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Spatial and temporal distribution of Atlantic salmon post-smolts in the Norwegian Sea and adjacent areas - Origin of fish, age structure and relation to hydrographical conditions in the sea

By

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Abstract

The aim of the investigations is to collect information on post-smolt ecology in the open ocean, a practically unnknown stage in the the life cycle of the salmon. The paper presents data from surface trawlhauls during cruises in the Norwegian Sea and adjacent areas in 1991 - 1998 where an area delineated by approximately 55°N, 11°W, 76°N; and 15°E has been covered during the summer cruises from June to August. A total of 380 trawl-hours have yielded 459 post-smolts. Although the short time series and limitations in the area covered still do not allow conclusions on distribution and density of smolts in these feeding areas, a distribution pattern with high likelihood of smolt captures can be distinguished. The highest incidence of post-smolt-catches is found in the southern survey area following the slope current northward along the Thomson Wyville ridge, between the Shetland - Faroes and spreading fan- like over an area covering most of the international waters between Norway's, Faroes' and Iceland's EEZ up to about 73°N. With the exception of 1997, when almost no smolts were caught in the northernmost areas even if catches in the southern survey-areas were similar or higher than the previous years. The fish are found in the warmer, saline Atlantic water, in a distribution very similar to the prevailing Atlantic and Norwegian Coastal current pattern. Scale readings show a dominance of 1 and 2 year smolts in all catches, indicating a mid-and south European origin of the fish. Recapture of Irish, Welsh and south English microtagged smolts in the northern areas further support this assumption.

Key words: Atlantic salmon, marine distribution, post-smolts, tag recovery

Introduction

Most available information on Atlantic salmon post-smolts relates to the first weeks after they have left freshwater (Holm *et al.* 1982; LaBar *et al.* 1978; Dutil and Coutou 1988, Levings *et al.* 1994; Sturlaugsson and Thorison 1995 ; Hvidsten *et al.* 1995). In a theoretical approach, based on comparison of observed return rates to reference rivers in North America, Scotland and SW Norway with seasurface temperatures (SST) Friedland *et al.* 1993 set forth a hypothesis that, thermal habitat, notably the extension of SSTs of 8-10°C or more in May define the habitable areas for post-smolts and significantly correlates with tag return rates that can be used as a mesure of survival of these fish. In a atudy from 1998 Friedland *et al.* have further elaborted this method, and found very clear effects of the thermal habitat on survival on a Scottish and a Norwegian salmon stock stock sharing the same thermal habitat in the North Sea. Until the early 90-ties, however, very few investigations of the post- smolts in the open ocean had been made (Reddin and Short 1988; Holst *et al.* 1993)

In pelagic research cruises conducted by the Institute of Marine Research (IMR), Norway, in the North-east Atlantic and the western Barents Sea Atlantic salmon post- smolts and larger salmon were only occasionally caught in the trawl before the early 90-ties. However, in a herring study in 1991 a two boat surface trawl (pair trawl) was used in the northern Norwegian Sea. 34 post- smolts were caught as a by-catch (Holst *et al.* 1993). This was the first significant catch of post- smolts in these areas, and it initiated trials in 1993 to collect salmon post- smolts in the ocean from the IMR research vessels with a newly developed pelagic research trawl.

The motivation for the IMR investigations of the marine ecology of salmon arose from the need of finding explanations to the variations in return rates of salmon released in a large scale coastal salmon release project started in 1990. Many of the observed deviations from the expected return could only be explained by unknown factors occurring during the marine life stage of these fish. This coincided with the start part of a large scale ecological research programme, the Mare Cognitum Programme (**MCP**). The MCP set off an extended cruise activity in the areas that, based on information from the Danish and Faroese long-line and driftnet fishery for salmon, has been assumed to be an important feeding area for salmon. One of the working hypotheses for the project is that in line with other northern pelagic species the post- smolts would utilise the productive northerly areas of the North Atlantic as summer feeding habitats, and that, like other pelagic fish, the largest and most fast growing smolts would migrate to the northernmost areas.

From 1995 onwards salmon surveys have been included in the IMR research cruises within the MCP framework. The aim of the study is to find the postsmolt and salmon summer habitats and to throw light on the ecology if this important but little known life stage, in order to augment the general biological knowledge of the species and to enable more holistic management models.

Trawl sampling has been the predominant method, but we have also made attempts to catch salmon with other gear. This paper, however, summarises only the results of the posts-molt trawl-surveys in 1991 -98. Fishing methods aimed at catching larger salmon are reported in Holm *et al.* 1996, and the catches of 1-2SW salmon in 1991-98 will be reported in another context later.

Material and methods

The research trawl, an Åkra trawl with Thyborøn doors, can be rigged both for mid water and surface trawling. When used in surface mode (fishing from 0 m down to 25 m depth) four large floats are attached to the trawl wings in order to keep the floatline at the surface (Valdermarsen and Misund 1995). In 1998 an additional large float has been attached to the midpoint of the floatline to prevent this part from sagging under the surface. The trawl time is 30 min as a standard, and the trawl is operated with as long warp as possible without the floatline loosing surface contact, i.e. normally 280 - 300 m behind the boat. The trawling is performed at 3-4 knots in large arcs to keep the trawl from going in the wake of the ship. The salmon sampling is made in conjunction with the surveying of important commercial pelagic fish stocks and the trawl transects are set in accordance with the needs and standards for managing these stocks. Table 1. presents an overview of the high seas salmon sampling performed since 1991. In 1998 salmon sampling has been carried through on four more cruises which are not reported here, because at the time of finalising the paper, the cruises were either still ongoing, or the cruise journals were unaccessible for various reasons.

Temperature and salinity profiles from close to surface to the bottom are normally taken prior or posterior to the trawl stations, i.e. at least every 60 nm. In addition certain standard hydrographical transects with a more dense grid of CTD- stations have been monitored on most of the cruises. All together the fished areas are well covered with in situ hydrographical observations.

Results

Distribution

Since 1991 around 950 pelagic trawl-hauls (approx. 475 trawl-hours) have been conducted in the Norwegian Sea with adjacent areas on those cruises where salmon has been included in the survey programme. The results of 867 of these trawl-stations are summarised in Table2. Fig.1. shows the positions of the trawl-stations in 1991-96 with the number of post- smolts in the catches indicated. Fig. 2- 3 show an overview over trawl-stations with and without salmon catches in 1997 -98. Except for 1997 when extremely few smolts were caught in the Norwegian Sea, the distribution pattern is fairly similar between the years with a distinguishable high density area in the international waters in mid Norwegian Sea, and another occurring further north (Fig. 1-3). In 1998, for the first time since the surveys started, the area was extended beyond 75°N. Post- smolts were captured north of 73°30'N which had beeen the earlier northernmost recording (Fig. 3). It is also worth noting that, in 1997, also for the first time, smolts were caught in the Faroes EEZ in June during cruise 1997208 (cf Tab. 1, Fig. 2) and that 142 post-smolts were caught during one 0.5 h haul in the North Sea at 60°45'N;1°57'E (Fig. 2).

Distribution of post-smolts in relation to temperature and salinity

Fig. 4 - 8 present the positions and numbers of smolts caught in 1995 - 98 in the Norwegian Sea in relation to salinity and temperature isotherms at 5m depth. Fig. 9-10 present same type of data for 1996 -97 in the North Sea- southern Norwegian Sea. In the Norwegian Sea 1997 (Fig. 7) differs from the other years by high SSTs stretching far out along the coast- evidently influenced by the extremely high air temperatures in July- August that year. Yet the western areas are relatively cold. This year sticks out also in the sense that although smolt catches were abundant in the Shetland- Faroes channel and the North Sea in June, only a total of 3 post- smolts were caught in the subsequent cruises in July and August in the Norwegian Sea. No evident reason for this lack of smolts could be found other than the possibility of being constantly fishing in the "wrong place at the wrong time" as the east-west trawl trajectories were slowly taking the vessels northwards possibly at the same pace as the northward migration/transportation of the smolts, but lagging behind the main smolt aggregations.

Age structure in catches
Table 3 shows the distribution of age of entering the sea for post-smolts captured in 1991- 97. The smolt age has been determined from scales and otoliths. With the exception of 1991, there is a striking absence of higher smolt ages in the material. In 1997 all the aged fish were caught in the southern areas and are dominated by 1-2 year smolts. The 1998 scales are not yet analysed.

Origin of fish
So far 4 microtagged fish have been found in the catches. One microtag from the river Test in south England and one Irish microtag were found in catches around 70°N in 1995 and 1996 respectively. In 1997 two microtags were retrieved from catches in the Shetland-Faroes area. Not surprisingly one fish came from an Irish river while the other one was of Welsh origin The scale readings reveal that annual catches regularly have a portion of post- smolts of hatchery origin. At this life stage it is not possible to determine whether these fish are farm escapees or fish released for enhancement purposes.

Diurnal distribution of catches
Similar to observations made by Shelton *et al.* 1997 in the Shetland- Faroes- northern Norh Sea area the majority of IMR post-smolt catches were taken during daytime. Only 17, 14 and 5 % respectively of the catches in 1995, 1996 and 1997 and none of the until now analysed 1998 catches were taken during the "dark hours". The 5 smolt catches registered at "night-hauls" all turned to be taken north of the latitudes where the sun stays over the horizon in July-beginning of August (cf. Tab.4).

Size distribution
Fig. 11. shows mean size of fish based on minimum three smolts in the catch in various cruises in 1995-97 The fish of hatchery origin are included, which may lead to a higher mean than if only the wild fish were included. The mean size of the 8 smolts caught north of 73°N in mid august 1998 was 28.7 cm.

Discussion
In the natural distribution area of Atlantic salmon, the smolts leave their respective home rivers during April-July, and the further north, the later seasonal smolt migration. When leaving the rivers, the movement of post- smolts seems to be highly dependent on speed and direction of surface currents (Holm *et al.* 1982; Hvidsten *et al.* 1995). Inshore, the post-smolts have periods of active and directed movement alternated with at least seemingly passive drift periods. Prolonged periods of active swimming with the current, i.e. that the fish move faster than the recorded current, has been observed when acoustically tagged smolts approach the hydrographically more uniform waters in the fjordmouths or at the coast. Speeds of 40 - 50 cm s^{-1} (Holm unpublished).

Fig. 12. shows the pattern of the surface circulation in the Norwegian Sea as observed from Lagrangian drifter data (Poulain *et al.* 1996). When comparing the pattern in Fig. 12. with the post-smolt distribution patterns in Fig. 1-3. it is evident that the post-smolts take advantage of these currents on their northward migration. The observed high speed of the current along the Norwegian shelf edge is indicative of how fish from the southern areas may reach the northern latitudes within a relatively short time. A similar coherence between current patterns as measured with Argos buoys released by the SEFOS programme (Anon 1997b) and the dispersion of post- smolts can be observed in the areas from west of the Hebrides via the Wyville-Thomson Ridge to the Norwegian trench. However, the transport of the surface layer

as measured by these buoys seems to be much slower than indicated by the speed calculated for the microtagged Irish and English smolts.

When looking at the distribution of our post-smolt catches in 1995 -98 the majority are found in temperatures >8°C and salinities ≥ 35 ppm (Fig. 4 -10) conforming with the observations made by Shelton *et al.* 1997 and in good concordance with Friedland *et al.* 1998. On the other hand, the temperature regime in 1998 was favourable with large areas in the western and northern part of the Norwegian Sea with temperatures in 5 m depth above 8°C, where salmon would be expected to occur. Yet there were virtually no smolts caught (Fig. 3). It is not possible, from the material analysed so far, to conclude whether the absence of salmon in the catches in these areas is coincidental as a consequence of a scarcity of sampling stations, or, whether it reflects an impact of some other essential environmental factor, e.g. the absence of suitable food organisms, unfavourable current gyres preventing the fish from easy access to the area, or from fishing the areas at an unfavourable time in relation to the assumed northward migration of the post-smolts.

Other causes than just bad timing of fishing can be discussed in conjunction with the low 1997 catches in the Norwegian Sea. The zooplancton biomass in the central Norwegian Sea was reported to be very low in May and June 1997 compared with previous years, and temperatures were not favourable for the herring in the western part, where the plancton seemed to be more abundant. That situation was reflected in a low condition factor and low fat content of herring later in the year (Holst *et al.* 1998). Salmon are distributed in much the same areas as the herring, and are likely to have encountered the same conditions. On the other hand, unofficial reports of good returns of 1-SW salmon to most regions in Norway in 1998 do not at this stage suggest marine mortality as an explanation to the low 1997 postsmolt catches. A closer analysis of the scales of these 1 SW fish will probably reveal if the fish have been succumbed to food scarcity during some period of their marine life.

The dominant smolt-ages observed in all catches, i.e. 1-2 years, indicate that the majority of the fish caught originate from mid- and south- European (possibly to e lesser extent also from south Norwegian rivers). The smolts from the mid- and north- Norwegian and the Russian rivers are 3-5 years old when they enter the sea. Those ages are to a large extent absent in this material. Different stocks may occupy different areas of the Norwegian Sea. Thus it is obvious that we have still not found neither the migration routes nor the summer feeding areas for a large portion of the north European salmon stocks.

The 1998 catch of 3 and 4 post-smolts (Fig.3) at 74° and 75°N between12-17 August extends the observed post-smolt habitat in accordance with the hypothesis that the later in the summer the further north the smolt occur. However, since these areas have not been surveyed regularly for salmon at that time of the year before, it is not possible to conclude whether the fish migrate regularly to these areas, or whether they are found there only in years with high SSTs like 1998.

There are still large areas of potential post-smolt and salmon summer-habitats that have been poorly covered or not covered at all. This is demonstrated by the absence of smolts from cold rivers in mid- and north-Norway and Russia in the areas surveyed. We are suggesting that the trajectories of the dominating surface currents in these areas would give indications of where to search for them.

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Tables and Figures

Table 1. Pelagic cruises with salmon sampling in 1991 - 98

Cruise ID	Ship	Gear used	Time-frame	Area
1991	Hired fishing vessels	Surface pair trawl	23 .07 - 27.08t	Norwegian Sea N
1993010	R/V G.O.Sars	Surface trawl	25.07-15.08	Norwegian Sea, (E and N)
1995206	R/V J. Hjort	Surface trawl Otter board	30.05-01.07	Irish Sea, Shetland - Faroes, Norwegian Sea (S)
1995207	R/V J. Hjort	Surface trawl	07.07-01.08	Norwegian Sea, east and north
1995013	R/V G.O.Sars	Surface trawl	30.07-14.08	Mid-and northern Norwegian Sea, Barents Sea (W)
1996207	R/V J. Hjort	Surface trawl	05.06.-15.06. / 03.- 07.07.	NW of Scotland - Shetland - Faroes/ North Sea (N)- Norwegian Sea (S)
1996208	R/V J. Hjort	Surface trawl[1]	23.06.-02.07	North Sea
1996209/210	R/V J. Hjort	Surface trawl Drift line Drift -net	09.07-04.08.	Norwegian Sea (N)/ Greenland Sea (E)
1996010	R/V G.O.Sars	Surface trawl	19.07.-15.08.	Norwegian Sea (E)
1997007	R/V G.O. Sars	Surface trawl	01.05-01.06..	Norwegian Sea (E)
1997208	R/V J. Hjort	Surface trawl	28.05 - 17.06	NW of Scotland - Shetland - Faroes/ North Sea (N)- Norwegian Sea (S)
1997209	R/V J. Hjort	Surface trawl Drift net and - line	19.06 - 12.07.	Norwegian Sea SE- NW
1997010	R/V G.O. Sars	Surface trawl	25.07.-15.08.	Norwegian Sea SE- NE
1998209	R/V J. Hjort	Surface trawl	01. -30.07	Norwegian Sea (SE - NW)
1998210	R/V J. Hjort	Surface trawl Drift net	01. -23.08	Norwegian Sea (N)/ Greenland Sea (E)

Table2. Catches of post- smolts and 1-SW- salmon in 1996 og 1997 in the the North East Atlantic the Norwegian Sea and the eastern Greenland Sea in 1991, 1993 and 1995-1998.,

Cruise ID	Mean towing speed in knots	Number of poststsmolts captured	Number of 1- SV salmon	Total num-ber of hauls	Surface hauls with salmon %
1991		34	2	75	24
1993010		13	1	61	3
1995206	3.5	46	2	46	19
1995207	3.7	62	4	57	32
1995013	3.0	2	0	50	4
1996207	3.7	66	1	73	19
1996208	3.7	0	0	8	0
1996209/2 10	3.7	2	0	33	9
1996010	3.6	12	1	89	8
1997007	3.0	0	3	75	4
1997208 [1]	3.6	201	3	75	29
1997208 [2]	4.1	0	1	3	33
1997209	3.0	1	1	34	6
1997010	3.0	2	0	82	2
1998209	3.3	61	6	84	21
1998210	3.7	8	0	22	14
Total 1991-98		**510**	**25**	**867**	

[1] Åkra- trawl [2] A smaller Harstad- trawl was used

The R/V Johan Hjort (ID finishing with 2XX- series)has more motorpower, and the towing speed can therefore be kept higher on this ship than on the G.O. Sars (ID finishing with 0xx).

Table 3. Smolt ages (river years) derived from readable scales and otoliths from postsmolt catches in 1991 - 1997. If discrepancy between readings, otholit age was chosen.

River years	1991	1993	1995	1996	1997	Total nr	Per cent
1	3	0	26	3	93	125	30,5
2	11	5	73	58	99	246	60,0
3	7	3	9	11	2	32	7,8
4	5	0	0	2	0	7	1,7
Total	26	8	108	74	194	410	100,0

Tab.3. Times in UTC for the sun's passage over the horizon at various latitudes (1998) (Norsk Fiskeralmanakk 1998)

		May 25	**June 1**	**July 1**	**August 1**
Place	**Latitude/ longitude**	**Up / down**	**Up / down**	**Up / down**	**Up / down**
Kristiansand	58°09'N; 08°00'E	02:44 / 19:53	02:34 / 20:17	02:28 / 20:35	03:19 / 19.48
Trondheim	63°26'N; 10°24'E	01:43 / 20:49	01:26 / 20:08	01:11 / 21:33	02:31 / 20:16
Bodø	67°17'N; 14°23'E	00:11 / 21:41	Midnight sun	23:22 / 22:20	01:28 / 20:46
Honningsvåg	70°40'N; 25°59'E	Midnight sun	Midnight sun	Midnight sun	23:03 / 21:26

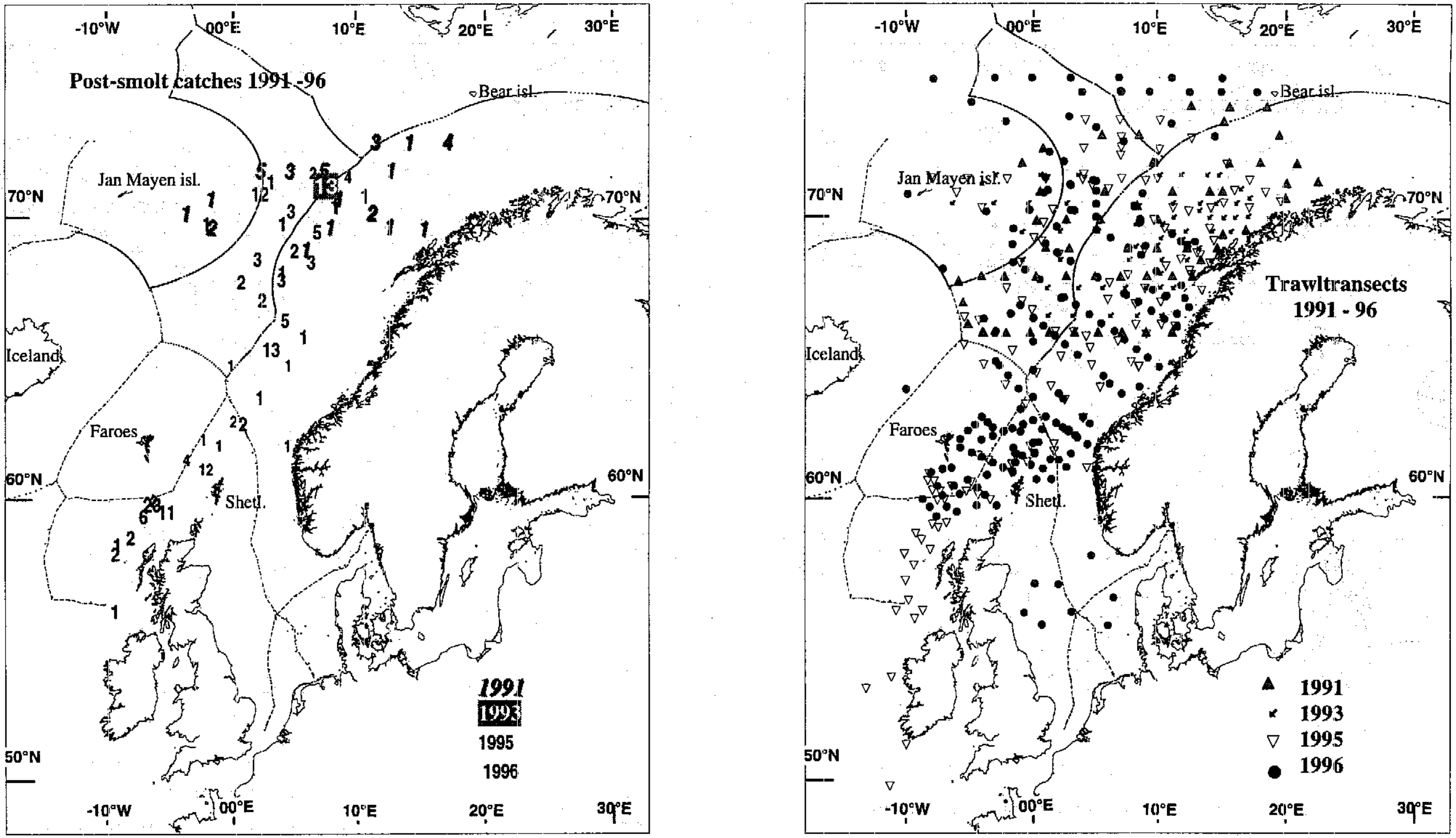

Fig. 1. Post- smolts caught in surface trawl in 1991 -95 (left panel). Surface trawlhauls without smolt catches 1991 -95 (right panel). Legends in the figures

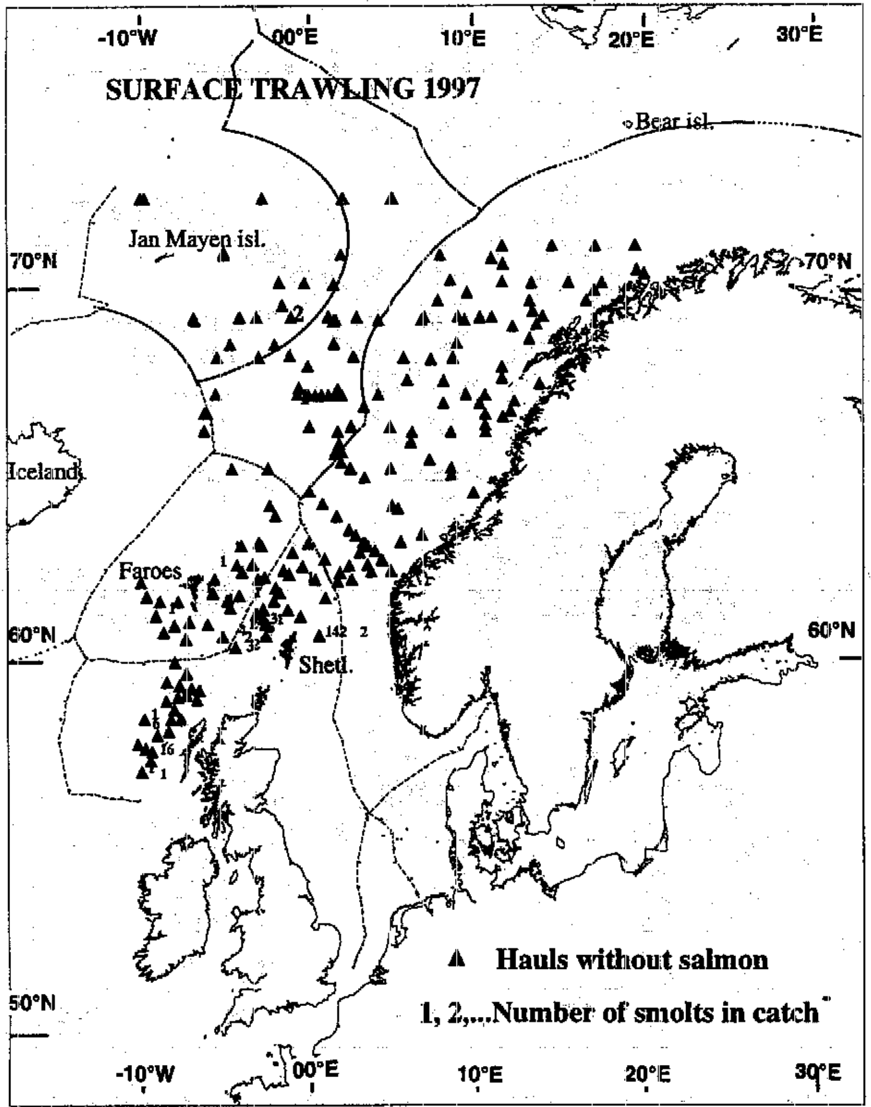

Fig. 2. Surface trawl-stations in 1997 with nr of postsmolts and without catch. Legends in figure. Location of smolt capture in midpoint of number.

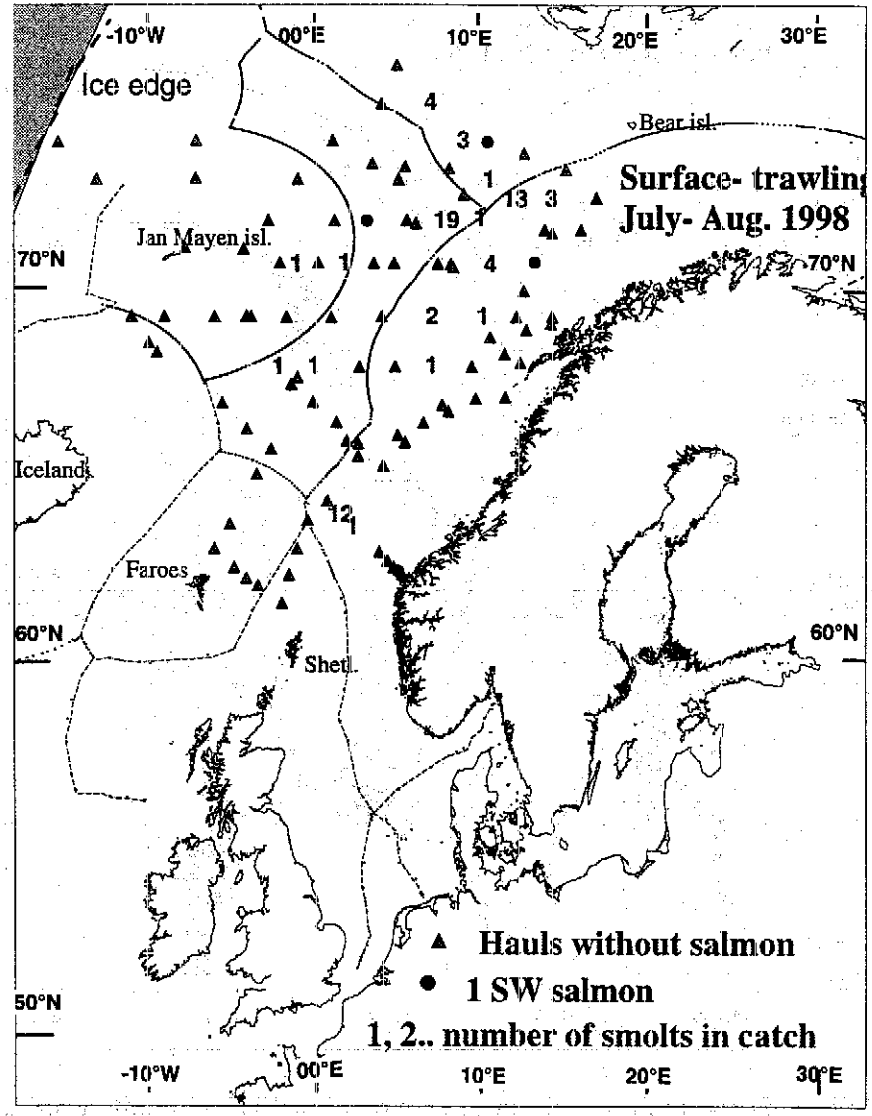

Fig. 3. Surface trawl-stations in 1998 with nr of postsmolts and

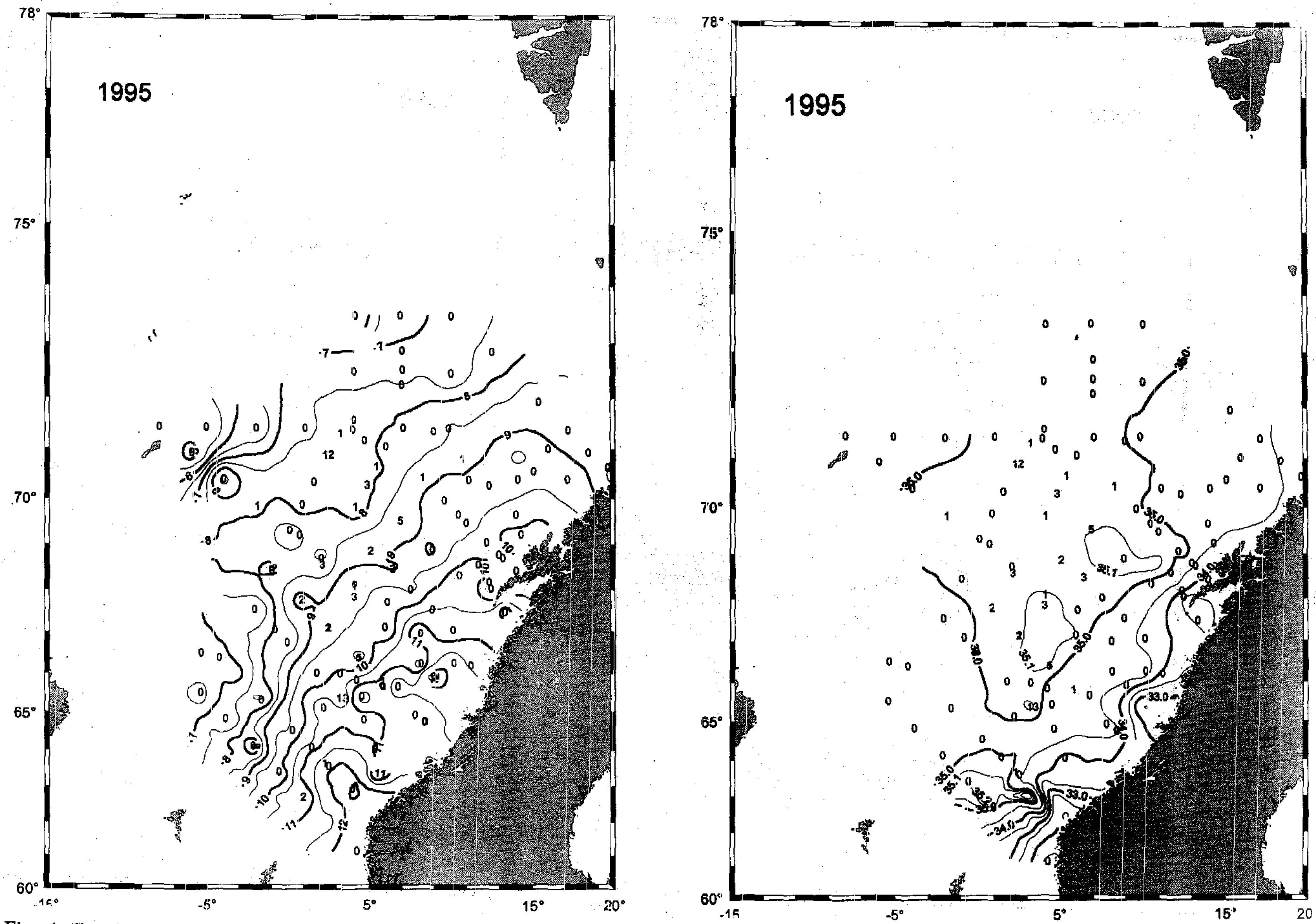

Fig. 4. Trawl stations in 1995 without (0) and with nr of smolts (1,2, etc) in relation to temperature (left panel) and salinity (right panel) isotherms at 5 m depth in the Norwegian Sea in July - 1st week of August.

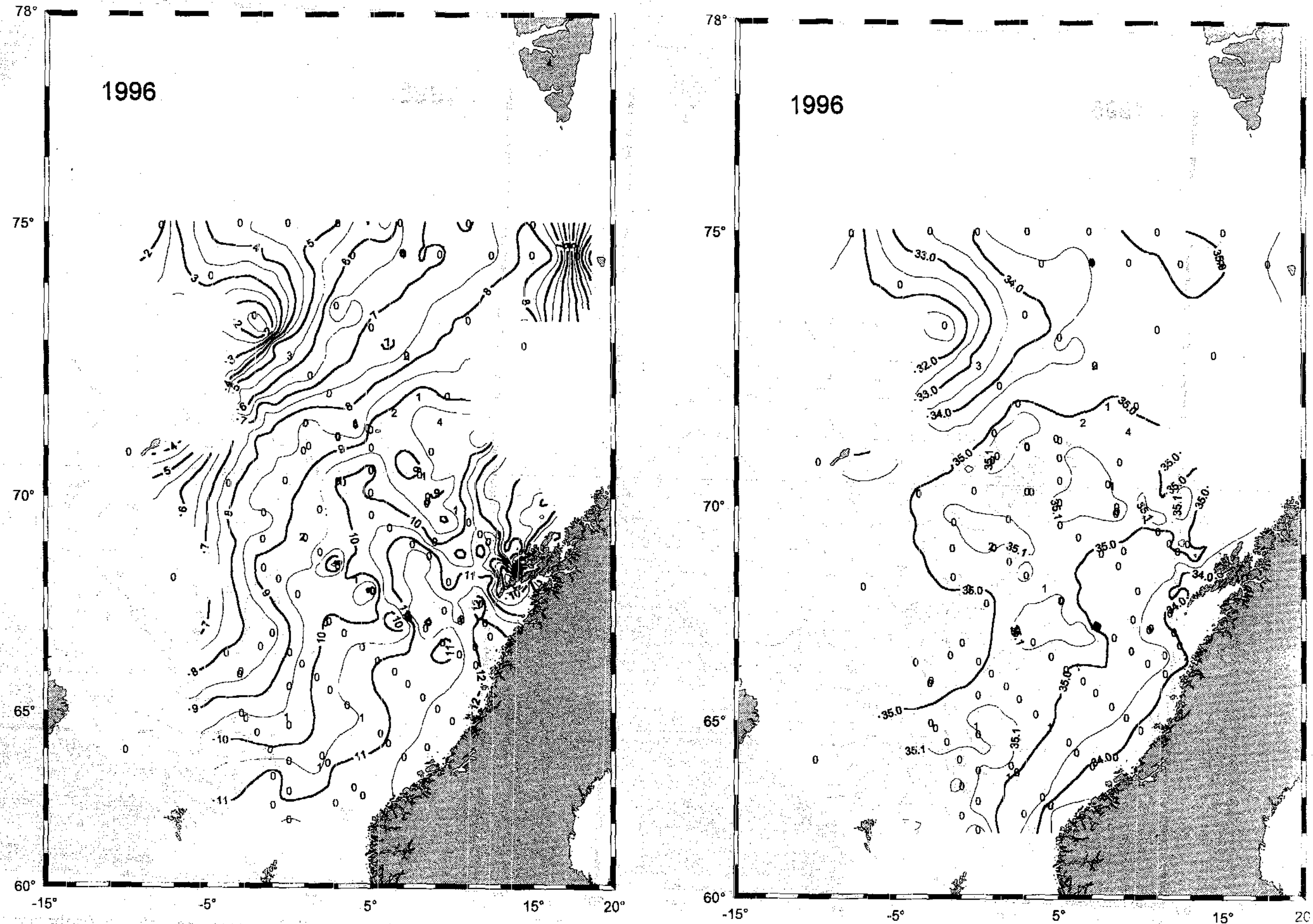

Fig. 5. Trawl stations in 1996 without (0) and with nr of smolts (1,2, etc) in relation to temperature (left panel) and salinity (right panel) isotherms at 5 m depth in the Norwegian Sea in July - middle of August.

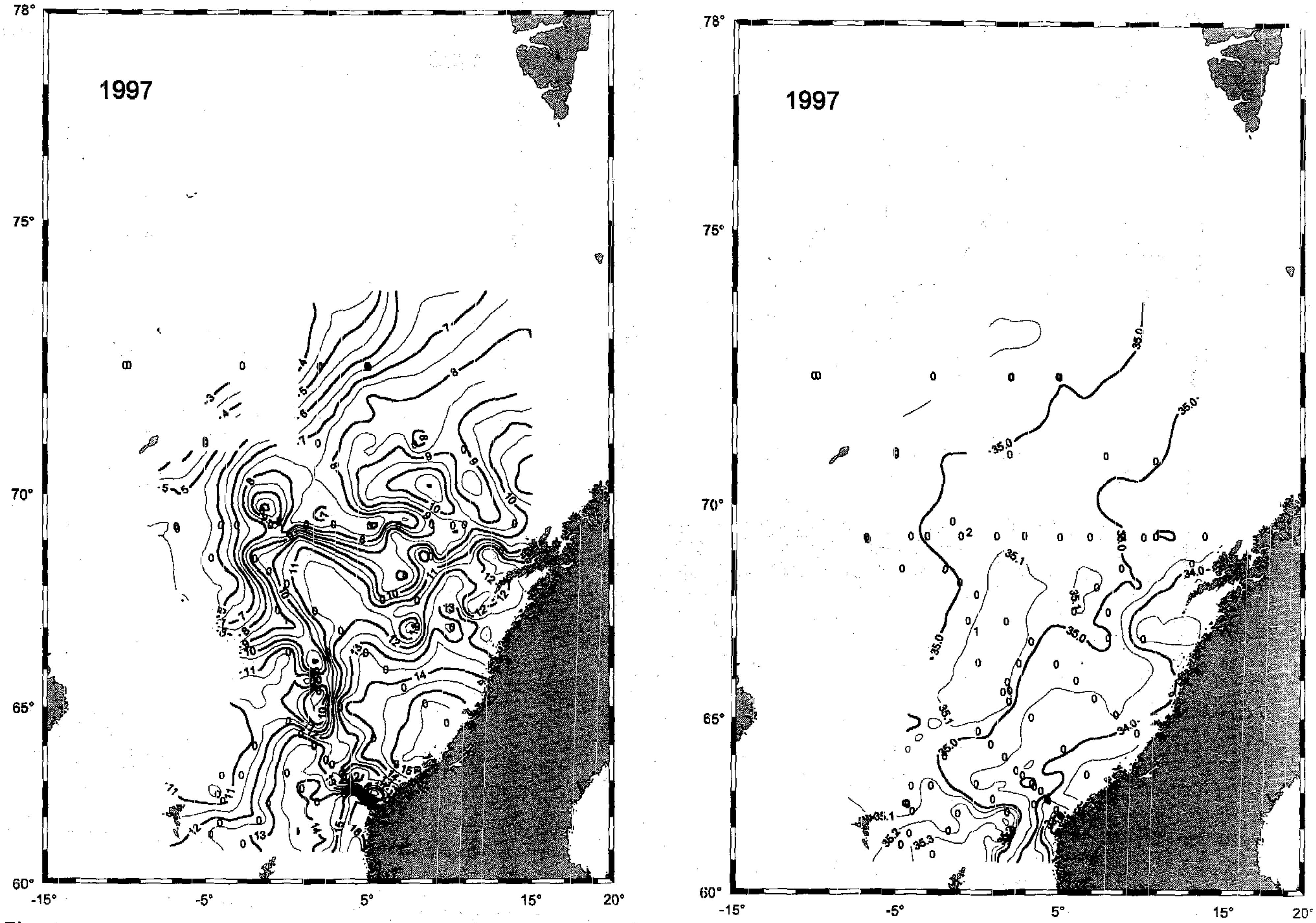

Fig. 6. Trawl stations in 1997 without (0) and with nr of smolts (1,2, etc) in relation to temperature (left panel) and salinity (right panel) isotherms at 5 m depth in the Norwegian Sea in last week of June- 1st week of August.

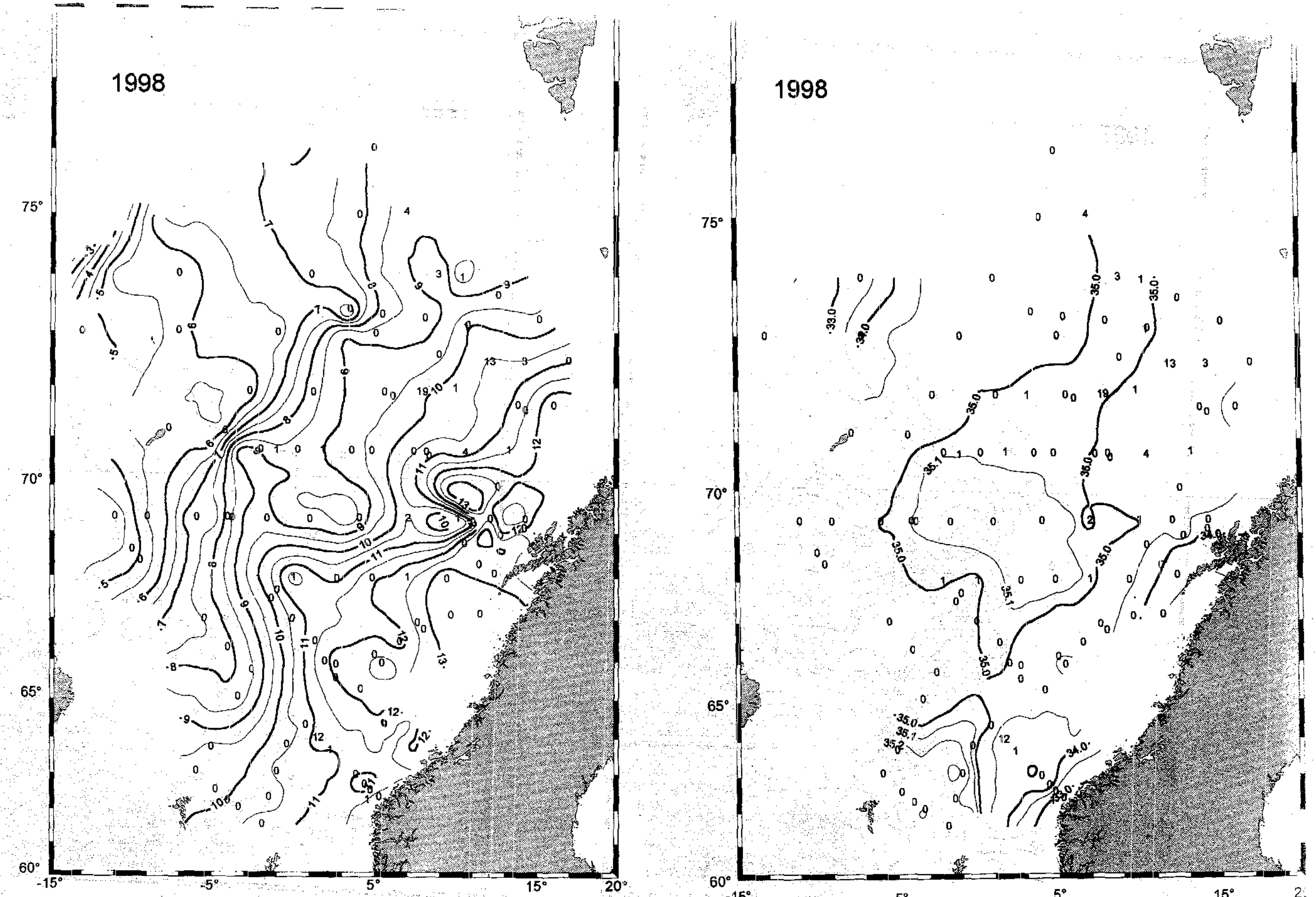

Fig. 7. Trawl stations in 1998 without (0) and with nr of smolts (1,2, etc) in relation to temperature (left panel) and salinity (right panel) isotherms at 5 m depth in the Norwegian Sea in July - 3^{d} week of August.

Fig. 8. Trawl stations in 1996 without (0) and with nr of smolts (1,2, etc) in relation to temperature (left panel) and salinity (right panel) isotherms at 5 m depth in the North Sea and southern Norwegian Sea in June.

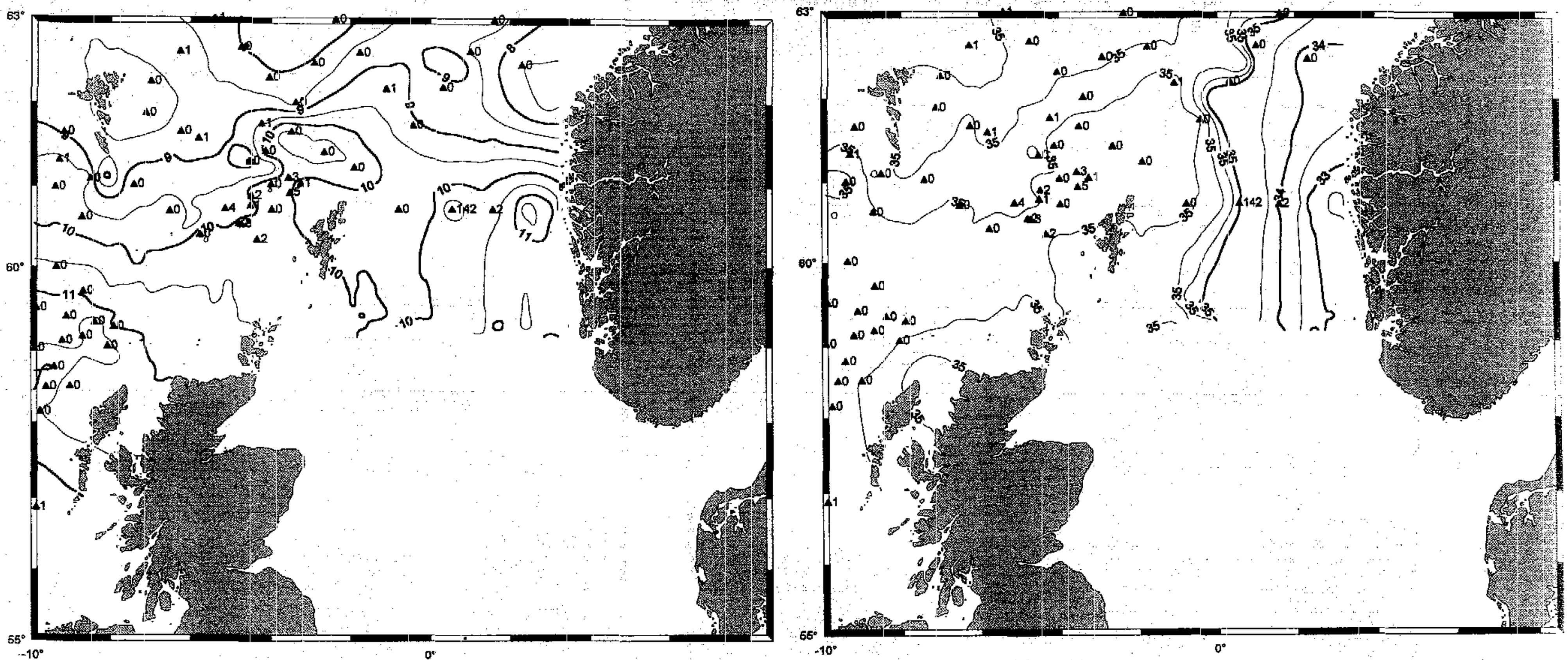

Fig. 9. Trawl stations in 1997 without (0) and with nr of smolts (1,2, etc) in relation to temperature (left panel) and salinity (right panel) isotherms at 5 m depth in the North Sea and southern Norwegian Sea in June.

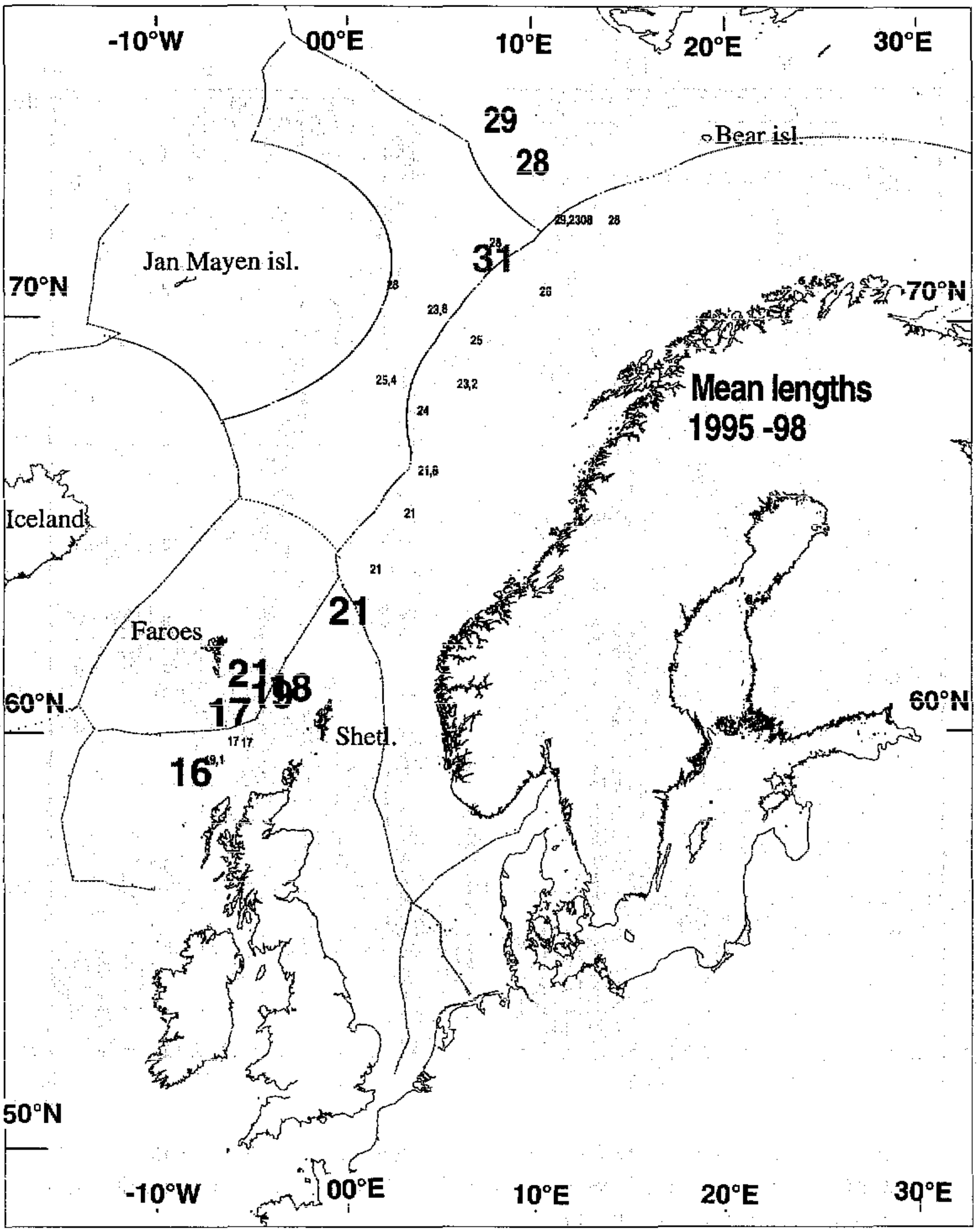

Fig. 10. Mean lengths (cm) and geographical location of molts in catches with minimum 3 post-smolts in 1995 -98

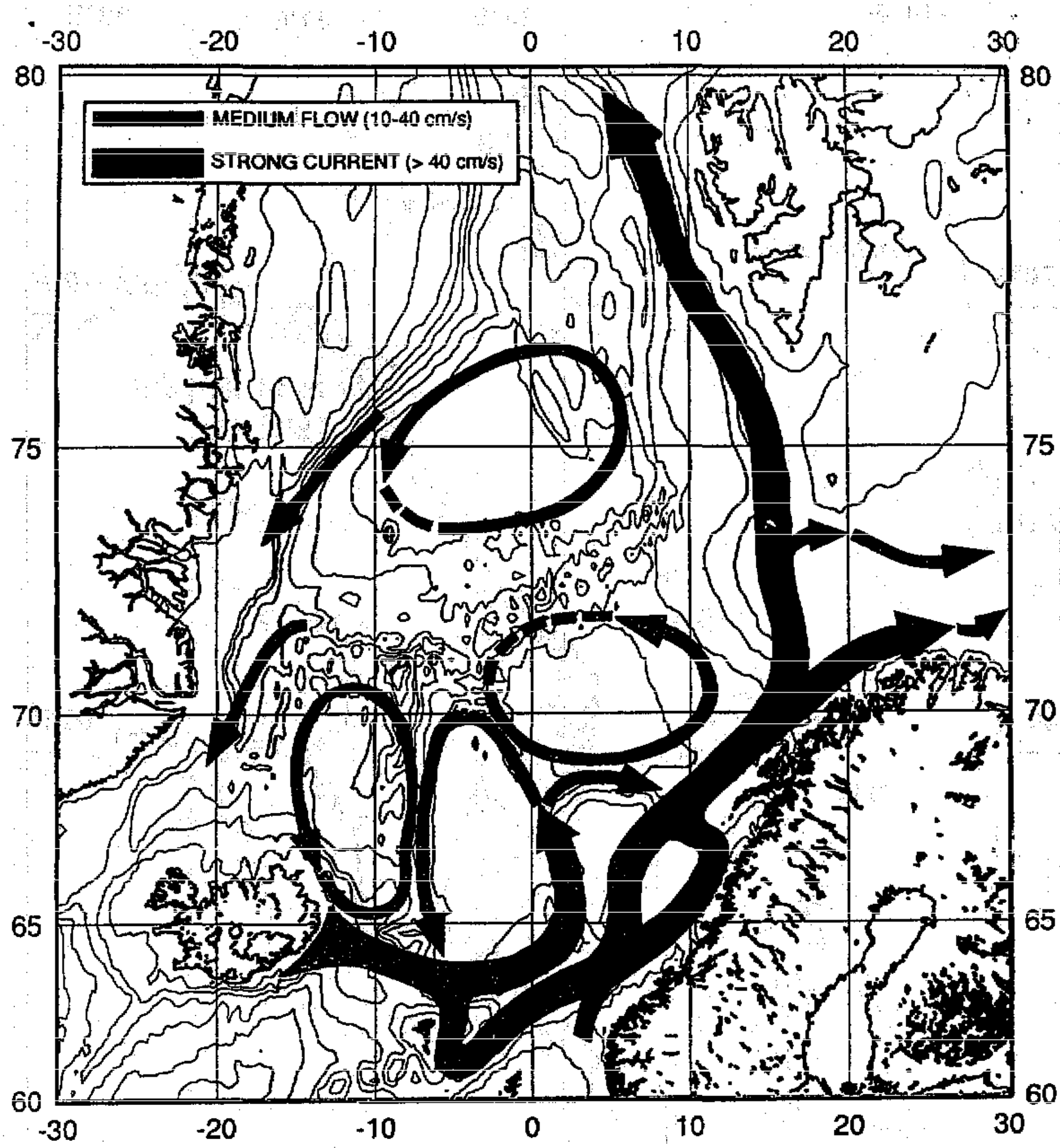

Fig.1$. Schematic of surface circulation in the <norwegian Sea derived from Lagrangian drifter data. The East Greenalnd Current is not depicted due to to Ice coverage. From Poulain *et al.* 1996.