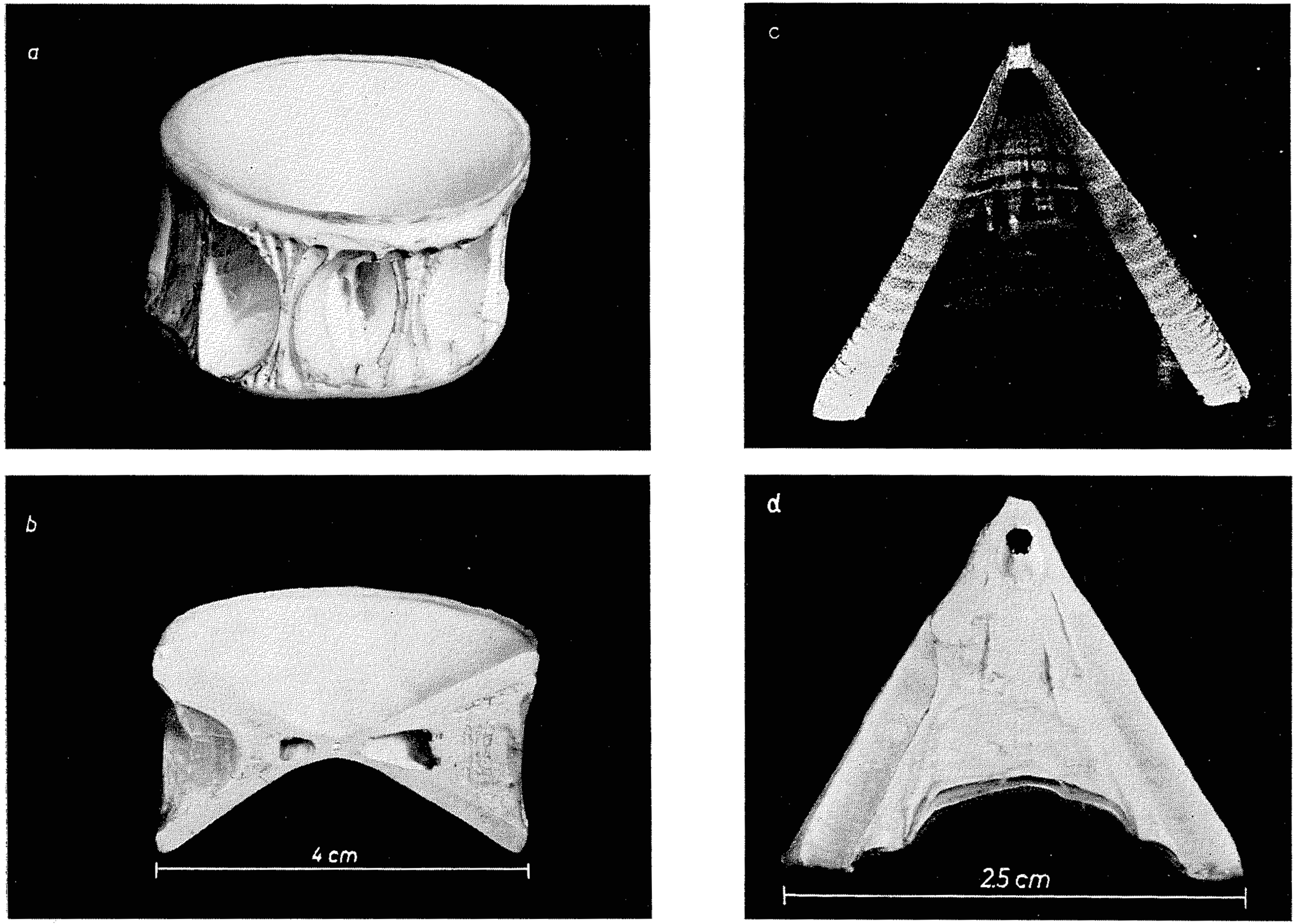

Plate I. a) Photograph of a vertebra from a porbeagle. b) Photograph of half a vertebra. c) *x*-ray photograph of a 1 mm thick section. d) Ordinary photograph of the same section as c). See footnote p. 33 and Table 2.

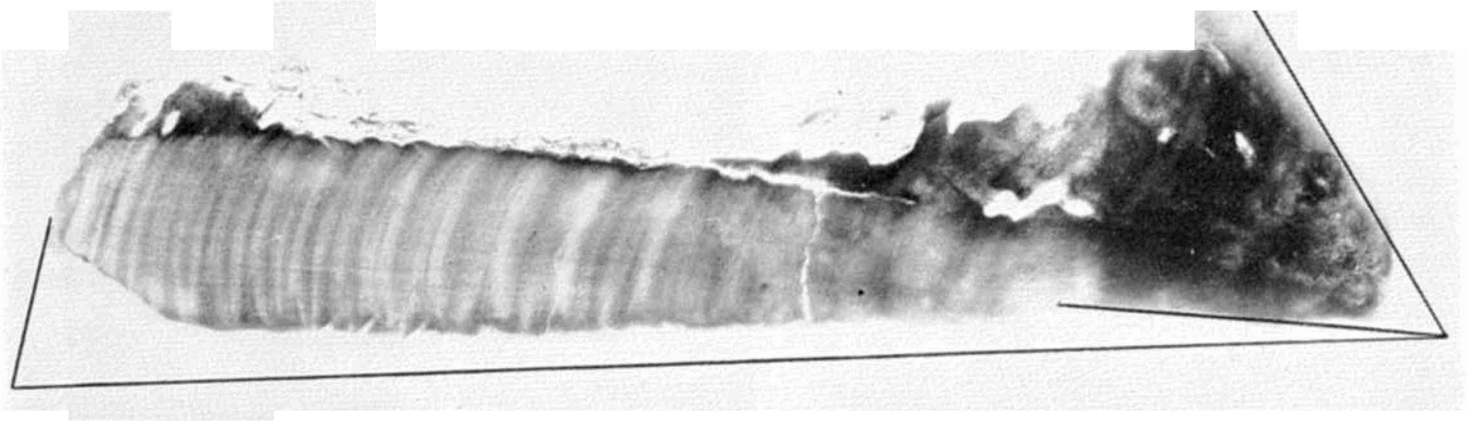

Plate II. Demonstration of growth zones in a vertebra. A 0.3 mm thick section is used as a negative for reproduction on photographic paper. On the transparent paper the growth zones are shown in diagrammatic form. See footnote p. 33 and Table 2.

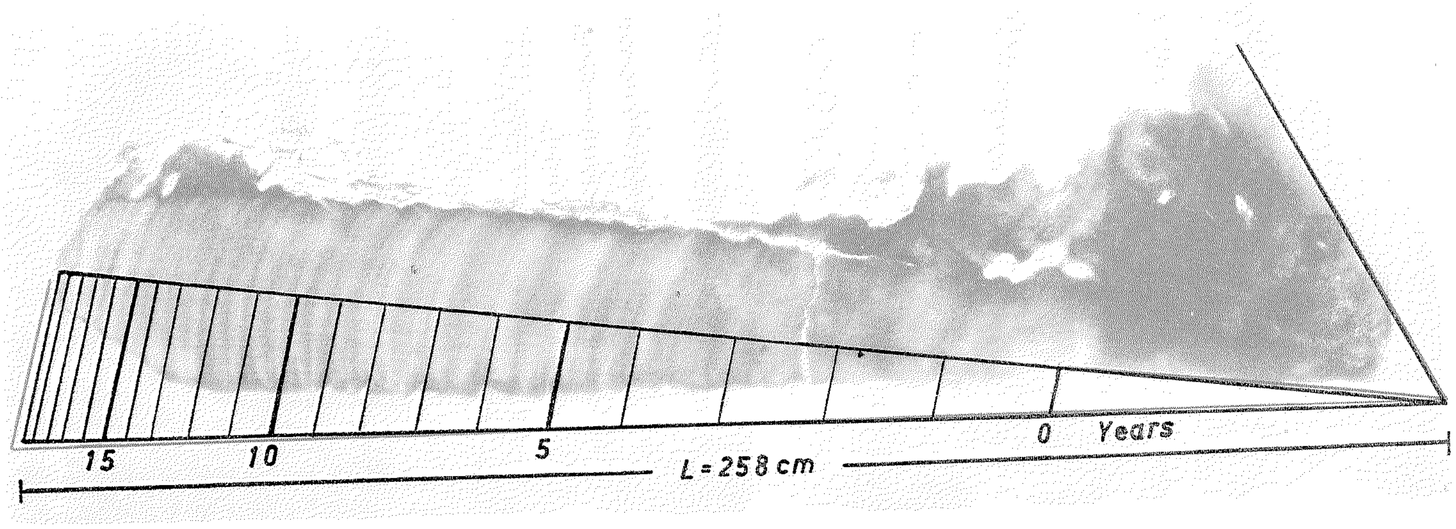

Plate II. Demonstration of growth zones in a vertebra. A 0.3 mm thick section is used as a negative for reproduction on photographic paper. On the transparent paper the growth zones are shown in diagrammatic form. See footnote p. 33 and Table 2.

Table 5. *Basic data for calculation of k from frequency modes.*

t Age	$L_{t+\Delta t}$ cm	$L_\infty - L_{t+\Delta t}$ cm	β $ln(L_\infty - L_{t+\Delta t})$	Averages and sums of squares and cross-products
1+	98	182	5.205	$\bar{t} = 3$
2+	119	161	5.080	$\bar{\beta} = 4.967$
3+	137	143	4.961	$S(t^2) = 55$
4+	152	128	4.850	$S(\beta^2) = 123.596$
5+	164	116	4.750	$S(t\beta) = 73.398$

The intercept on the β-axis is equivalent to $ln(L_\infty - L_{\Delta t})$ and consequently the mode of the 0-group at this time of the year ($L_{\Delta t}$) is 80 cm. The growth formula for the porbeagle, calculated on the basis of modes in the length frequencies is accordingly:

$$L_{t+\Delta t} = 280 - 200e^{-0.1107\,t} \tag{8}$$

where the length is expressed in cm and t the age in full years. Δt is a constant so far unknown, but if the time between the middle of Spring to the middle of Summer is set to about 3 months, it will roughly amount to 0.3. (Fig. 5).

2. *Evidence from the vertebrae*

During the field work an attempt was made to analyse the vertebrae for growth zones and determine the age. Unfortunately, the facilities for such work aboard the commercial fishing vessel were exceedingly poor, and it is, therefore, not surprising that the results obtained were not very accurate (Aasen, 1961). It was, however, established that growth zones did in fact exist, and further work with more refined methods has furnished conclusive evidence of this finding. In Plate I are shown photographs of a vertebra from a porbeagle (*a*) and of half a vertebra (*b*) cut in a plane lengthwise through the axis. Plate I (*c*) shows an enlarged *x*-ray photograph of a 1 mm thick section of a vertebra, and (*d*) is an ordinary photograph of the same section. In Plate II the growth zones of a vertebra are demonstrated, using a 0.3 mm thick section as a negative for reproduction on photographic paper.[1] Superimposed (on transparent paper) is shown in diagrammatic form the growth zones which are interpreted as the yearly growths. There is no definite birth-mark on the vertebra;

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[1] In Plate I (*b*), (*c*), and (*d*) and Plate II the same vertebra was used, taken from a 258 cm long female fished at Artimon Bank (45° 24′ N, 58° 29′ W) 19th August 1961. (See Table 2).

Table 6. *Basic data for calculation of k from growth zones in a vertebra.*

t Age	V_n mm	L_t cm	$L_\infty - L_t$ cm	β $ln(L_\infty - L_t)$	Averages and sums of squares and cross-products
1	77.7	93.0	187.0	5.230	
2	95.0	113.8	166.2	5.115	
3	110.0	131.8	148.2	4.997	
4	125.1	149.8	130.2	4.872	
5	136.0	162.9	117.1	4.761	
6	147.3	176.4	103.6	4.641	$\bar{t} = 10$
7	156.4	187.3	92.7	4.530	$\bar{\beta} = 4.186$
8	164.5	197.2	82.8	4.415	
9	171.8	205.9	74.1	4.305	$S(t^2) = 2468$
10	178.2	213.5	66.5	4.197	
11	185.0	221.6	58.4	4.069	$S(\beta^2) = 340.498$
12	190.5	228.2	51.8	3.945	
13	196.1	234.8	45.2	3.813	$S(t\beta) = 729.740$
14	199.9	239.3	40.7	3.706	
15	202.6	242.7	37.3	3.619	
16	206.5	247.2	32.8	3.491	
17	208.8	250.0	30.0	3.402	
18	212.0	253.9	26.1	3.262	
19	214.0	256.3	23.7	3.165	
19+	215.3	258.0	22.0	3.092	

The value of V_n at 19 + = V.

but it is, perhaps, significant that the extrapolated value for zero age coincides with the point where the edge of the section changes its angle. It is a straight-forward matter to measure these zones with sufficient exactitude and a series of data is obtained from which the lengths at the various ages can be calculated. Here is used the simple proportion formula: $L_n = \frac{V_n}{V} L$ where V and V_n are the distances from the centre to the edge of the vertebra and to the completion of the n^{th} growth zone respectively. (Table 6). A Walford graph gives $L_\infty = 280$ cm as in the former case (page 32). Using the same symbols as in (7), the regression will be:

$$\beta = 5.341 - 0.1155t \tag{9}$$

The intercept on the β-axis, gives a value of $L_0 = 72$ cm which in this case is the length at birth. By substituting the values of L_∞ and L_0 in (5) the growth formula is obtained:

$$L_t = 280 - 208e^{-0.1155\,t} \tag{10}$$

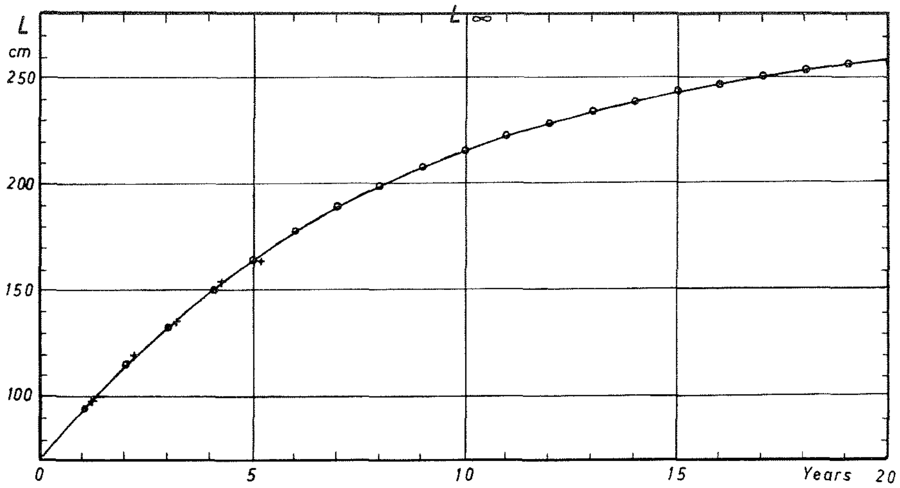

Fig. 5. The growth curve of the porbeagle based on growth zones in a vertebra. Circles: Observation points. Crosses: Modes in frequencies from Fig. 4. For further explanation see text.

The two equations (8) and (10) agree very well. A test of the difference between the two calculated values of k gives: $t=0.23$ and $P>0.8$ and this is definitely not significant. From the fact that identical results are obtained through two independent approaches, it is fair to conclude that for the first, the modes apparent in Table 3 do in reality express the average lengths of successive year-groups, and secondly, that the growth zones in the vertebrae, as interpreted, represent the yearly growths. The growth curve is shown in Fig. 5. From (7) and (9) is derived: $-k\Delta t = = ln(L_\infty - L_{\Delta t}) - ln(L_\infty - L_0) = -0.042$; $\Delta t = 0.36$. This implies that the usual time for production is about 4 months prior to the average time of observations (early August) provided that the growth is uniform throughout the year. This is certainly not the case. Most probably the growth curve within the year is sigmoidal in appearance. If the values obtained from the modes in Fig. 4 are fitted in at 0.2 of the unit ($\Delta t' = 0.2$), they agree very well with the growth curve constructed from the vertebra (Fig. 5). This corresponds to a growth period of 9 months with uniform growth, and a rest period of 3 months within the year. The average propagation time would accordingly be in early June and possibly late May. This coincides approximately with the time of the year when the porbeagle ascend from deeper water into the surface layers and begin feeding intensively.

If the gestation period were longer than 12 months, embryos should be present all the year round in some of the females. Since this is evidently not the case, the porbeagle will in general reproduce every year. Judged from the available information, the gestation period is about 8 months. The filling sperm-sacs, towards the end of August, point to the Autumn as mating time. However, the ripeness of the sperms was not investigated, and the evidence is rather vague.

The total length frequency distribution combined with the information on the growth may be used to estimate the total mortality in the stock: The calculated length at the age *n* corresponds to a certain frequency in the distribution. Plotting the logarithms of these frequencies against age, a series of points is obtained which from a certain age should theoretically lie on a straight line if the lengths are normally distributed. The slope of this line is equal to the total instantaneous mortality coefficient (M). In the present case where the distribution of the total lengths is represented by range, mean, and standard deviation, this method is of no immediate use. However, remembering that in calculating these data, the procedure followed is that of fitting a normal distribution, this fact may be utilized for calculation of any desired frequency. Writing the normal distribution in the form:

$$lnf = lnC - \frac{1}{2}\left(\frac{L-\bar{L}}{\sigma}\right)^2 \tag{11}$$

the relevant data are obtained directly by substituting the lengths calculated from the growth formula (10) for L in (11). Since, as mentioned before (page 27), the stock is practically a virgin one with respect to fisheries and only about 10 000 specimens were caught by the Norwegian long liners from March to September in 1961, the fishing mortality at the time of observation must be regarded as insignificant. M will therefore be the same as the natural mortality coefficient (N) and also expressive of the recruitment rate. When the method is applied to the total distribution in Table 4, the estimate of the coefficient is $M = N = 0.18$, which seems reasonable in an unexploited stock where the individuals have a long life span.

IV. SUMMARY

The measurements of the length of the porbeagle in the North West Atlantic, collected aboard a commercial long liner in the summer of 1961, are examined.

The analysis is in the main based upon measurements of the "dorsal lengths", and the total lengths are derived from these by means of regression formulas, which are slightly different, although significantly so, for males and females.

In the individual catches one or the other sex is, as a rule, dominant numerically, but the final summation shows that there is but little difference (49:51) in the stock as a whole.

The mean total length increases from the West towards the East within the area of investigation. This is explained as due to segregation caused by different migration patterns for smaller and larger fish. The overall estimate of the length distribution is characterized by: Range = 85 – 262 cm, mean = 188.57 ± 0.77 cm, and $\sigma = \pm 34.2$ cm.

There is no significant difference between the mean total lengths of ♂ and ♀. From this fact it is inferred that males and females have the same average growth rate.

The growth has been analysed in two ways: from the modes in the frequency distribution and from the growth zones in a vertebra. The results are in good agreement. L_0 is found to be 72 cm and $L_\infty = 280$ cm. The growth is described by the formula $L_t = 280 - 208e^{-0.1155\,t}$.

So far only a few vertebrae have been analysed, but it is evident that the porbeagle may reach a considerable age, at least up to 20 years and very likely some 10 years more.

Probably the porbeagle reproduce every year. The usual time for production is apparently in late spring (May/June). The mating presumably takes place in autumn (September/October), and the gestation period runs roughly to 8 months.

From the growth formula, the mean length and variance of the length distribution an estimate of the total mortality coefficient, $M = 0.18$, is obtained.

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Some observations on the Iceland scallop *Chlamys islandica* (Müller) in Norwegian waters

BY

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INTRODUCTION

In 1961 Fiskeridirektoratets Havforskningsinstitutt started exploring the natural resources of edible bivalves in Norwegian coastal waters. One of the species in question was the Iceland scallop, *Chlamys islandica* (Müller), which was known to occur in considerable quantities in some fjords in northern Norway (Sars 1878, Storm 1878—80, Sparre Schneider 1881, Kiær 1906, Soot Ryen 1924). There is also information on the occurrence of this species in adjacent waters, the Barents and White Seas (Filatova 1957, Zenkevich 1956, Ivanova 1957).

The present paper is based on material collected in the coastal areas of northern Norway in May-June of 1961 and 1962.

MATERIAL AND METHODS

In 1961 some dredgings with a six foot Baird scallop dredge (Baird 1955) were made in the Balsfjord near Tromsø, and in the Kvænangen fjord farther north. In 1962 exploratory dredgings were carried out with a four foot Baird mussel dredge (Baird 1959) between the Vestfjord and Kirkenes.

All scallops taken were measured with a sliding rule in five mm groups (e. g. 13—17 mm), the measure taken being the height, from the hinge to the edge of the shell. A number of scallops was also measured with regard to length and breadth.

In samples of 100 specimens, selected according to the percentage size distribution (height), the number of concentric rings on the upper valve was also counted. Scallops with conspicuous rings were selected for growth studies, the distance from the apex to the edge of the dark rings measured to the nearest mm.

The total volumes of a number of scallops of various size groups (usually five from each five mm group) have been measured by displacement, by the method of Baird (Baird 1958). Before measuring, the meat had been removed from the shells, which were afterwards filled with a plaster mass.

Total weight, weight of adductor muscle plus gonad, and of empty shells, were determined on scallops of various size groups, (usually of ten specimens from each five mm group) by means of a balance, adjustable to 100 or 500 gr. The sex of the scallops was determined visually in the field by the colour of the gonads, individuals with whitish gonads being taken as males, and those with pink gonads as females. The determinations were later confirmed by microscopical investigations on smears from gonads, both fresh and preserved in formalin.

DESCRIPTION

Chlamys islandica belongs to the order Anisomyaria, family Pectinidae. In common with most pectinids it has a nearly circular shell, a little higher than long, laterally compressed (Fig. 1). The relative proportions vary both with increasing size and from one locality to another.

The two valves are nearly equal, the ear on the right (lower) valve has a deeper incision than the left one. The valves have a number of radial ribs provided with tiny transversal ribs like a rasp. The shell may sometimes be folded, with 3—6 ribs in each fold. The colour of the shell varies from nearly white, to grey, bright red or yellow, violet, or brown, the growth rings sometimes being more intensely coloured. The mother

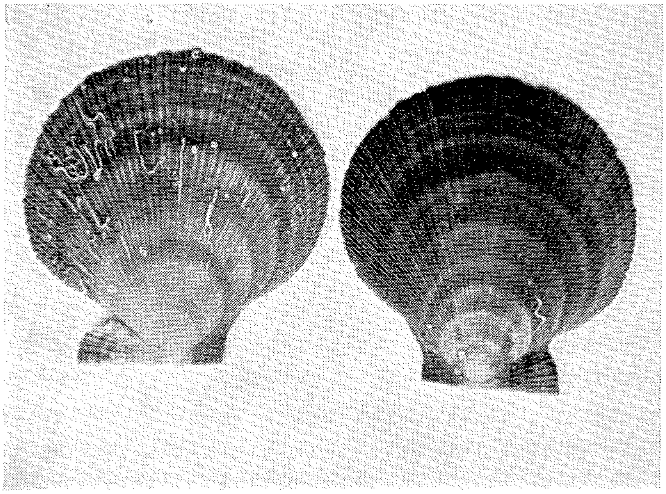


Fig. 1. The Iceland scallop (*Chlamys islandica* (O. F. Müller). ~~Left~~ Right: upper (left) valve, ~~right~~ left: lower valve (right valve).

of pearl layer on the inside of the valves may also be intensely coloured. The mantle edge or velum is usually more or less pigmented, sometimes with black pigment in transversal bands.

In sexually mature specimens the female gonads have a pink colour, the male ones are whitish coloured.

DISTRIBUTION

Chlamys islandica is a sub-arctic or northerly boreal species, occurring along the western and northern coasts of Norway, along western and northern Spitsbergen, Bear Island, Hopen Island, Murman coast, White Sea, west coast of Novaja Zemlja, Kara Sea, around the Jan Mayen Island, Iceland, East and West Greenland, east coast of North America and Canada from Cape Cod, to, and including the Parry Islands. It is also recorded along the Bering Strait, Bering Sea, Okhotsk Sea and is said to occur along the coast of Alaska southwards to Puget Sound (data from Sars 1878, Jensen 1912, Dall 1921, Madsen 1949, Zenkevich 1956, Ivanova 1957, Ockelmann 1958). According to Jensen (1912) only subfossil shells have been found at the Faroes, while Ockelmann (1958) says that it lives there. However, he does not give any authority for this statement.

According to Sars (1878) *C. islandica* is mainly distributed in Norwegian waters from Lofoten to Vadsø. Farther south it is more scarce. Storm (1900) found a large bed of this species along the northern shore of the island Tautra in the Trondheimsfjord, at depths down to 75 m. Nordgaard (1903) reports the finding of a single specimen of 45 mm at the entrance of the Lysefjord near Stavanger, and of single small specimens in the Alverstrømmen and Radøy sounds north of Bergen. Information on localities where living scallops had been found in this century was kindly supplied by the Tromsø Museum, and during the cruises fishermen and others also reported on beds of scallops. In many of these localities however, only empty shells were found during the present investigation. Living scallops were only found in fjords which had one or more shallow sills, 10—15 m deep or less, at the entrance (Fig. 2). The beds of Iceland scallops charted in 1962 are the following:

1) The Balsfjord beds, covering an estimated area of 70—100,000 m^2. The scallops were found at 30—40 m, on a sandy bottom partly covered with shells and stones. The density of scallops decreased inwards in the fjord. The innermost part of the Balsfjord has not yet been investigated.

2) In the Andamsfjord a small bed is situated in a narrow sound at 18—35 m depth. The bottom is poorly suited for dredging being very

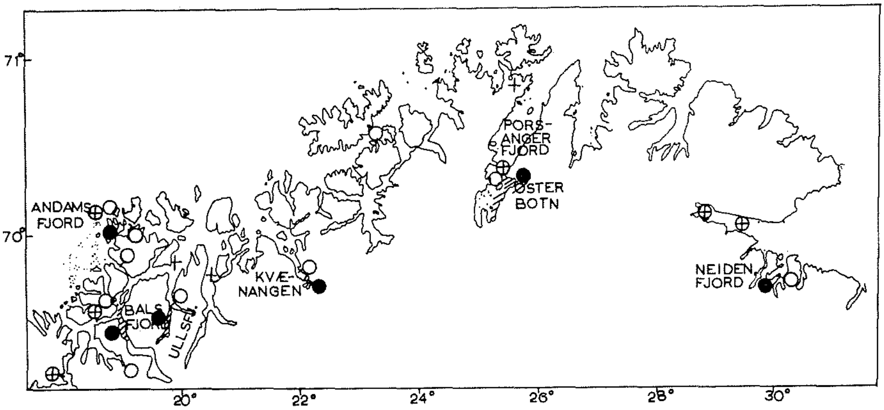


Fig. 2. Beds of *Chlamys islandica* located in northern Norway in 1962 (hatched areas and filled circles). Areas with empty shells and a few small living scallops — open circles, extinct bedscircles with cross, negative stations — crosses.

uneven with steep clefts and stones. The tidal currents are also very strong.

3) In the inner part of the Ulfsfjord, the Sørfjord, scallops were found inside a sill of ten m, at 40—60 m depth on even, sandy bottom. Most of the catch, up to 9/10, consisted of empty shells. Further inwards the bottom in some places is more uneven, clayey, with stones. The scallops were larger than farther out, and the percentage of living scallops greater (Cp. Fig. 11 page 50).

4) In the innermost part of the Kvænangen fjord there is a small bed at 25—40 m near a small island. The scallops have a very thin shell, and are usually overgrown with sponges. This bed was studied sixty years ago by Kiær (1906).

5) In the Porsangerfjord the size of the scallop beds may be compared with that of the Balsfjord. The innermost part of the fjord, the Østerbotn, is separated by a number of sills from the outer part. Near the bottom the temperature may be below 0° C for part of the year. The scallops live mainly at 40—60 m, but a rich bed was also found on a slope running from 20 to 60 m.

6) In the fjord system on the southern side of the Varanger fjord (Neiden Fjord) there are several small beds, at 10—30 m depth. The bottom consists partly of clay, with projecting boulders. For detail charts see: Wiborg 1962.

No attempt has yet been made to estimate the quantity of scallops on the various beds. In the Balsfjord a four feet mussel dredge was usually filled with scallops in a haul of 10 minutes, including setting and hauling. Half the catch consisted of living scallops, which numbered 200—300. In the Balsfjord, the dredge was completely filled with living scallops, 400—500 specimens, five minutes being allowed for the total haul.

ECOLOGY

C. islandica may occur from four to 250 m of depth or even more, but real beds are most often found between 15 and 60 m. The substratum usually preferred is sand, gravel, shells, stones and sometimes clay. According to fishermen the scallops are said to lie freely on the bottom and even undertake migrations, moving into deeper water during the summer and back again in winter (Soot Ryen 1924). Similar to other pectinids, *C. islandica* is able to swim by opening and closing the valves quickly. I have observed swimming both in aquaria and when the scallops have been caught and thrown overboard into the sea. Young scallops swim more frequently and swiftly than the older ones. On the beds however, I have most often found the scallops attached with a thin bundle of byssus to the substratum or to each other. When dredged from a clayey bottom, the scallops were attached to stones which had probably projected from the bottom.

Being a filter feeder, the Iceland scallop is most abundant in areas with strong currents, in some areas completely covering the bottom. The scallops are usually accompanied by a rich epiflora and -fauna. The plants are mainly red algae, both calcareous and foliaceous, but filamentous brown algae have also been found. The larger scallops are always found below the Laminaria zone. — In addition to the algae the scallops are often overgrown with bryozoans, hydroids, barnacles, *Anomia* shells, tubiferous annelids and sponges. The epigrowth may sometimes be very dominant and even exceed the weight of the scallop. One might wonder whether this fouling sometimes might outweigh the elasticity of the ligamentum and prevent the opening of the shell. Experiments however showed that the most heavy epigrowth did not prevent the shell from opening, even in the air.

Nordgaard (quoted by Soot Ryen 1924) lists 20 species of bryozoans found on *C. islandica*, and Kiær (1906) mentions the animals commonly occurring on the scallop banks.

The bottom temperature on the scallop banks may vary considerably. In the Balsfjord the temperature in the 10—50 m layer usually varies between 4° and 7° C during the year, and in a fjord near to the Andamsfjord (see p 41) the temperature at 25 m level may reach 9.0 °—9.5° C for two weeks during the summer (Sælen 1950). In the Ulfsfjord the scallop beds are situated at a depth of 40—60 m inside a sill of ten m. At 100 m the temperature varies between 1° and 8.5° C during the year, reaching 9° C for a short time at the 50 m level (Sælen 1950). In the Østerbotten in the Porsangerfjord negative bottom temperatures are recorded during part of the year (Dragesund & Hognestad 1960). The data given agree with those found in adjacent waters. In the Barents Sea the temperature range of the scallop is from —1.34° to 8° C (Miloslavskaja 1958); on the southwest coast of Iceland the maximum temperature is 9.3° C in August (Jensen 1912).

At the Norwegian coast the Iceland scallops are found in the fjords were the salinity is comparatively low. In the Balsfjord the maximum salinity at 50 m was about 33.5 o/oo, in the Ulfsfjord nearly the same (Sælen 1950). But where the scallops occur in the open sea, such as in the Barents Sea or near Jan Mayen Island, the salinity on the banks may reach 34.7—34.9 o/oo.

As mentioned on page 40 the scallops have now disappeared from some localities where it had previously been found. In the innermost part of the Varangerfjord large beds were present before 1930, but later no living scallops have been found there.

The extinction of the scallop beds may be correlated with changes in the environmental conditions, e.g. a sudden rise in temperature. As in generally known, there has been a steady rise in temperature in the northern waters inclusive of the Barents Sea, beginning about 1930. This change may not have influenced the temperature in fjords with a shallow sill at the entrance, and the scallops found here have therefore survived. It might be expected that the scallops would again spread to in the outer parts of these fjords when the conditions came to an equilibrium. This seems, however, not to be the case. Just outside the sill were usually found a few small living scallops with a maximum size of 50 mm and a supposed age of 4—5 years. Simultaneously a large quantity of empty shells of all sizes were present. This fact seems to indicate a mass depletion of the beds some time ago, and later on the scallops settling there are destroyed after a few years because of unfavourable conditions. Sudden variations in temperature and/or salinity may also account for the great percentage of empty shells on the Ulfsfjord beds just inside the sill.

PROPAGATION

Ockelmann (1958) asserts that C. *islandica* according to Pelseneer (1935) is a hermaphrodite. The latter, however, does not mention this species at all. Under the heading "Hermaphroditisme normal" (Pelseneer 1935 p. 416) the following species are included: "*P. maximus, jacobaeus, asper, pyxidatus, nux, aequisulcatus, opercularis, glaber, flexuosus, magellanicus, irradians* et quelques especes indeterminées".

Among 12 adult C. *islandica* investigated Ockelmann (loc. cit.) found four to be in a hermaphroditic stage, but three of these had very little sperm, and only one with ripe sperm and large oocytes. Of nine adult scallops from the Jan Mayen area, six were reported to be females, three — males. Ockelmann is of the opinion that C. *islandica* is a protandric hermaphrodite.

I have investigated more than a thousand C. *islandica* during the summer, when the gonads were well developed. The latter could easily be divided into two cathegories, either of whitish or pink colour. The percentage of the two kind was usually near 50/50, sometimes with a surplus of white gonads. Smears from the gonads were investigated in a

Table 1. Number of mature and immature specimens of C. *islandica* at three localities in May—June 1962.

Height of shell, mm	Balsfjord			Andamsfjord			Ulfsfjord		
	♂	♀	imma-ture	♂	♀	imma-ture	♀	♂	imma-ture
30			all	0	0	2	9	4	13
35	2	2	21	1	1	4	14	7	1
40	11	7	15	6	4	1	15	16	
45	18	8	2	8	8	1	27	36	
50	23	15		12	6		30	28	
55	30	23		7	4		25	35	
60	36	47		6	4		20	21	
65	58	56		11	10		30	35	
70	41	34		34	16		18	20	
75	20	19		18	20		9	7	
80				26	25		3	4	
85				26	33		2	2	
90				28	48				
95				9	16				
100				1	1				
105				0	2				
Total	208 +31	194 +17		168 +15	185 +13		183 +18	208 + 8	

fresh state under the microscope. The white gonads invariably contained sperm in different degrees of development, the pink ones immature eggs. Immature individuals had a very slim mesosoma of a yellowish colour.

No hermaphrodites have hitherto been observed. This does not exclude the possibility that in Norwegian waters hermaphroditism may exist in a small percentage of individuals. In *Modiola modiolus,* in which the sexes are also separate, hermaphroditism has been observed in 2—8 o/oo of the individuals (Wiborg 1946).

Sexual maturity has been investigated in relation to size in three localities (Table 1).

The individuals in Balsfjord and Andamsfjord were all mature at a size of 50 mm, those in the Ulfsfjord already at 40 mm. From the number of growth rings it was assumed that in the Balsfjord 20 percent of the individuals were mature at an age of three years, 93 percent at four years of age, whereas all the five year old scallops were mature. In the Ulfsfjord 86 percent of the scallops seem to be mature when three years old, but reservations have to be made on the age determination.

In Norwegian waters the spawning has not been observed directly. In the Balsfjord the gonads of *C. islandica* were fairly well developed. In the male gonads some of the spermatozoa were mobile while in the females the eggs were immature. The same picture was observed in the middle of June 1962. Spent scallops have been found in the Balsfjord at the beginning of August. (P. Hognestad, pers. comm.). The larvae are thought to be pelagic.

SIZE AND AGE DISTRIBUTION OF THE SCALLOPS ON THE VARIOUS BEDS

In Fig. 3 are shown size distributions of scallops from various localities. As the dredge used had meshes 45 mm square, it might be expected that scallops smaller than 60 mm high were not quantitatively. Nearly all the scallops, however, were attached by byssus, either to each other or to empty shells, stones or other subjects. The smaller scallops were most often attached to the inner side of empty shells. It is therefore assumed that the samples are fairly representative of the population present.

In most localities the majority of the scallops have a height of 60 mm or more, in the Porsangerfjord even 80 mm. Small scallops are scarce, except in the fjord system adjacent to the Varangerfjord, where there are secondary peaks at 25 and 50 mm. This may be related to the fact mentioned earlier that the smaller scallops are found mainly in shallow waters. The sample in the Korsfjord was taken in a dredging at a depth from 24 to ten m.

The open columns represent size distributions of scallops found outside the sill of the fjords investigated. These scallops had a normal growth, but were only 4—5 years old. It is assumed that the variations in temperature and/or salinity in these beds may sometimes be destructive to the scallops, and that they are therefore depleted at intervals. Large quantities of empty shells of all sizes usually accompanied the small living scallops found. In a longitudinal section of the inner Ulfsfjord (Sørfjord) an increasing size of the scallops from the outer to the inner part (Fig. 4) was accompanied by a decreasing quantity of empty shells. According to Sælen (1950) the temperature variations at 50 m level in the inner part of the Sørfjord are not so marked as near the sill.

Fig. 3. Size distributions of Iceland scallops from various localities in northern Norway. Black columns — size distributions on the main beds, open columns — small scallops found just outside the sill of the fjord.

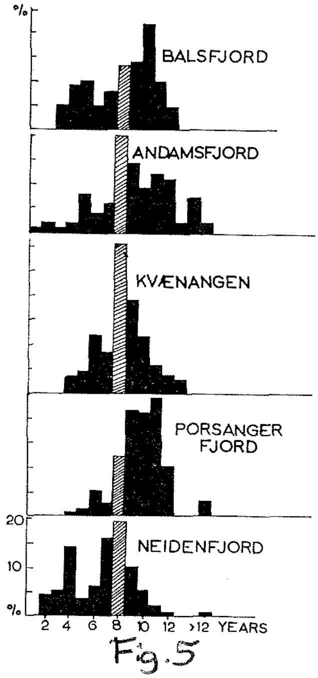


Fig.5

Fig. 4. Size distribution of Iceland scallops in a longitudinal section of the Inner Ulfsfjord. Outermost station to the top.

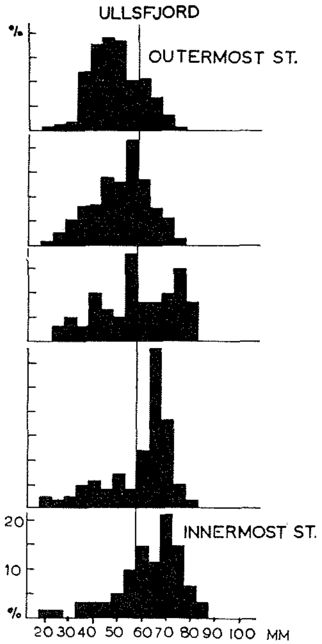


Fig. 5. Age distribution of Iceland scallops in various localities.

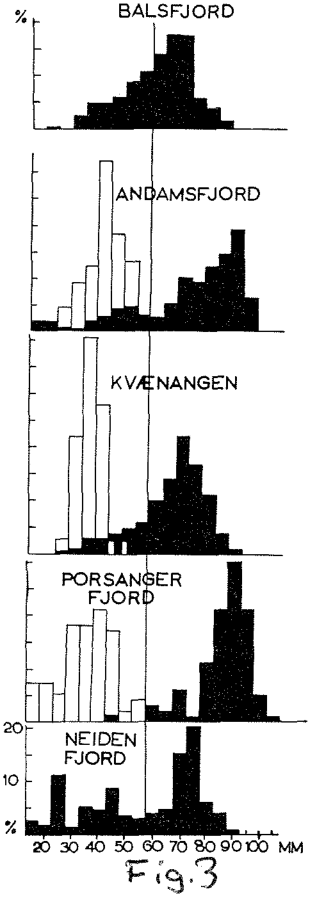


Fig.3

As is generally known, the concentric rings found on the shell of bivalves may as a rule be interpreted as annual zones, especially when the individuals are not subjected to too many changes in the surrounding medium.

In the Iceland scallops there are often very conspicuous dark and light rings see (Fig. 1 page 39). The dark rings are usually finished by a thin, sharp line which may have some relation to the spawning. The light rings seem to be formed during winter and spring (October—May) and then gradually change into the darker zones. If the spawnings takes place in July—August, the first annual rings will represent at most half a year. In June the smallest scallops found in the beds were usually 15 mm in height, those in the fjords east of Varanger ten mm. The latter had an outer growth zone 3—5 mm wide. If the pelagic larvae of *C. islandica* settle in comparatively shallow water, and afterwards move into deeper water, secondary rings are likely to be formed. Reservations have therefore to be made as to the interpretation of the first one or two zones. Age distributions from various localities are given in Fig. 5. For the readings the upper (left) valves have been used. A large number of age groups are present, and the scallops are assumed to be from two to 12 years old or more. There is a fairly good agreement between the size and age distributions, except for the Andamsfjord. On most of the beds there is a peak at eight years, in the Porsangerfjord at 9—11 years.

As mentioned above, the small scallops found outside the sills in the Kvænangen, Porsangerfjord and Andamsfjord were supposed to be 2—5 years old.

GROWTH

In an attempt to study the growth of *C. islandica* the rings on the shell have been measured to the nearest millimetre from the apex of the shell to the edge end of the dark zones. In Fig. 6 each growth zone is represented as a mean of 20—50 measurements, somewhat less for ten or more zones.

In the localities investigated the growth seems to be approximately the same up to an age of five years, with an annual growth of 7—8 mm. In Kvænangen the growth is slow, decreasing after the tenth year. In the Korsfjord the growth is better until the seventh year, but then decreases rapidly. In the Andamsfjord the scallops have the best growth, especially after the seventh year. Individual scallops may grow ten mm or more per year during 8—9 years.

The volumes of the scallops from two localities have been measured by displacement (Fig. 7). The empty shells were filled with plaster

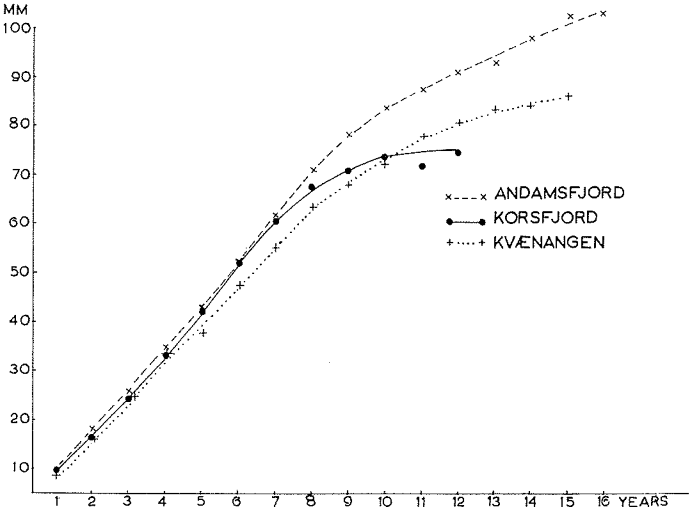


Fig. 6. Growth curves for Iceland scallops worked out from measurements of the growth rings.

Fig. 8. Weight analyses of Iceland scallops from the Andamsfjord, June 1962. Continuous curve — total weight, broken curve — empty shells, dotted curve — adductor muscle plus gonad, lower curve with crosses — gonad. →

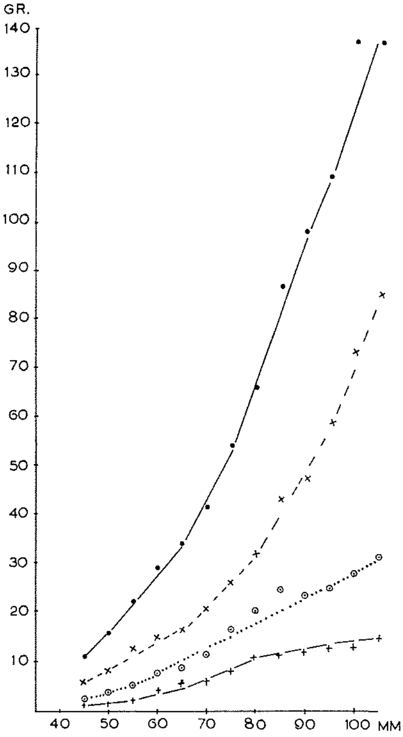
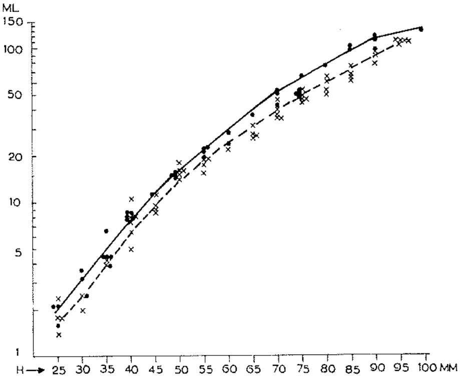


Fig. 7. Individual volume measurements of Iceland scallops in relation to height, from the Andamsfjord (dots and continous curve) and the Kjøfjord (crosses and broken curve).



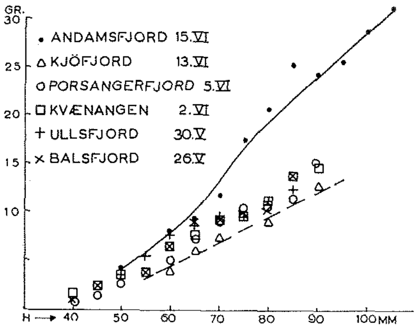


Fig. 9. Weight of adductor muscle plus gonad in relation to height of shell in Iceland scallops from various localities in northern Norway, June 1962.

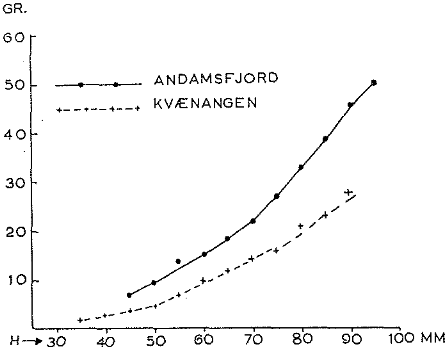


Fig. 10. Weight of empty shells in relation to height of shell in Iceland scallops from two localities in northern Norway.

(plasteline) before the measurement. As a rule, five scallops from each five mm group were measured.

The volume increases from 1.8 ml in scallops 25 mm high to 130 ml in 100 mm scallops. From a size of 45 mm to 90 mm the volume is increased approximately ten fold.

The Andamsfjord scallops have a comparatively larger volume than those from the Kjøfjord (Neidenfjord).

Between the volume and the height of the scallops there is a relation $V = L^3.k$, from which the volume can be calculated. k is a factor which has been found by experience to average 0.114 for the Kjøfjord scallops and 0.128 for those in the Andamsfjord.

From a commercial point of view it is of interest to know both the total weight of the scallops and the weight of the meat. During the cruise in May—June 1962 a number of weight analyses were made in the field. Usually ten specimens from each five mm group were investigated. All epigrowth was removed before weighing. The meats and empty shells were as far as possible freed of surplus liquid by drying in a handkerchief or on filter paper. The measurements are necessarily crude, but have been considered sufficient to give an impression of the approximate weight variations. In the Andamsfjord, where the scallops were found to have the best quality of all the localities investigated, the total weight increased from ten gr in 45 mm scallops to 140 gr in specimens 100 mm high. (Fig. 8). The edible part, adductor muscle plus gonad, has a more even increase in weight, from two to 30 gr within the same size interval. The gonad accounts for about half of the meat weight. In scallops of commercial size, 60 mm or more, the yield of meat is a maximum of 20—25 percent of the total weight during the pre-spawning period of March—August and later is probably not more than 10—15 per cent.

The weight of the meat in relation to the size of the scallops from various localities is shown in Fig. 9.

The weight of the shells in relation to size may vary from one locality to another. Andamsfjord and Kvænangen have been chosen as examples (Fig. 10). In the Andamsfjord the currents are stronger than in the Kvænangen fjord, and the salinity may also be somewhat higher.

SHELL PROPORTIONS

In bivalves the proportions of the shell of a certain species may vary from one locality to another, and also with increasing size. Such variations have been studied e.g. in *Mytilus edulis* (Soot Ryen 1927) and *Modiola modiolus* (Wiborg 1946). In *C. islandica* the shell proportions have been studied in scallops from the Kjøfjord and the Andamsfjord beds. From each five mm size group the length, height and breadth of ten individuals, if available, have been measured. The relations height: length and breadth have been calculated for each size group and plotted against height (Figs. 11 and 12). Small scallops (ten mm or less in height) are nearly circular, but are higher (H/L increases) at a size of 20—30 mm. With increasing size the scallops again grow comparatively longer, *i. e.* more circular. The changes are, however, relatively small, and there is no essential difference between the scallops in the two localities.

The proportion height: breadth is more variable, the shells getting broader with increasing size. The change is most conspicuous between heights of 15 to 40 mm. The scallops from the Andamsfjord are broader than those from the Kjøfjord. The latter locality may be considered as representative of most of the other localities investigated.

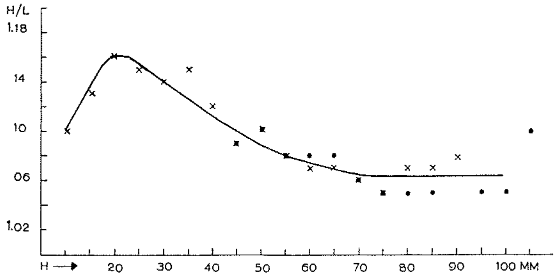


Fig. 11. The height/length relationship plotted against height in Iceland scallops from the Andamsfjord (dots) and Kjøfjord (crosses) beds.

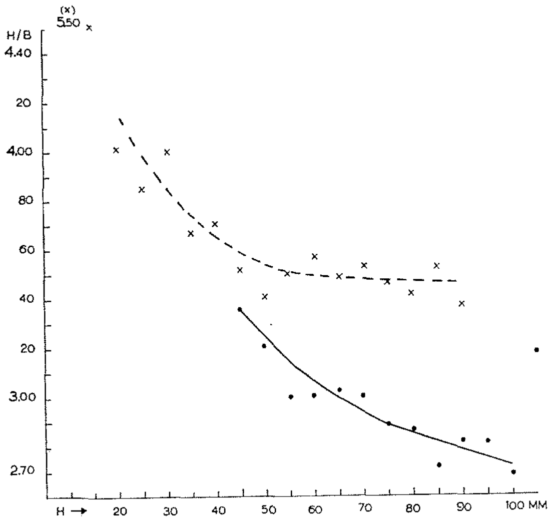


Fig. 12. The height/breadth relationship plotted against height in Iceland scallops from the Andamsfjord (dots and continuous curve) and the Kjøfjord (crosses and broken curve).

COMMERCIAL EXPLOITATION

The Iceland scallops have hitherto mainly been used as bait in the local fisheries. Practically nothing has been fished for human consumption. Attempts are now being made to interest the industry. Instructions for fishing and handling the scallops have been worked out, various methods of culling and storing the meats tried, and dishes prepared. A certain quantity of frozen meats, raw and steamed, which was brought into the market, has been accepted with enthusiasm by the restaurants.

It is to be hoped that the beds of Iceland scallops found may support a small industry.

With the comparatively slow growth of the scallops one might fear that the beds may soon become exhausted. In most of the beds, however, there are places where it is impossible to dredge, and the scallops found there, may be sufficient to secure the recruitment.

To insure a rational exploitation a minimum size limit of 60 mm will probably be necessary. A minimum mesh width in the dredges will also be of importance. Small scallops ought to be returned to the beds as soon as possible.

It is to be expected that more beds of Iceland scallops will be found in other fjords in northern Norway, and it might also be possible to find suitable beds in the Barents Sea and along the coasts of Spitzbergen and Jan Mayen.

SUMMARY

An investigation has been started on the Iceland scallop, *Chlamys islandica* (O. F. Müller). In northern Norway this species is mainly found in fjords with a narrow sill at the entrance and on a bottom with sand, gravel or shells in 10—60 m of depth. Some scallop beds (known from earlier times) have been extinguished during recent years, probably because of climatic changes. The Iceland scallop is sexually mature at a shell height of 30—45 mm and a supposed age of 3—5 yeras. The sexes are separate, spawning taking place in July—August. In the localities investigated, the size of the scallop varied between ten and 105 mm, with maximum abundance at 45—90 mm.

Distinct growth rings have been interpreted as annual rings. Usually, scallops from two to 12 years old are present in the beds, the majority being eight or more years in age. The annual growth has been estimated to 5—10 mm during the first seven years, gradually decreasing to 1—2 mm in the older scallops. The shell proportions change with increasing size, the scallops getting relatively thicker, broader. The volume varies from about ten ml in scallops 45 mm high to 70 ml in 80 mm scallops, the total weight from ten gr to 65 gr in the same size interval. The weight of the edible meat, adductor muscle plus gonad, constitutes 15—25 per cent of the total weight. In commercial sized scallops (60—100 mm) the meat weighs from five to 30 grams.

It is supposed that the scallop beds already mapped will support a minor commercial fishery.

ACKNOWLEDGEMENTS

Valuable assistance and information has been given by the leader of the Biological Station, Tromsø Museum, P. T. Hognestad, and by the curator at the Tromsø Museum, Mr. B. Christiansen. To the officers and crew of the R/V "Asterias", in charge captain T. Karlsen, I also owe my sincere thanks for their untiring assistance.

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On the life history of the spotted catfish (*Anarhichas minor* Olafsen)

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INTRODUCTION

The spotted catfish or wolffish, *Anarhichas minor* Olafsen, is an arctic boreal species common near Spitsbergen, Bear Island, in the Barents Sea and along the coast of Finnmark in Northern Norway. It has been found as far south as Bergen. It is also common in Iceland and Greenland waters (Saemundsson 1949) and along the American coast where it occurs southwards to Gulf of Maine (Bigelow and Schroeder 1953).

According to Barsukov (1957) *A. minor* occurs in the Barents Sea and adjacent areas mainly in waters with temperatures from –0,96° to 7,4°C and depths of 25 to 450 m. The maximum numbers are found at 100 to 150 m depths at temperatures from 4° to 6°C.

Investigations on the age and growth of the Anarhichidae have been limited. Maslov (1944) gives the mean length for each age group according to age determination from scales of *A. minor* and *A. lupus*, taken by trawl during 1933–39 in the Barents Sea. Lühmann (1954) states that age determination of *A. minor* from vertebrae is difficult due to false rings, probably caused by the difference in time between spawning period, tooth exchange and the winter period with limited food supply. In *A. lupus,* however, tooth exchange and spawning occur during the same period of mid-winter when the growth has probably stagnated, and false rings are rarely observed in the vertebraes.

Length-frequency curves and the relation between length and weight of *A. minor* taken by long-line in Greenland waters have been published by Hansen (1958). The morphology, distribution and feeding of the young of Anarhichidae in the Barents Sea has been studied by Baranenkova et al. (1960).

A. minor and *A. lupus* are usually marketed as «ocean catfish» to distinguish it from the freshwater catfish *Ictalurus* sp. In the fishery statistics the landings of *A. minor* and *A. lupus* are combined.

The latter species is, however, more restricted to coastal waters and no regular fishery is carried out for it. About 80 per cent of the landings in Norway are taken on the banks of Finnmark and in the Barents Sea, where A. minor completely dominates.

Before the last world war the total annual catch of catfish in the Norwegian Sea, Barents Sea and near Spitsbergen and Bear Island was about 2,000 tons. After the war the catch increased and in 1960 more than 16,000 tons were taken in these waters. Until 1950 the Norwegian catch made up more than 80 per cent of the total, but it has since dropped to less than 20 per cent. The main part of the catch in recent years has been taken by trawlers from USSR (72 %), and England (10 %). The Norwegian catch is mainly taken by long-line on the banks of Finnmark from April to August.

In view of the growing demand of frozen catfish-fillets an investigation on the life history of *A. minor* was initiated in 1953 by the Institute of Marine Research in Bergen.

A preliminary report of the result of the first years' tagging experiments has been published (Østvedt 1956). In the present work all returns received until January 1963 are included.

MATERIALS AND METHODS

The present investigation is based on examination of catfish captured by long-liners fishing off the coast of Finnmark in June 1953 and 1954. In June–July 1954 the exploratory fishing vessel «Thor Iversen» was used near Bear Island for two weeks fishing with long-line. On various cruises in 1953 and 1954 with R/V «G. O. Sars» to the Barents Sea a small number of *A. minor* were caught by trawl. Most of them were used for tagging experiments, but 75 of the smallest catfish taken in the spring of 1953 are included in the present growth study.

The total length was measured to the nearest cm. The mean length for each age group has also been calculated to the nearest cm, but in the figures and the tables the length-frequency is given to the 5 cm group below, with no correction, however, for the ½ cm offset scale used on the measuring board.

The maturity was classified in four different stages; stage I-immature, stage II-maturing, stage III-mature or spawning and stage IV-spent.

As the catfish usually are landed headless, otoliths for age determination could not be collected from commercial catches on land. In addition, the otoliths are minute and rather difficult to dissect from the skull. The scales (cycloid) have previously been used for age determination of Anarhichidae (Maslov 1944), but they are very small, having a diameter of about 2 mm on a fish of 100 cm in total length. The vertebrae appeared to show sharp rings and since they were more convenient to use than the scales, all age determinations in the present investigation refer to those from vertebrae.

After the head was removed immediately after capture, four or five anterior vertebraes were collected and placed in envelopes or boxes for drying. The rings in the vertebrae could easily be counted with a microscope without any special treatment. In reflected light the narrow opaque rings have been counted as winter zones and the broader, hyaline rings as summer zones. The interpretation of the first winter ring in the center was not always quite clear.

For the tagging experiments Lea Hydrostatic tags (same size as those used for cod) were attached in front of the dorsal fin by nylon thread.

AGE AND GROWTH

In Figure 1 and in Table 1 and 2 are shown the length (to the 5 cm group below) and age distributions for males and females of *A. minor* taken by long-line at Nordbank in 1953, at Hjelmsøybank and Bear Island in 1954. The samples from Nordbank and Hjelmsøybank show only small variations in age and length distribution. The range in length of males and females combined was 60—140 cm with a mean of 99,9 cm at Nordbank and 103,5 cm at Hjelmsøybank. In both years there was an excess of males in the length group above 95 cm as well as a corresponding dominance of males in the older age groups. The sample from Bear Island showed a similar range in length compared with the two other samples, but the dominating length groups were 80—90 cm and the mean length 90,4 cm. The age determination also revealed that at Bear Island more young fish were present, 8 and 9 year old fish being most abundant, as against 12—14 year old fish at Nordbank and Hjelmsøybank.

Also shown in Table 1 is the length distribution of catfish taken by trawl on different fishing grounds in the Barents Sea in the spring of 1953. It can be seen that fish smaller than 60 cm were caught by the trawl, but in small numbers. Most of these fish bigger than 60 cm were used for tagging experiments (total 77).

The length distribution of all fish in the different age groups based on the combination of all the data in both years is shown in Table 3. This table also lists the mean length of each group of males

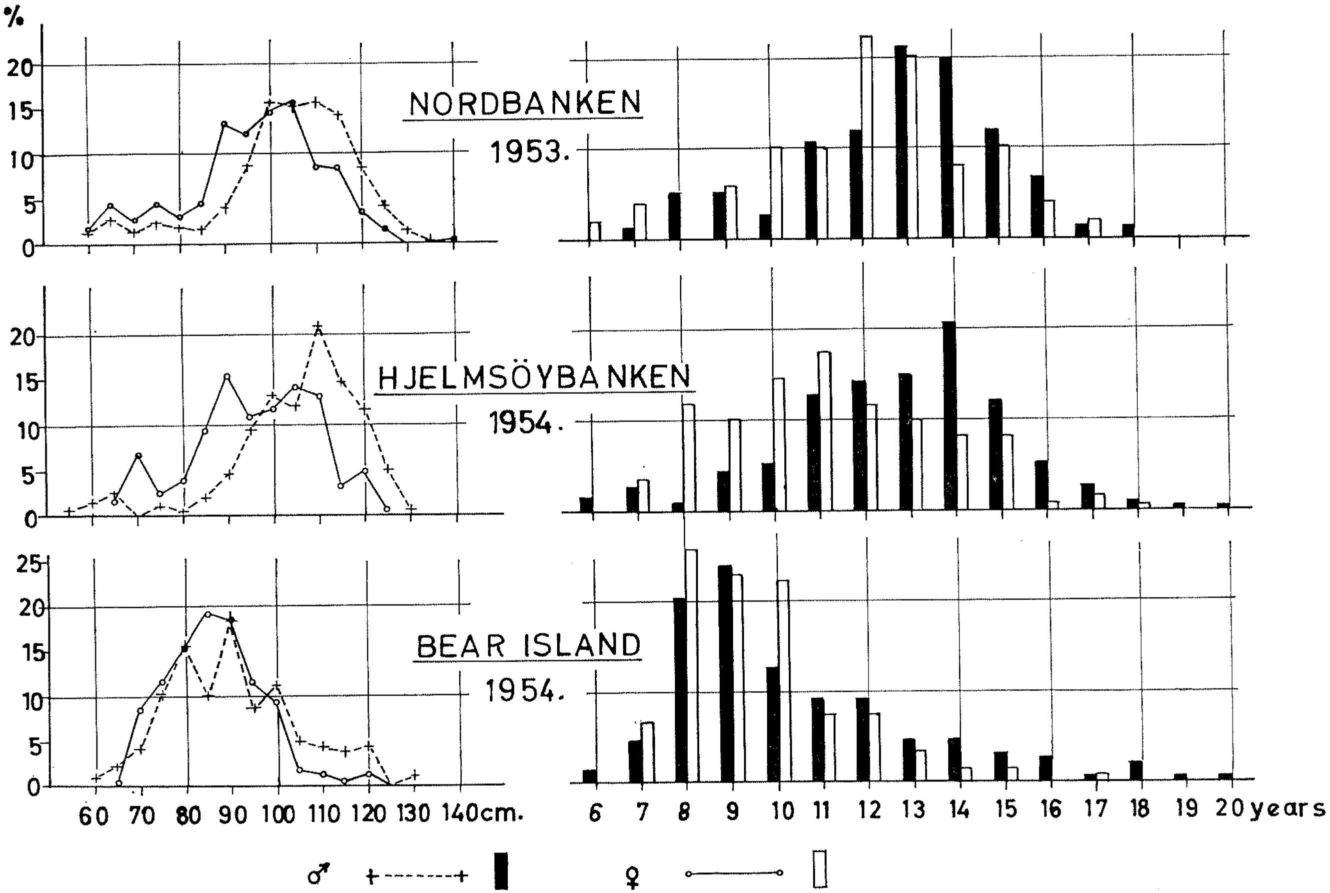

Figure 1. Length and age distribution of spotted catfish.

Table 1. Length composition of spotted catfish taken by long-line and trawl in 1953 and 1954 (%).

Barents Sea 1953		*Nordbanken 1953*			*Hjelmsøyb. 1954*			*Bear Island 1954*		
Length cm	Trawl Total	Long-line			Long-line			Long-line		
		♂	♀	Tot.	♂	♀	Tot.	♂	♀	Tot.
20	1.3									
25	1.3									
30	2.6									
35	2.0									
40	2.6									
45	3.3									
50	5.3									
55	10.5	—	—	—	0.5	—	0.3	—	—	—
60	13.8	1.4	1.8	1.5	1.5	—	0.9	1.0	—	0.6
65	15.1	2.7	4.5	3.4	2.5	1.7	2.2	2.4	0.6	1.7
70	9.9	1.4	2.7	1.9	—	6.8	2.5	4.3	8.3	6.1
75	9.2	2.2	4.5	3.1	1.0	2.5	1.6	10.1	11.5	10.7
80	4.6	1.9	3.2	2.4	0.5	4.2	1.9	15.5	15.4	15.4
85	5.3	1.6	4.5	2.8	2.0	9.3	4.7	10.1	19.3	14.0
90	2.0	4.1	13.3	7.5	4.5	15.3	8.6	18.4	18.6	18.4
95	2.6	8.8	12.3	10.1	9.5	11.0	10.2	8.7	11.5	9.9
100	2.6	15.7	15.0	15.5	13.1	11.9	12.6	11.2	9.7	10.5
105	0.7	15.1	15.5	15.2	12.1	14.4	12.9	4.8	1.9	3.6
110	1.3	15.7	8.6	13.0	21.1	13.6	18.3	4.3	1.3	3.0
115	2.6	14.4	8.2	12.0	14.6	3.4	10.4	3.9	0.6	2.5
120	0.7	8.5	3.6	6.7	11.6	5.1	9.1	4.3	1.3	3.0
125	0.7	4.4	1.8	3.4	5.0	0.8	3.5	—	—	—
130	—	1.6	—	1.0	0.5	—	0.3	1.0	—	0.6
135	—	0.5	—	0.3	—	—	—	—	—	—
140	—	—	0.5	0.2	—	—	—	—	—	—
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total numb.	152	364	220	584	199	118	317	207	156	363

and females separately and combined. No significant differences in growth rate of males and females were found. The annual length increment determined by comparing the mean length of each age group at capture seems to be about 10 cm during the first 6—7 years. The overlap in the length distribution of the different age groups increases considerably beyond these age groups. In the older age groups, therefore, length is of little significance for the age determination.

The present data on mean length for age of the catfish may be used for calculation of the asymptotic length L_∞. By using Walfords

Table 2. Age distribution of spotted catfish taken by long line in 1953 and 1954 (%).

Age Years	*Nordbanken 1953*			*Hjelmsøyb. 1954*			*Bear Island 1954*		
	♂	♀	Tot.	♂	♀	Tot.	♂	♀	Tot.
6	—	2.0	0.8	1.6	—	1.0	1.5	—	0.9
7	1.3	4.1	2.4	2.7	3.6	3.0	4.6	6.8	5.5
8	5.3	—	3.2	1.0	11.9	5.1	20.4	25.8	22.7
9	5.3	6.1	5.6	4.4	10.1	6.4	24.0	23.1	23.6
10	2.7	10.2	5.6	5.3	14.7	8.8	12.7	22.4	11.8
11	10.7	10.2	10.5	12.8	17.6	14.4	9.2	7.5	8.5
12	12.0	22.5	16.2	14.4	11.9	13.5	9.2	7.5	8.5
13	21.4	20.4	21.0	14.9	10.1	13.1	4.6	3.4	4.1
14	20.0	8.2	15.4	20.8	8.4	16.2	4.6	1.4	3.2
15	12.0	10.2	11.3	12.1	8.4	10.8	3.1	1.4	2.3
16	6.7	4.1	5.6	5.3	0.8	3.7	2.6	—	1.5
17	1.3	2.0	1.6	2.7	1.7	2.4	0.5	0.7	0.6
18	1.3	—	0.8	1.0	0.8	1.0	2.0	—	1.2
19	—	—	—	0.5	—	0.3	0.5	—	0.3
20	—	—	—	0.5	—	0.3	0.5	—	0.3
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total number	75	49	124	188	109	297	196	147	343

graphical method (Walford 1946), plotting L_t against L_{t+1} and fitting the best line by the method of least squares, a value of L∞ of 155 cm is obtained.

MATURITY

The maturity stage distribution according to length is given in Table 4. The males show only little variation in maturity, and only fish in stage I and II have been encountered. The males in maturity stage I had thread-like testes with greyish colour and were obviously immature. The fish in stage II had wrinkled testes with dark colour, but were all of a small size and showed no sign of an approaching spawning season. On various cruises in the Barents Sea during spring and autumn catfish caught by trawl have been examined, but males with ripe gonads have so far not been observed.

As seen in Table 4, 85,5 % of the females taken at Nordbank and Hjelmsøybank were in maturity stage II. The size of the eggs of the females in this stage varied greatly and more detailed classification might have been possible. It seems likely that females in

Table 3. Length — frequency distribution and mean length of the age groups of spotted catfish.

Length/ Age cm	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Sum
20	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
25	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
30	—	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
35	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
40	—	—	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
45	—	—	1	1	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	5
50	—	—	—	5	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8
55	—	—	—	2	9	2	—	—	—	—	—	—	—	—	—	—	—	—	—	13
60	—	—	—	—	6	6	—	—	—	—	—	—	—	—	—	—	—	—	—	12
65	—	—	—	—	1	15	10	3	—	—	—	—	—	—	—	—	—	—	—	29
70	—	—	—	—	1	6	26	6	—	—	—	—	—	—	—	—	—	—	—	39
75	—	—	—	—	—	5	24	9	4	1	—	—	—	—	—	—	—	—	—	43
80	—	—	—	—	—	6	28	24	9	2	—	—	—	—	—	—	—	—	—	69
85	—	—	—	—	—	1	14	30	20	3	—	—	—	—	—	—	—	—	—	68
90	—	—	—	—	—	—	4	36	34	19	10	3	—	—	—	—	—	—	—	106
95	—	—	—	—	—	—	—	9	16	24	24	9	2	—	—	—	—	—	—	84
100	—	—	—	—	—	—	—	1	10	26	30	15	11	5	—	—	—	—	—	98
105	—	—	—	—	—	—	—	—	1	9	16	19	16	8	1	—	—	—	—	70
110	—	—	—	—	—	—	—	—	—	2	9	21	24	14	4	—	—	—	—	74
115	—	—	—	—	—	—	—	—	—	—	1	9	17	14	6	4	2	—	1	54
120	—	—	—	—	—	—	—	—	—	—	—	2	9	9	10	4	5	1	—	40
125	—	—	—	—	—	—	—	—	—	—	—	1	1	2	2	3	1	1	1	12
130	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	3
	2	4	9	9	22	42	106	118	94	86	90	79	80	55	23	11	8	2	2	842
Mean length																				
♂	—	27.5	39.6	52.3	60.4	69.8	77.3	86.4	90.9	98.6	101.8	108.7	112.1	114.6	119.5	121.7	120.7	125.5	121.5	
♀	23.0	30.5	38.5	50.0	56.2	70.0	78.4	86.3	91.5	97.3	100.7	104.8	108.6	114.1	114.0	121.5	122.0	—	—	
Total	23.0	29.0	38.2	50.8	58.5	69.9	77.8	84.4	91.3	97.9	101.3	107.4	111.5	114.5	118.7	121.6	120.9	125.5	121.5	

Table 4. Maturity Stage distribution according to length of spotted catfish.

Maturity stage / Length cm	Nordbank 6/6—15/6 1953						Hjelmsøybank 31/5—10/6 1954						Bear Island 14/6—4/7 1954					
	♂		♀				♂		♀				♂		♀			
	I	II	I	II	III	IV	I	II	I	II	III	IV	I	II	I	II	III	IV
55	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
60	5	—	4	—	—	—	3	—	1	—	—	—	2	—	—	—	—	—
65	10	—	9	1	—	—	3	2	2	—	—	—	5	—	1	—	—	—
70	4	1	5	1	—	—	—	—	7	1	—	—	9	—	5	8	—	—
75	4	4	5	5	—	—	—	2	3	—	—	—	18	3	8	10	—	—
80	2	5	3	4	—	—	—	1	2	3	—	—	25	7	6	17	1	—
85	2	4	2	8	—	—	—	4	2	9	—	—	12	9	1	25	4	—
90	—	15	—	29	—	—	—	9	—	18	—	—	3	35	—	22	5	2
95	—	32	—	27	—	—	—	19	—	13	—	—	—	18	—	7	11	—
100	—	57	—	33	—	—	—	26	—	14	—	—	—	23	—	6	8	1
105	—	55	—	32	2	—	—	24	—	16	1	—	—	10	—	2	1	—
110	—	57	—	19	—	—	—	42	—	15	—	1	—	9	—	—	—	2
115	—	52	—	18	—	—	—	29	—	4	—	—	—	8	—	—	—	1
120	—	31	—	8	—	—	—	23	—	6	—	—	—	9	—	—	—	2
125	—	16	—	3	—	1	—	10	—	1	—	—	—	—	—	—	—	—
130	—	6	—	—	—	—	—	1	—	—	—	—	—	2	—	—	—	—
135	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
140	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Sum	27	337	28	188	2	2	7	192	17	100	1	1	74	133	21	97	30	8
%	7.42	92.58	12.73	85.45	0.91	0.91	3.52	96.48	14.29	84.03	0.84	0.84	35.75	64.25	13.46	62.18	19.23	5.13

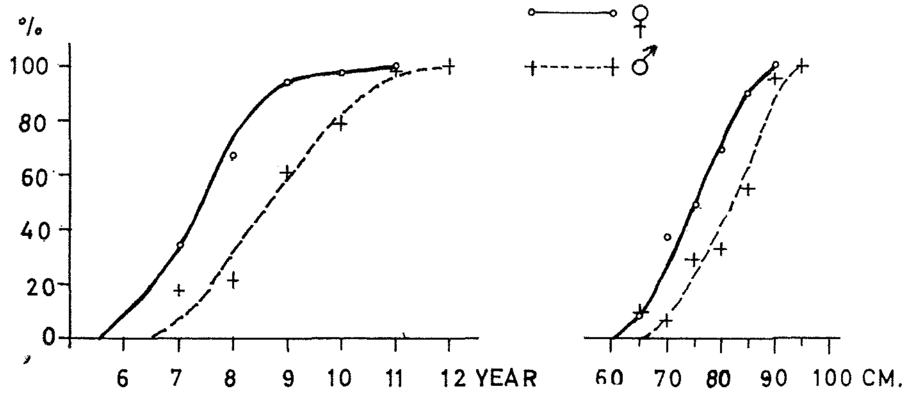

Figure 2. Percentage of [redacted]mature spotted catfish in each age and length group.

stage II with the smallest eggs not would spawn within the same year, but they were nevertheless more developed than the females in stage I. Fish in stage III were, both at Nordbank and Hjelmsøybank, caught in insignificant numbers. The sample from Bear Island taken at the end of June and beginning of July, about 3—4 weeks later than the two other samples contained, however, 19,2 % females in stage III and 5,1 % in stage IV. This observation indicated that around Bear Island spawning occured in July. As a large propotion of the females were still in stage II, it seems likely that the spawning season also extended into August.

The percentage of [redacted]mature fish in each length and age group of males and females is given in Figure 2. The figure reveals that the majority of the females mature at an age of 7—8 years with a corresponding length of 75 cm. Age and length at earliest maturity is probably 6 years and 60—65 cm. The males mature approximately one year later than the females and at a critical length (50 % mature) of 80—85 cm and at an age of 8—9 years.

TAGGING EXPERIMENTS

During 1953, 1954 and 1955 a total of 432 catfish were tagged with Lea Hydrostatic tag attached in front of the dorsal fin with nylon thread. As listed in Table 5 the fish were liberated on various localities in the Barents Sea and off the coasts of Finnmark and Bear Island.

Until January 1963, 72 tagged catfish were returned. The return of the tagged trawl-caught fish was 60 or 21,8 % whereas only 12 or 7,6 % were returned from the fish caught by long-line. During the

Table 5. Release and recovery data for tagged spotted catfish.

Year of tagg.	Date	Tagging locality	Fishing gear	Number of tagged fish	Year of recapture										Total
					1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	
1953	23/2—10/4	South. Barents Sea ..	Trawl	8	3	—	—	—	1	—	—	—	—	—	4
1953	8/6—16/6	Nordbank	Longline	33	1	1	—	—	—	—	—	—	—	—	2
1953	17/8—14/10	Bear Island, Centralbank, South. Barents Sea................	Trawl	77	1	4	1	2	2	1	—	—	—	—	11
1954	17/3—2/4	Finmarkbank, Centralbank, S. Barents Sea	Trawl	50	—	9	1	1	2	2	—	—	—	1	16
1954	3/6—10/6	Hjelmsøybank	Longline	50	—	2	—	1	2	1	—	—	—	—	6
1954	26/6—1/7	Bear Island	Longline	74	—	1	3	—	—	—	—	—	—	—	4
1954	7/10—25/10	Finmarkbank, Centralbank, South Barents Sea	Trawl	73	—	5	3	—	3	1	—	1	—	—	13
1955	2/3—21/5	Bear Island, Centralbank, Southern Barents Sea	Trawl	67	—	—	3	2	3	4	1	1	1	1	16
			Total	432	5	22	11	6	13	9	1	2	1	2	72
			Sum trawl	275	4	18	8	5	11	8	1	2	1	2	60
			Sum longl.	157	1	4	3	1	2	1	—	—	—	—	12

Years in liberty	0–½	½–1	1–1½	1½–2	2–2½	2½–3	3–3½	3½–4	4–4½	4½–5	5–5½	5½–6	6–6½	6½–7	7–7½	7½–8	8–8½
Number of recaptures ..	26	11	1	2	4	9	5	4	4	0	3	0	0	0	1	0	1

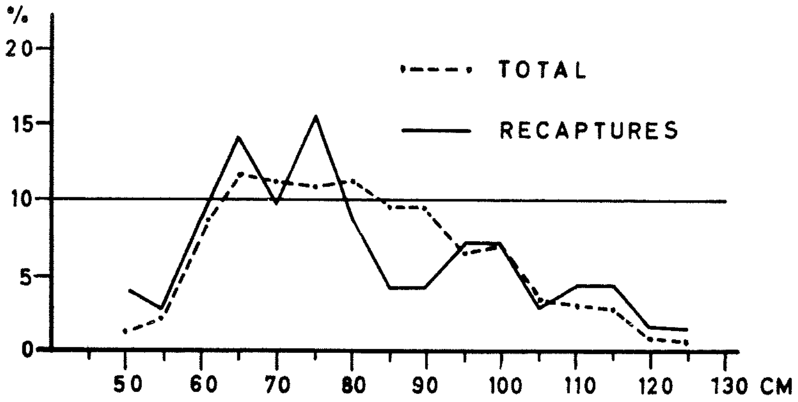

Figure 3. Length distribution of tagged and recaptured spotted catfish.

tagging experiments it was observed that fish from the long-line catches were often in very poor condition and not suitable for tagging.

The length distribution of the tagged and recaptured fish, depicted in Figure 3, follow the same trend. The range in total length is from 50—125 cm with a maximum between 60 and 80 cm. The majority of the tagged fish has most probably been immature or in the first stage of maturation.

The majority (52 %) of the recaptured fish was taken by Soviet trawlers. The others were taken by English (14 %), German (7 %) and Norwegian trawlers (4 %) and Norwegian long-liners (19 %). For 3 (4 %) returns from Norwegians fishing boats gear were not stated.

Tagging localities and position at recapture for 63 returns with complete information are shown in Figure 4. Of these, 28 were taken within 50 n. miles or less from the tagging locality, even after periods of more than 3 years (two returns). Long-distance migration was demonstrated by fish released at Finger Bank near Bear Island and recaptured at Skolpen Bank, a distance of more than 300 n. miles.

Figure 4 demonstrates that there is a great deal of intermingling between catfish from the different areas. One fish released and recaptured off Hornsund at Spitsbergen is not included on Figure 4. Only five fish have been tagged in Spitsbergen waters and so far none has been recaptured outside this area.

The catfish is supposed to be a slow moving and inactive fish. The present tagging experiments show, however, a maximum average migration distance of 5 n. miles per day (one fish recaptured 44 days after liberation about 250 n. miles from tagging locality).

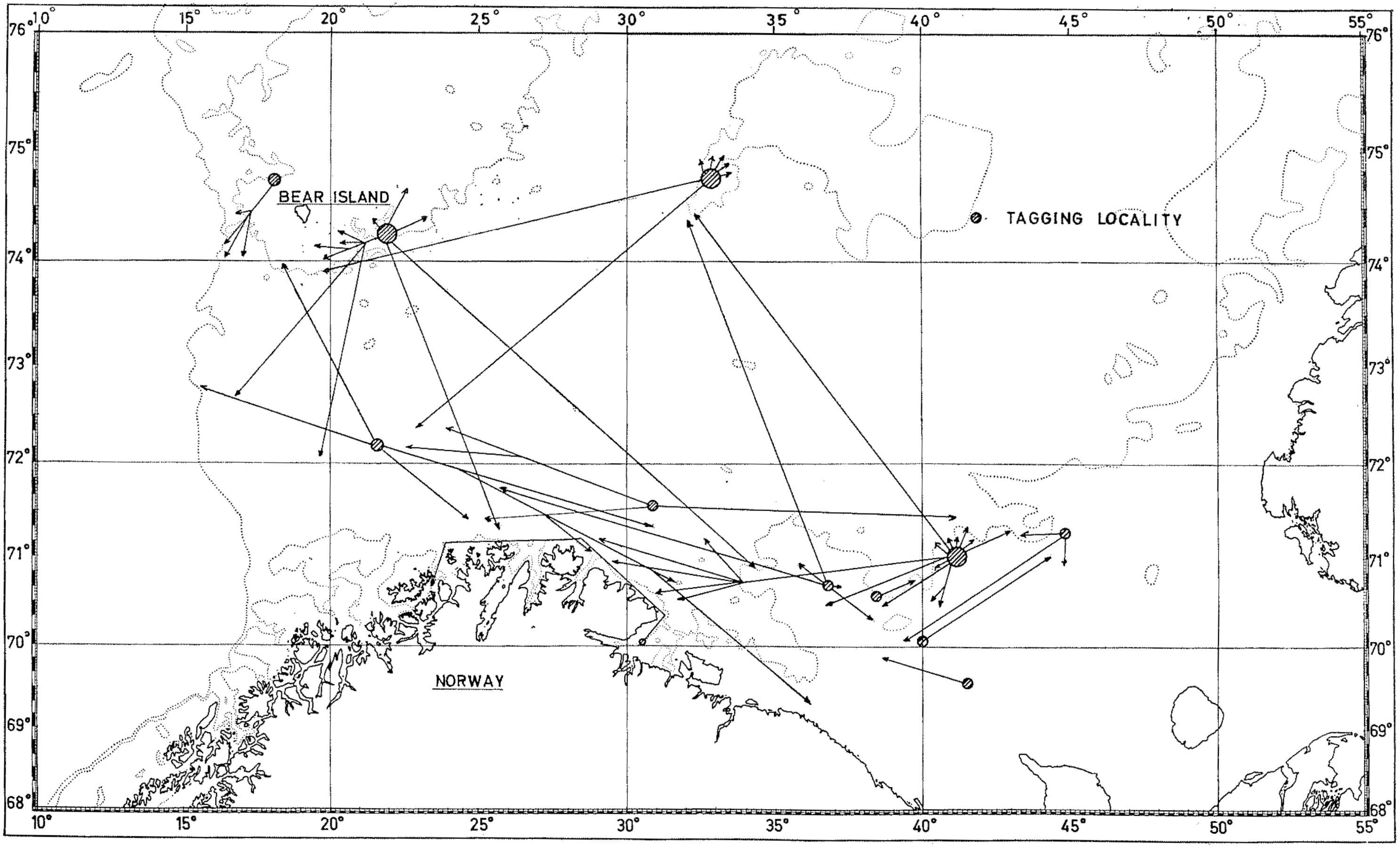

Figure 4. Tagging locality and place at recapture for spotted catfish tagged in 1953, 1954 and 1955.

Table 6. Number of recaptures in each month according to area.

Month/Area	South of lat. 73°N			North of lat. 73°N	
	East of long. 35°E	Between long. 30–35°E	West of long. 30°E	Centralbank	Bear Island
January	2	—	—	—	1
February	1	—	—	—	—
March	7	1	—	—	—
April	2	1	3	—	2
May	1	2	4	—	1
June	2	2	4	—	1
July	1	—	2	1	4
August	2	—	—	3	1
September	—	—	—	1	—
October	2	—	1	1	—
November	1	1	—	1	2
December	2	—	2	—	1
Total .	23	7	16	7	13

The number of returns within half a year after tagging is rather high, totalling 26, and of these 19 were caught during the first three months after tagging. Most of the tagged fish and especially those caught by trawl were released on fishing grounds where fishing was in operation. One fish was even recaptured the same day as it was released. This explains the high number of recoveries soon after tagging. As appears from the table only three fish have been recaptured 1—2 years after liberation, while more tagged fish were returned from the same experiments during the following years. The years with few returns are mainly 1955 and 1956.

Table 6 shows the number of recaptures each month in the different areas irrespective of the time in liberty. East of longitude 35°E the maximum number of recoveries was taken in January—March, while further west, off the coast of Finnmark, most of the recoveries were taken in April—June. In more northern waters, at Bear Island and the Centralbank, tagged fish were mostly recaptured in the autumn.

The growth of the tagged fish is demonstrated in Figure 5 which shows the difference between length at recapture and length at release for 32 returns. The other returns were not accompanied by information of length or the fish were measured headless. The reported

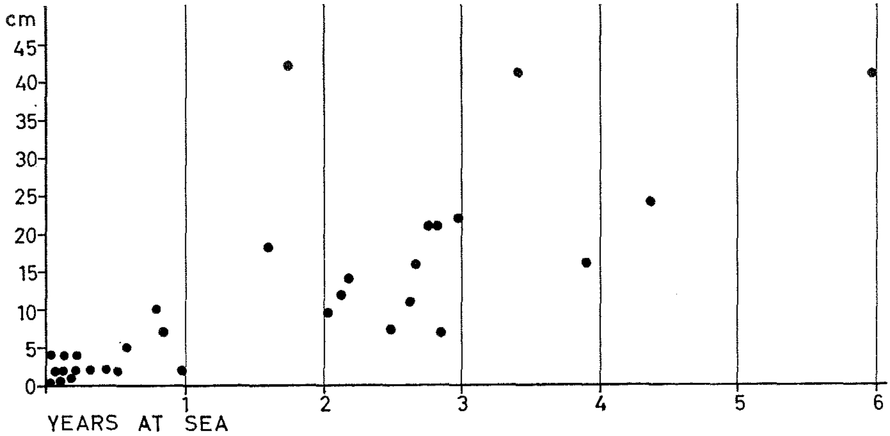

Figure 5. Length increment of recaptured spotted catfish according to time at liberty.

length of some of the recaptured fish is obviously too great. One fish measuring 78 cm at release was reported to be 120 cm after only 1 year and 9 months, while another fish 93 cm at release showed a growth of 42 cm after nearly 6 years at sea.

DISCUSSION

The growth rate of *A. minor* as determined from this study is in agreement with the data given by Maslov (1944). His values tend, however, to be slightly lower. This discrepancy may probably be ascribed to the time of the year the samples have been secured. Maslov's material was obtained from trawlers throughout the year, while the present samples, except 75 young fish (Table 1), were taken from long-liners in June—July.

The reported lengths of the recaptured fish from the tagging experiments (Figure 5) may be used to test the estimated growth rate. In Figure 6 the length of the recaptured fish is plotted according to length at release and time at sea. For most of the recaptures the deviation from the empirical growth curve is less than 5 cm. It seems therefore fair to conclude that the estimated growth rate based on age readings from the vertebrae is not very far from the true value.

The size composition of the catfish taken by long-line (Figure 1) shows that fish smaller than 60—70 cm and larger than 130 cm were only caught in small numbers. The maturity stage distribution according to lenght shows that *A. minor* reaches sexual maturity at a length of 70—90 cm with a critical length at 75 cm for females and 80—85 cm for males. This result indicates that *A. minor* is not caught

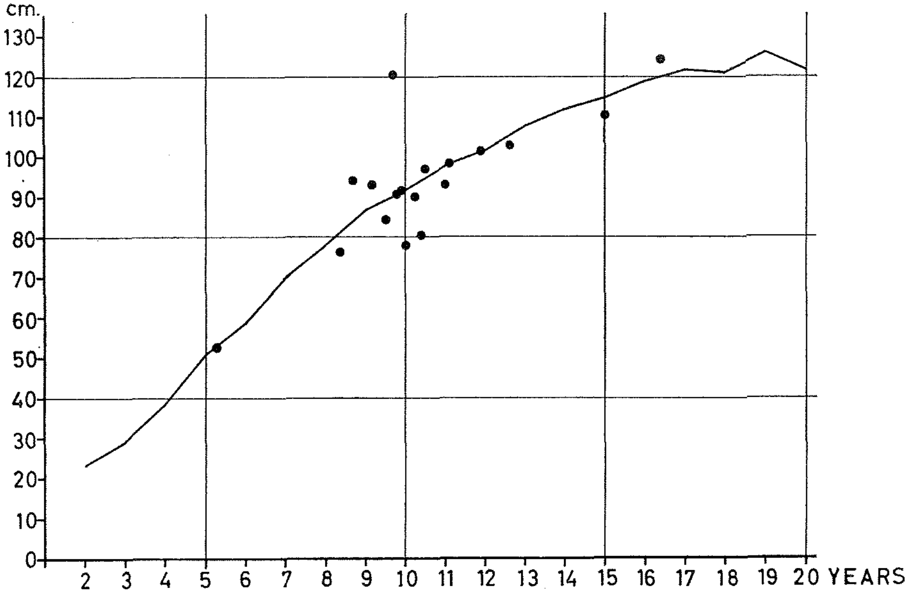

Figure 6. Age — length relationship of spotted catfish and the length at recapture of tagged fish plotted according to time in liberty.

to any great extent by long-line before reaching maturity. In Greenland waters fish smaller than 80 cm were also scarce in the long-line catches and the size composition was similar to that found off Finnmark (Hansen 1958). Information on maturity is not given by Hansen, but his data on length and weight show that, in the length group between 70—90 cm, length decreases in relation to weight which is typical when a fish reaches sexual maturity. Barsukov's (1957) data shows that immature catfish are caught in greater numbers by the trawlers and the same result is indicated by the present material. The size composition in the catches is apparently dependent on the depth of fishing. According to Barsukov nearly 40 % of the catfish with total length of 20—59 cm, were taken by the trawlers at depths greater than 200 m, whereas less than 30 % of the bigger fish 60—130 cm were caught at this depth. The long-line fishing in April—July off Finnmark usually occurs at depth from 100—150 m. The depth distribution of *A. minor* also varies with the time of the year and Barsukov found the maximum concentration of fish in all length groups between 100—150 m in August—October and in deeper water throughout the rest of the year.

According to Smitt (1892) and later authors the maximum size of *A. minor* is 180 cm or more. The present growth data show, however, that the asymptotic length is about 155 cm and no records of bigger fish have been found in the literature. The biggest fish from the present material measured 144 cm and was about 25 years old.

A. minor has been regarded as a late winter spawner (Maslov 1944). The present investigation shows, however, that *A. minor* spawn in the vicinity of Bear Island in July. The samples taken off Finnmark in June also indicate spawning in late summer. It is most likely, therefore, that the main spawning season for *A. minor* in the Barents Sea and adjacent waters is in July and probably also August. This is in agreement with the time of spawning stated by Barsukov (1957) who, however, does not give any further information or references. In Icelandic waters Lühmann (1954) observed females with ripe eggs in July—August and he concluded that spawning occured later in the year around Iceland than in the Barents Sea where *A. minor* according to previous authors was reported to spawn at the end of the winter.

From the maturity stage distribution it is seen that males in stages III and IV have not been observed and information on maturity stages in males from other areas has also not been given. Since histological investigation not has been undertaken, it cannot be acertained that all the males grouped in maturity stage II were in this stage, but the size and the form of the testes were similar. On the assumption that the present observation is correct, the duration of maturity stages III and IV in males may be very short or the maturity cycle different from the females with regard to the time of the year. In the latter case mating and internal fertilization probably must occur. Further investigations are needed before the sexual development and spawning of *A. minor* can be fully explained.

The eggs of *A. minor* and the other species of Anarhichidae are deposited on the bottom in large loose lumps. According to McIntosh and Prince (1890) the eggs of *A. lupus* hatch after 2—3 months and it takes another 3½ months after hatching before the yolk sac is absorbed. Seydlitz (1957), referring to eggs of *A. lupus* found off the west coast of Spitsbergen in August, says that *A. lupus* larvae are able to hatch in a very early stage of development by shock, but normally do not hatch until the yolk is absorbed and fin rays are formed. According to Andrijashev (1954), *A. lupus* spawn in December—January. The observation of Seydlitz suggest, therefore, that the larvae do not hatch until the following summer, 6—8 months after spawning. If the larvae of *A. minor* need approximately the same time before hatching and assuming the spawning season to be July—August the larvae would normally not hatch until late winter or early spring. This would explain the previous assumption of *A. minor* being a late winter spawner.

The result of the tagging experiments show that catfish from the eastern part of the Barents Sea, off the Norwegian coast and around Bear Island intermingle to a great extent. So far none of the tagged fish have been recaptured outside this area. *A. minor* also occurs along the west coast of Spitsbergen, but none of the tagged fish released near Bear Island or further south has been recaptured in Spitsbergen waters. It does not seem reasonable, however, that the stock of *A. minor* off Spitsbergen should be isolated from the stock further south and that intermingling not takes place. Most probably the stock of *A. minor* in the Barents Sea, along the coast of Northern Norway, at Bear Island and Spitsbergen belong to one single unit.

The age and length distribution of the samples taken near Bear Island and off Finnmark show that more young fish were present near Bear Island. This different distribution of the age groups may, however, be seasonal. The recaptures during the first years indicated a westward migration from the eastern part of the Barents Sea to the banks off Finnmark in the spring and westward migration in the autumn (Østvedt 1956). By including recaptures from all years, this seasonal migration is more confused. The number of recaptures in each area for the different months show, however, that east of longitude 35°E the maximum number of recoveries were taken in January—March, as against April—June further west. In the northernmost areas, Central Bank and Bear Island, tagged fish were mainly recaptured in July—August. The Norwegian long-line fishery for catfish usually starts in April—May on the Skolpenbank. By the end of June the best catches are taken at Hjelmsøybank or even further west. Since a great part of the catch consists of maturing fish it is reasonable to link this change in fishing areas during the spring and summer with a westward migration to spawning grounds off Finnmark.

It has been shown that a higher percentage of returns was obtained from trawl-caught fish than fish tagged and liberated from the longliners. It should be noted that fish from trawl catches were liberated on several localities as against only three localities for fish caught by long-line. Besides, the trawl-caught fish were mainly liberated on the usual trawling grounds where fishing often was in operation and the tagged fish may have been exposed to a higher fishing effort than the fish liberated from the long-liners.

These tagging experiments are too limited and have been conducted on so many localities that it seems unwarranted to correlate the number of returns in the different years with the total landings of catfish. A striking feature is the low number of returns 1½—2 years after liberation, refering to the years 1955 and 1956, while the total landings show an increase nearly every year since these experiments were undertaken.

SUMMARY

Spotted catfish, *Anarhichas minor* Olafsen, were sampled from long line and trawl catches taken along the cost of Finnmark, near Bear Island and in the Barents Sea in 1953 and 1954. Age was determined from vertebraes. Fish younger than 6 years were not found in the long line samples. The age groups 12—14 were most abundant in the long line samples taken off Finnmark as against 8—9 years old fish dominating the samples taken near Bear Island.

The females were found to attain sexual maturity at an age of 6—7 years and a length of about 75 cm and the males approximately one year later at a length of 80—85 cm.

The present study indicates that the spotted catfish spawn in July—August.

In 1953, 1954 and 1955 a total of 432 catfish were tagged with Lea Hydrostatic tag. Until January 1963 71 were recaptured. The seasonal distribution and migration of the catfish are discussed.

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Artificial Propagation of Cod

Some recent results of the liberation of larvae

BY

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The sea-fish hatchery at Flødevigen was founded in 1882 by Capt. G. M. Dannevig. At that time the cod had become less abundant on the Skagerak coast of Norway, and captain Dannevig's idea was to increase the local stock of cod by liberating large quantities of larvae in the fjords and between the skerries. From the very beginning the opinions differed considerably as to the utility of such a programme. The experiences of the fishermen indicated that the recruitment to the stock was increased by the liberation of larvae, and so did the results of direct experiments by K. Dahl and G. M. Dannevig (1906). It was impossible, however, to arrive at a definite conclusion without a far more thorough knowledge of the biology of the cod than was then available.

Alf Dannevig, who was given charge of the station in 1911, started an extensive research programme in order to study the biological and hydrographical factors involved. Simultaneously the hatchery was kept going in order to obtain more experience. Large scale experiments on the usefulness of larvae liberation were postponed for many years, however, and systematical experiments were not started before 1950. In this paper the problem of artifical propagation of cod will be dicussed on the basis of the experimental evidence now at hand and in light of our present knowledge of the cod in these waters.

The methods developed by G. M. Dannevig (1910) for hatching cod eggs on a large scale have proved to be very efficient and have been used unaltered up to the present time. Mature fish for the hatchery are collected during the months of January and February. Both the male and female fish are kept together in a special spawning pond. Provided a suitable temperature, the cod will spawn here as under natural conditions and the fertilized eggs will accumulate at the surface. The wastewater from the pond is drained from the bottom so that the eggs will not be lost.

The eggs are generally collected once a day. When doing so, the water outlet from the bottom of the pond is closed and the surface water passed out through a large filter of silk gauze that retains the eggs. From the collector the eggs are subsequently transferred to special hatching apparatus.

The sea water used in the hatchery is always filtered through large sand filters. This filtration was originally introduced in order to remove the plankton that might cause clogging of the silk gauze used in the hatching boxes and subsequent overflow and loss of eggs. Several later observations indicate, however, that the filtration is also of importance for other reasons. Thus we evidently eliminate to a great extent the microorganisms that may cause diseases and mortality to the eggs and larvae. Of no less importance is the fact that the excess gases in supersaturated water are liberated when the water passes through the sand. Several experiments have shown that it is often difficult to maintain fish larvae in water supersaturated with oxygen (Alf Dannevig and Gunnar Dannevig (1950)).

At favourable temperatures of 4 to 5°C the eggs will hatch after approximately three weeks, and the total mortality up to that time is generally less than 10 %. At lower temperatures, however, the mortality may be somewhat greater as a consequence of the prolonged incubation period.

The larvae are liberated at an age 3 or 4 days, before the yolk sac is absorbed. It has proved impossible to rear cod larvae on a large scale in ordinary aquaria. When fed on *Artemia,* they may thrive well for a few weeks until the gas gland begins to function. Then the swimbladder becomes strongly distended with gas and the larvae float to the surface and succumb. The fatal effect seems to be due to the fact that the larvae are kept at too low a pressure when the gas gland begins to function. Direct experiments have demonstrated that the larvae seem to prefer a higher hydrostatic pressure and in nature they are most abundant at depths between 10 and 30 meters.

Originally the fry were liberated directly at the surface. Now we take into account that the hydrostatic pressure is presumably an important factor and liberate the larvae at a depth of about 8 meters. This is performed by means of a large rubber hose with a weight at one end and used as a siphon. The larvae are generally transported onboard our own research vessel which is then equipped with special tanks for that purpose. Provided the sea is not too rough, the larvae may be transported for 12—15 hours without significant mortality.

The type of cod occurring along the southern coast of Norway does not undertake any long migrations, even in the spawning season.

Tagging experiments have clearly demonstrated that there is little or no exchange between the stocks of different fjords, or between the fjords and the adjacent waters outside.

Another fact is that there is generally no influx of pelagic eggs or larvae into the fjords from other districts. The recruitment to the populations here is mainly dependent on the local spawning. Thus the cod population along the southern coast of Norway is split up into a number of local and quite independent stocks.

The cod in these waters is heavily exploited by fishing and few fish survive to become sexually mature. It is most likely, therefore, that the recruitment is limited by the number of spawners. It is realized that in many species there are no clear indications of a pronounced relationship between the abundance of spawners and the numbers of subsequent recruits. It has to be kept in mind, however, that the presence of extremely large fluctuations in recruit numbers from quite other causes will tend to obscure such a relationship. It is logical to assume that under identical conditions the number of recruits will vary linearly with the numbers of eggs spawned. This must hold good as long as the rate of natural mortality during the earliest stages is not affected by the density of the population considered.

Extensive investigations in the coastal waters have demonstrated that the number of cod eggs is greatly reduced during development and that the number of pelagic fry is exceedingly low compared to the number of eggs in early stages. A very large persentage of the eggs is evidently being destroyed in nature. In the hatchery at Flødevigen, however, there is only a slight mortality on the eggs and about 90 % of them will hatch. The number of larvae produced by each spawner is therefore greatly increased when the eggs are maintained in a hatchery. If the recruitment to a local stock is limited by the number of spawners and the production of larvae, there is at least a chance that it may pay to take the spawners to a hatchery. In this connection it is certainly also of importance that the whole production of larvae at Flødevigen represents a net contribution to the fjords were they are liberated. The fish used for the hatchery are always purchased on the open market and thus given an opportunity to reproduce themselves before being killed.

The fact that we are dealing with local and heavily exploited stocks of cod certainly affords favourable conditions for artifical propagation. The most efficient method for studying the usefulness of artifical hatching would be to tag or mark the larvae in such a way that they could be recognized as older fish. Lacking tagging methods suitable for such a purpose, Rollefsen (1940) made an attempt to study the problem by producing larvae of a bastard (Pleuronects platessa ♀ × Pl. flesus ♂) and liberating these larvae in a small fjord. Some months later the ratio of bastards to plaice in the littoral region was ascertained by sampling the flatfish population with a seine. The results were as follows:

Year	Bastards liberated	Percentage of bastards
1935	2 millions	1,5
1936	13 »	30,0
1937	7 »	0,5
1938	10 »	96,0
1939	7 »	40,0

In some years the bastards evidently had a very high survival rate. It was shown with rearing experiments, however, that the plaice and bastard larvae did not thrive well together in the same pond, and that the rate of survival was higher for the bastards than for the plaice. For that reason, the bastards could not be used to study the usefulness of liberating plaice larvae, as was the actual problem in this case.

At Flødevigen we have carried out since 1950 a special research programme in order to study the usefulness of artifical propagation of cod. Our plan has been to liberate 100—150 million larvae in the Oslofjord every second year and then try to ascertain whether these liberations are of consequence to the abundance of young fish. Such investigations will, of course, require many years to give conclusive results as the effect of the liberations may be more or less obscured by great natural fluctuations in the strength of the year-classes. We have, however, no better way of elucidating and eventually solving the problem.

The liberation of larvae has hitherto been accomplished according to plan, with the exception of one year in which the hatchery operations were impeded by exceptionally cold water. The fry have always been well scattered on both sides of the fjord inwards to Drøbak, whereas no larvae have been liberated in the innermost and heavily polluted part of the fjord.

The strength of the year-classes has been evaluated on the basis of the abundance of the 0-group and I-group fish in the littoral region during the autumn. At that time of the year the youngest age-group has attained a size of about 10 cm or more and is then most abundant in the littoral region. Here the 0-group cod may easily be caught by a shore seine of suitable construction. Simultaneously we get samples also of the I-group, even though this age group has largely migrated into deeper water. The catch from each haul is counted and grouped according to age and the various age groups are treated separately.

The codling population has each year been sampled at 35 fixed localities distributed on both sides of the fjord inwards to Drøbak. Every precaution has been taken to ensure that the material from the various years is really comparable with regard to the numbers of fish caught. The seine used has been of the same size and construction each year and the hauls are always taken at the same time of the year. Also of importance is the fact that the seine has always been worked by the same crew.

In the following discussion the mean number of fish per haul is used as a measure of the abundance of the various yearclasses. As the 0-group and I-group fish are being treated separately, we get two indepedent measures of each year-class. The catches of the former are presumably the most representative as much of the I-group cod has left the littoral region.

No attempts have been made to evaluate the relative strengths of the various year-classes on the basis of the age composition within catches of older fish. Such a procedure is, in fact, rather difficult when concerned with populations that are heavily exploited by fishing.

The mean number of fish per haul of the different year-classes is shown in Figure 1. Considering the 0-group first, one sees that there are large fluctuations from year to year irrespective of whether fry have been liberated or not. The survial rate of the larvae liberated will, of course, depend on the environmental conditions in quite the same way as for the larvae originating from the local spawning. It is seen, however, that larvae have been liberated in each of the three years that yielded the most numerous catches, viz. 1955, 1957 and 1961. Another fact is that none of the years in which larvae were liberated has yielded substantially smaller catches than the best of the intervening years. Thus the 0-group cod have on the whole been most abundant in those years in which larvae were liberated.

The I-group cod are far less abundant in the littoral region than the 0-group and the catches are correspondingly smaller. It is evident, however, that all of the four year-classes that yielded the largest catches of this age-group originated from years in which larvae were liberated. Only two years when larvae were liberated have shown smaller catches than the best of the other years.

The material now at hand indicates, therefore, that the liberation

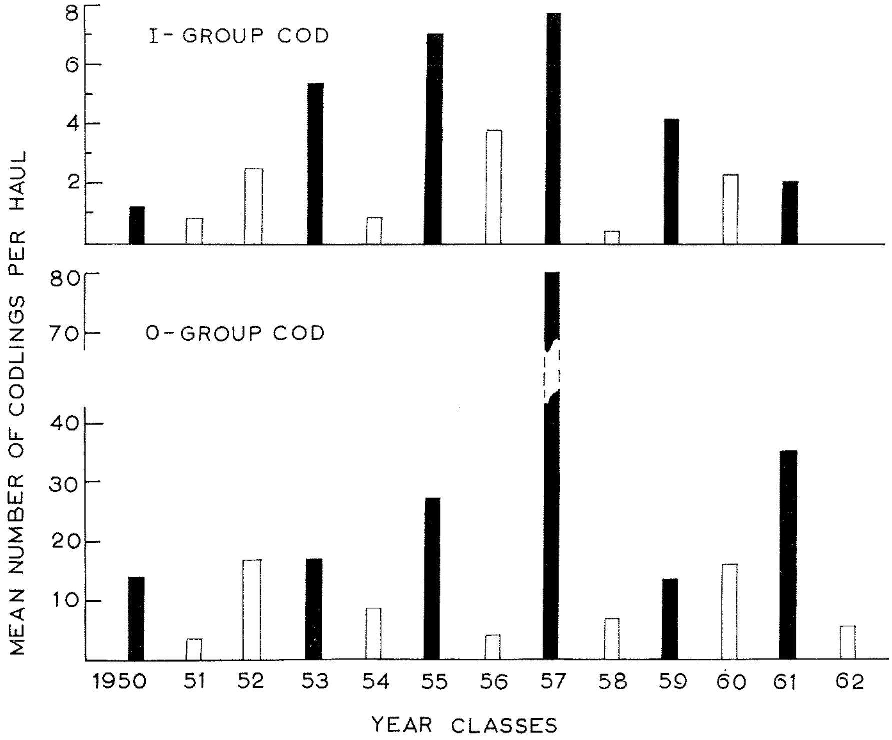

Fig. 1. Mean number of O-group and I-group cod per haul from the year-classes 1950 to 1962. Black columns: Year-classes with larvae liberated. Open columns: Year-classes with no liberation of larvae.

of larvae has had a noticeable effect on the abundance of young cod in the Oslofjord district. These results are in close agreement with the experiences of the fishermen who maintain that the liberation of larvae has been of great consequence. The fishermen have, in fact, good possibilities for evaluating the abundance of the different year-classes as they exploit the cod from its second year of life.

These preliminary results from the Oslofjord indicate that the artificial propagation of cod may prove profitable when concerned with local stocks that are heavily exploited by fishing. The investigations in this fjord will be continued in order to get more experimental evidence for judging the usefulness of this programme. Plans are also being developed for carrying out a similar research programme in other districts.

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The non-returning of fish tags recovered by Norwegian fishermen

BY

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When fish are tagged and released the actual recovery is out of the hands of the investigators conducting the experiments. The responsibility of detecting and reporting the tags is left to the fishermen, workers in the fish processing industry, the sellers and to some extend the consumers too. Some non-returned recovered tags may be the result and this may lead to biases in the estimate of mortality and population size. A correction factor for non-returning can be calculated by planting a known number of tagged fish in the catch. This method is used by Ruud and Øynes (1954) in a study of the returning of whale tags from the Norwegian floating factories in the Antarctic and by Aasen (1958) in estimating the returning rate of internal herring tags from the reduction plants along the Norwegian coast. Margetts (1961) studied the reporting of tags which had passed the fishing vessel and the market respectively.

Tagging experiments may be designed to contain some provisions for testing the non-returning rate of recaptured tags. A direct method of estimating this rate is to have trained observers examine a portion of the catch for tags (Paulik 1961). This method may be difficult to carry out because of the manpower requirements and the costs.

Advertising, educational programs and different reward schemes have been used for the purpose of increasing the interest of the fishermen to search for and to return recovered tags. The size of the rewards differ from country to country as they do for different species. For returning a tag to the Inter-American Tropical Tuna Commission the fishermen receive $ 1 and a chance in an annual $ 300 drawing (Schaefer 1958). From two ponds in a Massachusetts stream $ 1 was offered for each tag returned, and a monthly lottery was held for prices of greater value (Stroud and Bitzer 1953). A partial creel census was made at the same ponds, and a comparison of the returning rate in these ponds with returning rate in other waters without rewards or a creel census indicated a non-returning of 25 per cent. Several tagging experiments on warm-water game fishes in California with $ 5 reward tags and non-reward tags have demonstrated that 35—60 per cent of non rewards tags actually recovered by anglers were not returned (McCammon and LaFaunce 1961).

Fiskeridirektoratets Havforskningsinstitutt is offering 5 N. Kr. for each cod, haddock, coalfish, halibut, catfish, sprat, spiny dogfish and mackerel (2.50 N.Kr. when the tagged mackerel is recovered just after release in the neighbourhood of the tagging locality), rewards of 10 N.Kr. for each returned herring and capelin tag and 25 N.Kr. for each tunny, porbeagle and seal tag. In 1959 the Institute introduced an annual 1000, 500 and 250 N.Kr. drawings for cod, coalfish, haddock, halibut and catfish tags, Norwegian and foreign, returned by Norwegian fishermen. The purpose was to estimate the non-returning rate of tags recovered by Norwegian fishermen.

MATERIAL AND METHODS

During January 1959 the extra reward system was made familiar to the Norwegian fishermen through the local newspapers and placards along the coast from Bergen to Kirkenes. The first drawings took place in June 1959 over the Norwegian Broadcasting Company. All tags from the mentioned species returned between the 1st of January and the 15th of May 1959 had the chance to receive the extra rewards.

In 1960 and 1961 the same extra reward system was used and all tags returned between the 16th of May one year and the 15th of May the next year were taken into consideration. The drawings took place in June with a representative of the fishermen present. In 1960 the outcome of the drawings together with some facts about tag returning and the aim of tagging experiments was given in a "Fishery item" on the Norwegian radio, and in 1961 the outcome was given in some newspapers along the Norwegian coast.

In the following all recoveries of tagged cod, haddock, coalfish, halibut and catfish made by the Norwegian fishermen during the period of 1947—1962 have been taken into consideration.

RESULTS

During 1959 one tag recovered in each of the years 1922, 1944, 1950 and 1955 and some more tags recovered in 1956—1958 were returned. In recent years a few tags recovered earlier than 1957, but not earlier than 1952, were returned. The extra rewards and the advertising may

Table 1. *Total number of tags returned by Norwegian fishermen.*

Year of recapture	Year of return															
	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
1922													1			
.																
.																
1944													1			
.																
.																
47	182	1														
48		392	2													
49			483	1												
1950				410	1					1						
51					759	10										
52						810	8	1	1			1				
53							661	18	1		1	2				
54								869	22	4	1	1				
1955									1 525	25			2			
56										1 720	122	8	4	1		
57											1 376	68	13	4		
58												1 686	146	15		
59													2 158	107	7	
1960														1 410	42	3
61															1 588	84
?						9	1	4	4	11	5	2	4	36	10	12

Table 2. *Percent of tags returned in the years after the recapture year.*

Year of recapture	Returned in the					
	First	Second	Third	Fourth	Fifth	Sixth
	year after recapture					
1947	0,5					
48	0,5					
49	0,2					
1950	0,2					
51	1,3					
52	1,0					
53	2,7	0,1				
54	2,5	0,1	0,1			
1955	1,6	0,4	—			0,2
56	6,6	—	0,1	0,1		—
57	4,7	0,4	—	0,1	0,3	0,1
58	8,0	0,9	0,2	0,1		
59	4,7	0,8	0,3	0,1		
1960	2,9	0,3				
61	5,0	0,2				

have stimulated people to send these "older tags". Since the number of tags that would not have been returned without the system is unknown, there are difficulties in estimating the real effect of the extra rewards.

If the extra rewards stimulate the returning of recovered tags, it is expected that the returning rate of tags recovered and returned at once and returned after some time will be higher. The present material gives no possibility of estimating the effect of the new system on the reporting of tags recovered and returned the same year, but the stimulating effect may be reflected in the reporting rate of tags returned one, two and three years after they are recovered. Unfortunately the mailing dates are not listed in our tagging journals nor transferred to the punchcards of the recaptured fish. However, the returning year may be established. Every returned tag from each experimental year gets a serial number, and the distinction between two returning years is in the following based on the first serial number with a new recapture year.

All the tags recovered each year from 1947—1961 and returned the same year as recovered and one or more years after, are given together with the number of returned tags with unknown recapture years in Table 1. During 1948—1953 the returning rate of the tags returned one year after they were recovered (Table 2) was about 1 per cent or less. The rate increased to 8 per cent in 1959, but decreased to about 3 per cent in 1961. In 1962 it increased again to 5 per cent. More or less the

Table 3. *Total number of tags recovered in different periods of a year and returned the next year.*

Year of recapture	Number of tags recovered the first six months of a year			Number of tags recovered the third quarter of a year			Number of tags recovered the fourth quarter of a year		
	Total returned	Returned the next year		Total returned	Returned the next year		Total returned	Returned the next year	
		No	Per cent		No	Per cent		No	Per cent
1947	177	—	—	6	1	16,7	—	—	—
48	390	2	0,5	4	—	—	—	—	—
49	467	—	—	12	1	8,3	5	—	—
1950	408	1	0,2	3	—	—	—	—	—
51	750	4	0,5	12	—	—	7	6	85,7
52	780	3	0,4	12	—	—	26	5	19,2
53	601	6	1,0	42	4	9,5	36	8	22,2
54	757	3	0,4	49	2	4,1	85	17	20,0
55	1 150	4	0,3	292	7	2,4	108	14	13,0
56	1 227	8	0,7	440	65	14,8	175	49	28,0
57	918	15	1,6	380	32	8,4	146	21	14,4
58	1 186	53	4,5	477	72	15,1	169	21	12,3
59	1 725	25	1,4	376	42	11,2	164	40	24,4
1960	1 130	15	1,3	206	9	4,4	116	18	15,5
61	1 336	43	3,2	244	31	12,7	92	10	10,9

same tendency is recognizable in the reporting rate of tags returned two years after they were recovered. The highest rates are given for the reporting years 1958—1961. The tags returned three and more years after recovery were mainly returned in 1957—1960.

Since some tags might always be reported some time after recovery the reporting rate of tags recovered one year and returned the next may vary for different periods of the year. In Table 3 is given the reporting rate of tags recovered in the first six months, the third and fourth quarters of a year, but returned the next year. During 1948—1957 the rates are mostly less than 1 per cent in the first period of the year, but it increased in 1959 to 4,5 per cent. In the next two years the rates decreased but in 1962 it was higher again. The same tendency is recognizable in the second period, while the corresponding values for the last period show a slight decreasing tendency from 1951 and onwards, with an interruption of higher values in 1956 and 1959. However, these calculations demonstrate a higher returning the year after recovery for tags recovered in later periods of a year.

DISCUSSION

The reporting rate of fish returned one or more years after recapture has been studied. Since exact information on the reporting year is not available, the distinction between the "returning years" is based on the first serial recapture number with a new recapture year. This may cause some biases in the number of tags returned each year. Tags returned at the beginning of a year, but recovered the year before, may get an earlier serial recapture number than the first tag recovered this year. For some tags the bias of the year of recapture may be serious. If a tag is recovered in the same year as the tag with the recapture number just before or in an earlier year, but returned several years afterwards, it will get the same year of returning as the serial number just before. For example, the tag recovered in 1950, but returned in 1956 (Table 1), is in fact returned in 1959.

The methods used in estimating the year of return cause some tags to get an earlier and some tags a later year of return than is correct. But the bias in the number actually returned one or more years after recapture is probably insignificant or it may be of the same order each year.

The returning rate of tags recovered in the first 6 months of a year, but returned the next year, is smaller than the rates of the third and fourth quarters of the year (Table 3). The reason may be that the fishermen are waiting for a quiet fishing period before the tags are mailed. Another reason is that it is much easier for the fishermen to return tags in the first part of the year. During the bigger seasonal cod and herring fisheries the recovered tags can be delivered to official inspectors along the Norwegian coast, which write down the recovery data and mail it to the Institute.

During 1947—1952 most of the returned tags were from recaptured cod, tagged and recaptured in Lofoten during the skreifishery from January to April. The tags could be delivered to the fishery inspectors, and this may account for the low reporting rate of tags returned the year after they were recovered (Tables 2 and 3). An extensive cod and coalfish tagging program started in 1953—54 in the North-eastern Atlantic waters. Many tags from these experiments were recovered during summer and autumn (Table 3), when very few fishery inspectors are present along the coast. The consequence may have been an increased reporting of tags recovered in the third quarter of a year but returned the next.

During the spring of 1957 the advertising in newspapers along the Norwegian coast was intensified, and this may have stimulated the fishermen to increase their reporting in 1957 of tags recovered in 1956 (Table 2). The increase in the relative number of tags returned in 1959 but recovered in 1958 and earlier might be the effect of the extra reward system introduced in 1959. The relatively smaller number of tags returned one year after recovery in 1960 and 1961 was then caused by the higher returning of tags recovered and returned in 1959 and 1960 respectively. However, the same might happen with a decreasing interest in returning tags, but the great number of tags returned in 1960—1962 without information of recapture year (Table 1) may reflect a continuous interest in returning tags. Most of the mentioned tags without recapture years may have been returned as a response of advertising, because it was said that the Institute was interested in "old tags" even if the recapture data should be incomplete.

The reporting rates during 1948—1958 of tags recovered in the first six months and the third quarter of a year, but returned the next year are 0.5 and 9.0 per cent respectively. With a constant reporting rate in these years the increase in the rates in 1959 reflects an annual loss of 4—6 per cent in earlier years. This estimate of the non-returning rate by Norwegian fishermen is a minimum, because in spite of the extra rewards there may be some non-response in 1959, which is reflected in some tags returned in 1960 two years after recapture (Table 2).

The non-reporting rate of recaptured Danish cod tags in West-Greenland Waters is estimated to be between 50 per cent (Poulsen 1957) and 58 per cent (Horsted 1961). The basis for this calculation is that the Portuguese dorry-vessel fishermen are reporting recaptured tags to a much higher degree than other fishing fleets, and that the actual number of tags recaptured per 1000 tons of cod landed is the same for all fishing fleets. The non-returning rate of the Portuguese trawlers was estimated to be about 50 per cent (Poulsen 1957) and 60 per cent (Horsted 1961), while the non-reporting rate of the Norwegian fishing fleets, mostly longliners, was 82 per cent (Poulsen 1957). The estimated non-returning rate of the Norwegian fishermen is in disagreement with the estimation based on all tags reported by Norwegian fishermen after the extra reward system was introduced.

Many circumstances may effect the estimated non-returning from West-Greenland Waters. In 1955 the younger fish were more numerous in the Danish (Hansen 1956) and the Portuguese (Ruivo 1956) samples than in the Norwegian (Rasmussen 1956). This may reflect a segregation in fish size or age according to depth, because the Norwegian samples are from catches taken between a depth of 150—350 m., while the Danish and Portuguese are from less than 100 m. According to Hansen (1956) the recaptured fish in 1955 consisted of a great number of younger fish, which then were available to a lesser degree for the Norwegian fishermen. The estimated non-returning rate of tags recovered by Norwegian Fishermen in West-Greenland Waters is therefore less than estimated by Poulsen.

SUMMARY

In addition to 5 N.Kr. reward for each returned cod, coalfish, haddock, halibut and catfish tag, Fiskeridirektoratets Havforskningsinstitutt introduced in 1959 an annual drawing of 1000, 500 and 250 N.Kr. for tags, Norwegian and foreign, returned by Norwegian fishermen. The extra reward system was in use during 1959—1961.

After the extra rewards were introduced, the reporting rate of tags returned the same year as recovered and one or more years afterwards has increased. The non-returning rate of tags recovered by Norwegian fishermen in 1947—1957 was estimated to be at least 4—6 percent and the indication from the calculations is that the non-returning rate is decreasing with the continuous advertising and with people in the fishing ports to receive the recovered tags.

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A method of finding an empirical total selection curve for gill nets, describing all means of attachment

BY

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INTRODUCTION

A symmetrical or slightly skewed selection curve probably describes the selection of a gill net fairly accurately when the range of fish size does not greatly exceed the normal selection range. In some gill net fisheries, however, significant numbers of fish outside the size range of that for normal meshing are caught by other methods of attachment, for example, meshed by the maxillae, attached by the teeth, entangled by the tail, completely embedded in the net, etc.

In such a case the total selection curve for the net may deviate significantly from one that can be adequately described by a reasonably simple mathematical expression.

The present paper discusses a method of overcoming this difficulty when data are available on the methods of attachment of the fish caught, and it gives an example of how the method has been applied to establish selection curves for halibut gill nets. A preliminary report on this topic was presented at the 1961 statutory meeting of the International Council for the Exploration of the Sea (Olsen and Tjemsland 1961).

THEORY

We assume that the selection curve for the fish meshed in the normal way (i.e. by the operculum and point of greatest girth) closely approximates a normal curve or a slightly skewed curve which can be determined, for example, by the method described by Holt (1957).

Let y_l be the ordinate of this curve at length l, and n_l the catch in number of fish caught by this method of attachment. Similarly $y_l{}'$ and $n_l{}'$ refer to the selection curve and catch of all other methods of attachment.

Then,
$$n_l = N_l \cdot P \cdot y_l \tag{1}$$

and
$$n_l' = N_l \cdot P \cdot y_l' \tag{2}$$

where N_l is the number of fish of length l encountered by the net and P is a constant.

We have now:

$$\frac{n_l}{n_l'} = \frac{y_l}{y_l'} \tag{3}$$

and
$$y_l' = y_l \cdot \frac{n_l'}{n_l} \tag{4}$$

and the ordinate of the total selection curve at length l

$$Y_l' = y_l + y_l' = y_l \left(1 + \frac{n_l'}{n_l}\right) \tag{5}$$

or, if we choose y_{lm} as unity $= 1$

$$Y_l = \frac{y_l}{Y_{lm}'} \left(1 + \frac{n_l'}{n_l}\right) \tag{6}$$

APPLICATION TO DATA

a) *Material*

The material was obtained from experimental fishing conducted during January and February in the years 1957 to 1960 in an area at the entrance to the Alta Fjord in Northern Norway. The nets used were hemp and nylon nets of about 16″ mesh size and nylon nets with mesh sizes of approximately 19″ and 23″. Measured under a tension of 4 kg, the mesh sizes for the three different types of nylon nets averaged 42.8 cm, 49.6 cm and 61.9 cm respectively.

The nets were spread in groups of two to five of each type throughout the fleets, and the positions of the groups were changed during the season. The type of net for each individual fish was recorded and the total length measured. In 1959 and 1960 girth measurements were also taken, and for part of the material records were kept of the way each fish was attached to the net.

In analysing the data the methods of attachment were divided into group 1) meshing by the operculum and point of greatest girth, and group 2) all other methods of attachment (i.e. meshed by the maxillae, attached by the teeth, entangled by the tail, completely embedded in the net etc.). Table I gives the numbers caught according to type of net and attachment method.

Table I. Numbers of halibut caught in 1959 and 1960 according to type of net and method of attachment.

Type of net	Numbers caught	
	Attachment 1	Attachment 2
Hemp 16″	82	23
Nylon 16″	145	44
Nylon 19″	92	29
Nylon 23″	78	25

b) *Calculation of selection curves*

For the meshed fish (attachment group 1) selection curves for the three different mesh sizes of nylon nets were calculated by the method described by Holt (1957):

$$n_l \propto \exp. -(l - l_m)^2 \,/\, \sigma^2$$

where: n_l is the number of fish of length l caught,
and l_m is the mean selection length.

Table II gives the length distribution and log ratios when adjusted for differences in effort (number of nets fished), and in Fig. 1 the log ratios are plotted against length and lines fitted by the method of least squares.

From the lines of best fit values for K (the ratio between mean selection length and mesh size), l_m and the variance σ^2 were computed.

The values of K were estimated as

$$K_{BA} = 3.325,\ K_{CA} = 3.133 \text{ and } K_{CB} = 3.154,$$

where the indices A, B and C refer to the mesh sizes 16″, 19″ and 23″ respectively. The aritmetic mean of these, $\overline{K} = 3.204$ gives:

${}_{A}l_m = 136.96$ cm, ${}_{B}l_m = 158.72$ cm, ${}_{C}l_m = 198.08$ cm, and the variance: $\sigma^2 = 2886$.

The selection curves established in this way for meshing by the operculum and point of greatest girth were then used to find the total selection curves for all methods of attachment, following the procedure described previously.

As a first step a free hand curve was fitted to the ratios between the numbers of fish meshed and those attached in other ways. This curve has a parabolic shape with a minimum approximately at the length of greatest selection by meshing (Fig. 2). This shows that other

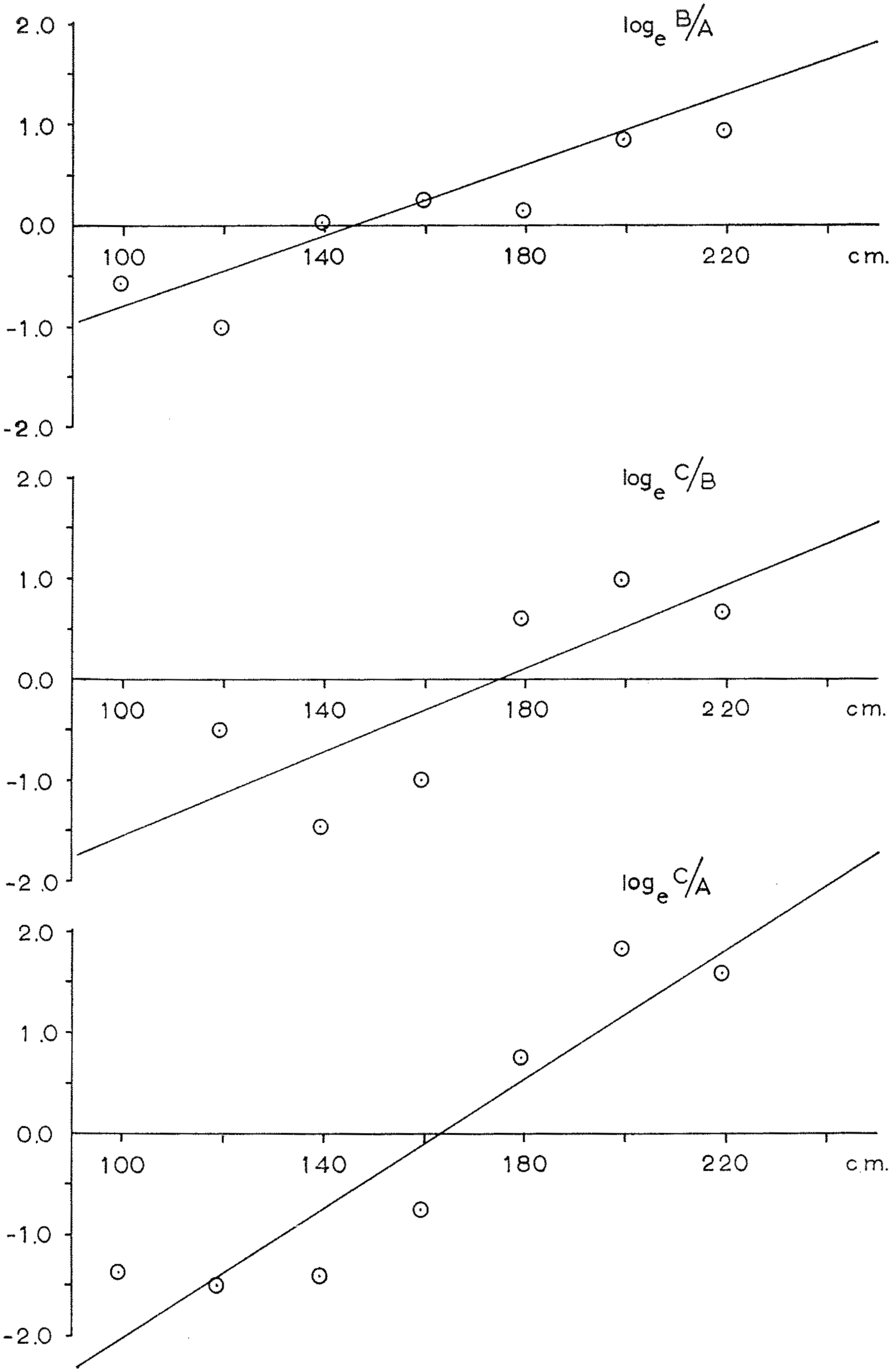

Fig. 1. Plots of log ratios against length for the data of the 16" (A), 19" (B) and 23" (C) nylon nets.

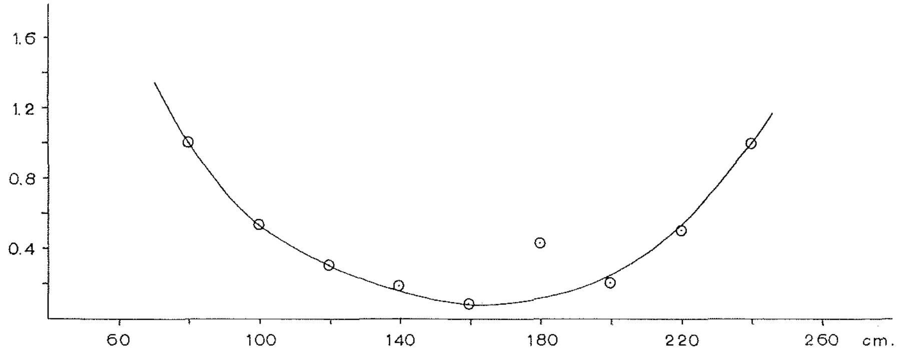

Fig. 2. Ratios between numbers of fish meshed and those attached in other ways, 16" nylon nets.

methods of attachment are of significance mainly for the small and very large fish and thus tend to increase the efficient selection range of the net; i.e. make the selection curve more flat-topped.

c) *Discussion*

From Fig. 1 it appears that the plots of the log. ratios deviate considerably from linearity, as would be expected considering the heterogeneity with regard to attachment method and the relatively small number of observations covering a very great size range. Nevertheless there is no great difference between the three independent values of K and they compare fairly well with a figure of 3.04 estimated for the ratio of half the girth to the total length.

In order to test the validity of the assumption that the mean selection length is proportional to the mesh size, the lengths at which the log. ratios equal zero were plotted against the sum of the mesh sizes as described by Olsen (1959). The plots fit fairly well to a straight line through the origin with a slope of 1.599. This corresponds to a value of $K = 3.198$, against $\bar{K} = 3.204$.

The total selection curves for the four different types of nets used are shown in Fig. 3. The curves are fairly flat-topped, i.e. the halibut gill nets are effective over a great range of fish size. Thus the nylon nets have an efficiency of 50 % or more, with respect to the mean selection length, over a range of about 104 cm, 110 cm and 110 cm for the 16″, 19″ and 23″ mesh sizes respectively.

The selection curve for the hemp net is more peaked and the 50 % selection range equals about 83 cm, which is 20 % less than that of the 19″ nylon net.

Table II. Halibut meshed by operculum and point of greatest girth. Length distribution and log. ratios when adjusted for differences in effort.

Range in cm	$\bar{l}$	A	B		C		$\log_e B/A$	$\log_e C/B$	$\log_e C/A$
		Nylon 16" 171 nets fished	Nylon 19" 117 nets fished		Nylon 23" 106 nets fished				
		n_l	n_l	adj. for diff. in effort	n_l	adj. for diff. in effort			
70—89	79.5	5	4	5.84	—	—	—	—	—
90—109	99.5	13	5	7.30	2	3.22	—0.5771	—	—1.3956
110—129	119.5	44	11	16.06	6	9.66	—1.0079	—0.5084	—1.5162
130—149	139.5	34	24	35.04	5	8.05	0.0296	—1.4708	—1.4407
150—169	159.5	24	21	30.66	7	11.27	0.2450	—1.0009	—0.7559
170—189	179.5	14	11	16.06	18	28.98	0.1371	0.5902	0.7275
190—209	199.5	5	8	11.68	19	30.59	0.8475	0.9628	1.8112
210—229	219.5	4	7	10.22	12	19.32	0.9381	0.6369	1.5748
230—249	239.5	2	1	1.46	7	11.27	—	—	—
≧ 250	—	—	—	—	2	5.22	—	—	—

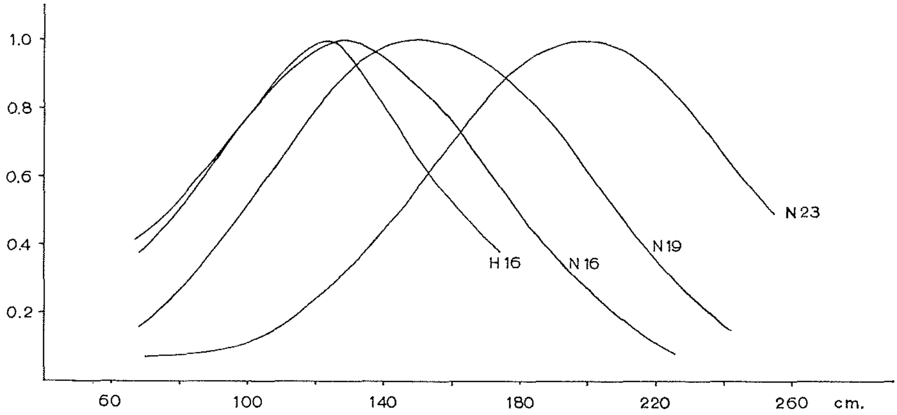

Fig. 3. Relative selection curves describing all methods of attachment. H16 — hemp 16", N16 — nylon 16", N19 — nylon 19", N23 — nylon 23".

It is a general experience in all gill net fishing that nets made of pylyamide fibres are more efficient than similar nets made of natural fibres (see, for example, Sætersdal, 1957). The results of these experiments would suggest that part of this difference in fishing power is caused by the extended selection range of polyamide nets.

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A recording transparency meter for oceanic plankton estimation

BY

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INTRODUCTION

The transparency meter for *in situ* measurements of the light attenuation of sea water was introduced by Petterson (1936). Improved models were presented by Johnson (1944), Joseph (1955) and Jerlov (1957). Except for a model constructed for fitting to the sounding wells of the German research ships (Joseph loc. sit.) the instruments were intended for submerged measurements at oceanographic stations.

In addition to its value in describing and separating different water masses as to their absorbance and scattering of light, the transparency measurements have shown to give useful indications of particle concentrations in the sea. Operating the instruments within the red range of the light spectrum, variations in light transmission are mainly due to different contents of suspended particles (Joseph 1955), the effect of dissolved organic matter like "yellow substances" being negligible (Jerlov 1957). In the waters of the North Sea, Joseph (loc. sit.) also observed a high correlation between the content of particulate organic matter and the extinction of red light and suggested the use of extinction measurements as a valuable aid in plankton density determinations.

Berge (1961) introduced a stationary, recording transparency meter with continous water feeding. The instrument was specially intended for tracing plankton density in oceanic waters, recording continously the red light transmission of the water at a depth of five meters. In a survey of the Norwegian Sea in 1958, the variations in the recorded transparency also demonstrated a close relation to simultanously observed values of the productivity per unit time and light. The transparency measurements were found satisfactory for superficial surveys of the productivity in highly productive areas like the Norwegian Sea, provided that they were evaluated in conjunction with selected measurements of the productivity.

The recording transparency meter has been used by the Institute of Marine Research for several plankton surveys. Results so far obtained on standing stock or productivity have been used in the studies of fish distribution and migration and have also been helpful in conjunction with other planktonic observations (Lie, 1961; Berge, 1961). A working description of the transparency meter together with examples of its use in planctology is given below.

DESCRIPTION

The water delivery system, (Fig. 1).

The water intake is a 1 1/4" tube which extends 50 cm below the bottom of the ship and is protected with a streamlined housing made of wood ①. This placement of the water intake has proven necessary in order

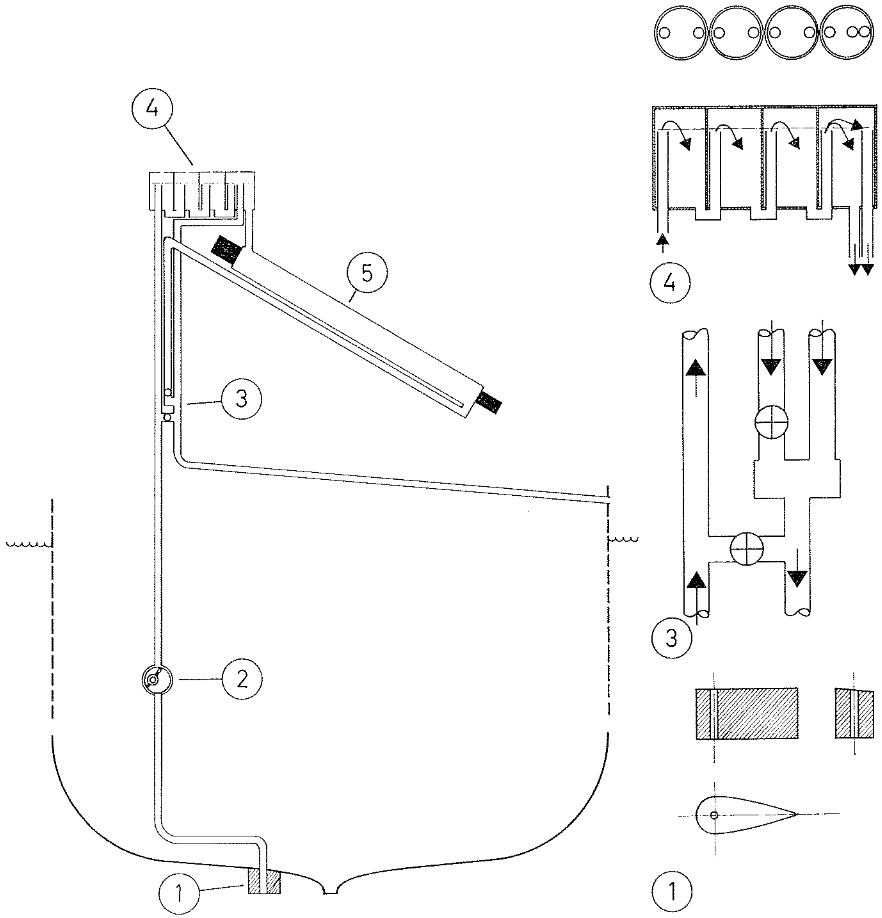

Fig. 1. Schematic illustration of the tranparency meter showing its placing relative to the ship hull and the sea surface. ① water inlet, ② screw pump (Monopump GH30), ③ by-pass and throttle valves, ④ bubble trap and overflow, ⑤ the cylinder with light source and detector at opposite ends.

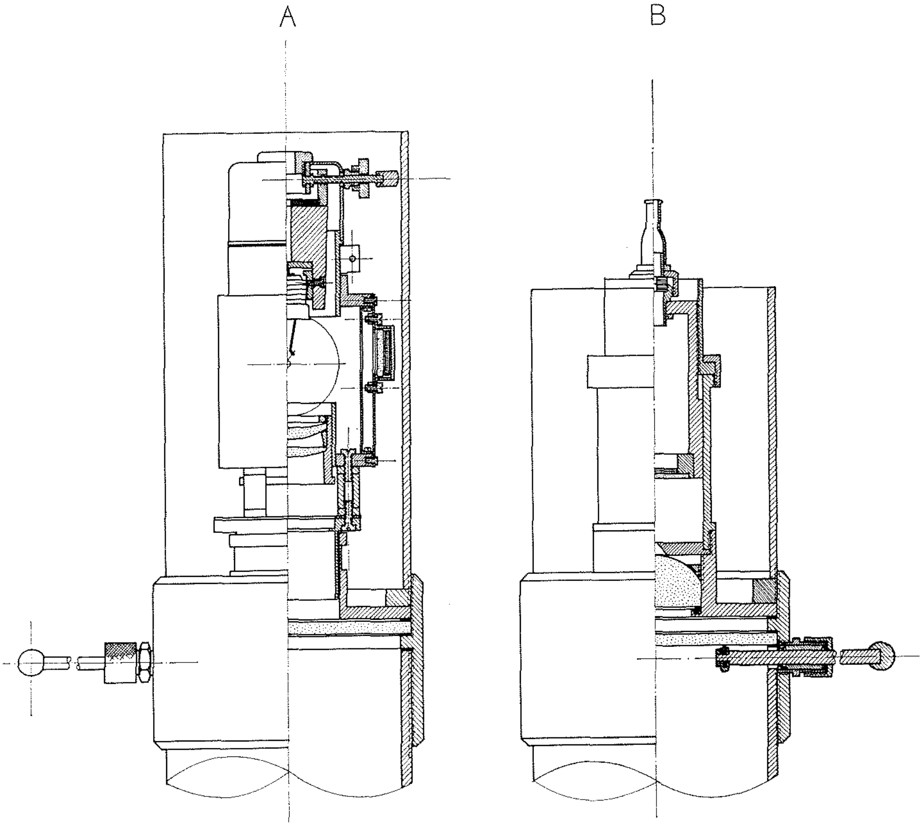

Fig. 2. The construction of the light source (left) and the light detector. A photo resistor for control of light stability is mounted on the side of the lamp housing. The figure also shows the connections of the units to the cylinder, and the window wipers.

to avoid the milky water due to the presence of minute air bubles which occasionally occurs close to the ship hull. Placed in the engine room below the water line, a screw pump with nylon stators (Monopump 1 1/4" type GH30) ② provides the supply of water to the transparency meter in the laboratory on deck. The capacity of the pump is approximately 40 l/min., but by means of a "by pass" ③ the water supply to the instrument can be reduced. A "bubble trap" ④ is placed before the entrance of water to the cylinder of the instrument to remove any air bubbles in the water. The trap allows the incoming water to come into contact with the atmosphere in a series of four chambers. This system has proven to be satisfactory if weather conditions and the stirring of the sea by waves are causing only moderate milkiness of the water.

From the "bubble trap" the water is siphoned through the transparency meter ⑤. The siphoning is regulated by a throttle ③ in such a way

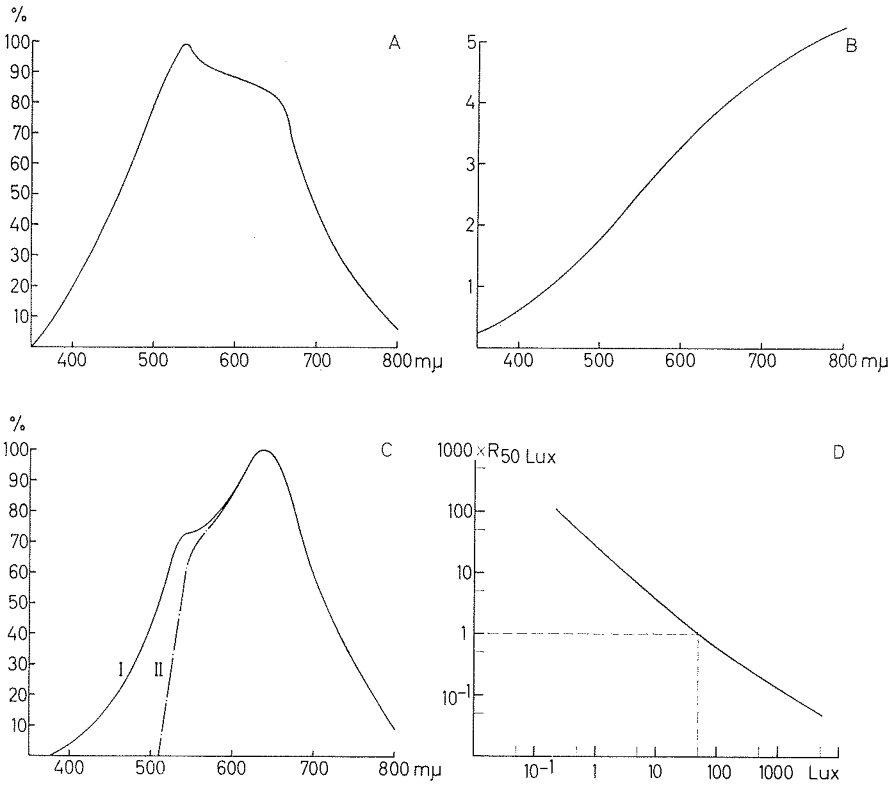

Fig. 3. Optical characteristics of the transparency meter. A) Spectral response of the PTW R III photo resistor. B) Spectral composition of the light source at 3100 K° C) Reaction spectrum of the transparency meter with the above photo detector and light source: I — without light filter, II — with Jena RGI filter. D) Response of the photo resistor to varying light intensities (I). The curve can closely be expressed by the equation: $\frac{R}{R_0} \approx I^{-f}$ where R_0 is the dark resistance and f a constant.

that the water transport through the instrument is less than the supply to the "bubble trap", the surplus water passing out through a second by-pass situated in the trap. Ordinarily the instrument is operated with a water supply of approximately 20 l/min.

A tap system on the "bubble trap" makes parallel sampling for other analyses possible, and the by-pass stream might also be used e.g. for net sampling of plankton. Except for the inlet walve, all tubes are made of alcathene plastic.

The transparency meter, (Fig. 1 and 2).

The cylinder, 1.5 m long and 10 cm in diameter, is made of clear perspex, closed at both ends by glass windows with waterproof gaskets.

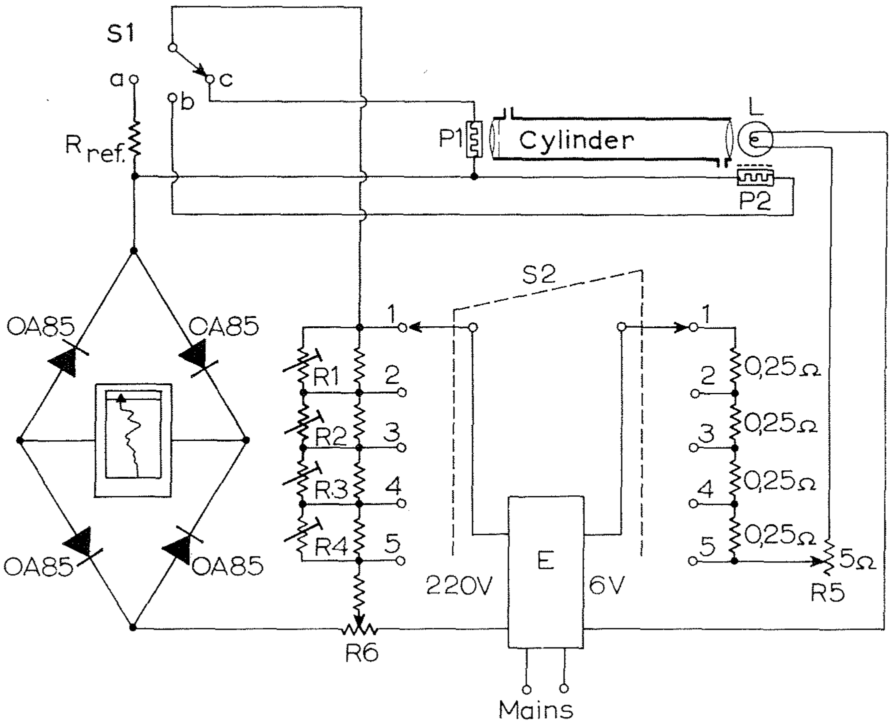

Fig. 4. The electronic circuit of the transparency meter. E stabilized a.c. power supply. L light source. P 1 photo detector. P 2 photo detector for control of light stability (adjustment at rheostat R5). R ref. reference resistor checking stability of the measuring circuit (adjustment at potentiometer R6). S 1 switch for selecting checkpoints (a and b) and automatic recording (c).

Its sloping position and the downward direction of the water current has been found suitable for reducing turbulent mixing and minimizing sedimentation of particles on the end window. Window wipers with waterproof fittings are mounted at both ends of the tube.

The light source (Fig. 2a) is an Osram 6 V, 5 A bulb in a Leitz Ortholux EUMZE housing. The spectral composition of its radiation at 3100° K (sensitivity range 5 on the instrument, Fig. 4) is given in Fig. 3b. A convex lens provides parallel light which can be accurately focused on the light detector by adjusting the movable lamp socket. A photo resistor for control of light stability is mounted on the lamp housing (Fig. 2a).

The light detector (Fig. 2b) consists of a convex lens, a pin hole diaphragma to remove non-parallel incident light and a PTW R III photo resistor. The spectral response of the photo resistor is shown in Fig. 3a. The sensitivity of the instrument with the above described light source will be in the red region of the spectrum (Fig. 3c I).

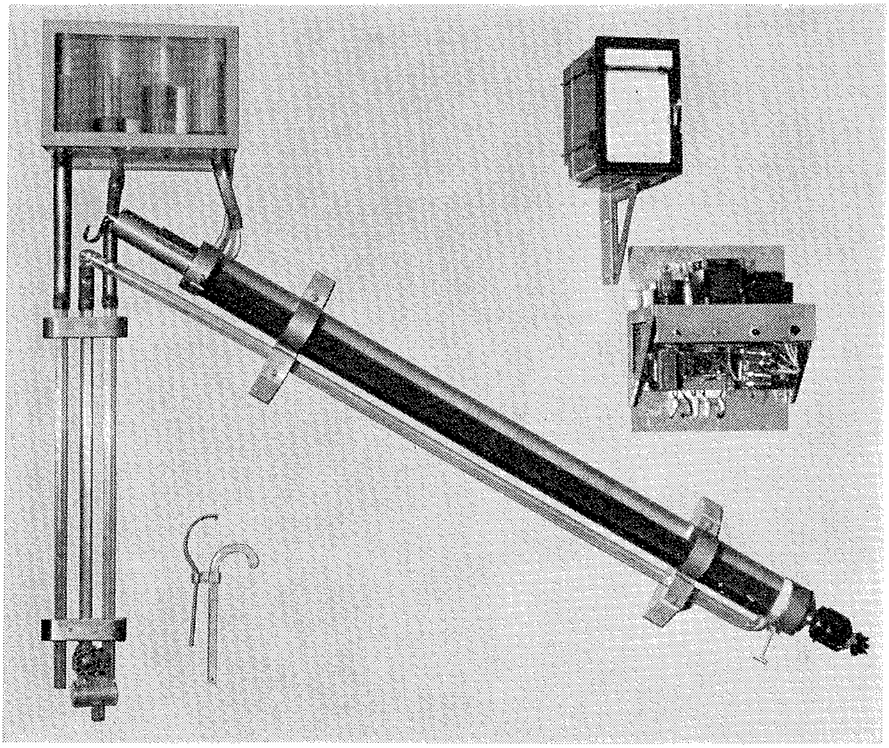

Fig. 5. A photograph showing the laboratory unit of a transparency meter made for FAO by Bergen Nautic.

Variations in the conductivity of the photo resistor, when the instrument is operated with a stabilized light source, are due to different transparency properties of the water. These variations are suitably recorded either by means of a millivolt potentiometric recorder or a bolomatic current recorder, connected to a full wave rectifying bridge, (D.C. currents tend to polarize the PTW R III photo resistors. Improved types of resistors without such tendencies are now available, however).

The response of the photo resistor to varying light intensities (Fig. 3d) demonstrates that the sensitivity of the instrument will be increased by a decrease in light. Different ranges of sensitivity can thus be obtained by an appropriate choice of the initial light intensity. In the present instrument five ranges have been obtained through four calibrated resistors which in turn can be switched in series with the light bulb. The electronics of the instrument is shown in Fig. 4.

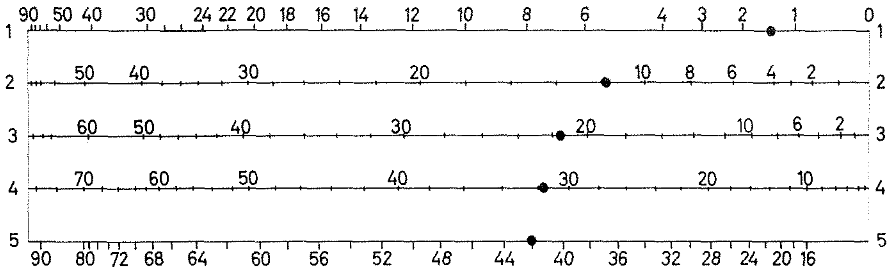

Fig. 6. Examples of the relative scales of partial extinction. Scale 1—5 corresponds to the 5 ranges of sensitivity in Fig. 4.

CALIBRATION

The primary aim with the present instrument is to record the effect (Δ a) on the extinction coefficient (a) by the suspended matter:

$$(1)\ \Delta a = a - a_0;$$

where a_0 refers to the extinction coefficient of the medium when free of particles. Accordingly, the response of the transparency meter to varying consentrations of hydrosols was determined emperically. Hydrosols were prepared from distilled water with varying additions from a freshly made stock suspension of black china ink in water ($E_{4mm} = 1.0$ at $\lambda = 575$ mμ). One ml of this suspension in 10 l of distilled water was given the value of one. Examples of the relative scales thus obtained for the 5 ranges of sensitivity on the instrument are shown in Fig. 6.

When using the transparency meter for the relative evaluation of plankton concentrations or productivity, the above standardisation should be satisfactory. From Beer's law, however, it follows that the relative units (n) of the recorder are related to the light transmission of the suspensoids (ΔT) the following way:

$$(1)\ \Delta T = \frac{I_n}{I_0} = e^{-a.n.l}$$

where a is the extinction coefficient of the unit and l the length of cylinder. I_n and I_0 are the light intensities transmitted by the suspension and the distilled water, respectively. By measuring the I_n of a suspension with the concentration n, and the I_0, ΔT as well as a can be determined. Such measurements have been made by replacing the photodetector with a selenium cell combined with a galvanometer. The responses on this instrument A_n and A_0 are proportional to the light intensities:

$$(2)\ \frac{A_n}{A_0} = \frac{I_n}{I_0} = \Delta T$$

Since (3) $\Delta T = e^{-\Delta a.1}$ it follows that $\Delta \mathrm{a} = \alpha.n$. The relative units on the scales can thus be converted to the difference in extinction coefficient between the sample and distilled water.

EXAMPLES OF RECORDINGS

In Fig. 7 selected examples of recordings obtained by the transparency meter in a survey of the Icelandic Sea with R/V "Johan Hjort" are presented. The recordings are given in relative units of particle concentration (n). Large variations are revealed in some areas (Fig. 7c), whereas other areas demonstrate a rather even particle distribution (Fig. 7b). Based on recordings from a network of sections (Fig. 7a) a survey map of the Icelandic Sea was made. 45 chlorophyll measurements spread over the whole area and sampled from the transparency meter, were compared with the recordings. A high correlation factor of 0.81 was demonstrated (Berge—Rossi, unpublished).

DISCUSSION

The transparency meter has worked well in continous operation on cruises of up to four weeks duration. Regular use of the window wipers and inspection of the electronic and light stability using the control switches is the only attention required. In bad weather a reduction in the water flow might be necessary to secure a full clearing of the water entering the cylinder. With this precaution observations have been obtained in weather conditions where outdoor instrumentation would have failed.

The system of pumping water into the transparency meter causes a delay between intake and recording as the ship proceeds. By placing a by-pass system close to the transparency meter and using the full capacity of the pump, the delay has been minimized to correspond to a displacement of approximately 150 m. Also, due to mixing in the system, a smoothing of minor variations in the transmission properties of the water will occur. The details thus lost are assumed to be of minor interest for general oceanic surveys.

The nearly inverse relationship between the response to the light intensities (Fig. 3d), makes the photo resistor specially suited for transparency measurements, resulting in nearly equal responses to differences in the transmission in turbid as well as clear water. By selecting the appropriate initial light, any suited range of sensitivity can be very simply obtained. Interchangeable ranges can be introduced stepwise using neutral filters of various densities. However, a more convenient operation has been obtained by the electrical reduction of the lamp

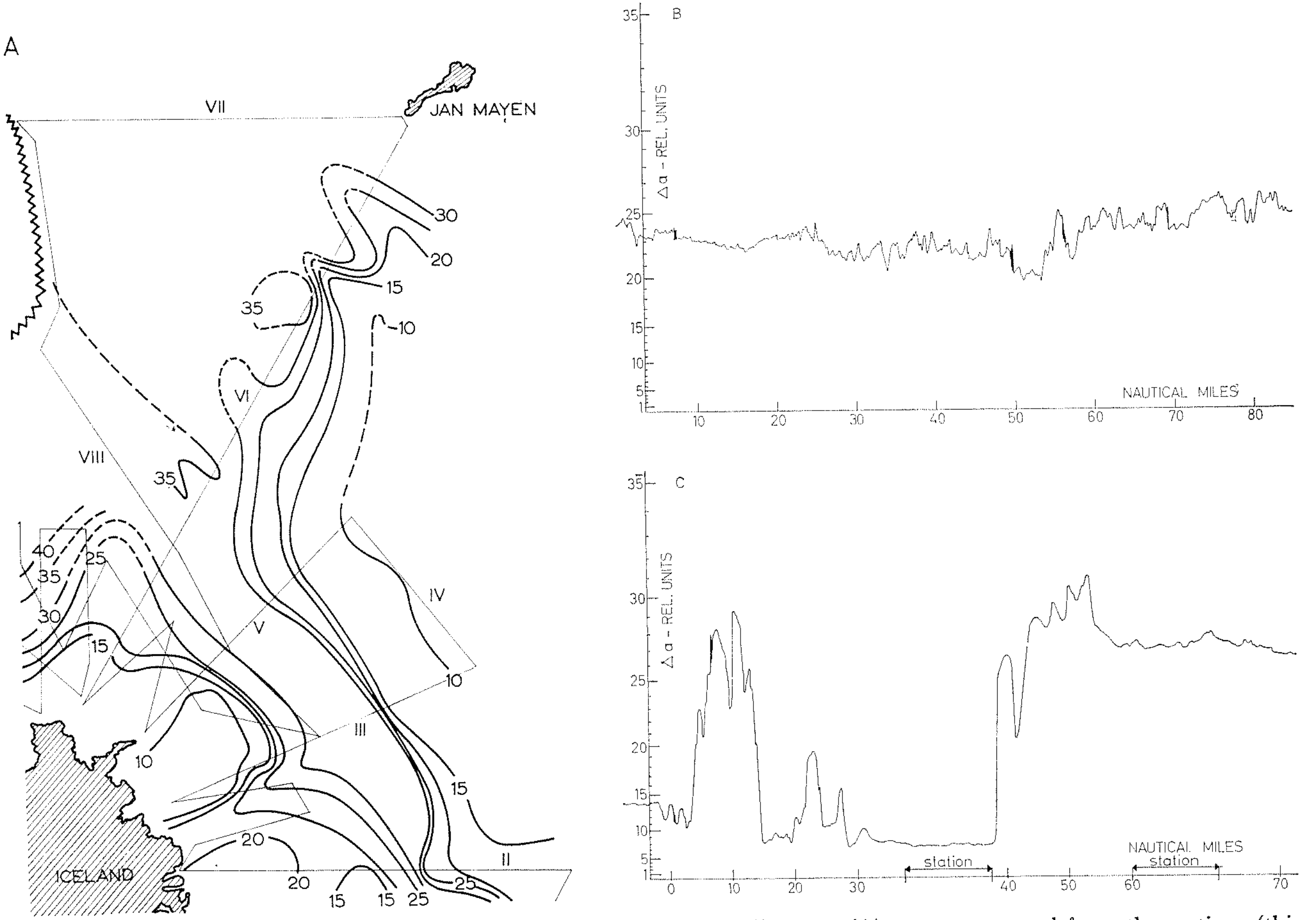

Fig. 7. Examples of a transparency meter survey of the Icelandic Sea. The map (A) was constructed from the sections (thin streight lines). In b and c selected examples of recordings are given to illustrate rather even (B) and uneven (C) distributio of particles.

current as shown in Fig. 5. The method involves a slight change in the light spectrum according to the temperature of the lamp filament. This change does not, however, seriously affect the spectral sensitivity of the instrument, the maximum peak at 645 mμ (Fig. 3c) being retained.

The calibration of the instrument as shown might easily be made using suitable absorbing solubles in known concentrations (Glover 1956). Since the scattering matrix of the suspended particles in the sea deviates from such solubles, a more valid calibration for particle tracing was assumed to be obtained by using suspensions similar to the actual particles in the sea as obsorbant. Lenoble (1961) used black colored polyvinyl chloride and acetate in water in reproducing the forward scattering of sea water, the hydrosols thus obtained containing even spherical particles varying in sizes between 0.2μ—75μ. China ink in water was assumed to be suitable for the special purposes required here, the ink forming uneven particles varying in sizes between 2μ—170μ, thus reproducing in size the dominating phytoplankton species in the Norwegian Sea (Paasche 1961).

With the spectral response curve obtained using the Osram 8110 bulb and the PTW photo resistor (Fig. 3c), the instrument will be negligably affected by the yellow substances according to the absorbance curve shown by Jerlow (1957). The pronounced sensitivity maximum at $\lambda = 645$ mμ, corresponds closely to the absorbance maximum by chloroplastic pigments present in the euphotic zone of the sea (Yentsch 1962) and thus increases the response of the instrument to autotrophic phytoplankton as compared with the main bulk of other particles present in the sea water.

The high correlations between transparency recordings and plankton concentrations observed in the Norwegian Sea, indicates that variations in Δ a recorded are mainly due to variations in the density of phytoplankton. The validity of the transparency recordings in plankton density indications is further supported by the close correlations with particulate organic matter observed by Joseph (1955). In coastal waters, estuaries with melting ice and areas with upwelling waters etc., the recordings will often probably be dominated by variations in inorganic particles similar to the findings by Wyrtki (1961) in the Coral and Solomon Seas, and as demonstrated by Joseph (loc. sit.) in selected localities of the North Sea.

It is concluded, however, that when properly used in connection with conventional methods of plankton determination, the transparency meter will afford detailed information about the relative density of phytoplankton, as well as primary productivity (Berge 1961). As demonstrated by the recordings in Fig. 6, the continuous information thus obtained reveals variations and details which would have been lost by conventional point observations.

The convenient handling of the transparency meter and the large volume of data which becomes available make the instrument specially suitable for area surveys in fisheries oceanography.

ACKNOWLEDGEMENT

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Some Technological Aspects of the Norwegian Tuna Purse Seining Fishery

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INTRODUCTION

Purse seining for tuna on a large scale has in recent years been developed on the Pacific coast of the United States. Although the purse seine technique was introduced in the previous century and has been applied for catching tuna species both in Japan and the United States for several years, this gear has until recently played an unimportant part in the tuna fisheries of the world. The success in the later years of the U. S. purse seiners converted from tuna clippers has been described by McNelly (1961). According to McNelly the new fishing method was developed so rapidly that it attained the character of a revolution in the fishery. As the primary causes for this development, McNelly points to (1) the adoption by the fishing fleet of synthetic twines, (2) the advent of the Puretic power block, (3) the use of aircraft in locating fish, and (4) possible favourable oceanographic conditions influencing availability of fish.

In the present paper an account of the development of the Norwegian tuna fishery is given, including a brief description of the purse seine method used at present, and a consideration on its efficiency compared to the American technique.

THE DEVELOPMENT OF THE NORWEGIAN TUNA FISHERY

The bluefin tuna (*Thunnus thynnus* L.) is the only tuna species occurring regularly in Norwegian waters. The fishery takes place from the beginning of July to the middle of October. Only adult tuna are caught, ranging from 30—400 kg (Hamre, 1960).

Up to 1920, Norwegian fishermen caught tuna with angling gear and hand harpoon. These gears were not very efficient, and the catch was quite insignificant. It was obvious that with the available gears the tuna stock could only be poorly exploited by the Norwegian fishermen, and in the late twenties intensive experiments to improve the methods of catching tuna were executed. As a first step the hand harpoon was modified to be fired from a gun, and the tuna harpoongun resulted in the first regular tuna fishery in Norwegian waters. According to Hanson (1958), nearly 200 small boats were hunting tuna on the Norwegian west coast during the late twenties, but the yearly catch amounted to only about 100 tons.

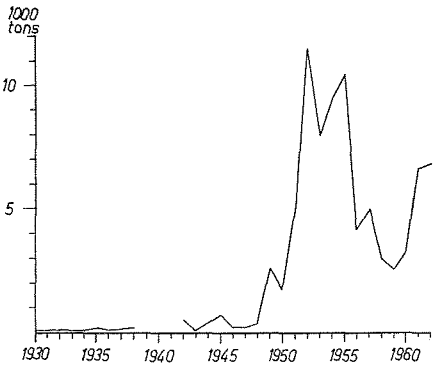

Fig. 1. Norwegian bluefin tuna catches 1930—1962 in 1,000 tons of gutted weight.

It required, however, a very high degree of marksmanship to hit this swift and rowing game fish, and from a commercial point of view the harpoon gun fell short of expectations. It was realized that other ways had to be sought for a rational utilization of the tuna resources, and it seemed natural to explore the possibilities of the purse seine technique. The idea of catching tuna with purse seine had been worked upon since the late twenties, but the experiments executed before the last World War had been rather discouraging. The difficulties were to construct a net which could hold the fish and at the same time be managable for fishing operation. It took about twenty years to work out the problem of combining necessary strength with sufficient net size, but the successful results obtained in the late forties caused a rapid expansion in the Norwegian tuna fishery (Fig. 1). Actually, what led to the final solution of the technical problems involved in constructing the tuna purse seine was the significant observation that the bluefin try to avoid net walls irrespective of whether the meshes are small or large and the twine flimsy or heavy, at least within very wide limits.

DESCRIPTION OF THE NET

The Norwegian tuna purse seine is an one-boat net and consists of two main parts, the wing and the bunt with a transition section in between (Fig. 2). The wing, which constitutes the longest part of the net, is made of very light material as its only function is to make it possible to encircle the fish schools. In the bunt, which is the final section left in the water after pursing and hauling in, the twine is considerably heavier, having sufficient strength to prevent the tuna to penetrate the webbing when drying up the fish.

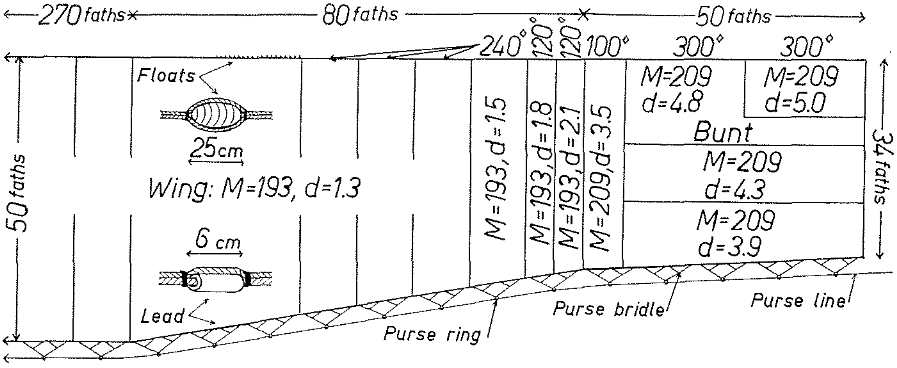

Fig. 2. Diagrammatic presentation of Norwegian tuna purse seine. ⟨⟩: meshes, M: mesh size, d: diametre of twine (in millimetres).

The wing is constructed by lacing together vertical strips of 240 meshes each. These are laced to the cork- and leadline selvedge strips which is hung-in about 60 % to the corkline, and some percent less to the leadline. In the first nets the webbing was made of hemp, which was later changed to cotton twine. At present, the fishermen are on the point of changing from cotton to nylon. In most of the nets in use the bunt is made of nylon, while cotton twine is still used in the wing.

The cork- and leadline are made up of double 12 mm diameter terylene ropes. Plastic floats are laced in between the corkline ropes. 12 mm terylene rope is also used for purse-ring bridles, one pursering for every 10 fathoms leadline is the usual ring density. The lead-weight on a 400 fathoms net is about 1200 kg, including the purse rings. 10 mm diameter stainless steel wire serves as purse line.

Actually, the nets in use differ with respect to details of construction, especially regarding the size of the nets. The original tuna purse seines were about 200 fathoms long and 30 fathoms deep. Improvements in handling technique and net materials have, however, made it possible to increase the net size considerably and the average size at present is roughly some 400 fathoms long and 50 fathoms deep. The increase in net size has been most spectacular in the wing, and nets are frequently enlarged by adding some strips of webbing each year. The length of the bunt, which is now about 50 fathoms in most of the nets seems to be of sufficient size for catching the biggest tuna schools occurring in Norwegian waters. The maximum catch in one shot was 91.5 tons (71.2 tons gutted weight).

THE FISHING OPERATIONS

The boats used for tuna purse seining are of the conventional type of medium size Norwegian fishing boats, with pilot house and engine room situated in the stern. On the aft deck is made space for the purse seine. The boats have no refrigerating system, the fish being delivered immediately after catching. On the average the seiners are about 70 feet long, the speed ranging from 8 to 12 knots. Most of the boats are built of wood, but during recent years several steel vessels have been added to the tuna fleet.

The seine skiffs measure approximately 18 feet in length, having engines of some 20 horsepower. When searching for tuna, the skiff is towed by the seiner. An additional powered boat of similar size as the skiff assists in towing on the corkline when the net is shot in order to hold the net open. If the net closes in, the fish will penetrate the light webbing of the wing. This assistance boat is carried on the main deck of the seiner, and comes into use when making successful shots only. A special towing boat of some 40 feet in length operates together with the seiner. Such boats are called "helpers" (Norwegian: hjelper) and its main task is to keep the seiner square with the shot net and from being pulled into the center of the net by the pursing operation. Furthermore, the helper assists in spotting fish, keeping in continuous radio contact with the seiner. Thus the tuna operation units consist of 4 boats, with a crew of 10 or 11 men.

All seiners are equipped with echo sounders, and a few with asdic. These fish-detecting instruments have, however, so far been of secondary importance in locating tuna schools, the fish being caught only when

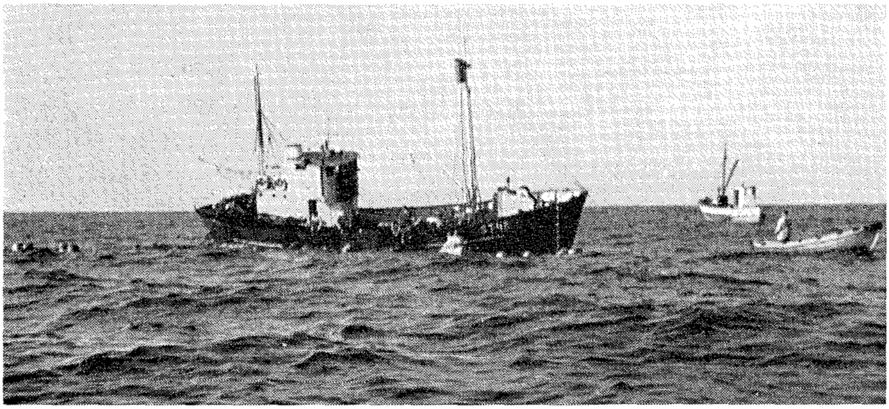

Fig. 3. Norwegian tuna seiner in action.

spotted at the surface. When operating on the tuna grounds, one or two mast-men, situated in a "crow's nest" at the top of the mast, are continuously searching for signs of tuna. Other members of the crew take positions at the roof of the pilot house, in the bow, or other suitable places for spotting fish. By radio contact with other tuna seiners the skipper keeps himself informed of the general situation with respect to fish concentration and the availability of the fish on various grounds.

The visibility of the tuna schools is closely related to the behaviour of the fish. Early in the season the fish are commonly observed swimming close to the surface, often without breaking the surface level. Under such circumstances the only tuna sign may be some rippling on the water or a little change in the colour of the sea. Using an American expression, such schools may be termed breezing schools (Norwegian: stripeflak). It requires a high degree of observation faculty to locate a breezing school, and the fishermen which are clever in spotting tuna, have great advantages in the competition on the tuna fishing grounds in the early season when fish spotting constitutes a very important part of the operation.

Later in the season the tuna changes its behaviour pattern, usually in late August, with the appearance of what the fishermen call a tuna knot. In the tuna knots the fish hunts its prey with great violence, making sea-spray as if it was a breaker. Very often such schools are marked by a cloud of gulls feeding upon the prey struck senseless by the tuna tails. In the case of tuna knots, the presence of the schools can be observed from several miles off.

When approaching a located school, the fishermen take their action stations for the shooting of the net. If the school is moving, the skipper must determine its speed and direction. This is important for the encircling maneuver. The net is shot at the maximum speed either in an approximate circle or in an elliptical curve, depending upon the movement of the school. To complete the encircling maneuver of the fish it often becomes necessary to use a net towing line and excess purseline. In such cases the fish is kept away from the open section of the net by fish scaring maneuvers of the skiff and the towing boat and by dropping calcium carbide into the sea where the fish have chances to escape.

The net is shot to starboard, and it takes about 3 minutes to shoot a 400 fathoms net. When the pursing is started, the helper begins its towing operations on the larboard side of the seiner. The skiff attaches a towing line to the corkline in the area between the bunt and the wing, and tows in the opposite direction of the helper in order to stretch the net out. To purse the net takes less than 10 minutes. If the shot is successful the boat on deck is put to sea for assisting the skiff in keeping the net open.

Up to 1960 the seiners used long rollers with mechanical drive for hauling in the net. These have now in most cases been replaced by hydraulic power blocks or by rollers of similar construction (Maloruller), which have reduced the hauling time of the net from about one to half an hour. When the light net has been hauled in, the towing on the net is stopped, and the skiff and the deck boat are laced on to the corkline. Big plastic balloon floats are attached to the webbing about one fathom under the corkline as an additional prevention against submersion of the corkline when drying up the fish. This is accomplished by using winch power, strapping aboard the heavy bunt webbing sectionally. Owing to lack of oxygen, the fish die quickly and are transferred to the seiner by using slings around the tails of the fish and hoisting them aboard in groups of 2 to 5 fishes.

THE SINKING VELOCITY AND THE OPERATION DEPTH OF THE NET

Employing a bathykymograph developed by Hester (1961), the sinking velocity and operation depth of a Norwegian tuna purse seine were tested in September 1962. This particular purse seine was of similar size and construction to that described above as a typical net. The instrument was attached to the leadline at the middle purse ring, and the result of the test is shown in Fig. 4 (N). The diagram shows the depth of the instrument at all times from entering the water until completion of the pursing operation.

From the time the instrument entered the water until pursing was started was 2 minutes. At that time the bottom of the net had reached a depth of 23 fathoms. The sinking velocity decreases very slightly before pursing but when this process starts the sinking velocity decreases rapidly, being reduced to zero after some two minutes pursing. The maximum depth reached by the instrument is $28\frac{1}{2}$ fathoms.

For comparison, corresponding tests of an American tuna purse seine are included in Fig. 4 ($U_1 : U_2$) (Hester, 1961). According to Hester these tests were made by attaching a bathykymograph to the leadline near half-net, the net measuring 435 fathoms in length and 43 fathoms in depth. The weight of the leadline including bridles and rings was about 7 tons (personal information). To shoot the half net took 1.5 minutes, which means that pursing starts about two minutes after the instrument entered the water. The two sets were made under different circumstances. The trace U_1 represents a set when wind and current were tending to drive the boat and the net apart, and U_2 when the boat

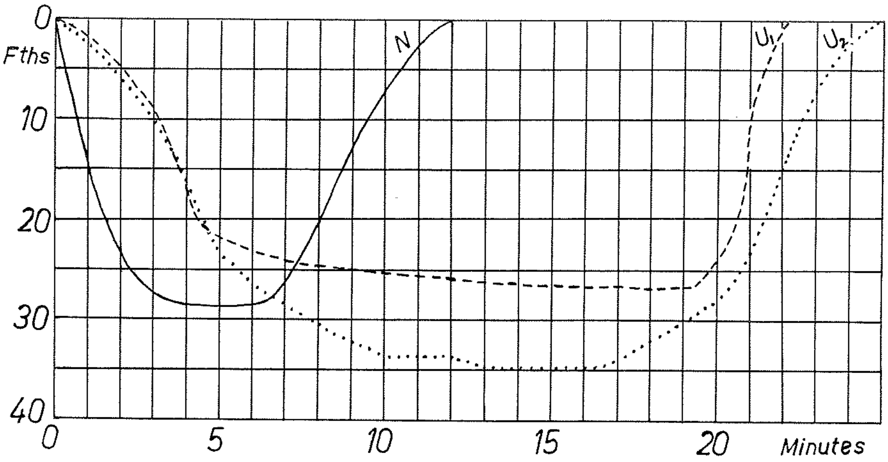

Fig. 4. Traces showing vertical movements of the leadline of tuna seines. N: Norwegian type, U: U.S.A. type. For further explanation see text.

drifted into the net. Concerning the conditions under which the Norwegian net was tested, the current and wind acted as in the case of U_2, but the helper prevented the seiner from drifting into the net.

From Fig. 4 it is evident that considerable differences exist between these two types of net with regard to sinking velocity and time used in pursing the nets. Although the "lead weight" per fathom of an American net is nearly 5 times that of the Norwegian one, the latter sinks with an average speed nearly 4 times greater in the time interval before pursing has been started. The time required to purse the Norwegian net is about half of that of the American one.

SOME THEORETICAL CONSIDERATIONS ON NET CONSTRUCTIONS

The size of a purse seine on the square of the net in action is determined by the length of the net, the depth, and the ratio of hanging. The length is usually given by the length of the corkline. The depth is either referred to as the number of meshes together with the mesh size used in the webbing, or it may be given as the depth of the net when the meshes are stretched vertically. The ratio of hanging may be expressed as the length of line divided by the length of stretched webbing. The ratio is termed the hanging coefficient (ϱ_1):

$$\varrho_1 = \frac{l_c}{l_w} = \frac{p}{100} \qquad (1)$$

where l_c is the length of the line and l_w the length of the stretched webbing. p is termed the percent of hanging. A more commonly accepted expression of hanging a net is the ratio:

$$\frac{l_w - l_c}{l_w} \cdot 100 = P \qquad (2)$$

P is termed the "percent of hanging-in", or the "looseness percent of hanging". From (1) and (2) it follows that $P = 100 - p$, i. e. P is the complementary value of p (Lusyne, 1959).

The effective depth of a purse seine depends upon, apart from the given depth, the hanging ratio of the webbing. If D is the given depth, i. e. the depth of vertically stretched meshes, one has:

$$D = n \cdot 2a \qquad (3)$$

where n means number of meshes and a the length of the mesh bars. In hanging the netting to the corkline, the shape of the meshes depend upon the hanging ratio so that if 2φ is the angle between the mesh bars, the following equation is obtained (see Fig. 5):

$$\cos \varphi = \varrho_1 = \frac{100 - P}{100} \qquad (4)$$

The height of one mesh is $2a \, . \sin \varphi$, and multiplying by n gives the actual depth of the net (D'):

$$D' = n \cdot 2a \cdot \sin \varphi = D \, . \sin \varphi$$

or

$$\sin \varphi = \varrho_2 \qquad (5)$$

where $\varrho_2 = \frac{D'}{D}$; ϱ_2 may be termed the "actual depth coefficient" of the net. Since $\cos^2 \varphi + \sin^2 \varphi = 1$, it follows from (4) and (5):

$$\varrho_1^2 + \varrho_2^2 = 1 \qquad (6)$$

This simple circle equation shows the relationship between the hanging coefficient and the coefficient of the actual depth. A graphical illu- stration of the equation is given in Fig. 6. Corresponding P-values are noted on the ϱ_1-axis.

The square of filtering area of one mesh is $2a^2 \cdot \varrho_1 \cdot \varrho_2$ (Fig. 5).

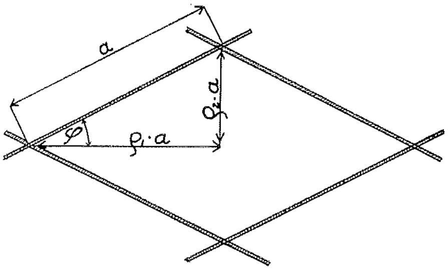

Fig. 5. Mesh diagram. ϱ_1: coefficient of hanging, ϱ_2: coefficient of actual depth, a: mesh bar.

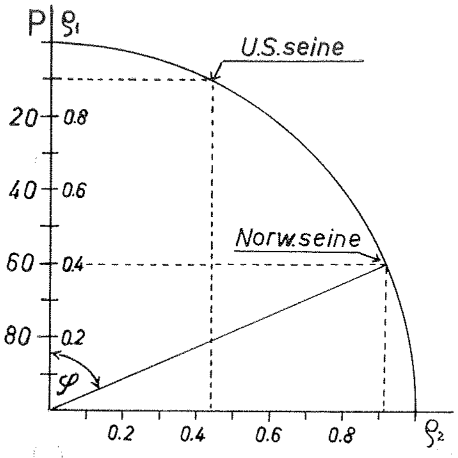

Fig. 6. Diagram showing the relationship between the coefficient of hanging (ϱ_1) and the coefficient of actual depth (ϱ_2). P denotes the hang-in percent, φ half the angle between the mesh bars.

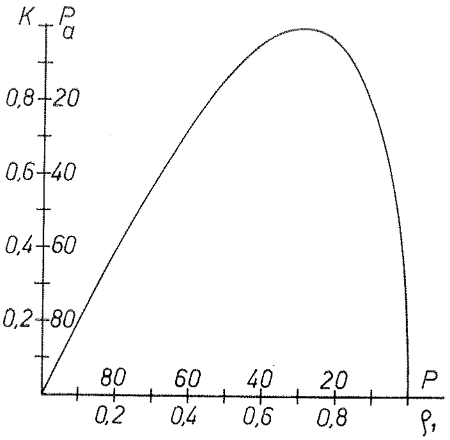

Fig. 7. Diagram of the filtering area of webbing. For explanation see text.

The filtering area (A) of a plane net, *n* meshes deep and *n*' meshes long is:

$$A = n \cdot n' \cdot 2a^2 \cdot \varrho_1 \cdot \varrho_2 \qquad (7)$$

and from (6) and (7) is obtained:

$$K = 2\varrho_1 \cdot \sqrt{1 - \varrho_1{}^2} \qquad (8)$$

where $K = \dfrac{A}{\mathrm{n} \cdot n' \cdot a^2}$ is the ratio between the filtering area of a net with hanging coefficient ϱ_1 and the filtering area of a net with square meshes ($\varrho_1 = 0.7071$, $P = 29.3\%$). K is termed the filtering coefficient of webbing. It equals 1 for $P = 29.3\ \%$ and decreases for higher and lower values of P. The variation in K as a function of ϱ_1 (or P) is shown in Fig. 7. The P_a values give the percent of area lost for P-values $\lesseqgtr 29.3\ \%$ $\left(K = \dfrac{100 - P_a}{100}\right)$, and may be termed the "area looseness percent".

A purse seine in action undergoes a change in shape owing to the forces acting on the net during the operation. The stress of the leadline which cause the net to sink is transmitted through the netting along the mesh bars, the direction of which depend upon the shape of the mesh. Decomponating a force F acting along one bar, the horizontal (F_H) and vertical component (F_V) of the force are as follows (Fig. 5):

$$F_H = F \cdot \cos\varphi = F \cdot \varrho_1 \qquad (9)$$

$$F_V = F \cdot \sin \varphi = F \cdot \varrho_2 \tag{10}$$

The horizontal stress component of the weight put on the leadline is proportional to the hanging coefficient, and thus decreases with increasing P. The component causes a lateral movement in the flexible net, which has the same effect on the length/actual depth ratio as increasing P. This means that when the net is shot in a circle, the circumference of the net selvedges decreases (the lines make turns) but the net will gain depth proportionally to the increment in P, as illustrated in Fig. 6.

The change in shape caused by the pursing operation is far greater and more complicated than that caused by the horizontal stress component. During pursing the decreasing circumference of the bottom selvedge makes the net deeper, which contributes to make the bottom in the net. The curvature of the net wall is, however, influenced by several factors, the most important are the length/actual depth ratio and the depth in which the net is pursed. The latter varies with the sinking velocity and the speed of pursing (Iitaka, 1955).

The resistance of webbing to sea current has been studied by several investigators, and a recent review has been given by Kawakami (1959). According to Kawakami, the resistance (R) varies proportionally to the area of the webbing and approximately proportionally to the square of the current velocity (u):

$$R = c \cdot A \cdot u^2 \tag{11}$$

where c is a coefficient depending upon the length and the diameter of the mesh bars, the twine, and the angle φ. c is found to be proportional to the area of the webbing projected on the plane perpendicular to the direction of the current. When the current is acting perpendicularly to the net plane, the value of c has its minimum for square meshes, $\varphi = 45°$, and increases for higher and lower values of φ.

DISCUSSION

The combination of a short but strong bunt with a long wing made of very light material has enabled the Norwegian fishermen to construct a tuna purse seine strong enough to hold a giant bluefin and at the same time be manageable for the fishing operation. The function of the wing is to encircle the fish and guide them into the bunt, in which the killing of the tuna can be executed. The catching principle is thus very similar to the technique upon which the tuna traps are founded. The wing corresponds to the guiding net of the traps, the bunt to the "death-chamber".

Before the nylon twine was introduced in the bunt, the fishermen had difficulties in handling the biggest catches, particularly in rough weather, and it happened that the webbing of the bunt was broken by the heavy weight, and the whole catch lost. With the change to nylon twine in the bunt this difficulty has been overcome. However, the greatest improvement in the catching efficiency of the net in recent years has been obtained by increasing the size and the handling speed of the wing section.

Actually, the size or filtering area of the tuna nets carried by the small Norwegian seiners are more than twice than that of an American net, owing to the higher hanging-in percent. According to McNelly (1961) the American tuna nets are hung-in about 10 %, which correspond to an actual depth coefficient (ϱ_2) of 0.44. For the Norwegian net ϱ_2 is 0.92 (Fig. 6). The American net tested by Hester (1961) has thus an actual depth of about 19 fathoms, its filtering area being approximately 8250 square fathoms. The corresponding figures of the wing of the net described in this paper are 46 fathoms (at half net) and 15500 square fathoms, the transition section included. Including the bunt, which is hung in about 38 %, the total filtering area of the Norwegian net becomes about 16,900 square fathoms. It should, however, be noted that due to the deformation of the nets in action, the American net will gain filtering area ($P < 29.3$ %), whereas the Norwegian net will loose area, probably very rapidly, as the pursing proceeds, owing to the high hang-in percent (Fig. 7).

As a matter of fact, 60 % hang-in is a very unrational hanging ratio. The loss of area when P equals 60 % is 26.6 % (Fig. 7), or about 5600 square fathoms in the wing and the transition section of the net shown in Fig. 4. For each percent increase in $P > 60$ % the increment in P_a is nearly 1.9 %. However, the deformation of the net, caused by the pursing operation which decreases the bottom selvedge mainly, makes the calculation of P_a more complicated than in the case of a plane net. It is, nevertheless, obvious that the pursing will decrease the filtering area proportionately to the hang-in percent of the bottom selvedge strip. An additional disadvantage is that the resistance coefficient of the webbing increases for P-values greater than 29.3 % (11).

Apart from size, the catching capacity of a purse net is mainly determined by the operational speed and the sinking velocity. The operational speed (shooting and pursing) decides the chanches of encircling, and the sinking velocity the chanches of preventing vertical escape. The time used to shoot the net has been reduced by introducing faster moving seiners, the average shooting speed is at present about 8—10 knots. With regard to the sinking velocity and the time of pursing, it becomes evident from Fig. 4 that the Norwegian seine leaves the fish a far lesser chance to escape than does the American type. This is mainly a result of the difference in the design of the nets. With respect to the vertical movement of the bottom margin the most obvious reason for the fast sinking of the Norwegian net is the small resistance of the light webbing used in that net (11). Another factor which may influence the sinking velocity in disfavour of the American type, is the difference in P. It seems likely that for so small values of P as 10 %, the horizontal stress-component (9) is considerable even before the net is stretched out, so that a part of the "lead-power" contributes to the deformation of the net before it has reached its actual depth. This suggestion is corroborated by the variation in depth between the two traces U_1 and U_2 (Fig. 4). As the wind and current in the case of U_1 drove the net and boat apart, this should result in a considerable stress on the corkline in a direction opposite to the horizontal stress component of the lead-weight. The trace U_1 indicates that the net was stretched out in a depth of 20 fathoms, and taking into account the influence of pursing, it seems fair to conclude that no active F_H can be recognised. However, if the latter force is active before the net is stretched out vertically and the stress on the corkline is removed, this should result in a change in the sinking trace similar to trace U_2. According to Hester, it was also observed that towing with the skiff when the net was being laid out caused the bunt to sink more slowly. The towing with the skiff will result in a similar stress on the corkline as in the case of U_1. Both observations indicate that small P-values may reduce the sinking velocity of a flexible net.

The light webbing used by the Norwegians is also an important factor in reducing the pursing time. Another important factor favouring the Norwegian type is the smaller length/actual depth ratio. By model experiments with a Japanese sardine purse seine, Iitaka (1955) found that when pursing the net before it had reached its actual depth, the stress on the purseline was insignificant compared to what it was after this depth was reached or when the net was streched out. The excess webbing, as a result of the difference between the actual depth and the operational depth contributes to make the bottom in the net when pursed. As long as excess webbing is left, the sea current force caused by pursing is acting in the net plane mainly, and consequently the resistance against the movement is relatively low. As soon as the excess webbing is consumed, however, further pursing produce a resistance force component acting perpendicularly to the net plane and consequently increases the stress on the purse-line (11). For the same operational depth a shallow net such as the American one in which the length/actual depth ratio is 100 : 4.4, requires therefore much more power to be closed than does net of the Norwegian type where the ratio is 100 : 11.5, even if they were made of the same material. In this connection it may be mentioned that in the Japanese tuna nets the length/actual depth ratio is about 100 : 13, using 20 %—30 % hanging-in (Takayama, 1962).

The most evident disadvantage of the Norwegian net construction is the low breaking strength of the webbing in the wing. It can only be used for catching fish species which shun a net wall, and it must be handled with the greatest care during the operation. In spite of the highest attention paid in removing things which may tear the light webbing, it happens that parts of the nets are broken during shooting and pursing. Sharks and other animals occurring together with the tuna often penetrate the net, making holes in the wing and the transition section. The operation requires high towing capacity because the greatest care must be taken in keeping the net open and in preventing the seiner from drifting into the net. Finally, this net construction does not allow separation of a big catch into batches, as can be done with a net construction as the American one (McNelly, 1961).

The object in choice of net design is to obtain the largest catching capacity of the net for the smallest coast of material and power requirement under actual fishing conditions. For the fisherman, an approach in the direction of a more rational gear involves a better income, and he has consequently been the driving force behind the development of the purse seine constructions and in the purse seining technique. Although the complexity of problems connected with the working pattern of a purse seine cannot be solved on a mathematical basis only, theoretical investigations on the behaviour of webbing may be a valuable tool. The calculation, for example, that more than 25 % of the webbing area in a Norwegian tuna purse seine seems not to be properly used, has unveiled a probable disadvantage in the net construction, and a more rational net may be obtained by changing the hanging ratio. This may also reduce the resistance of the net to current and motion caused by pursing (11). For keeping the actual depth unchanged, one can calculate that 15 fathoms of stretched meshes will have to be added to a 50 fathom deep net if the hung-in percent was reduced from 60 % to 30 %. However, the reduction in the hang-in percent will lead to changes in the stress components of the webbing [(9) and (10)]. How this may influence the working pattern of the net can only be found from experimental data.

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Studies of the dissolved organic compounds in the sea

A preliminary report on the isolation, separation and identification of free amino acids

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INTRODUCTION

The nature of the dissolved organic compounds in the sea is a subject about which relatively little is known and, as Vallentyne (1957) has pointed out, is one that is just beginning to be explored. The major difficulty in isolating these compounds arises from the great preponderence of inorganic salts in sea water. Thus, from the values of Duursma (1960) for Norwegian Sea coastal water (dissolved organic carbon 1.0 mg/l, dissolved organic nitrogen 0.1 mg/l), the ratio of inorganic salt: dissolved organic carbon is approximately 35,000 : 1 and the ratio of inorganic salt: dissolved organic nitrogen is approximately 350,000 : 1.

A few reports have recently appeared which describe the isolation and identification of various dissolved organic compounds in sea water. Jeffrey and Hood (1958) have evaluated and discussed a number of methods for the analysis of organic matter in sea water. Slowey *et al.* (1959) made use of ethyl acetate extraction, methylation and gas chromatography in a study of fatty acids in sea water.

Tatsumoto *et al.* (1961), using co-precipitation with ferric hydroxide as described by Jeffrey and Hood (1958) followed by paper and column chromatography, found 18 amino acids in four hydrolyzed samples of surface sea water. Park *et al.* (1962), using the same procedure, found 17 amino acids in deep-sea water samples and also found that the concentrations of amino acids in a hydrolyzed sample were about three times greater than in an identical unhydrolyzed sample. They did not state, however, whether the free amino acids were isolated and identified as such. Amino acids have also been reported from marine deposits by Erdman *et al.* (1956). In addition, Belser (1959) worked out a bioassay technique for organic micronutritients in sea water and found that isoleucine, glycine, tryptophan and threonine were present.

Study of trace organic compounds such as amino acids may well throw light on presently unexplained biological differences in sea water. This subject has been discussed by Lucas (1955) and Saunders (1957), but the lack of experimental evidence makes it difficult to draw any conclusion about the possible significance of these compounds in sea water.

The present report describes a study of the free amino acids in three water samples taken along the Norwegian coast.

MATERIALS AND METHODS

Sea water samples were collected at three localities along the Norwegian coast as shown in Table 1.

Table 1.

Sample No.	I	II	III
Place of collection	Nordnes, Bergen	Solsvik 60° 41' N 04° 50' E	Skrova 68° 07' N 14° 39' E
Date	2/5, 1961	8/8, 1961	5/2, 1962
Depth	135 m	50 m	50 m
Size of sample	7 l	13 l	25 l
Salinity	33.88 $^0/_{00}$	34.16 $^0/_{00}$	33.06 $^0/_{00}$

Sample I was taken from the sea water intake to the Institute of Marine Research, The Directorate of Fisheries, Bergen.

Samples II and III were collected by sucking the sea water through rubber tubing into a carboy by means of a suction pump. The samples were filtered through H. A. Millipore filters (0,45 μ) within six hours of collection, and were treated with a few crystals of thymol to prevent bacterial activity.

The samples were adjusted to pH 7 with hydrochloric acid and concentrated in a continuous Buchler vacuum evaporator at 40°C. The precipitated salts were filtered off at intervals and washed with water. The wash water was added to the filtrate and the process continued until approximately 40 to 80 ml of sea water concentrate was obtained. The samples were then diluted to 1 l and desalted by passing them through a column (4 × 71 cm) loaded with Dowex 50 W × 12 20/50 mesh cation exchange resin. The column was then washed with water until the eluate was neutral and eluted by the method of Buchanan (1957) with 0.1 M aqueous piperidine. The eluate, approximately 10 l, was concentrated in the continuous vacuum evaporator at 40°C and finally reduced to near dryness over phosphorus pentoxide in a vacuum dessicator. The sample was then redissolved in a measured volume of 10 % aqueous isopropanol and was ready for chromatographic analysis.

The circular paper chromatography technique originated by Rutter (1948) and modified by Giri and Rao (1952) was used to separate and identify the amino acids. Whatman No. 1 paper (circles of 27—35 cm diameter) was used in cabinets with a volume of approximately 1.5 l and the chromatograms were run at room temperature (about 20°C). The solvent systems used were mainly those employed by Grov (1963) together with a few described by Smith (1960).

The samples and the standard amino acids were applied with micro pipettes along arcs 2 cm from the centre on a paper marked into four or more sectors. The width of the spot-lines were kept less than 0.4 cm. After application of the samples and the standards the solvent was evaporated with warm air (approximately 40°C) from a hairdryer. The separations took from 8 to 24 hours depending on the solvent system used. The chromatograms were dried in a stream of warm air, observed under U. V. light, and the solvent front and any visible zones were marked with a pencil. The chromatograms or its sectors were then sprayed with different colour reagents (Grov 1963; Smith 1960) for identification. To separate amino acids with low Rf-values the chromatogram was run two or three times using the same solvent system, allowing the paper to dry in between, or the solvent was allowed to evaporate from the rim of the paper which extended outside the cabinet.

RESULTS AND DISCUSSION

The results of the analyses of the three samples are shown in Table 2. A total of 19 amino acids were identified and the following amino acids were present in all samples: cystine, aspartic acid, glycine, glutamic acid, threonine, β-phenylalanine, leucine and isoleucine.

These results indicate that the amino acid patterns of the three samples were different. It is not known if these differences reflect variations due to the different times of the year and/or different locations as the limited data so far obtained do not justify any conclusions on these points. The analyses will clearly have to be continued and it will be of great interest to determine whether a change

Table 2.

Amino acids found in three different sea water samples. The presence of an amino acid is represented by +

	Sample I	Sample II	Sample III
Cystine	+	+	+
Lysine	+	—	—
Histidine	+	—	—
Arginine	+	—	+
Serine	—	—	+
Aspartic acid	+	+	+
Glycine	+	+	+
Hydroxyproline	+	—	+
Glutamic acid	+	+	+
Threonine	+	+	+
α-Alanine	+	—	+
Proline	+	—	+
Tyrosine	+	—	+
Tryptophan	—	—	+
Methionine	—	—	+
Valine	+	—	+
β-Phenylalanine	+	+	+
Isoleucine	+	+	+
Leucine	+	+	+

of amino acid pattern will be found when repeated samples are taken from one locality at different times of the year.

It is realized that the filtration of large volumes of sea water containing relatively large quantities of phytoplankton, including many fragile species, may cause erroneous results if these organisms are broken up. In such a case their body fluids may contribute to the amino acid pattern of the sample. It is not known to what extent, if any, this has affected the present results but the filtrations were carefully done so that there was always a layer of liquid over the filter disc.

It is possible that the potential differences due to charged groups in a strong cation exchanger might cause hydrolysis of any peptides or proteins present in the concentrate. Paulson *et al.* (1957) have, in fact, reported the use of ion exchange resins as a catalyst in protein hydrolysis. As the present study concerns the free amino acids in sea water, it was of considerable importance to discover if the methods used would bring about such a hydrolysis.

Three di-peptides (glycyl-L-proline, glycyl-L-glutamic acid and glycyl-DL-aspartic acid) and one tri-peptide (DL-leucyl-glycyl-DLphenylalanine) were chromatographed before and after being subjected to the total concentration and separation procedure using an artificial salt water solution made from salts and distilled water. There were no differences in the chromatographic patterns so it was concluded that hydrolysis of the peptides did not occur.

SUMMARY

A method of concentrating and desalting sea water using evaporation and ion exchange techniques is described. Circular paper chromatography has been used to separate and identify free amino acids in desalted concentrates of sea water from three different localities along the Norwegian coast. The following amino acids have so far been identified: cystine, lysine, histidine, arginine, serine, aspartic acid, glycine, hydroxyproline, glutamic acid, threonine, α-alanine, proline, tyrosine, tryptophan, methionine, valine, β-phenylalanine, isoleucine and leucine.

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Swimming speed of fish as a factor in gear research

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INTRODUCTION

In fisheries gear research the locomotion of the animal to be caught plays an important role. The swimming speed of fish is of great interest in the development of pelagic trawls and similar active gear where the effect of escape by the fish is a major factor in the efficiency of the gear.

The literature on swimming speeds of fish has been reviewed by Bainbridge (1958) who has carried out further investigations on freshwater species (Bainbridge 1960, 1961, 1962). The only reports dealing with marine species of commercial importance, however, are those of Mangan (1930) and Blaxter & Dickson (1959).

The high swimming speeds of fish which have been mentioned by seagoing people generally have not been verified by the modern investigations. On the other hand, many of the experiments have been performed in aquaria or in traps where the conditions were far from normal. From other investigations (Dragesund & Leivestad 1959, Sundnes 1957a, 1957b) we know that fish behave peculiarly when in aquaria or similar conditions. They are able to set up a very high metabolic rate without locomotion when this is not possible. They seemingly do know that they cannot escape in the real sense of the word but only make "a local escape".

The most commonly used method for measuring the swimming speed in fish is to observe the live fish swimming. Most of the experiments dealing with marine species have been performed in aquaria where the fish swims against a current or where it swims towards the end of a relatively long basin (Mangan 1930 and Blaxter & Dickson 1959). Other measurements have been made in the open sea by piscatometer (Gero 1952) and other devices (Blaxter & Dickson loc. sit.). Another indirect method was used by the author (Sundnes 1957) whereby the resistance of a model of the body in water and the energy metabolism were used in the calculation of swimming speed. In the present investigation the fish itself has been used for dragging measurements. The swimming speeds reported in the present paper are calculations based on hydrodynamic and metabolic measurements.

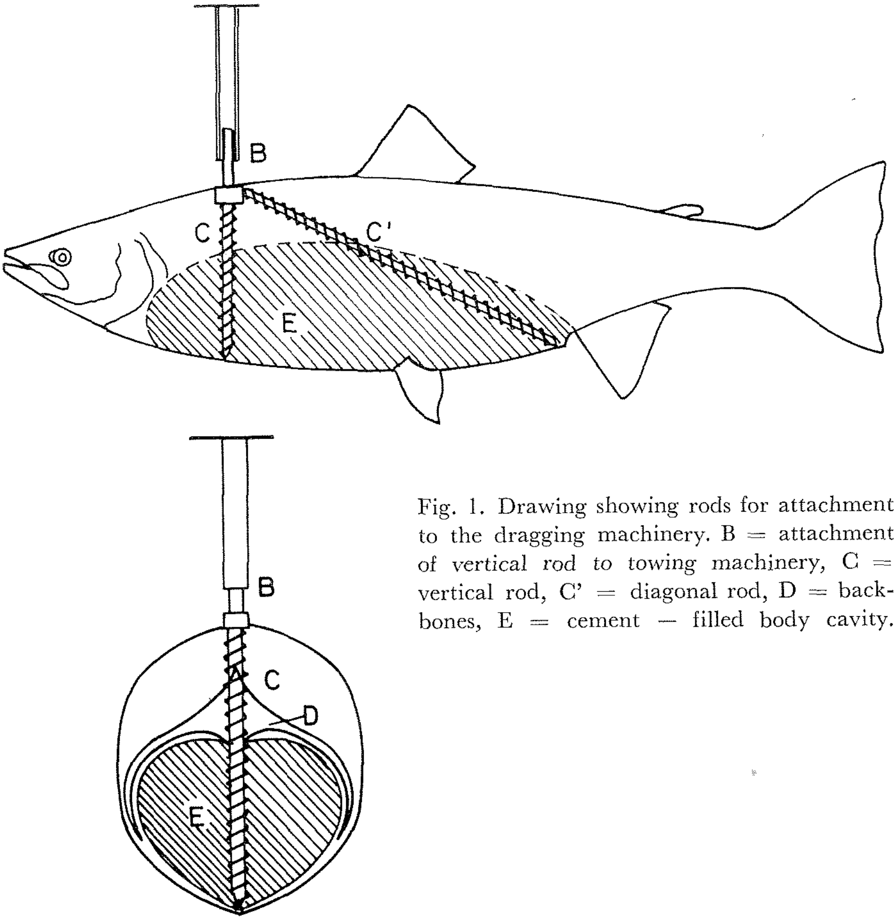

Fig. 1. Drawing showing rods for attachment to the dragging machinery. B = attachment of vertical rod to towing machinery, C = vertical rod, C' = diagonal rod, D = backbones, E = cement — filled body cavity.

MATERIAL AND METHODS

The bodies of the following species were used for dragging measurements:

Cod (*Gadus callarias*), saithe (*Gadus virens*), haddock (*Gadus aeglefinus*), mackerel (*Scomber scombrus*), salmon (*Salmo salar*), herring (*Clupea harengus*) and plaice (*Pleuronectes platessa*).

Immediately after the fish were killed the stomach contents were removed through the mouth and replaced by a rapid hardening cement of identical weight and volume. The body was made rigid for the dragging experiments by a stainless steel rod which was screwed diagonally through the back of the fish. Through this rod a second rod was screwed vertically into the hard stomach cement (Fig. 1). The upper part of the vertical rod extended several centimeters out of the back of the fish and

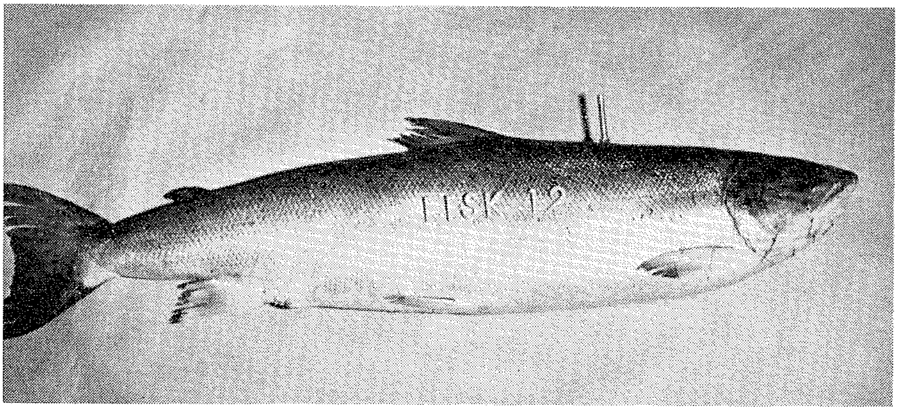

Fig. 2. Photographs of a salmon ready for dragging experiments.

was used as the fixation point for the dragging apparatus (Fig. 2). The resistance data were converted to calories versus distance swum. The dragging experiments were performed at The Norwegian Ship Model Experiment Tank in Trondheim.

The metabolism of live fish was measured in aquaria (Sundnes 1957a). From this data the available energy for locomotion was calculated. The estimation of the oxygen debt was based on the investigations of Leivestad, Andersen & Scholander (1957) and Hochachka (1961). The propulsion effect of the caudal fin was assumed to be 80 % and is used as a constant in the calculations.

RESULTS AND DISCUSSION

The dragging measurements show a hydrodynamic resistance of the fish body similar to other hydrodynamic models (Fig. 3). In the metabolic measurements the energy metabolism will stabilize at a level corresponding to a standard metabolic rate. Metabolic rates 300 % above the standard value in the absence of locomotion have been measured. The connection between swimming speed and the distance swum (Fig. 4) was obtained by making the following assumptions: 25 % of the extra energy produced by the body is available for locomotion (Zeuthen 1942) and this amount of energy in one hour can be produced anaerobically.

The hydrodynamic resistance of the fish has been measured as the total drag. The question of laminar and turbulent flow at the surface of the fish body is left open in these experiments but post mortem changes in the surface structure have been kept as small as possible by using freshly killed fish.

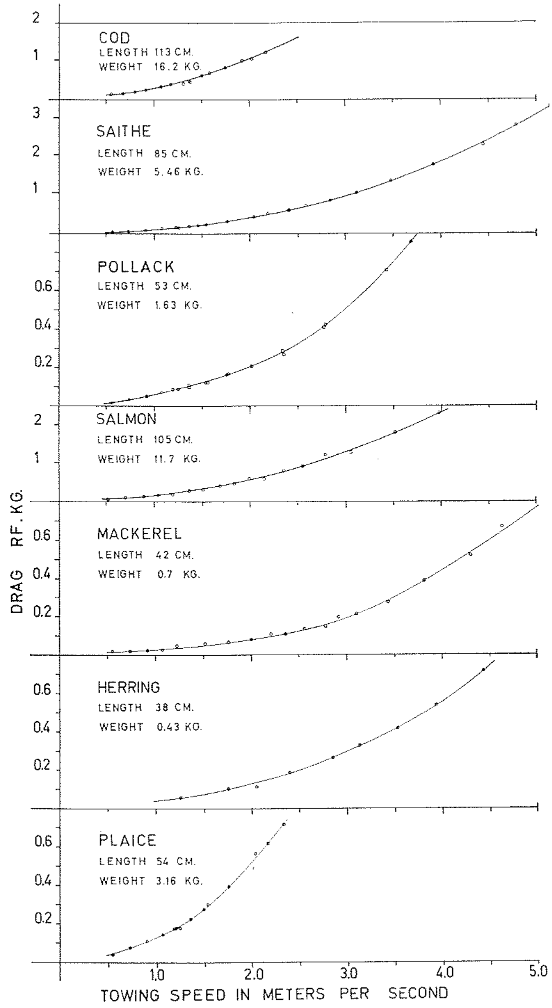

Fig. 3. Curves showing the relationship between drag and towing speed.

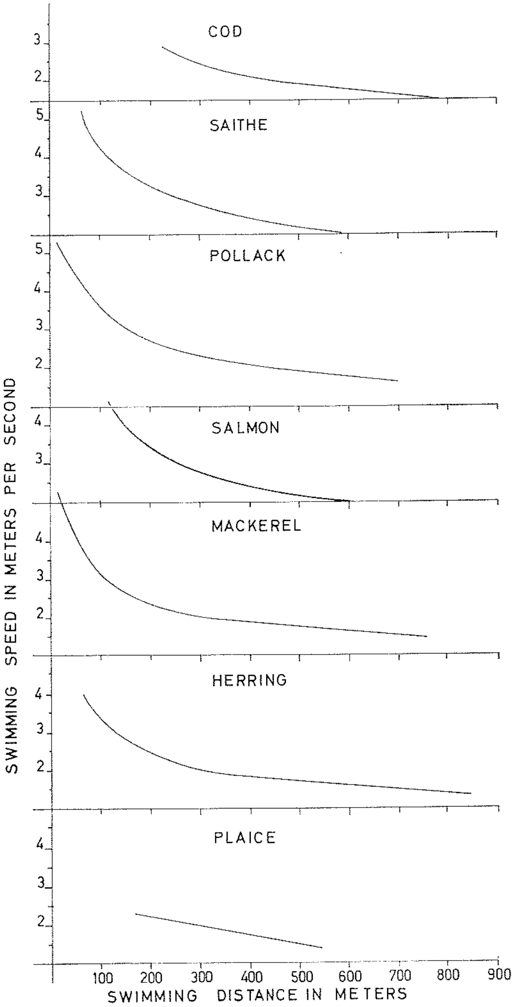

Fig. 4. Curves showing the relationship between swimming speed and distance swum.

The possible difference in the surface currents between the dragged bodies and living fish are mainly due to the swimming movements. Integument structures like those found in the dolphin (Kramer 1961) are not found in fish. However, the drag measured is at least as high as that in a live swimming fish, and the present results may therefore show a lower swimming speed than that actually obtainable since the calculated speeds in the present investigation are based on the energy available and an increased drag will result in a decreased speed.

The shape of the curves in Fig. 4 are based on a constant propelling effect of the caudal fin at all speeds and the curves indicate the limit where the fish are exhausted. The reason for the different result given by the plaice (Fig. 4) is not presently known.

It is of interest that the data show a possibility for the fish to swim relatively fast for short distances. The speeds are higher than those found in aquaria experiments, but they are in accordance with the data recently published by Dow (1962).

Most of the fish towed in the tank in the present investigation showed a theoretical cruising speed of 1 meter per second i. e. 48 nautical miles per day. This is in agreement with the observed speed of 40 nautical miles per day for the "herring front" when the Atlanto-Scandian herring migrate to the coast for spawning (Devold 1961). In addition, tagged salmon have shown an average cruising speed of 53 nautical miles per day for 11 days (Dahl & Sømme 1953).

While the relationship between swimming speed and body size has not been investigated in these experiments, the values in the present data appear high compared with other investigations. On the other hand, the actual speed of the river herring found by Dow (1962) is much higher in relation to body size, a finding which provides evidence for the high-speed swimming possibilities of fish in general. Of greatest interest for gear research is "the shooting effect" of the fish over short distances to escape from or match the speed of a trawl. The possibility for the fish to escape downwards from the pelagic trawl is of special interest.

From pilot experiments in a tank, it was found that cod fish react and try to escape from a fast moving device. By using slower movements, e. g. one-two knots, the fish do not try to escape but let themselves be overtaken by the device. They try to escape, however, when they come into mechanical contact with the gear. This is not so with the salmonids and clupeids as they react and try to escape from the device at all speeds tested. Open sea experiments should be carried out to make this point clear.

For active gear the problem of escape is a complex of factors in fish behavior where swimming speed may play a minor or dominant role according to the species involved. Blaxter, Parrish & Meadows (1960) have shown that the optical sense is of great importance in this connection. For fish which react strongly to active gear as a trawl, gear research probably has to solve problems of gear speeds up to six knots to get a maximum catching effect.

SUMMARY

The hydrodynamic resistance of the bodies of several species of commercially important marine fish has been measured. Based on the hydrodynamic resistance and the energy metabolism of the fish, theoretical swimming speeds and distances have been calculated. It is suggested that gear speeds of up to six knots may be required for species which react strongly to active trawling gear.

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