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Distribution, Growth and Exploitation of Greater Silver Smelt (*Argentina silus*) (Ascanius) in Norwegian Waters 1980-1983.

by

Arne Johannessen [1)] and Terje Monstad [2)]

1) Department of Fisheries and Marine Biology, University of Bergen, Norway
2) Institute of Marine Research, Bergen, Norway

Abstract

Greater silver smelt (*Argentina silus* L.) occurs regularly in Norwegian waters, near bottom over large areas of the continental shelf. Due to a directed fishery for human consumption off mid-Norway, the stock was regularly monitored every spring and autumn. Data on distribution and abundance, as well as age, length and sexual maturity formed the basis for evaluation of the state of the stock and were applied for management advice to prevent overexploitation.

During the spring greater silver smelt is more congregated at the continental slope and in the deeper parts on the shelf , while during the autumn it is mostly scattered over large areas. Immature specimens occur mainly at depths less than 300 m, and the mature ones predominate at greater depths. Within specific areas the age and length compositions vary between seasons, and hence growth variations from area to area were difficult to point out. However, there was a tendency for increased maximum length at increased latitude, and females were generally larger-at-age than males.

Great variations of the age at first sexual maturity occur, i.e. 4-12 years, with 7 years as the mean age for male and 6 years for female maturation. The sex ratio was rather equal in shallow areas but males frequently dominated at greater depths.

Keywords : Greater silver smelt, depth, length, maturity, sex-ratio

Introduction

Greater silver smelt (*Argentina silus*, Ascanius 1775), also called Atlantic or greater argentine is common over large regions of the North Atlantic and is distributed at depths of 140-1400 meters (Cohen 1984). In Norwegian waters, specimens of greater silver smelt are commonly distributed close to the seabed in fjords and along the coast from Skagerrak to western Barents Sea, at depths of 200 to 600 meters (Figure 1).

For years, greater silver smelt has been harvested as by-catch in the mixed industrial trawling fisheries, mainly in the North Sea and the catches were exclusively processed for reduction. However, from the mid-1970´s, a directed fishery for human consumption took place in the Skagerrak area as well as in the Sula depression off Møre (mid-Norway). The northern fishery developed rapidly, attracting more fishing vessels, and the fishing area expanded to other deep areas on the shelf and the slope. Since 1982 annual TAC´s were introduced for the area north of Stadt (62^oN). The total catches reached a maximum of 22.000 tons in 1983 (Figure 2). A TAC of 10.000 tons was introduced north of 62^oN in 1982. This increased up to 20.000 tons when Russian by-catches from the blue whiting

fishery were also included. The TAC was abandoned in 1992 and licensing of fishing vessels was maintained as the only restrictive management measure for the directed fishery of greater silver smelt north of 62°N. There is also a directed fishery for human consumption in the southern area (south of 62°N), but this fishery is negligible in size.

Little effort was allotted to studies of greater silver smelt in Norwegian waters prior to 1980. However, with greater prospects for continued increase in the fisheries for human consumption, demands for better management also increased. Better advice for the state of the stock and rational exploitation pattern would be possible if there was better biological knowledge and more regular monitoring of the stock. The Institute of marine research, Bergen, therefore initiated a three-year project (1980-83), with the overall aim to increase knowledge about the general biology and management of *A. silus* (Johannessen and Monstad 1984), on which this paper is based.

Material and Methods

Mapping and monitoring of the geographical distribution of greater silver smelt as well as collection of biological samples (age, total length, sex, maturity) were conducted by the RV Michael Sars and RV G.O. Sars during the spring (April-May) and the autumn (Oct-Nov), 1980-1983. Only data for the autumn 1981 (13. Oct-13. Nov) and the spring 1983 (6-27. April) are presented on fish distribution in the actual paper. Along the survey tracks fish were continuously recorded by means of an echo sounder with integrator connected (Figures 3 and 4). Recordings, expressed as mm deflection per nautical mile, with an average for every 5 nautical miles, were allotted to the various species or groups. For comparative purposes, the G.O. Sars – values were applied as standard, through intercalibration between vessels. Echo recordings were identified using demersal or pelagic trawls. It was difficult to distinguish fish recordings from the bottom layer and to identify particular species or groups of species from the mixture of fish recordings. A pre-determined bottom trawling program was conducted in order to compare catch rates between seasons. A standard Granton shrimp trawl with an inner net in the cod-end of 11 mm mesh size and a vertical opening of 4-5 m at a towing speed of 3 knots was used.

Supplementary sampling of fish data (total length, wet weight, sex, maturity and age) were conducted from landings of the commercial fisheries. The stage of maturity was based on macroscopic visual examination of their gonads (maturity scale of 8 points), used by Institute of Marine Research, Bergen. Age was determined by inspection of the otoliths. Capture diaries of individual vessels were made available and provided valuable information about commercial catch rates at specific locations. Temperature data was collected applying a CTD.

Results and Discussion

Distribution

Figures 5 and 6 illustrate relative densities of the horizontal distribution of “greater silver smelt” and “total fish” in autumn 1981 and spring 1983. Most echo recordings over the continental shelf off western Norway comprised a relatively homogeneous mixture of species with a bentho-pelagic or semi-pelagic life-style. Most often the greater silver smelt co-occurred with blue whiting (*Micromesistius poutassou*), ocean perch (*Sebastes marinus*) and Norway redfish (*S. viviparus*), but also Norway pout (*Trisopterus esmarki*) and silvery pout (*Gadiculus argenteus*) contributed in some areas (Table 1).

Greater silver smelt was distributed over most of the continental shelf deeper than 300 m from Stad (62°N) in the south to Vesterålen (68°N) in the north. Off Troms and Finnmark only faint recordings were found. In general, the acoustic recordings were more dispersed and less dense in autumn than in spring (Figures 5 and 6). Adult specimens were concentrated in some deeper areas on the shelf and the highest densities were found at about 400 meters depth in the Sklinna- (65°30´N) and the Sula (64°N) depressions and to the west of Lofoten and in the Vestfjord. The most dense recordings were observed in spring between 64° and 67°N along the slope area adjacent to the Norwegian Sea, between 300-500 meters depth. Up to 72°30´N, silver smelt was recorded along the slope in the western part of the Barents Sea. The echo recordings of greater silver smelt along the slope were distributed more off-bottom compared with those in the shelf depressions.

Temporal variations in distribution of silver smelt apparently occur. During spring, field surveys usually took place in April-May, and only one year in March (1982). In March, only negligible levels were recorded in the more

common spawning grounds on the shelf (Sula- and Sklinna depressions). In April-May the aggregations of silver smelt increased, with higher congregations in these areas. During autumn, echo recordings of greater silver smelt generally provided low densities over the shelf itself and somewhat higher recordings in specific shelf depressions. Although variation in density of greater silver smelt was found between years, areas and seasons, the proportion of silver smelt made up a rather consistent part of total fish catches (Table 1).

Temperature

Although the average surface temperature may vary between years and seasons, the temperature close to the bottom is relatively stable (Figures 5 and 6). Prevailing temperatures in the areas with greater silver smelt on the continental shelf, range between 5.4°C and 7.6°C (Figures 5 and 6). In the slope area on the western continental shelf, sharp temperature gradients down to 1°C are not uncommon. Only minor fluctuations in temperature within the range mentioned above were observed between years.

Commercial catches

Figure 2 shows annual catches of *A. silus* taken by the directed fishery and by-catches of the industrial trawling fisheries in Norwegian waters. The fishery takes place mainly north of 62°N by bottom trawl in the shelf depressions at Sula- and Sklinna, and along the continental slope by pelagic trawls just above the seabed. In this fishery it is mainly the mature adult portion of the stock that is exploited, whereas the immature stock in general made up a larger portion of the catches taken by the mixed industrial fishery in more shallow parts of the shelf. Since the directed fishery started in 1977, an increasing quantity was landed with a maximum in 1983 of about 11 000 tons. A TAC of 10 000 tons for the northern area was thus completed. Monthly catches of greater silver smelt for human consumption in the area north of 62°N for the years 1980-83 are given in Figure 7. It shows that in January – February some fishing vessels commenced the catching activity, mainly in the Sula depression. Increasing participation of vessels generally took place in April-May, when also the largest catches of greater silver smelt were taken. During the years 1980-1983 the number of vessels increased from 10 to about 30 in the limited number of fishing locations. In June the commercial fisheries came to an end, probably because the fish tended to disperse into shallower waters (Bergstad 1993). Catch rates for the three most important fishing grounds in the early 1980´s are given in Figure 8. This figure shows that up to about 1981-82 a steady increase in catches were recorded during the first half of the year for the Sula and Sklinna depressions, with a reduction in 1983. For the grounds northwest of Frøya Bank, the catch rates were comparatively low. The lower average catch rates for the Sula and Sklinna grounds in 1983 are probably related to the much higher number and activity of vessels. For the second half of the year, mean catch rates were comparatively low and rather similar between the years. This indicates that the autumn is not the main fishing season and greater silver smelt is not distributed in such a dense pattern as with spawning aggregates in the spring. High fishing activity probably also affects its behavior. Greater silver smelt is regarded as a good swimmer (Bergstad 1993) and fishermen know it to be rather shy and to move away from locations of high fishing activity. The limited spatial range of many locations (depressions) on the shelf with aggregations of greater silver smelt, suggest that non-fishing locations within reasonable distance may be more attractive to move to when fishing activity is high and catch rates decline.

Pre-determined catching locations.

During 1980-1983 some locations were trawled once every spring and autumn with standard bottom trawl in order to examine changes in stock structure by comparing relative length composition at similar times of the year. Also catch and effort data were collected to indicate possible differences between seasons. For two main fishing locations, the Sula and Sklinna depressions, relative high catches per hour trawling were not uncommon, as shown for 1983 in Table 1. Due to large variations in catch rates, no apparent trend was traceable. The same kind of gear was applied and the same procedures were followed to conduct identical trawl hauls at temporal and spatial scales.

Biological data

Distribution of the sexes

A general feature of the greater silver smelt nursery grounds at depths of 200-300 m was the normal distribution of the sexes. In deeper areas (>300 m) the sexes were frequently found to be distributed in different proportions (Figure 9). Males predominated in the traditional fishing grounds at the Sklinna and the Sula depressions as well as at most other localities during the spring and the autumn. Most of the samples contained sexually mature adult specimens larger than 30 cm in size (Johannessen and Monstad 1984). Features similar to these were not observed in the greater silver smelt in Vestfjorden. Neither did Bergstad (1993) find strong segregation of sexes with depth in the Norwegian Trench and the north-eastern North Sea. However, he found some indications of slightly different distributions of the sexes in the eastern Skagerrak, where males tended to be more abundant deeper.

Higher proportions of females were occasionally obtained during pelagic trawling just above the bottom along the continental slope. These findings suggest that females may be distributed more off-bottom than males. Different vertical distribution of greater silver smelt was also suggested by Westhaus (1982), who concluded that females prefer more pelagic layers than males.

Maturity and spawning

A. silus reached maturity from a lower age of about 4 years, with age at 50%- maturity at about 6 years for females and 7 years for males (Figure 10). At 12 years of age most greater silver smelt were mature. Mean age at first spawning of 5-7 years corresponded well with other reports from Skagerrak and western Norway (Kessler 1968, Thorsen 1979, Bergstad 1993). Also Beacham (1983) found females to mature at an earlier age than males. However, considering the higher age-at-length of males in this study (Figure 12), both sexes seemed to mature at similar lengths. Opposite to these findings, Bergstad (1993) and several others (Thorsen 1979, Westhaus 1982 and Magnusson 1988) found that males seemed to mature earlier than females. However, methodological problems with sampling size may cause bias due to segregation of ages with depth.

Spawning of greater silver smelt took place over large areas of the shelf and along the slope, in particular at depths greater than 300 m. From March onwards the proportion of fish with running gonads increased in the catches, with spawning maximum suggested in May (April-June). This is in accordance with observations by Bergstad (1993) that spawning in Skagerrak and north-eastern North Sea primarily took place in April-May. Some spawning also took place in the autumn (Bergstad 1993, Keysler 1968, Wood and Raitt 1968), until November off northern Norway (Johansen and Monstad 1982).

Age and length

No significant differences in age or length were found between samples from the continental slope and locations on the shelf. Greater silver smelt is long-lived, with a significant portion of age groups 20+. Age and length distributions of silver smelt from the area 64-66^{o}N are shown in Figure 11 for three depth intervals in two different years (1981 and 1983). This area represents the main fishing locations of greater silver smelt**.** Specimens in the size range 12-48 cm were caught and age and length compositions were skewed towards higher values with increasing depth. Apart from cumulative frequencies of age 20+ years, the age mode in 1981 tended to move from about 3 years at less than 300 m depth, towards 7 and 11 years at 300-400 m and deeper than 400 meters depth, respectively. In 1983 the age modes at the same depth intervals were 5, 9 and 9 years, respectively (Figure 11). The mean lengths for the same depth intervals were in 1981: 27.7, 36.8 and 38.4 cm, respectively, and in 1983: 28.6, 35.0 and 38.1 cm. For each sex there was a clear trend that meant values of age and length increased with depth, and the most obvious changes occurred from less than 300 m towards greater depths. The nursery grounds of *Argentina silus* are obviously located at depths less than 300 meters.

Growth

Von Bertalanffy´s growth curves were fitted to observed data on mean length-at-age of greater silver smelt in 1980-1983 for the geographical areas limited by latitudes 62-64^{o}N, 64-66^{o}N, 66-68^{o}N and Vestfjorden (Figure 12 and

Table 2). Young specimens (<2 years) were underrepresented in all samples. After an age of about 6 years, divergence in growth appeared between males and females and a general feature was the lower length of males than females. The estimated growth coefficients (K) of males and females were not different, but highly variable (Table 2). From the observed data in 1981-1982 it appeared that asymptotic length increased with increasing northern latitude. For the Vestfjorden area population growth pattern deviated from that of most other areas.

Conclusion

As an overall conclusion greater silver smelt tended to be scattered over large areas of the shelf and in spring congregated in the deeper parts and along the continental slope, which suggests some seasonal, vertical migration. An ontogenetic shift in vertical extension was observed, with preference for increasing depth with increasing age and size. Females were in general larger-at-age than males and were also found to mature one year (6 yrs) prior to males (7 yrs). Several biological features (growth rate, age distribution, sex composition) of greater silver smelt in the Vestfjord area differed from most other locations, but variations due to sampling and size segregation with depth give no reason to exclude it as a different stock component. Developing new tagging techniques which may provide information on environmental based behavior of greater silver smelt and other fragile fish living in deep water provide challenges to achieve improved knowledge on stock composition and migration patterns.

Acknowledgements

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Table 1. Spring 1983, R.V. "G.O.Sars".Catch in kg per trawl hour, bottom trawl. Latitudes 64° - 66° N.

Station no.	459	460	461	462	465	466	469	477	481	490	491	500	503	512	515		
Pos. N	6410	6408	6409	6405	6409	6404	6411	6450	6425	6406	6411	6501	6510	6539	6540		
Pos. E	0600	0704	0826	0820	0825	0823	0830	0610	0552	0824	0830	0618	0655	1053	0910		
Depth (m)	381	332	425	455	414	420	500	414	460	417	474	417	289	370	450		
																Sum	**% 64°-66° N**
Greater silver smelt	50	36	621	109	210	57	150	757	49	1155	3000	351	12	30	677	7264	63.1
Redfish	51	118	15	4	6	11		188	615	5	50	115	355	165	56	1754	15.2
Blue whiting	24	144	22	5	14	6		124	4	7	20	80	6	15	16	487	4.2
Rabbitfish	4	30	4			11			20		12	3	10	15	2	111	1.0
Blue ling	22	23		38	14	8	9	11	18	101	277	35	6	15	61	638	5.5
Common ling	12	8	2	1				5				24			4	56	0.5
Tusk	3	2		11	14		13	5	35	3	16	22	9		4	137	1.2
Velvet belly												2			2	4	0.0
Witch					1	1	7	2		2					4	17	0.1
Long rough dab			1		1			6								8	0.1
Saith	11	7						2	19			17	2	60		118	1.0
Cod	17	93						8	32							150	1.3
Halibut															19	19	0.2
Haddock	40							31	75			52				198	1.7
Norway pout														5		5	0.0
Roundnose grenadier																0	0.0
Rockfish/Catfish																0	0.0
Skate					11											11	0.1
Silvery pout	59		1	4		1	1	1				4	2		16	89	0.8
Angler/Monk	14				9	51			13	101	72	8				268	2.3
Shrimp																0	0.0
Squid								3								3	0.0
Lantern fish																0	0.0
Krill																0	0.0
Others	42	52	4	4	1		1					19			58	181	1.6
Sum	349	513	670	176	281	146	181	1143	880	1374	3447	732	402	305	919	11518	100.0
% Greater silver smelt	14.3	7.0	92.7	61.9	74.7	39.0	82.9	66.2	5.6	84.1	87.0	48.0	3.0	9.8	73.7		

Station no.	531	538	551	555	556	564	580						559	566	598		
Pos. N	6625	6703	6646	6714	6729	6758	6753						6802	6804	6926		
Pos. E	0700	0830	1010	1322	1320	1220	1009						1453	1223	1630		
Depth (m)	375	358	383	337	265	190	340						398	235	360		
								Sum	**% 66°-68° N**							Sum	**% > 68° N**
Greater silver smelt	108	46	20	744	84	198	75	1275	41.9				180	233	35	448	42.7
Redfish	180	91	60	2	65	13	400	811	26.7				219	11	7	237	22.6
Blue whiting	12	7	15	8	9	6	56	113	3.7				9	3	20	32	3.1
Rabbitfish		6	1		19	9		35	1.2				10		25	35	3.3
Blue ling	24	18		12			10	64	2.1				6		9	15	1.4
Common ling								0	0.0						5	5	0.5
Tusk	6	2	6		2		4	20	0.7					3	14	17	1.6
Velvet belly			1	2	4			7	0.2				1		1	2	0.2
Witch			2		1			3	0.1					1	2	3	0.3
Long rough dab		1	2			1	2	6	0.2					1	1	2	0.2
Saith	18	12	25	25	180	35	13	308	10.1				34	11	6	51	4.9
Cod					1	30	7	38	1.2				2	3		5	0.5
Halibut								0	0.0				17			17	1.6
Haddock	6	9					38	53	1.7				7	1		8	0.8
Norway pout				1	2	3		6	0.2					5		5	0.5

Table 1 (continued).

Roundnose grenadier								0	0.0		6			6	0.6
Rockfish/Catfish			2					2	0.1				2	2	0.2
Skate						1	9	10	0.3				10	10	1.0
Silvery pout		14	24		2			40	1.3				8	8	0.8
Angler/Monk								0	0.0		50		30	80	7.6
Shrimp				6	10	1		17	0.6		10	2	1	13	1.2
Squid	12	1						13	0.4				1	1	0.1
Lantern fish								0	0.0					0	0.0
Krill								0	0.0					0	0.0
Others		100	20		70	31		221	7.3			40	6	46	4.4
Sum	366	307	178	800	449	328	614	3042	100.0		551	314	183	1048	100.0
% Greater silver smelt	29.5	15.0	11.2	93.0	18.7	60.4	12.2				32.7	74.2	19.1		

Table 2. Parameters of von Bertananffy's growth function $l_t = L8\ (1 - e^{-K(t-t0)})$, adjusted to observed length data of greater silver smelt from various areas 1980-1983.

		19 80		19 81		19 82		19 83	
Area		female	male	female	male	female	male	female	male
North of 68° N	L8	-	-	48.5	51.0	50.3	43.7	-	-
	K	-	-	0.14	0.08	0.12	0.26	-	-
	t_0	-	-	- 1.0	- 4.1	- 2.0	0.9		
Vestfjorden	L8	-	-	44.3	40.1	46.5	38.9	39.0	38.4
	K	-	-	0.14	0.20	0.09	0.22	0.21	0.17
	t_0	-	-	- 1.4	0.7	- 5.1	0.4	- 2.2	- 3.8
66° - 68° N	L8	-	-	45.5	42.5	47.9	43.5	41.2	37.2
	K	-	-	0.15	0.15	0.11	0.14	0.24	0.25
	t_0	-	-	- 2.0	-2.4	- 2.8	- 1.7	0	- 1.2
64° - 66° N	L8	45.9	48.0	45.0	41.3	44.3	42.1	46.3	44.9
	K	0.14	0.07	0.17	0.14	0.22	0.19	0.12	0.09
	t_0	- 0.5	- 6.8	- 1.3	- 3.2	1.2	0.5	-3.7	- 6.5
62° - 64° N	L8	45.5	40.0	-	-	-	-	-	-
	K	0.12	0.19	-	-	-	-	-	-
	t_0	- 2.5	- 0.8	-	-	-	-	-	-

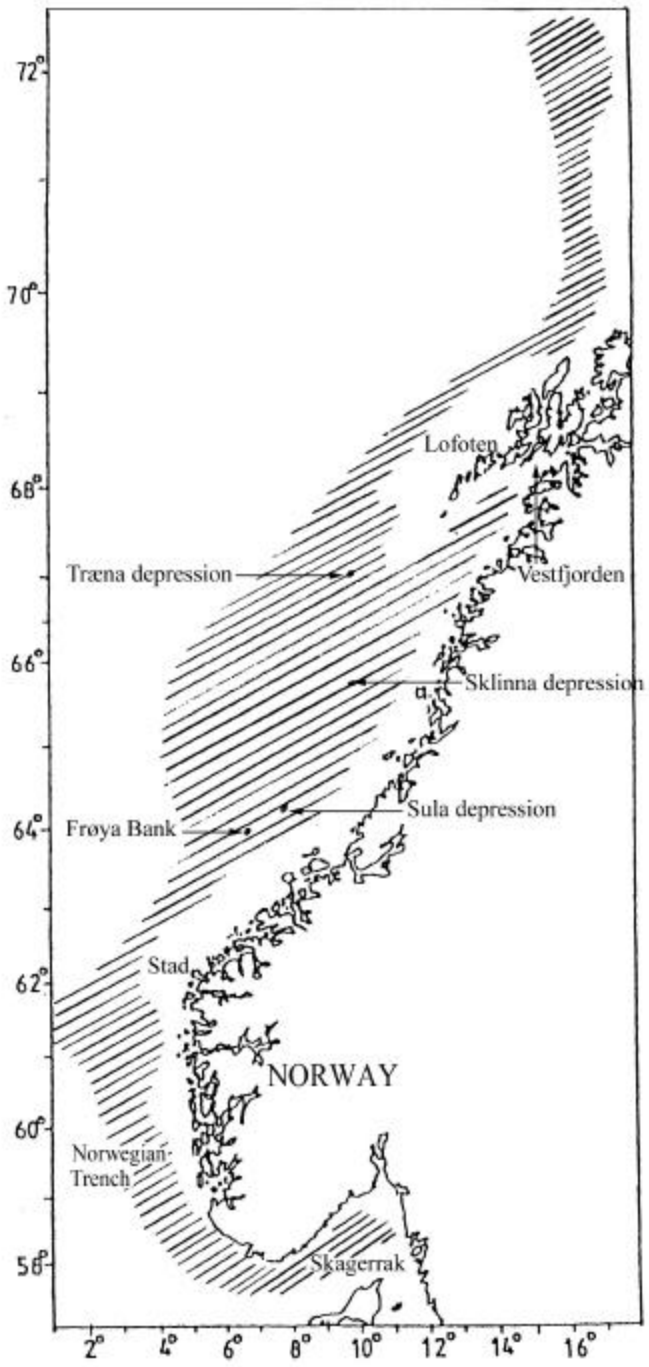

Figure 1. Map showing distribution of greater silver smelt (*Argentina silus*) in Norwegian waters, based on research surveys in 1980-1983.

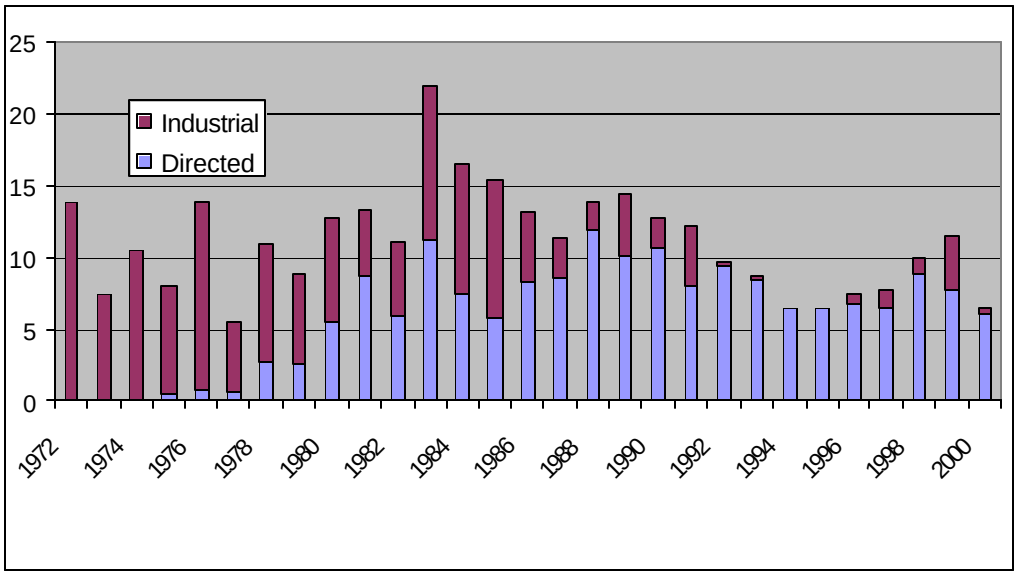

Figure 2. Catches (million tons) of greater silver smelt in Norwegian waters, 1972-2000, from directed fisheries (human consumption) and by-catches in the mixed industrial fisheries.

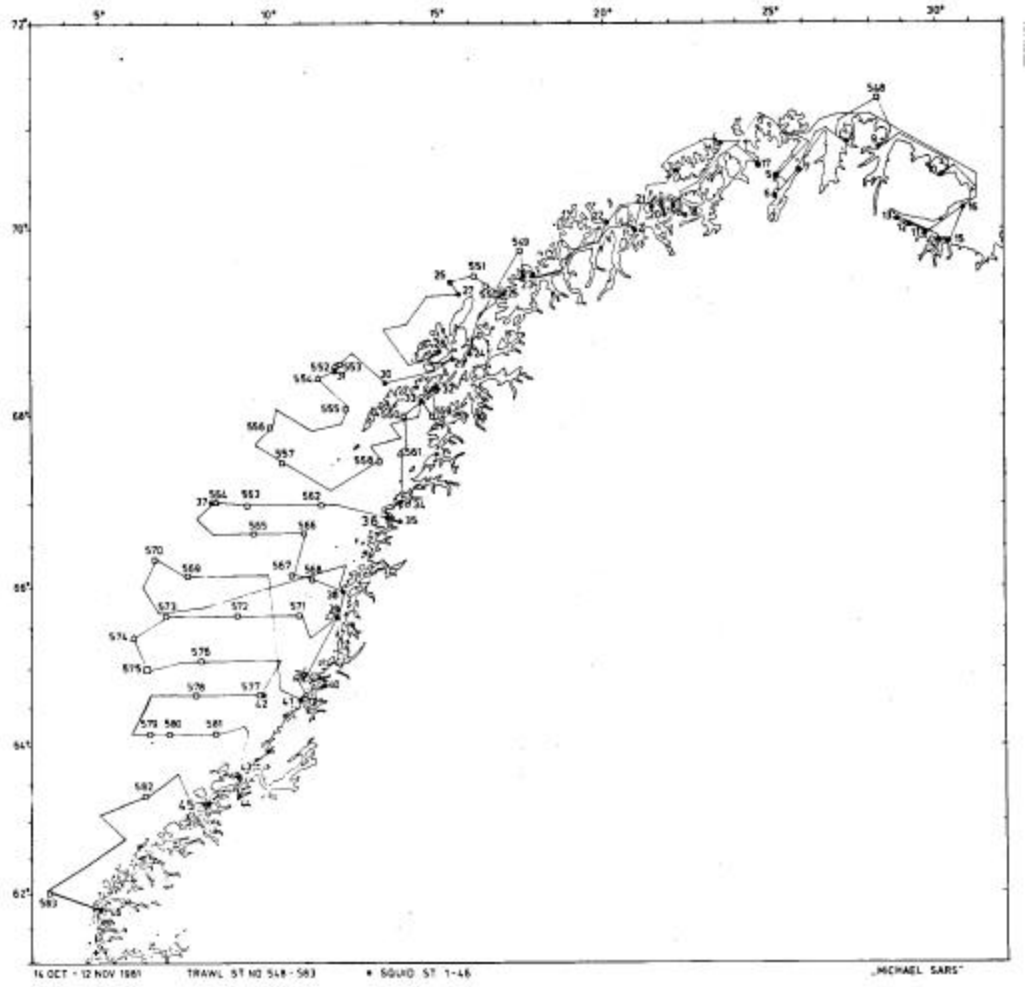

Figure 3. Cruise tracks with trawl stations of RV *Michael Sars* during 14 Oct.-12 Nov. 1981. Bottom (squares) and pelagic (triangles) trawl stations.

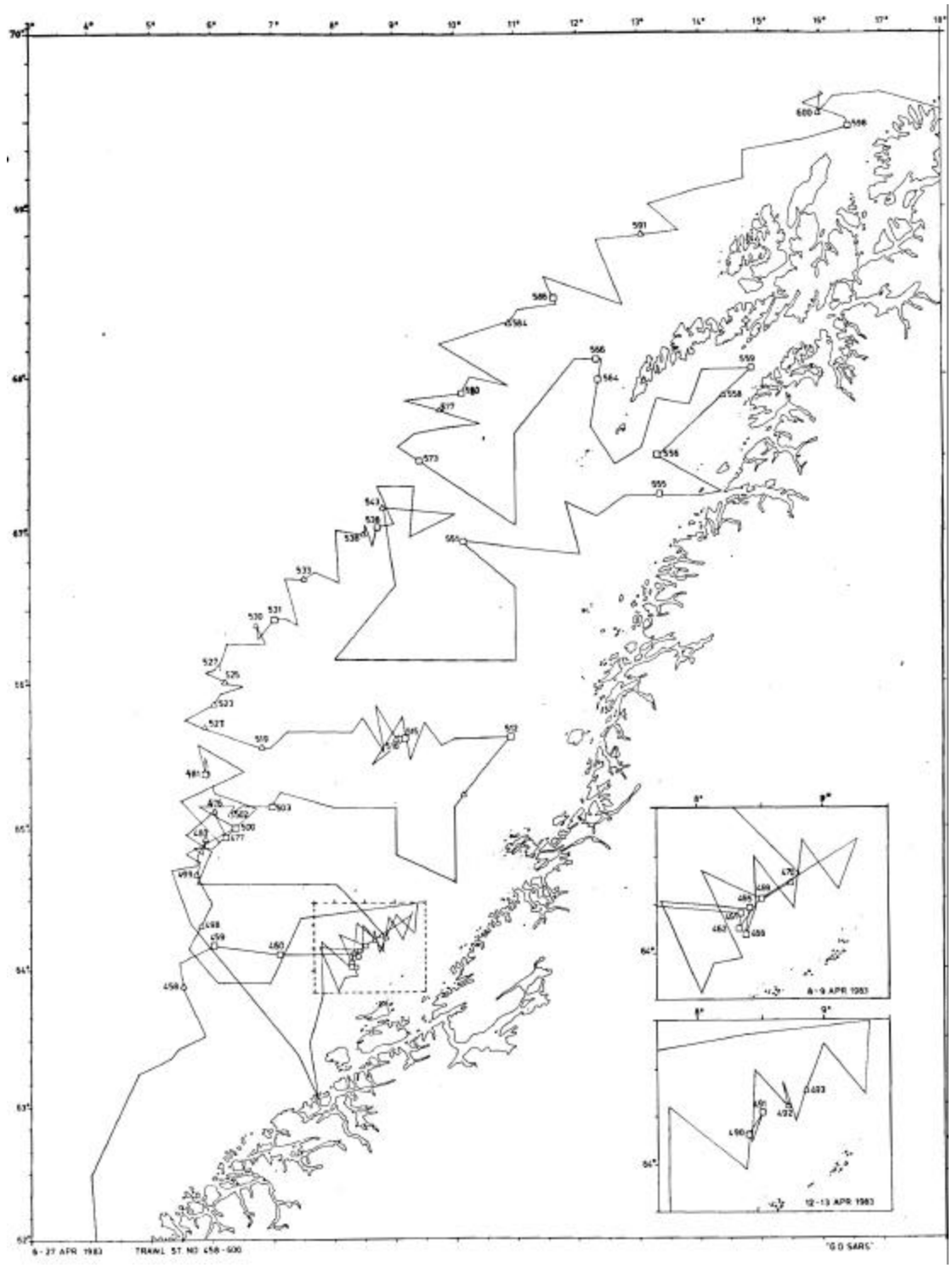

Figure 4. Cruise tracks with trawl stations of RV *G.O. Sars* during 6-27 Apr. 1983. Bottom (squares) and pelagic (triangles) stations. Cruise tracks with stations in the Sula depression inserted.

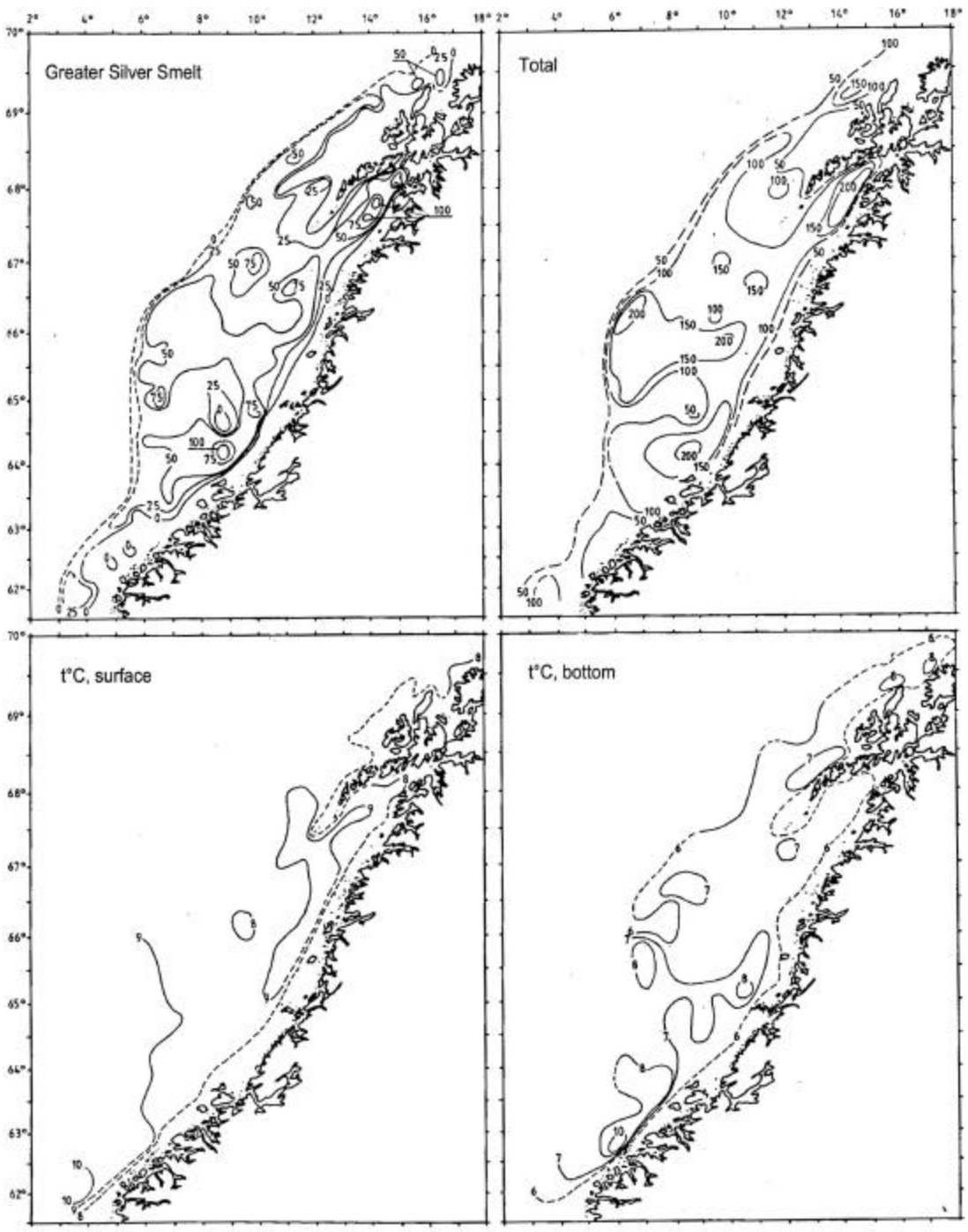

Figure 5. Integrator output values (mm deflection per nautical mile) of greater silver smelt and "total fish" distribution are given as, with surface and bottom temperatures, autumn 1981 (see also Figure 3).

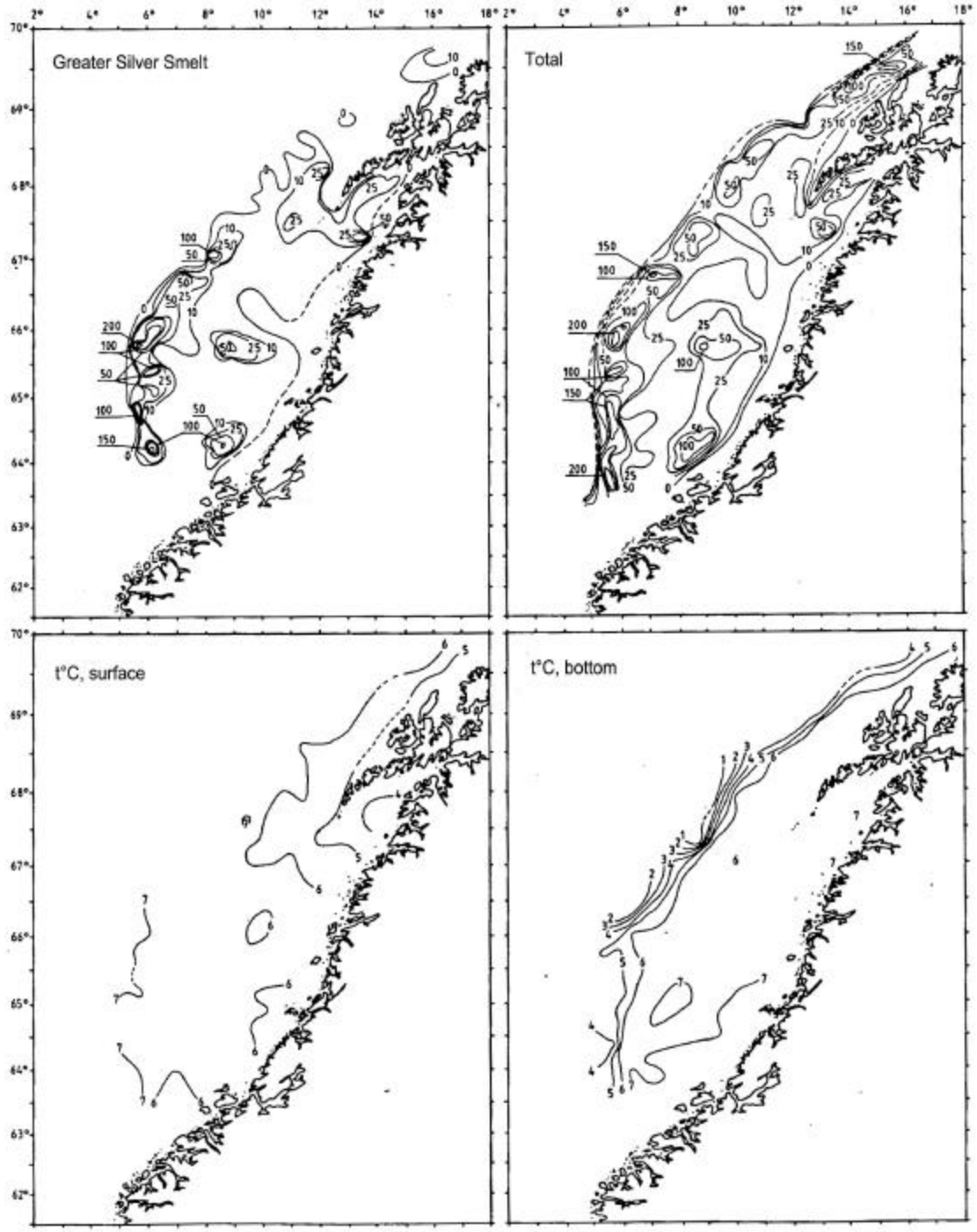

Figure 6. Integrator output values (mm deflection per nautical mile) of greater silver smelt and "total fish" distribution, with surface and bottom temperatures, spring 1983 (see also Figure 4).

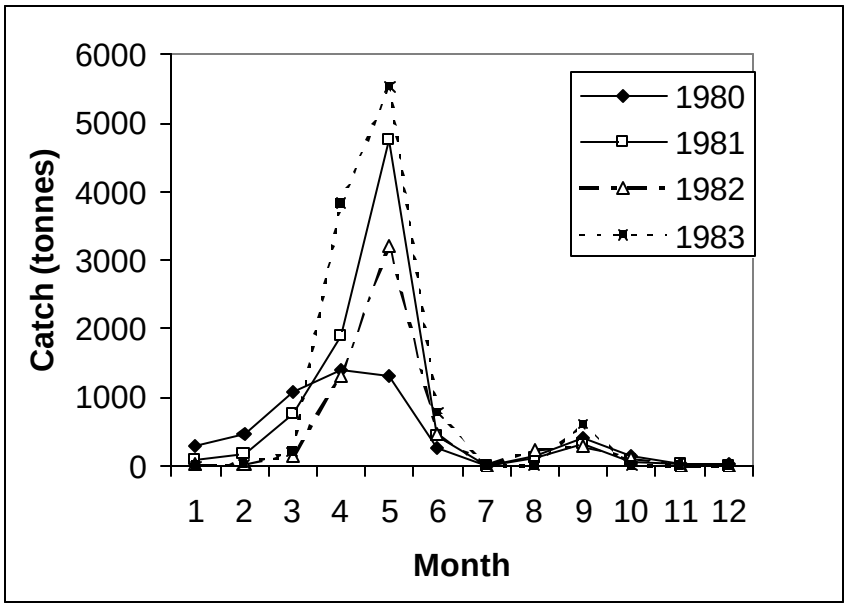

Figure 7. Monthly catches of greater silver smelt (*Argentina silus*) for human consumption north of 62 ^{o} N.

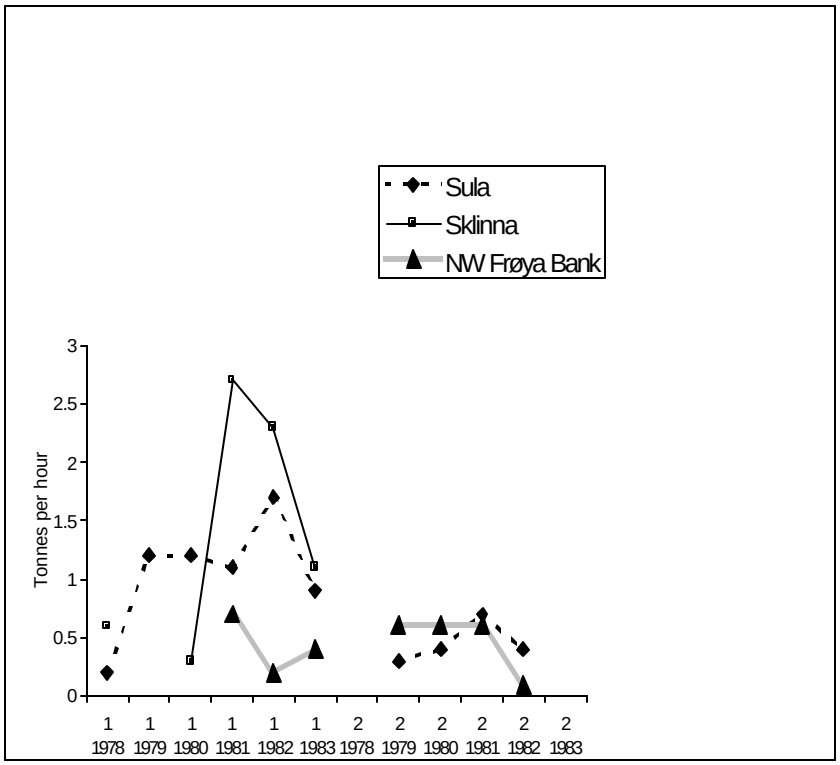

Figure 8. Catch rates (tons per hour) of greater silver smelt (*Argentina silus*) in the first (1) and second (2) half-year in the directed fishery from three catching localities (Sula depression, Sklinna depression and northwest of Frøya Bank), 1978-83.

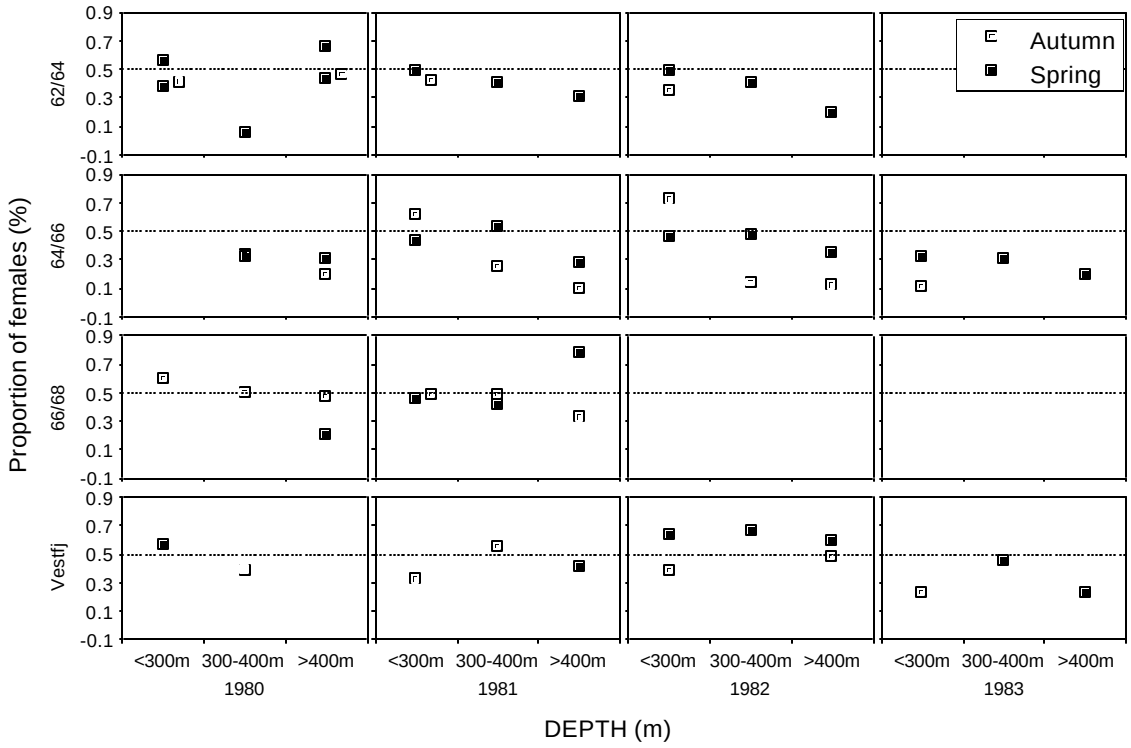

Figure 9. Sex-ratio as proportion of females, 1980-83, from three depth intervals, in four geographical regions: 62-64°N (upper), 64-66°N, 66-68°N and Vestfjorden (lower).

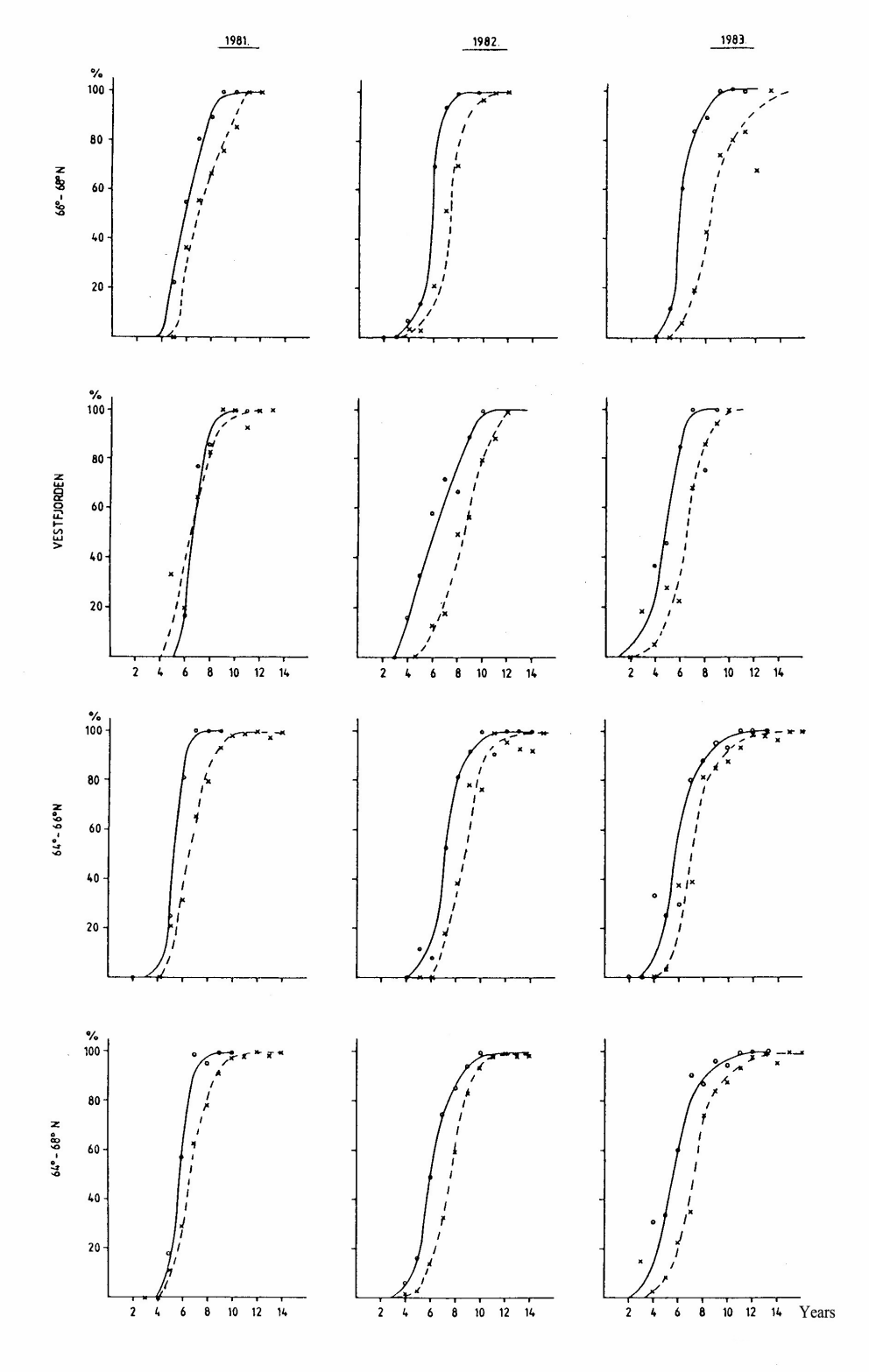

Figure 10. Age-and sex specific maturity ogives of greater silver smelt (o=females, x=males) for three geographical areas and pooled (bottom), 1981-1983.

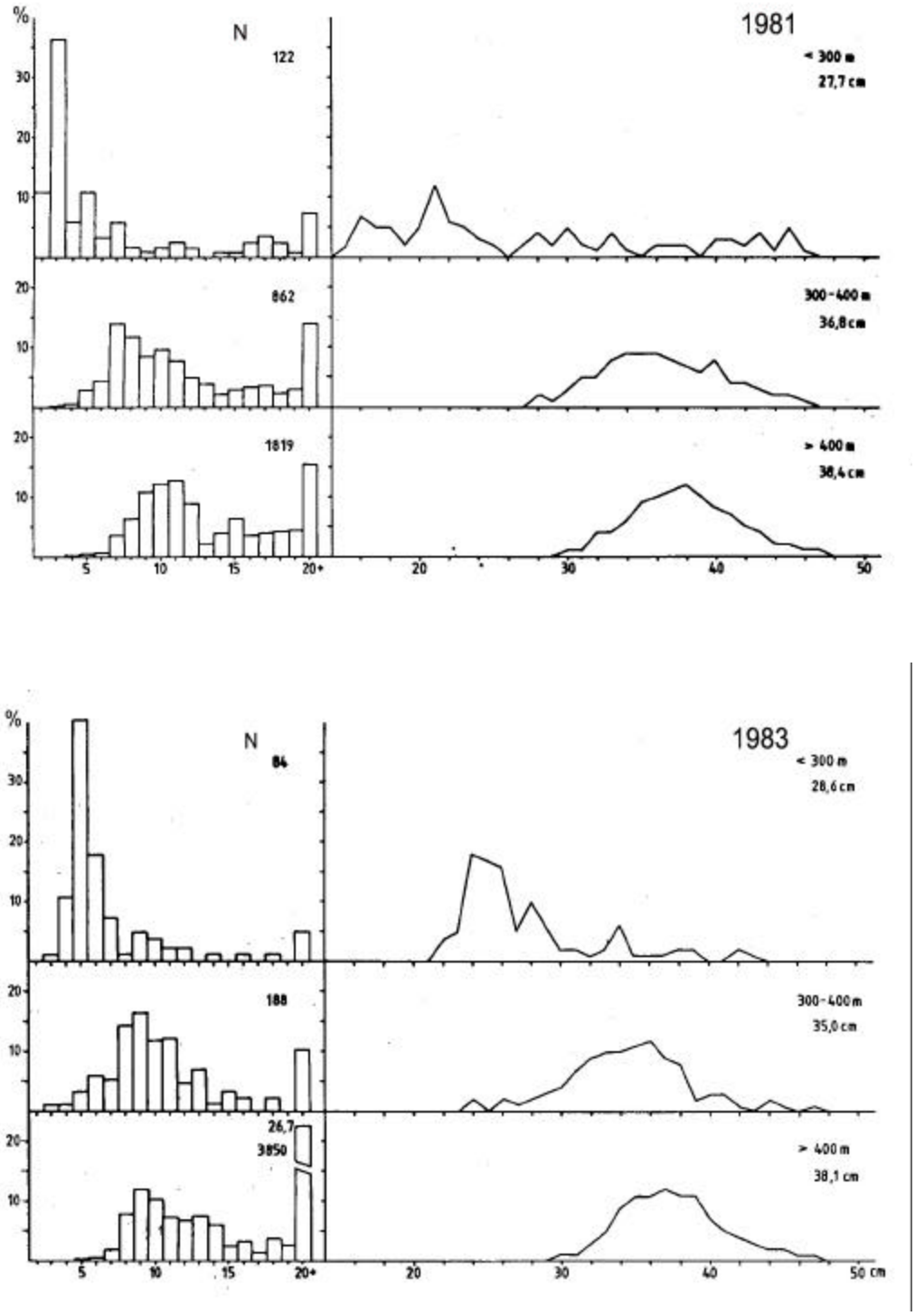

Figure 11. Age and length distribution of greater silver smelt, spring 1981 and 1983. Bottom trawl samples from three depth intervals in the geographical area limited by the latitudes 64-66? N. Sample size (N) and mean lengths for each depth interval are given.

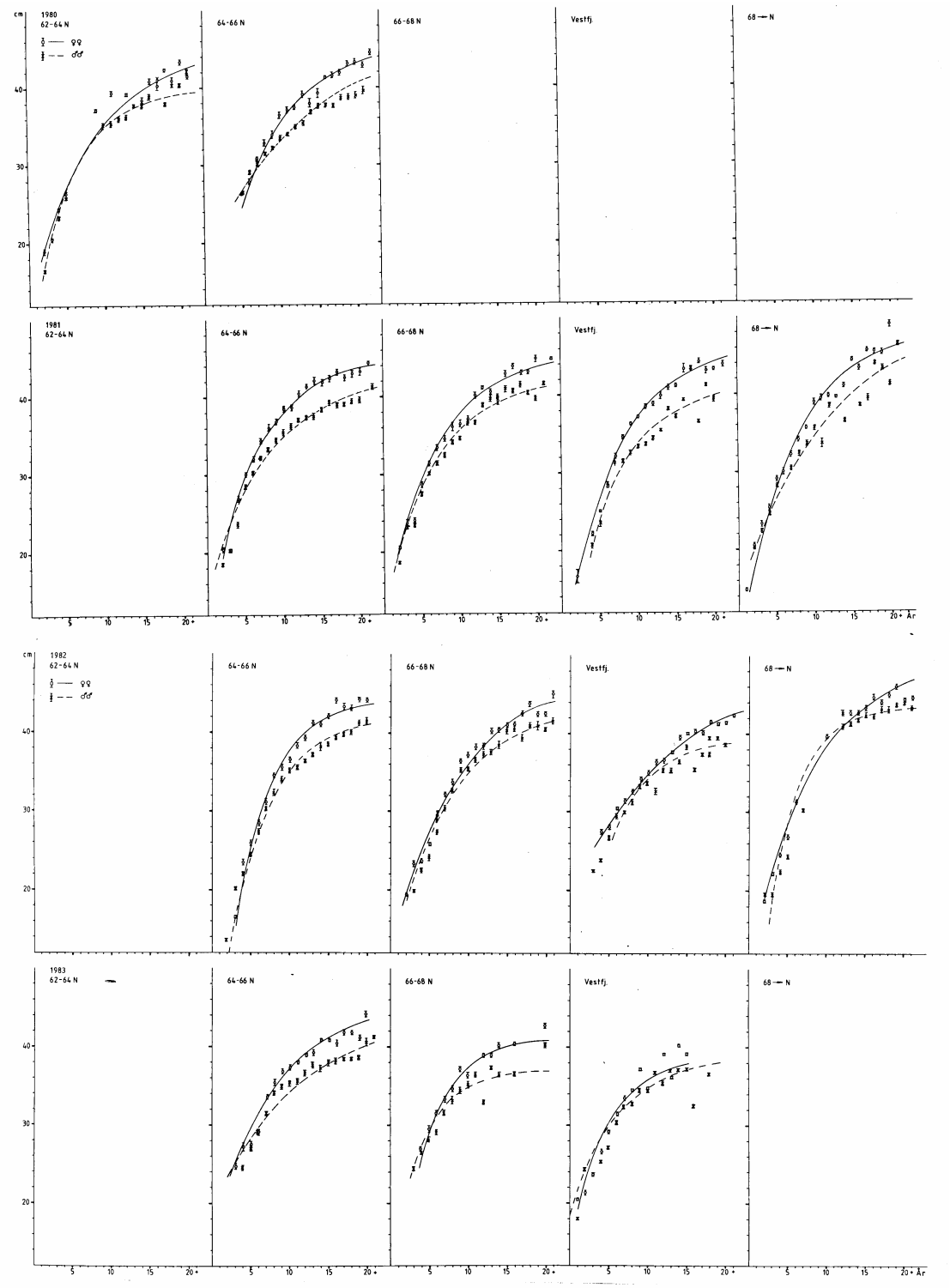

Figure 12. Von Bertalanffy´s growth curves fitted to estimates of mean length (± SD) per age group of greater silver smelt (o=females and x=males) for spring 1980-1983 in the geographical areas: 62-64° N, 64-66° N, 66-68° N, Vestfjorden and north of 68° N. See also Table 2 for growth parameters.