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MIGRATORY PATTERN OF HOMING ATLANTIC SALMON (*Salmo salar* L.) IN COASTAL WATERS W- ICELAND, RECORDED BY DATA STORAGE TAGS

by

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Abstract

A migration study on the homing of Atlantic salmon (*Salmo salar* L.) was carried out in coastal W- Iceland waters in August 1996. External data storage tags (DSTs) were used to record pressure (depth), temperature and conductivity (salinity) during the migration. The DSTs were programmed to measure at 3-30 minutes intervals for 17-24 days. The present DST recordings are the first to include salinity measurements. A total of 100 salmon were captured and tagged in the estuaries when entering their home waters at the ocean ranching stations in Laros and Hraunsfjord. Of these, 92 were transfered and released at the shore in Borgarfjord (shortest sea route 170-200 km), but the remaining 8 served as controls and were released near their home water. The recapture rates of different groups ranged from 58 to 65 %, whereof 40-51 % were recaptured in the ocean ranching stations 3-82 days after release, but others in inshore nets or in rivers. The mean travelling speed of the salmon from release to recapture, ranged from 0,1-1,8 km/hour, but examples up 4 km/hour were found based on the actual departure from release site and the arrival to home estuary.

Comparison with temperature data from satellites showed that most of the salmon migrated quite close to the coast. The DSTs salinity measurements showed that some individuals migrated into estuaries and even into rivers on their way to their home waters in Laros and Hraunsfjord. The depth records showed that the salmon migrated mostly in the uppermost few meters. The salmon often showed diurnal rythm in vertical movements, staying deeper at night. The salmon were closest to the surface during noon and the majority of the deepest dives were related to sunset and sunrise. The usual pattern of migration through deeper layers were a series of rapid dives. Usually the dives were just a few meters, but occasional dives were taken down trough the thermocline at 20-40 m depth, and even down to 110 meters. The migratory patterns of the salmon are further discussed in relation to the possible cues/clues used by the salmon while navigating to their home water.

Key words: Atlantic salmon, migration, homing, navigation, coastal waters, data storage tags.

Introduction

The sea migration of Atlantic salmon (*Salmo salar* L.) includes long migration routes but at the same time very precise spawning migration back to freshwater to spawn in their home water. Questions about the coastal waters part of the homing migration of salmon were the main reasons for that we started in 1993 to use Data storage tags (DSTs) to study this migration phase. This pioneering work lead to use of these tags on anadromous brown trout (*Salmo trutta* L.) to study their feeding migration and this summer we started DST tagging experiment on anadromous artic charr (*Salvelinus alpinus* L.). All together this work has given us lot of new information about the migration of these species in the sea, but also about their migration in estuaries and rivers (Sturlaugsson 1995; Sturlaugsson and Thorisson 1996; Sturlaugsson and Johannsson 1996; Sturlaugsson and Gudbjornsson 1997; Sturlaugsson and Johannsson 1997; Sturlaugsson et. al. unpublished). The DSTs we have used are manufactured in Iceland by Star-Oddi Ltd. These tags record series of measurements in relation to time from the environment of the fish. Until 1996 these parameters were temperature together with pressure giving the depth of the fish. In 1996 a salinity sensor was added to these tags, enabling us to get specially interesting information about the reaction of salmonids to this environmental parameter.

In the migration study on homing of salmon described here, a salinity sensor equipped DSTs were used for the first time on fish. The main aim was to use combined depth-temperature-salinity information to get new view of homing migration of salmon in coastal waters in relation to the environmental stimuli experienced. In relation to that we chose Borgarfjord as the main release site, because the fjord area is heavily influenced by freshwater from the large Hvita river system.

Material and methods

Study area, tagging and releases

In August 1996 100 salmon were tagged with DSTs at two salmon ocean ranching stations at Snæfellsnes peninsula at Breidafjord W-Iceland (Fig.1. and 2). Schools of homing salmon were caught in capture facilities in the estuaries when entering their home water. The salmon were tagged with DSTs and fork length and weight measured. Tags were fastened externally adjacent to the dorsal fin by the Carlin method using stainless steel wire.

Following tagging the salmon were transplanted in the sea away from the tagging site in order to get the information about the migration back to their home waters. Most of the salmon were transferred by truck (in freshwater) to Borgarfjord and released there at the shore 10. August (GMT: 0:30-1:30), following tagging in Hraunsfjord (8. August) and Laros (9. August) (Fig.1., Table 1). Small number of salmon were also DST tagged 13. August and released in Kolgrafafjord from boat and few were kept in net a pen in Hraunsfjord as control (Fig.2., Table 1).

Tag types and programming

The DSTs used were of DST-200 type from Star-Oddi. Half of the tags had no salinity sensors, and the results from those tags were mostly exluded from the data processing that this paper is based on. All fish were also tagged with conventional tags (Floy). In fact some of them were triple tagged, because when available microtagged fish were used in the taggings.

The DSTs used had 2 Kbyte memory. DSTs having pressure (depth), conductivity (salinity) and temperature sensors were programmed to measure either at 12 minutes intervals for 22 days or during 24 days at two different time intervals, that were 6 minutes intervals for one day (T1) followed by 30 minutes intervals for two days (T2), then 6 minutes intervals again etc. The DSTs not measuring conductivity had measuring intervals ranging from 3-12 minutes.

The DSTs data is preserved in the memory without battery backup. The DSTs are cylindrial in shape (48x17 mm) weighed less than 1 gram in water and 12 g in air. The temperature and pressure range were 0 to 20 °C and 0 to (90-110) m respectively. The salinity range were 4 to 37 (max value) psu (‰). The nominal accuracy for the temperature was +/- 0.2 °C and +/- 0.5 m for pressure. In case of salinity the nominal accuracy varies along the scale, being the most accurate in the lower values +/- < 0.5 psu but down to around +/- 1.5 psu at 34 psu.

Calibration of DSTs data

The measured conductivity (salininity) measurements were calibrated in the uploading program for the tags, by giving known value at given time, that were derived from comparative measurements on salinity before the salmon were released. In case of depth recordings, they were compared to the recordings received from the tagging and transport phases, when the salmon were in tanks with known height of water column. In some cases the depth recordings of salmon while in the tanks were a little bit below the water column of these tanks (0,8-1,4 m). In those cases the depth recordings were reset so that the values from periods in the tanks fitted to the maximum depth values possible in the tanks (0,8 - 1,4)m.

Comparative environmental data

Hydrographical data were sampled in Hraunsfjord, Kolgrafafjord, and Laros using conductivity, depth, temperature probe (CDT) and a light meter was used to measure visible light radiation ($\mu E/m^2/s$) (Fig. 2.). DSTs were used for sampling continuous series of hydrographical measurements (salinity, temperature) troughout the study period at 0,5 m depth in Laros near the fish trap and in Hraunsfjord (Fig. 2.). In addition hydrographical data from outer areas were received from the Hydrography department at the Marine Research Institute in Iceland and images of satellites sea surface temperature (SST) were received from the Royal Netherland Meterological Institute. Tidal stream data were received from the Icelandic Hydrographic Service.

Data handling

In this paper the DSTs data used is based on recaptures of salmon equipped with depth-salinity-temperature DSTs, although some references are made to the results from the DSTs without salinity sensor. In order to compare easily the environmental recordings received by means of DSTs to measured comparative environmental data, the DSTs data set was subsampled down to 30 min intervals, matching the measured environmental data. In the case of 12 minutes intervals the measuring per 36th (X:36) minute of each hour were set as the value opposite to comparative data measured at the half hour past a given hour (X:30).

The salinty values recorded by migrating salmon were used to group the migration into intervals to work with seperately. For tagged fish released in Borgarfjord, the migration was grouped the following way:

1) Migration in Borgarfjord was classified as the time period from release to the first salinity recording of $\geq$ 31 psu (maximum fish depth recordings during that period showed also to be within the bottom depth range in Borgarfjord). This first $\geq$ 31 psu recording were most often followed by higher salinity values shortly afterwards, but there were a few examples where salinity values typical for Borgarfjord were experienced after this $\geq$ 31 psu recording. In those cases the migration speed to home water based on this classification is underestimated.

2) Migration in the period ranging from the first salinity recording of $\geq$ 31 psu to the first low salinity recording in the home estuary (the actual sea migration). The fixed point of this first recording of low salinity value (< 30 psu) in the home estuary were based on values that were followed by regular tidal related fluctations in salinity (freshwater or very low salinity experienced each tide) until recapture. Therefore this method have the tendency to

overestimate (lengthen) this period compared to the actual behaviour if fishes does not stick continiously to the estuary area after first entering it.

3) The third and last phase of the migration were defined as the time period from first entering the estuary until captured (Hraunsfjord) or trapped (in Laros). Due to well mixed waters in most of Hraunsfjord this defination of this last period of the sea migration has the tendency to be shortened in relation to the actual behaviour in that area in cases where fishes did not migrate on regular basis into the head of the fjord after first entering the fjord.

The calculation of the migration speed of fish that were recaptured in Hraunsfjord and Laros were based on the time between the point when the salmon left the Borgafjord area until entry to home estuary. When calculating migration speed, it was based on the shortest seaway between the release site and recapture site. The shortest sea route from Borgarfjord release site to Laros and Hraunsfjord are 170 and 200 km respectively , but the shortest sea way along the shore is very little longer beacause of how unjagged it is and close to the shortest possible route. To compensate for the distance already migrated outward from the release site to the point when the salmon left Borgarfjord according to salinity values, a 20 km were taken off the shortest possible route that in fact does more than to compensate for the distance that the freshwater from Borgarfjord rivers are influencing in the degree worked with here.

The results of the homing migration study are presented here both as main trends that were observed and also by giving examples on individual basis of the homing migration patterns.

Results and discussion

Recaptures

Salmon of sizes ranging between 52.6 - 93.5 cm in length and 2010 - 8750 g in weight were tagged and the recaptures had the same size interval. Tagged salmon were grilse, except 2 individuals that were 2 sea winter old. The total mean recapture was 63% involving approximately a total of 250 thousand of recordings. Vast majority of the salmon were recaptured at Laros and Hraunsfjord, but all together the number recaptured at other places were considerably high and the sites involved quite many (Figs. 1.&3.). Double tagging did not indicate DST tag loss . Most of the recaptures in Laros and Hraunsfjord were during the 3 week interval that the tags were recording.

Migration into rivers in Borgarfjord

Following release some of the salmon migrated into the Hvita river system where some of them were recaptured by anglers (Fig.3, Table 1). In earlier transplantation studies in Iceland where salmon at the same life and migration stage have been released into full saline sea, salmon from the releases have only been recaptured in the salmon ranches where they were initially captured and tagged (Sturlaugsson 1995: Sturlaugsson and Thorisson 1996). The salmon recaptured by the anglers had started continuous migration in the rivers after being in the estuary area of Borgarfjord for 16 - 26 hours. The fish migrating up into freshwater were widely distributed in rivers in the area. The longest upriver migration reported was 30 km from sea (mean migraton speed 0,3 km/klst) and the fastest one migrated 8 km up River Hvita at the at the mean speed of 0,8 km/hour according to time of recapture (Fig. 3., Table 1).

Notably some of the fish migrating into rivers in Borgarfjord following release (continuous freshwater migration among them started 20-52 hours after release), but migrated out of freshwater some weeks later. These salmon had then stayed in that system at least during the 3 weeks that the tags recorded and then migrated back to sea and to their home waters. Five salmon that showed this behaviour were recaptured in late September or October. Timing of their recapture indicates that there could have been more fish that behaved in this way. Two of these fish were recaptured by fishermen in the lake above Laros estuary in September and 3 salmon were recaptured in Hraunsfjord in October two together on the 15th and one on the 29th of October. This special migration reflects the strong nature to migrate to home water prior to spawning, and also indicates that all the fishes captured by anglers could have migrated back to home waters after the angling season finished.

Although it is reasonible to conclude that the transplantation from home water to Borgarfjord have confused these fish so that it resulted in such migration pattern, it should be borne in mind that similar straying behaviour of salmon into rivers other than their home river (for period up to 4 weeks) have been reported from tagging experiments where no transport was involved (Milner 1989). Such behaviour is believed to be influenced by the proximity and relative size of salmon river . The River Hvita is the largest salmon river system in Iceland.

Recapture in coastal nets and in rivers out of Borgarfjord

Two salmon from the Borgarfjord release were captured in coastal nets, at Lambastadir in Borgarfjord and Innri Holmur and they were captured in the nets 0.5 m and < 30 m from the shoreline respectively (Fig. 1.). That indicates close relationship to the shore. Also one salmon from the Borgarfjord release was recaptured in River Leirvogsa. That salmon was microtaggedwas released as smolt in the river next to River Leirvogsa (Kollafjord salmon ranching station). This showed that the fish were not disoriented, as it is common phenomenon that salmon from Kollafjord migrate into River Leirvogsa during their spawning migrations. The recordings from that fish showed that it had migrated into another river (according to very low temperature) where it stayed for one day (in the cold river of Kollafjord ?) before migrating back into sea, followed later on by migration into River Leirvogsa. One of the salmon released in mouth of Kolgrafafjord (Fig. 2.) was recaptured in Kollafjord and that one could as the fish recaptured in River Leirvogsa have been originated from Kollafjord as reflected by micro tagged salmon from Kollafjord in the captures in Hraunsfjord every year.

Horizontal distribution of salmon during migration from Borgarfjord to homewater

Shoreline related migration

The salmon migrating to Laros and Hraunsfjord migrated out of Borgafjord 1.3-4.9 days after release. The vertical distribution of DST equipped homing salmon during their sea migration shows that the temperature recorded during that period is mostly reflecting sea temperature measured in the uppermost meters (Table 3, Figs 5-6a). The hydrographical data (Figs.7-12) can give indication in relation to this but not the least in relation to at what depth the thermo- and haloclines are in this sea area.

SST images are valuable to compare to temperature recordings from migrants in order to locate them approximately (Karlsson et.al. 1996). But their usefulness is dependent on the size of the area of interest (length of the migration) the cloud cover in the area of interest at a given time and of course of the available temperature gradients in a given area and also the migration speed of the fish.

Figure 13 is SST composite image for the period 6.-22. August. That figure is in a coarse scale but shows the main trends in the temperature gradient out from the west coast of Iceland, decreasing temperature oceanward and a tongue of cold water that goes into Breidafjord. SST images from the best satellite circumstances (clear sky on the 17. August) from this sampling period were processed separately to get as good a resolution of the temperature distribution as possible for the area out from shore between Borgarfjord and Breidafjord where Laros and Hraunsfjord are located (Fig. 14.). That SST composite showed clearly that there was a narrow zone of high temperature 11,5-12,4 °C laying along the shore north to where Breidafjord opens out at the tip of Snaefellsnes peninsula. According to the temperature recordings the salmon were migrating largely in this area closest to shore after they migrated out of Borgarfjord (Figs. 14,15, 17-20b). Occasional pulses of low salinity were also noted when migrating in this high temperature also underlining this shoreline related "orientation" (Fig. 17).

During the homeward migration of the DST equipped salmon it was common that the temperature in the surface layer decreased during some from around 12 °C down to around 11°C and then sometimes shortly afterwards down to around 10 °C. This stepward temperature pattern in relation to the SST distribution, taking the the migraton speed of the fish and how shortly afterwards some of them entered Laros, leads to the conclusion that this started at area where the current-complex area lying out from the Snæfellsnes peninsula, reflected by the temperature boundaries indicated by arrow on Fig. 14.

Estuarine and river migration during the homeward sea migration period

Many of the salmon entered estuaries on their way to homewater, most often for a brief period (Figs. 17,18 & 20b). Examples of riverine migration during this phase were also seen, where the fish stayed in the river up to more than a day, as for example fish number 166 (Fig. 19). That fish is also a good example of the high versatility of the salmon often recorded, as shown by non-acclimating behaviour as the fish migrates straight from high salinity into freshwater. Salmon recorded estuarine salinity more freqeuntly during daytime than during nighttime. Salmon were found that experienced estuarine salinity during daytime and were diving down to depths close to the 40 m bottom depth during night . Such behaviour must stand for closer relationship to the shore during daytime than during nights. It is likely that the odor sensing is playing role in the final homing in coastal waters and use of that sense might explain some of these estuarines-rivers experienced (Westerberg 1982)

Vertical distribution during homing

The vertical distribution of salmon migrating from Borgarfjord to home estuaries in Hraunsfjord and Laros showed how stongly the salmon preferred the uppermost meters while homing, with overall of 91% of the migration time spent in the uppermost 2 meters (Table 3, Fig. 5.) One fish showed though exceptional swimming behaviour from the others preferring deep layers for part of the migration (6a, 6b).

Hydrographical data from section measurements in August and from Hraunsfjord together with distribution of sea surface temperature (SST) during the homing migration gives a picture of the distribution of temperature and/or salinity at given depths for comparison to depths preferred by the salmon (Fig. 7-14).

When fish depth was compared to light measurements and strength of tides, some individuals showed significant relationship to the overall fluctation of those parameters, especially to light. But the tides were more influential during the estuarine migration that followed.

When the very deepest dives are examined it shows that they are mostly distributed within the dusk hours (Fig. 6a).

Many examples were observed, when salmon experienced large changes in temperature in the surface layers in short time (as shown by temperature before and after dives), that seemed to trigger on diving activities (Fig. 17-18,20a, 21a,b). Paralell to the temperature changes there can be some currents disturbance involved as in the area out of Snæfellsnes peninsula.

The most interesting information in context to the vertical distribution of the salmon is that the salmon were highly significantly closest to the sea surface during noon, although the depth distribution of them at other time of day were not necessary in relation to the position of the sun or the light condition. This informations may indicate that the salmon is using sun compass, given that the sea surface preference at noon is related to the orientation of the salmon, because of the homing. It is also interesting to note that due to the position of the sun at that time, the magnetic field generated by the earth movements are also strongest at that time and in addition these magnetic potentials have the highest values in the surface layer.

Migration speed

The mean migration speed of the salinity DST equipped salmon that were recaptured in Laros and Hraunsfjord in August, were respectively 1.8 km/hour (st.dev.=1.0) and 1.2 km/hour (st.dev.=0.1). The northward moving surface current in the coastal area W-Iceland is moving at the speed $< 5 \text{ cm} \cdot S^{-1}$ (Malmberg et.al. 1972).

Concluding remarks

This first results from use of salinity measuring DST in migration study of homing salmon have given valuable new information about the coastal part of their spawning migration, not the least in relation to migration trough non-native estuaries and river while homing.

Acknowlegdments

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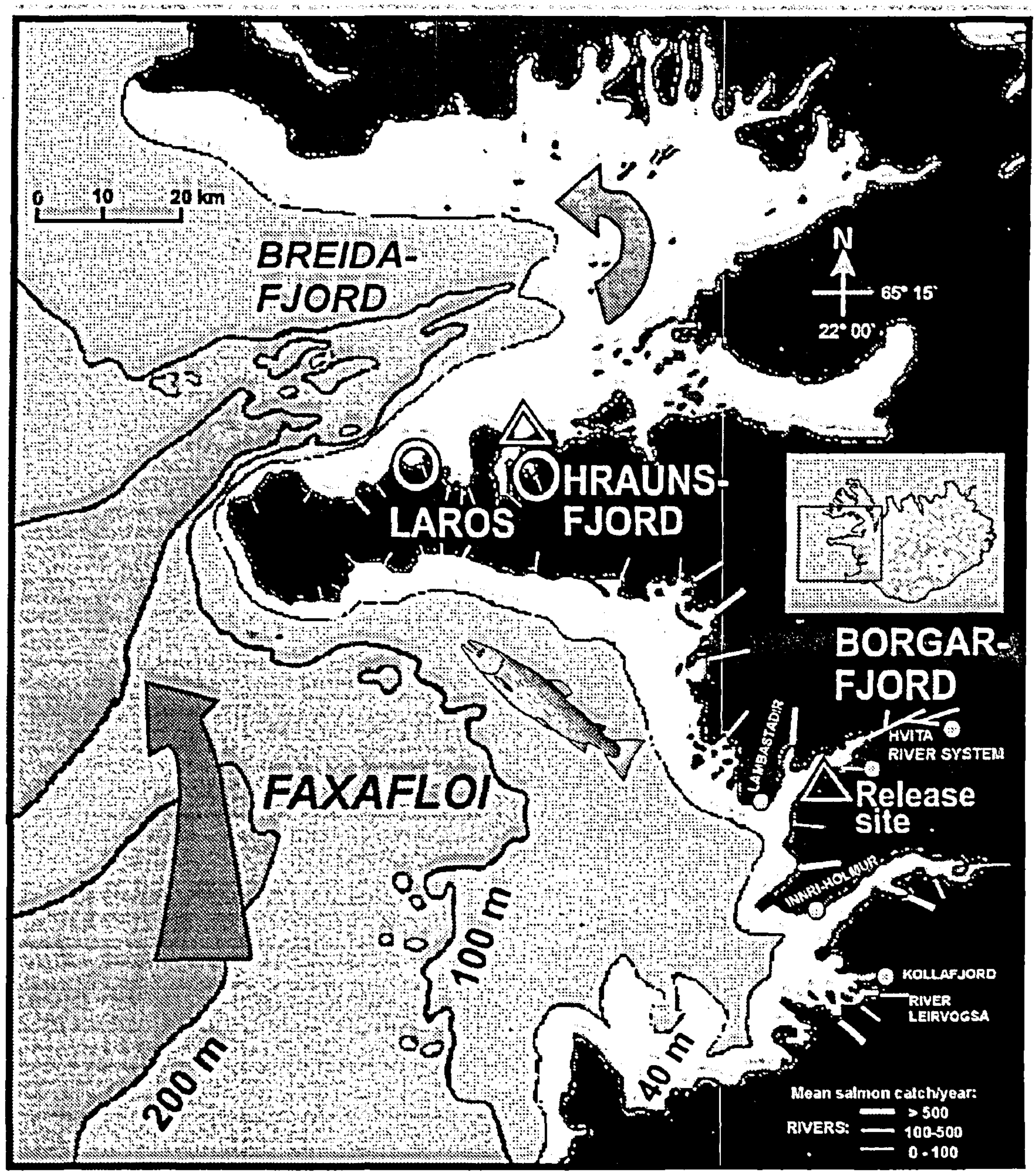

Fig. 1. Map of West coast of Iceland, showing the area that the DST tagged Atlantic salmon migrated through. Locations are shown for the release sites, the capture sites and the recapture sites. Rivers are also shown at shores in the region from Hraunsfjord and southward. Rivers are symbolized in relation to mean salmon catch per year (1974-1996). Water depth intervals are shown by 40, 100, and 200 m bottom depth isolines. The main coastal current direction is symbolized with arrows.

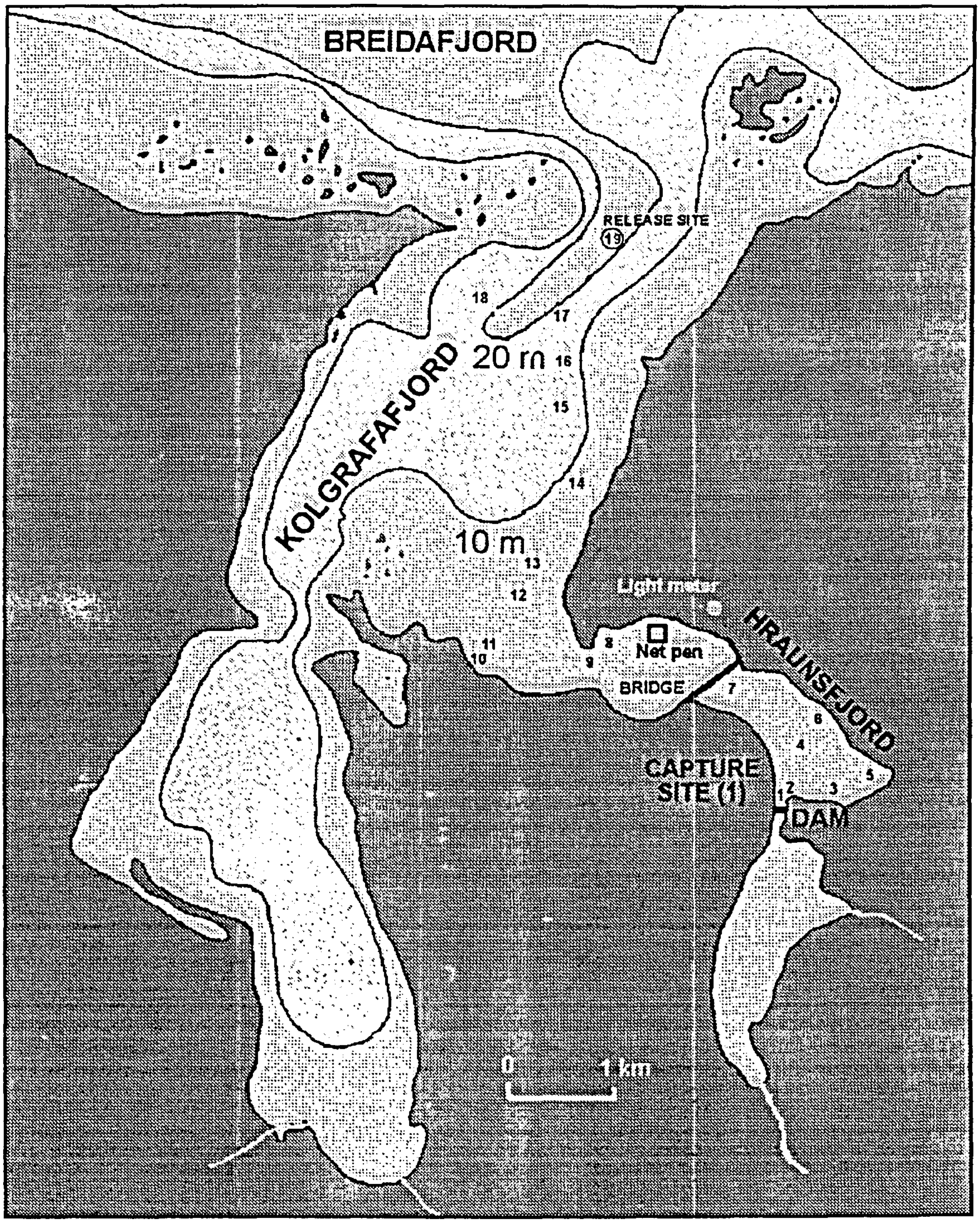

Fig. 2. Map of Hraunsfjord and Kolgrafafjord and the nearest vicinity. Locations are shown for the release site (19), the capture- and recapture site (1), hydrographical stations (1-19), light meter and net pen for control fish. Water depth intervals are shown by 10 and 20 m bottom depth isolines.

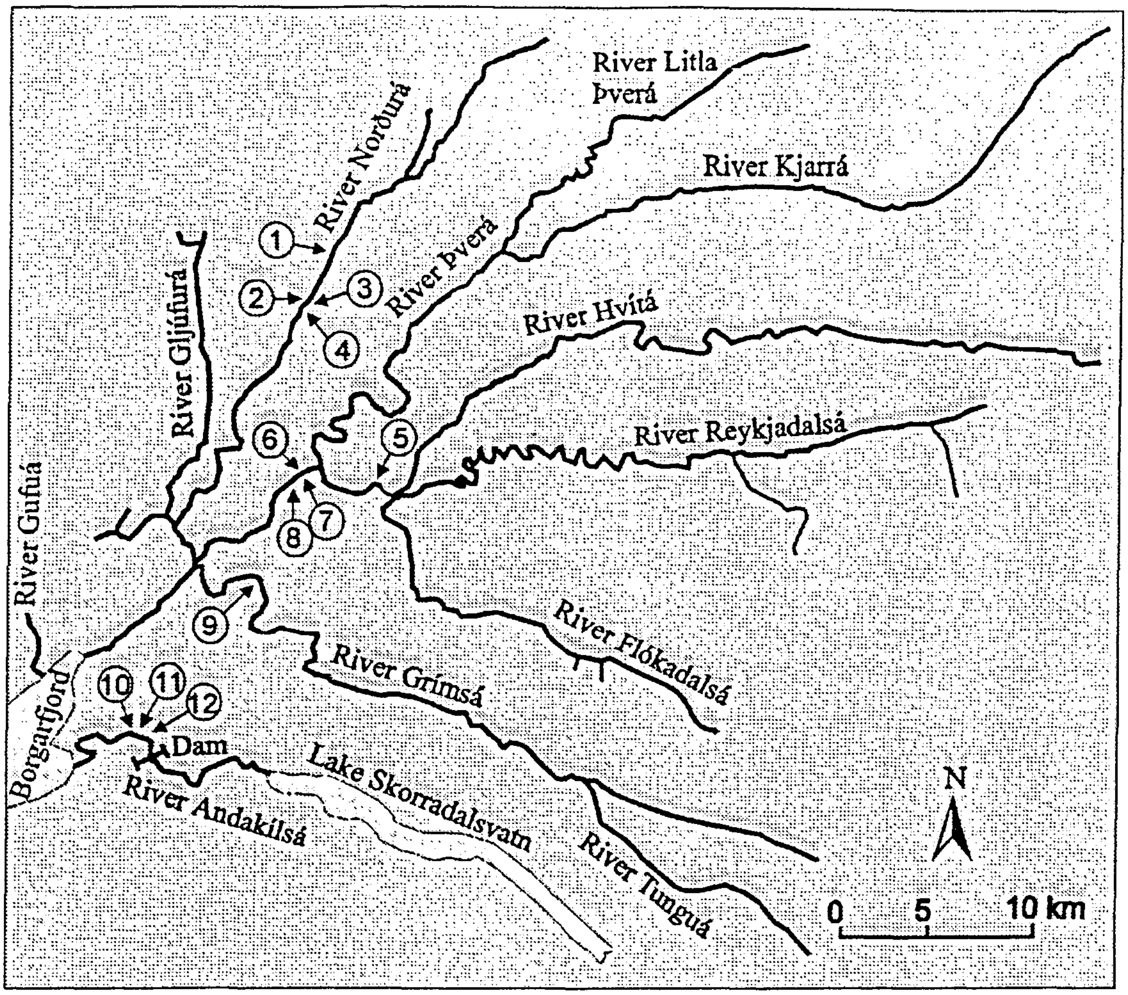

Fig. 3. Map of the Hvita river system in Borgarfjord and other rivers that runs into the head of Borgarfjord. Location are shown for the recapture sites of DST equipped Atlantic salmon from the Borgarfjord release 10. August (GMT: 0:30-1:30). The largest river, is the glacier River Hvita, that is also largely springfed (mean yearly river discharge around 75 $m^3 \cdot sec^{-1}$). Other rivers are runoff rivers, some of them partially springfed. All the rivers are salmon rivers except River Gufua. Total mean yearly salmon catch in these rivers (1974-1996) is 6035 salmon.

Table 1. Timing of the recapture of salmon in rivers in Borgarfjord. Date of recapture is given and in cases where DSTs with salinity sensor were involved, the timing of beginning of continiuous river migration is given.

		Continuous river migration starts		Timing of recapture*	
River	Number of salmon	Date	GMT	Date	GMT
River Nordurá	1	11. August	18	14. August	8
	2	10. August	18	26. August	13
	3			18. August	
	4			18. August	
River Hvítá	5			17. August	
	6			2.sep	
	7			23. August	19
	8			11. August	15
River Grímsá	9			29. August	
River Andakílsá	10	10. August	22	11. August	12
	11	10. August	18	15. August	8
	12			26. August	

*Recaptures from anglers (no angling in these rivers after 1.-20. September)

Table 2. Recapture sites and number and rates of salmon recaptured, in relation to capture (tagging) sites. Number of control fish in net pen is also given.

Sites of capture and release			Recapture rates								
Capture- and tagging site	Release site [1]Control site	Number of DST tagged salmon	Total recapture rate (%)	Recaptures at tagging site Number	(%)	Recaptured in nets in sea[1] Number	(%)	Recaptured by anglers in the Hvita river system Number	(%)	Recaptured in other rivers[2] Number	(%)
Laros	Borgarfjord	49	65	25	51	2	4	5	10		
Hraunsfjord	Borgarfjord	43	58	18	42			7	16	1	2
Hraunsfjord	Kolgrafafjord	5	60	2	40					1	20
Hraunsfjord	[1]Hraunsfjord	3									

[1] Innri Holmur and Lambastadir [2] River Leirvogsa and in Kollafjord salmon ranch in trap

Table 3. Overall depth distribution of DST equipped salmon during their homing migration from the Borgarfjord mouth area to Laros and Hraunsfjord shown as time proportion at given depth intervals. Total number of salmon= 17 and the total number of DSTs recordings = 5817 (121 days).

Time	Depth intervals (m)						
(%)	0-10	10,1-20	20,1-30	30,1-40	40,1-50	50,1-60	61,1- ≥ 110
Proportions of time	97,1	1,6	0,6	0,2	0,1	0,1	0,3

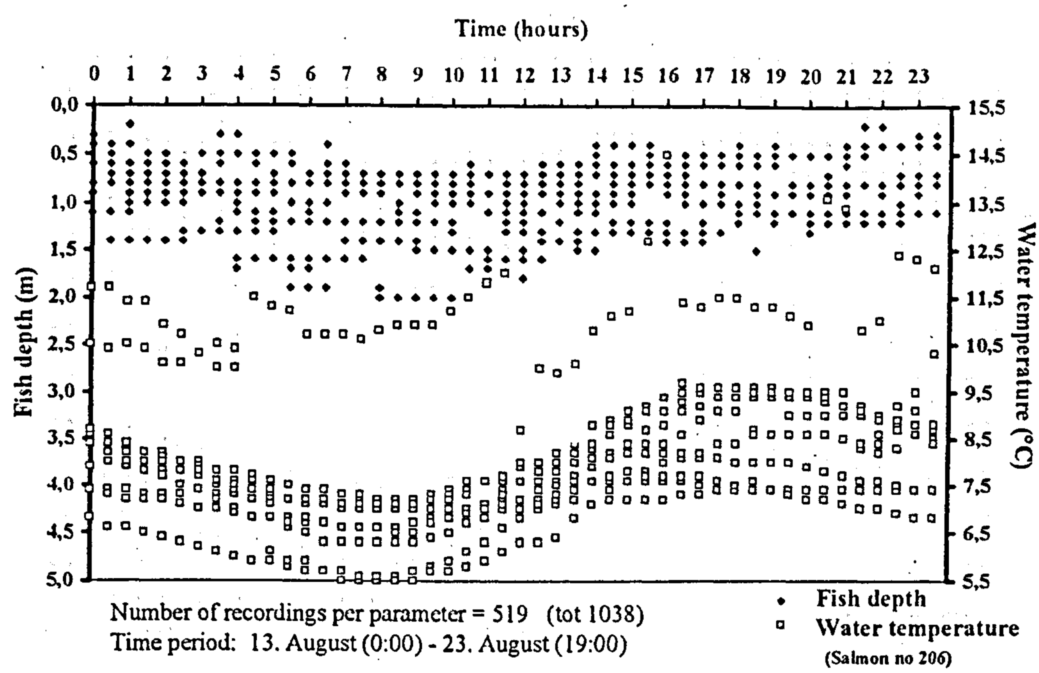

Fig. 4. Overall daily depth distribution of one DST tagged salmon during river migration in River Hvita and corresponding river temperature. The relationship between the fish depth and the corresponding river temperature was cheked for one fish (Fig. 4.) and showed to be significant (<0,001 and $r^2 = 0,17$).

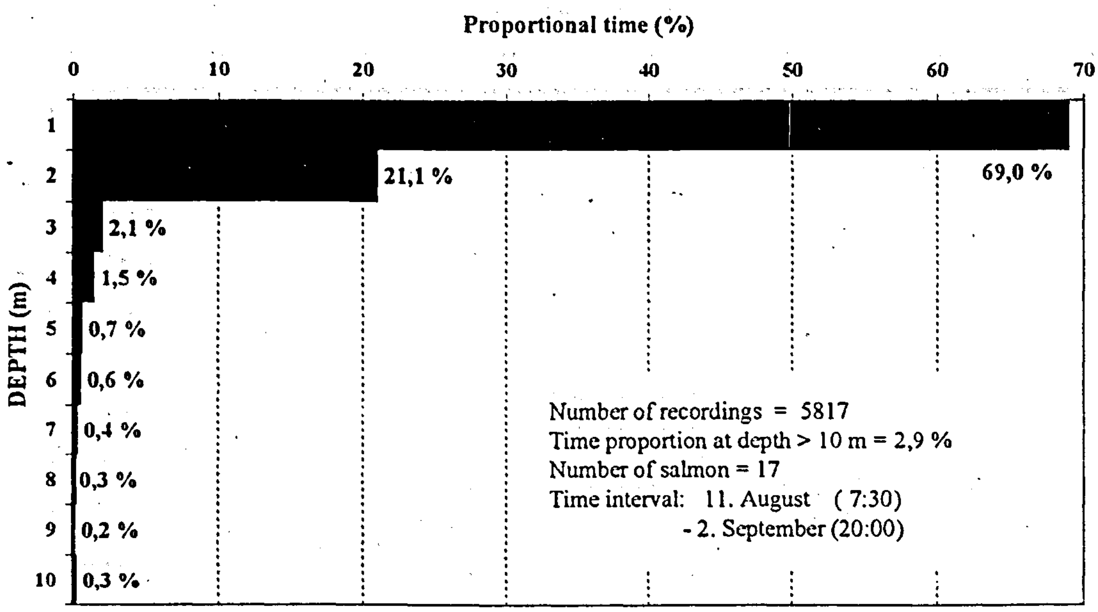

Fig. 5. Overall depth distribution of salmon in the uppermost 10 meters of the sea, from DSTs recordings during their homing migration from the Borgarfjord mouth area to Laros and Hraunsfjord. Bars represent the proportions of time spent at 1-m depth intervals (% of total depth distribution). Total number of the DSTs recordings involved are given along with time proportion spent below 10 meter depth. The number of salmon are given and the total time interval involved.

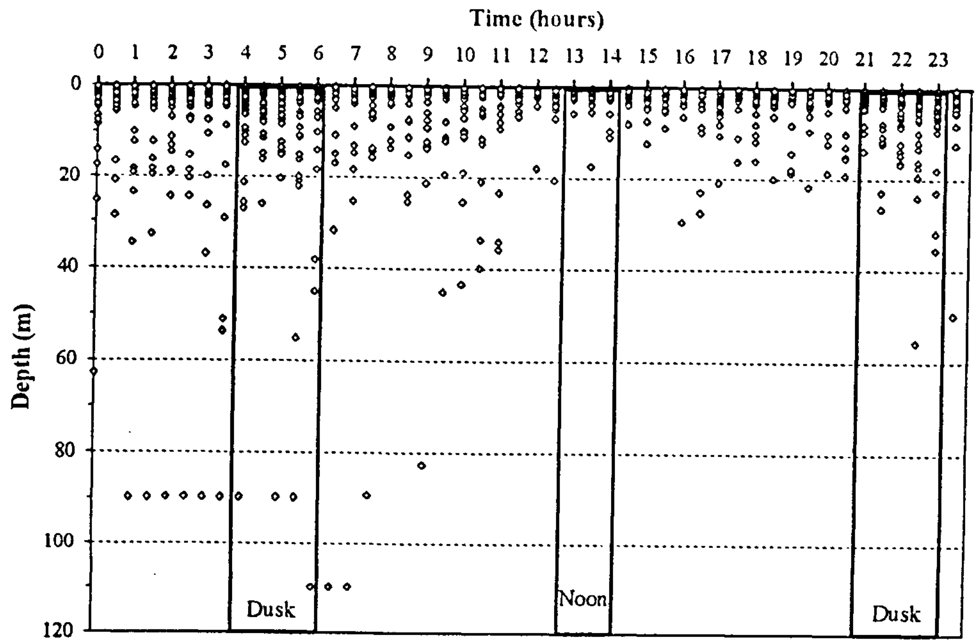

Fig. 6a. Overall daily depth distribution of 17 out of 18 salmon equipped with DSTs with salinity sensor that migrated out of Borgarfjord and to Laros or Hraunsfjord during the DSTs total recording interval. Open bars represent noon and dusk intervals during the recording period. Total number of DSTs recordings involved are 5817 (121 days).

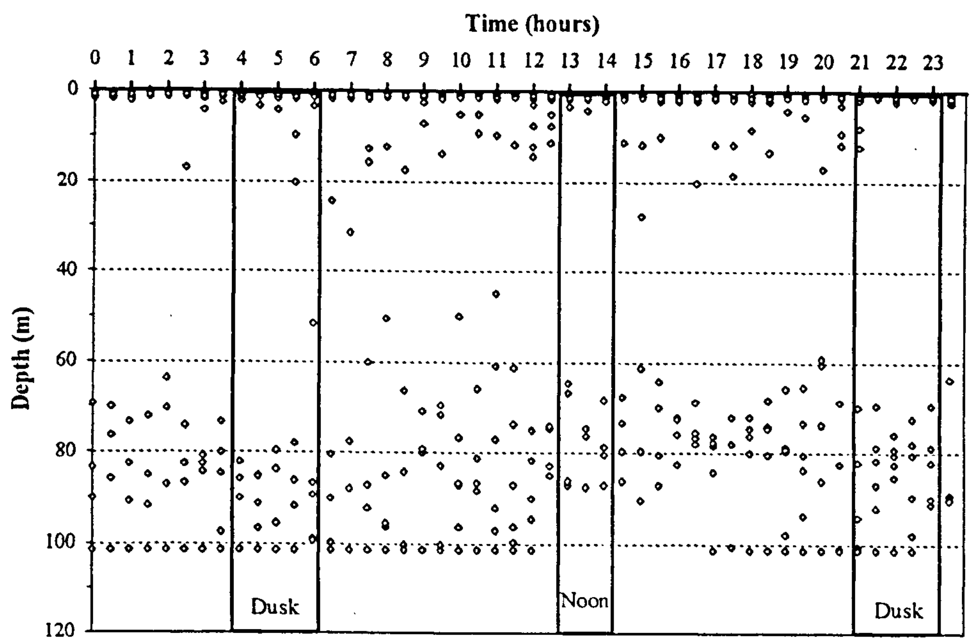

Fig. 6b. Overall daily depth distribution of one deep swimming salmon equipped with DSTs with salinity sensor that migrated out of Borgarfjord and to Laros during the DSTs total recording interval. Open bars represent noon and dusk intervals during the recording period. Total number of DSTs recordings involved are 1000 (21 days).

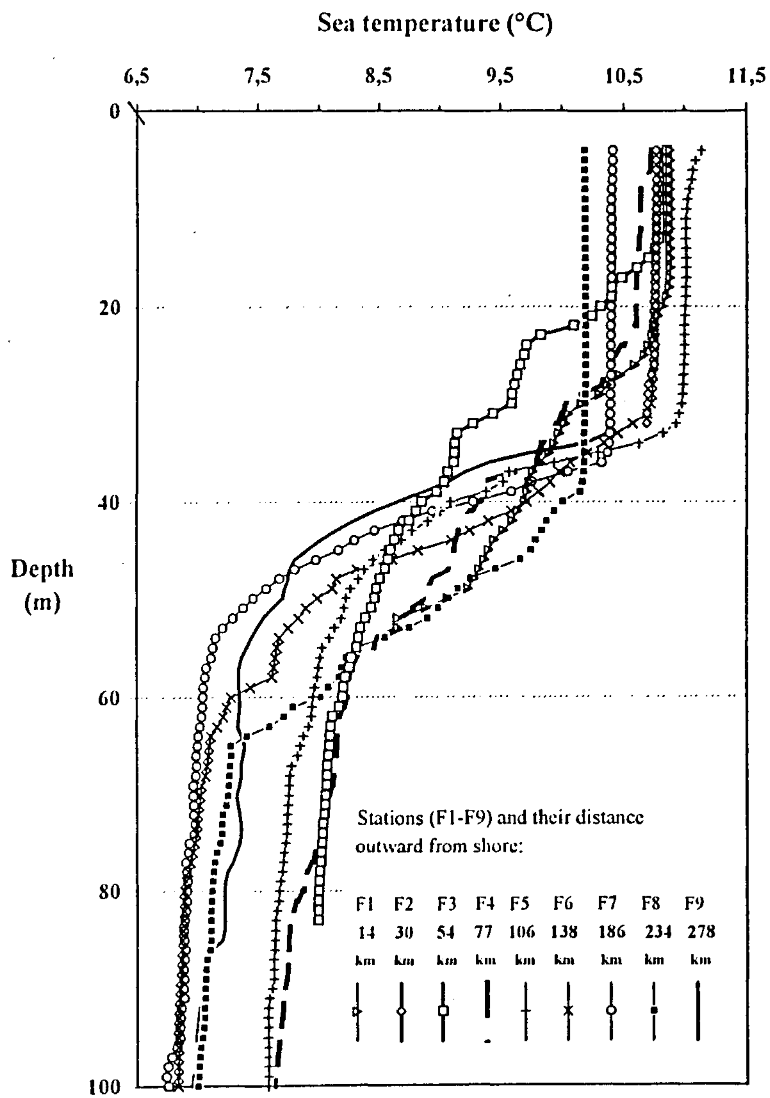

Fig. 7. Sea temperature profiles measured 27.-28. August 1996, using conductivity, temperature, depth (CDT) probe at a hydrographic stations at section along latititude N 64° 20' at longitudes 22° 25' to 27° 55' (Faxabay - Irminger sea). The temperature profiles are shown in relation to depth (3-100 m). The positions of the stations are given as their distance in km from the shore nearest to station L1 (Akranes).

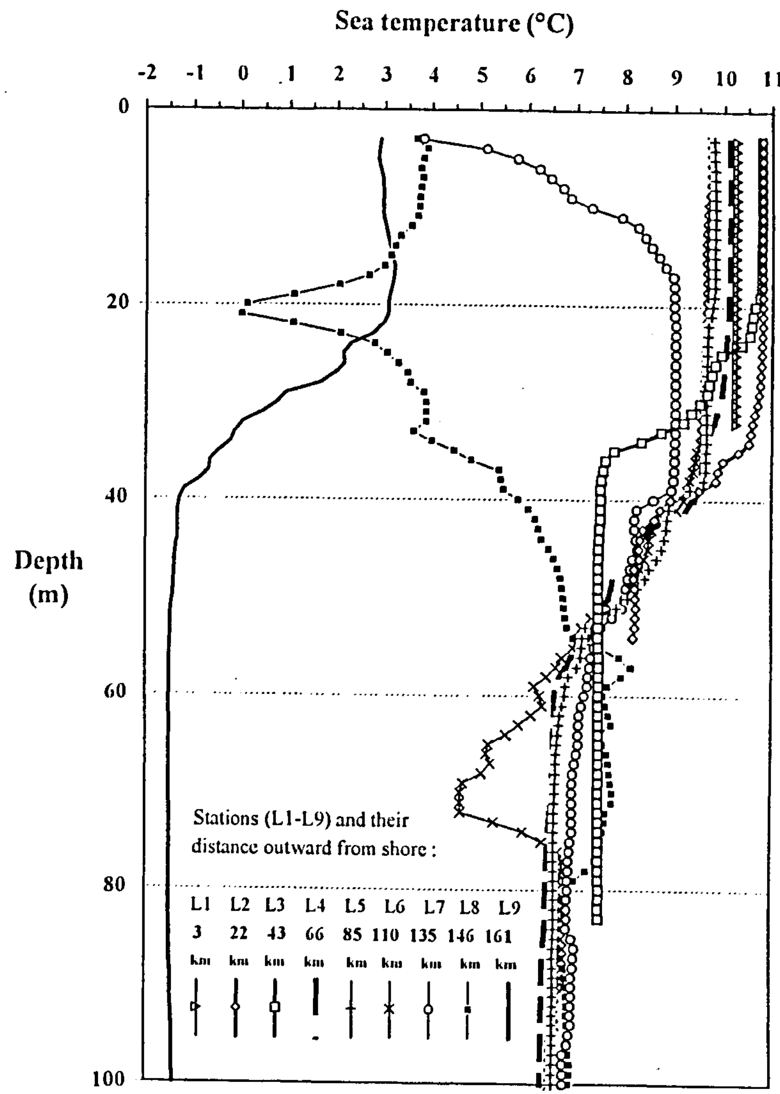

Fig. 8. Sea temperature profiles measured 25.-26. August 1996, using CDT probe at a hydrographic stations at section between latititudes N 65° 30' and N 66° 09' at longitudes 24° 34' to 27° 15' (Latrarost coastal waters = L1, north through Irminger sea, to the sill of the Iceland - Greenland Ridge = L7-L9). The temperature profiles are shown in relation to depth (3-100m) for each station. The positions of the stations are given as their distance in km from nearest shore (Latrabjarg).

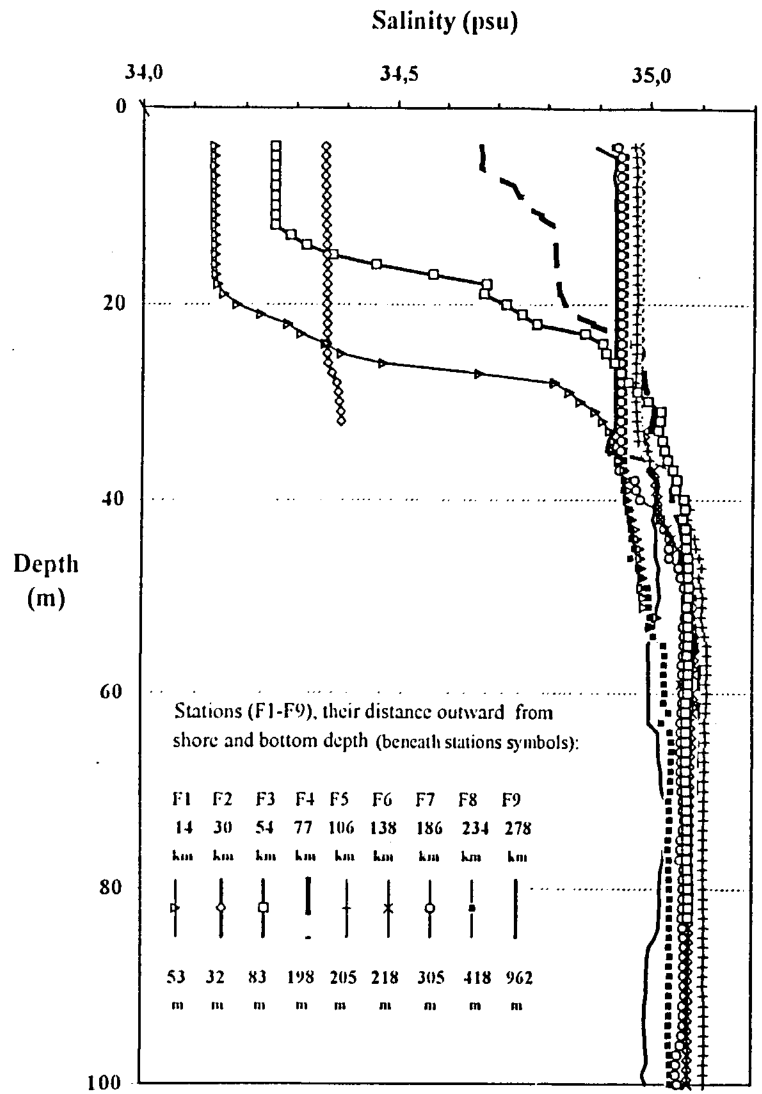

Fig. 9. Salinity profiles measured 27.-28. August 1996, using CDT probe at a hydrographic stations at section along latititude N 64° 20' at longitudes 22° 25' to 27° 55' (Faxabay - Irminger sea). The salinity profiles are shown in relation to depth (3-100 m) for each station. The positions of the stations are given as their distance in km from shore (Akranes). The bottom depth at the stations are shown.

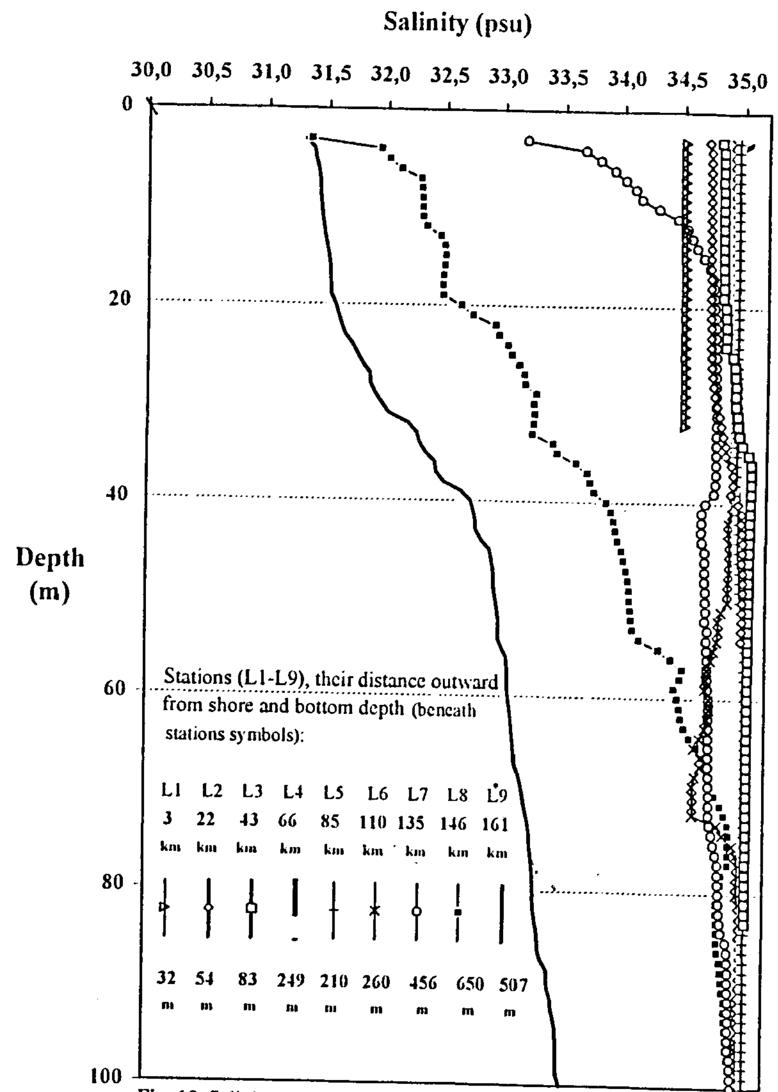

Fig. 10. Salinity profiles measured 25.-26. August '96, using CDT probe at a hydrographic stations at section between latititudes N 65° 30' and N 66° 09' at longitudes 24° 34' to 27° 15' (Latrarost coastal waters = L1, north through Irminger sea, to the sill of the Iceland - Greenland Ridge = L7-L9). The salinity profiles are shown in relation to depth (3-100 m) for each station. The positions of the stations are given as their distance in km from shore (Latrabjarg). The bottom depth at the stations are shown.

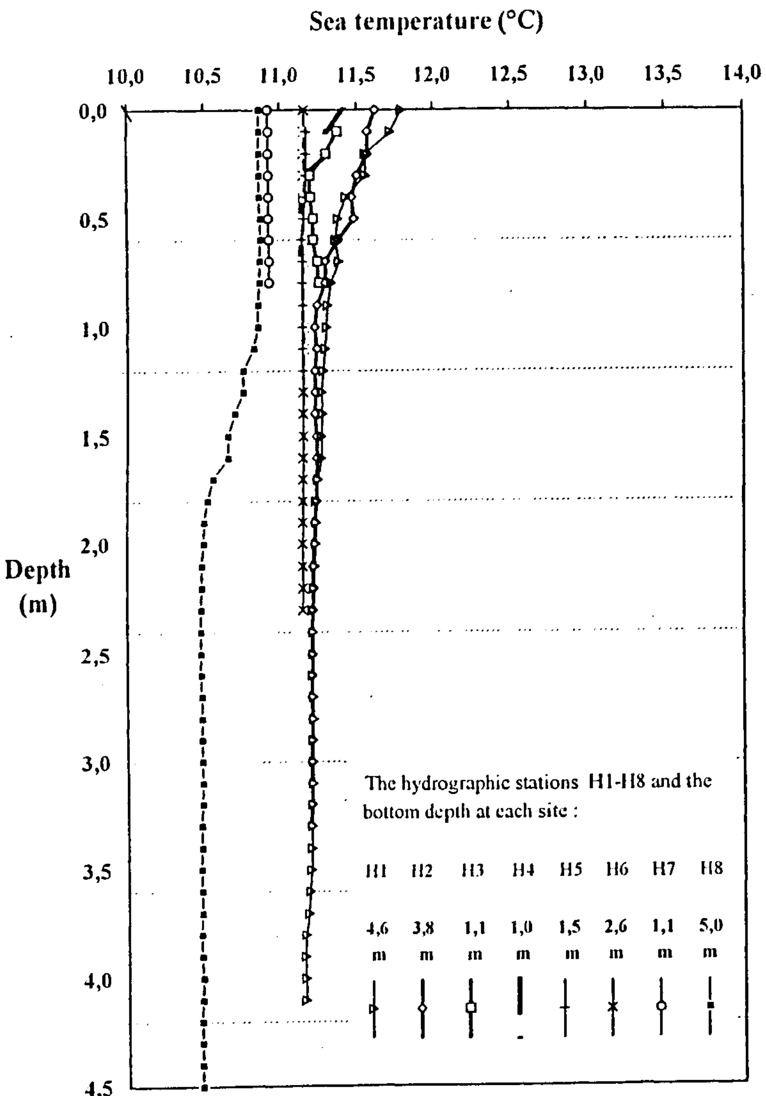

Fig. 11. Sea temperature profiles measured using CDT probe at a hydrographic stations in Hraunsfjord, from the head of the estuary (H1) and out to the mouth area of the fjord (H8), 11. August 1996 (time interval GMT: 14-16). The temperature profiles are shown in relation to depth (0,05-4,5 m) for each station. The bottom depth at each station are shown.

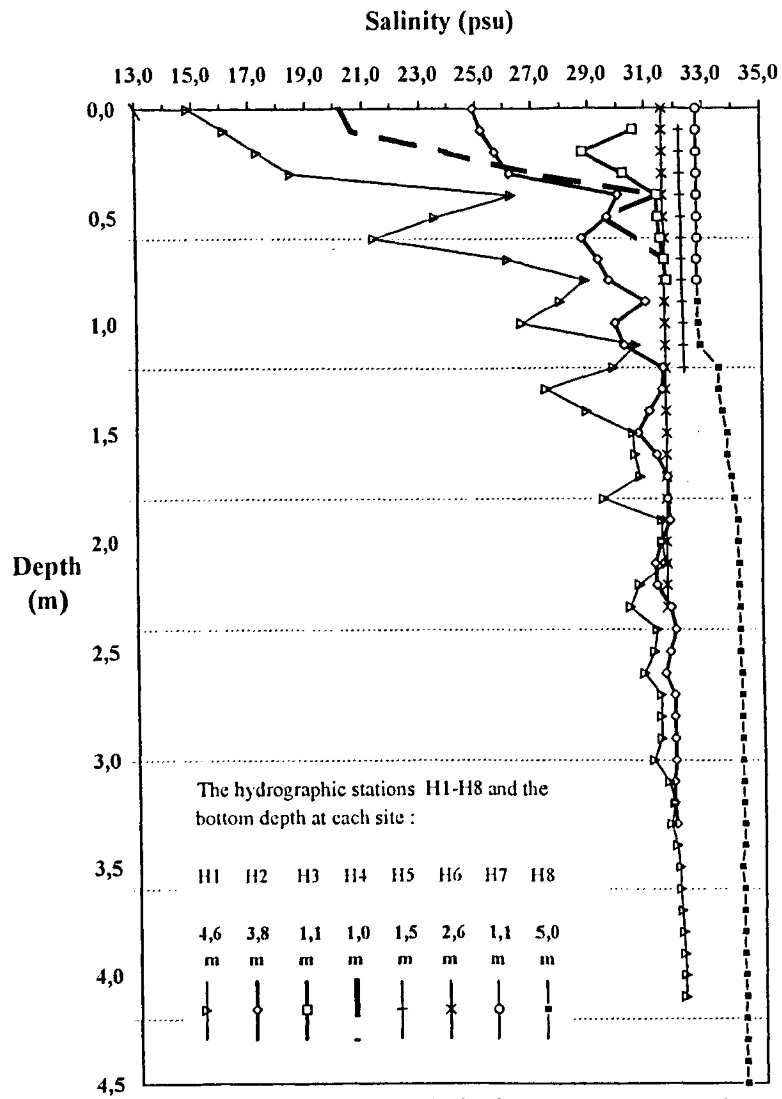

Fig. 12. Salinity profiles measured using CDT probe at a hydrographic stations in Hraunsfjord, from the head of the estuary (H1) and out to the mouth area of the fjord (H8), 11. August 1996 (time interval GMT: 14-16). The salinity profiles are shown in relation to depth (0,05-4,5 m) for each station. The bottom depth at each station are shown.

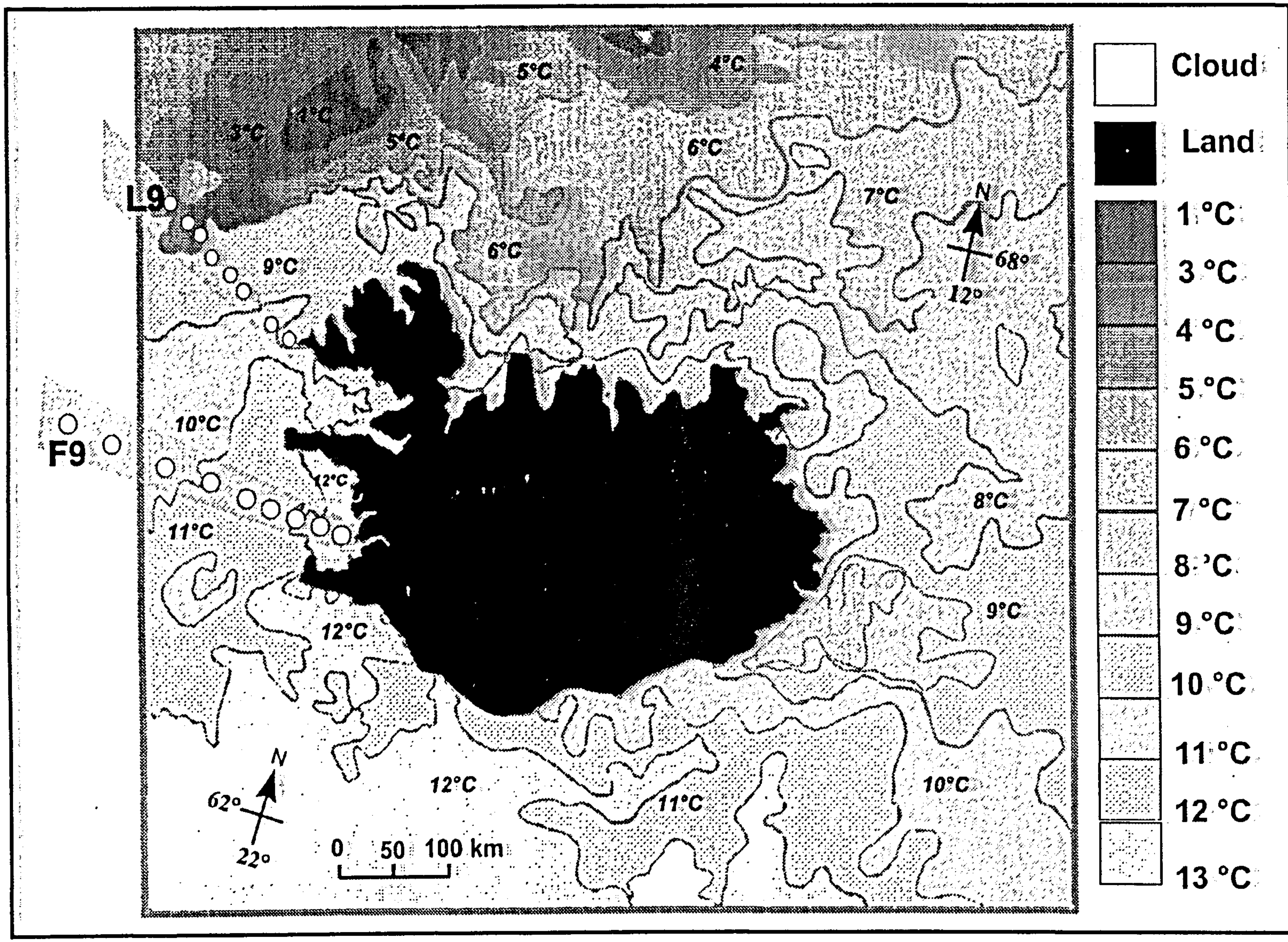

Fig. 13. Map of mean sea surface temperature (SST) in the area around Iceland in August 1996. The mean SST are composite of 60 NOAA AVHRR satellite images (6.- 22. August). The temperature scale is shown in relation to given gray-scale stepward gradient and also with few sea temperature values within different temperature zones (the lower value of the SST intervals of each zone is shown). For comparision are given the locations of the F and L sections of hydrographical stations.

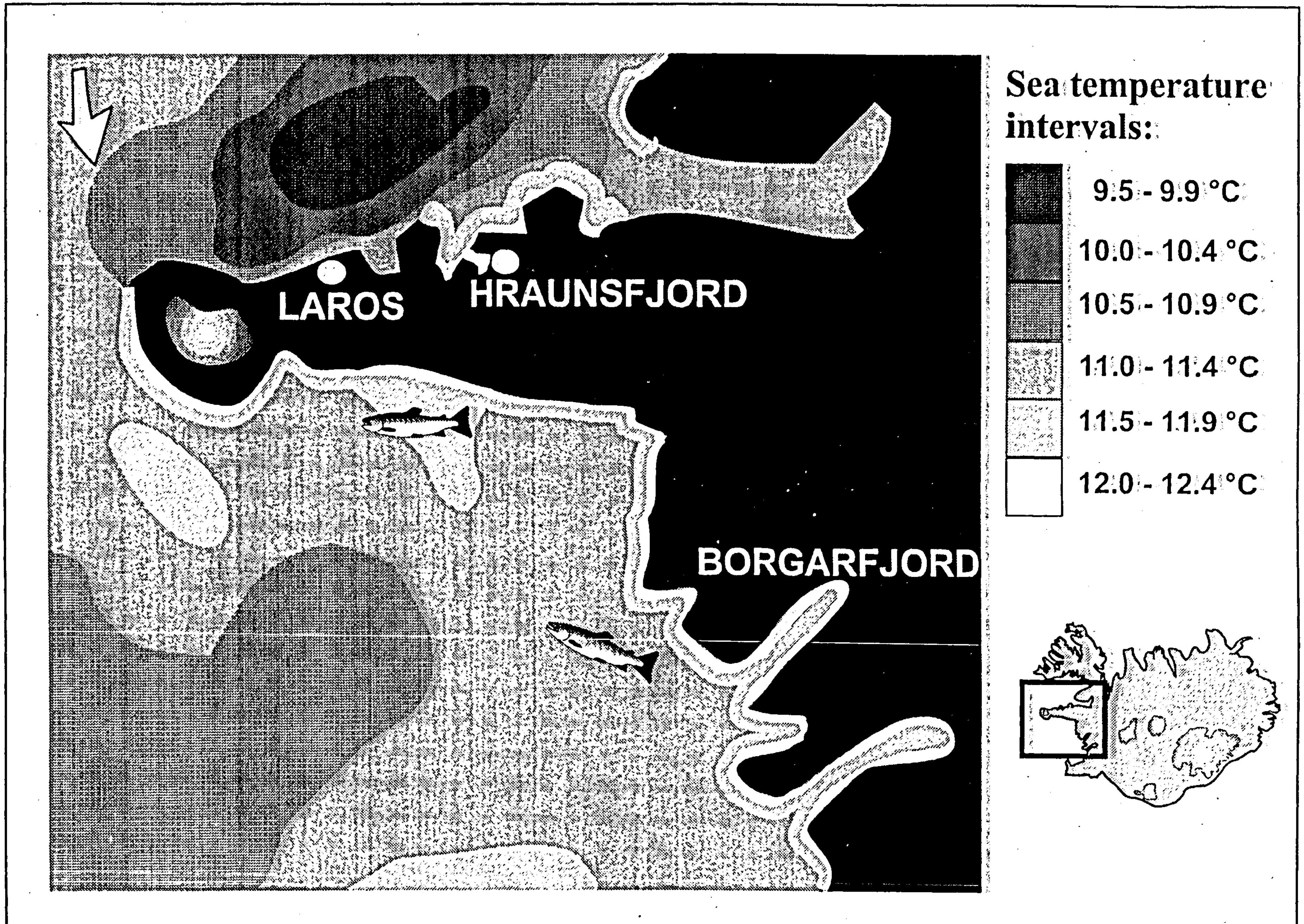

Fig. 14. Map of mean sea surface temperature (SST) 17th of August 1996, in the area between release site in Borgarfjord and recapture sites in Laros and Hraunsfjord. The mean SST are composite of 4 NOAA AVHRR satellite images (GMT: 8-18). The temperature scale is shown in relation to given gray-scale stepward gradient. The arrow points towards the area where SST starts to decline rapidly along the last part of the migration route of the salmon homing towards Laros and Hraunsfjord.

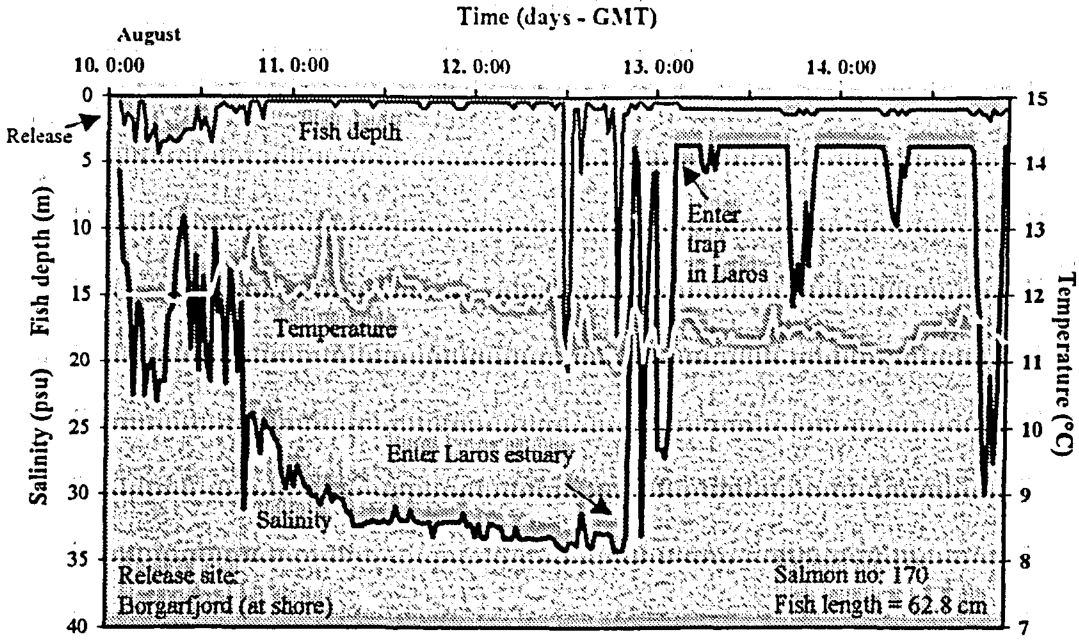

Fig. 15. Depth distribution of homing salmon in coastal waters in the area Borgarfjord - Laros and corresponding temperature and salinity. This salmon was the first one to return back to home water, of the salmon released in Borgarfjord. The end of the salinity profile shows well the regular decrease in salinity shown after the fish is trapped, because of sea water entering the trap facilities at high tide. The difference in the strength of the tidal waters are reflected both in the scale of salinity decrease and is also reflected a little in depth shown as the fish is lowering a little bit in the water column when the water column is rising in the trap paralell to high tide.

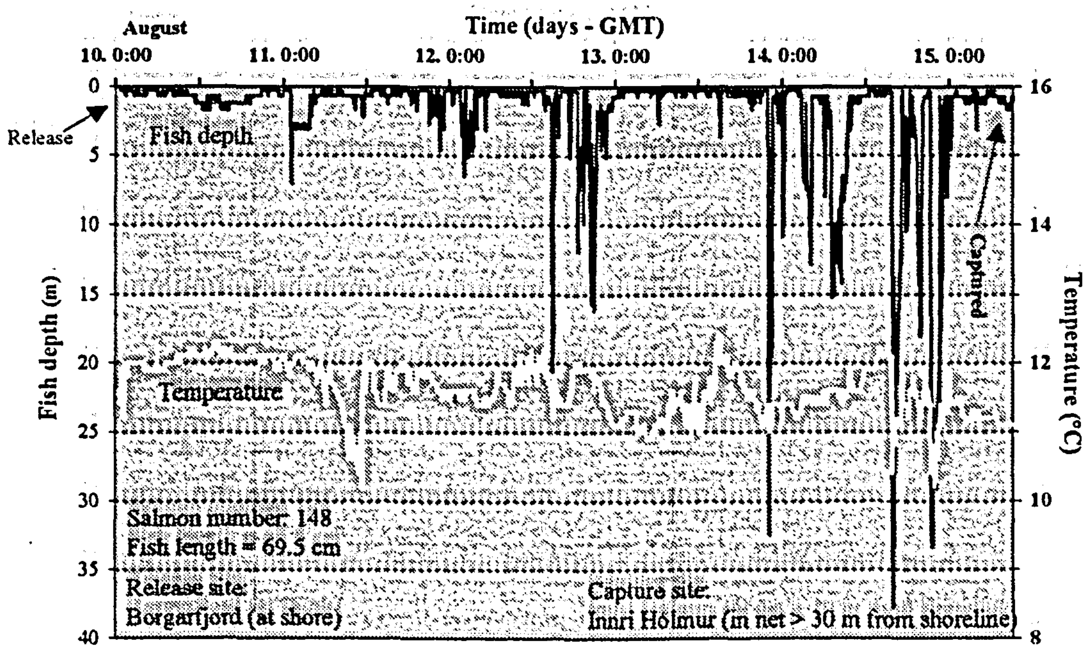

Fig. 16. Depth distribution of homing salmon in coastal waters in Borgarfjord and the area out from Borgarfjord and corresponding temperature and salinity. The depth of the dives shows that the fish had left shallow Borgarfjord 12th of August. The stepward increase in maximum depth during diving activity that follows, shows that the fish have moved at least couple or more of kilometers from shore. The swimming depth pattern, the capture site at Innri Holmur (at 30 km from release site and < 30 from shoreline) together with the temperature gradient in the uppest meters indicates that the fish were migrating between areas close to shore and outer areas.

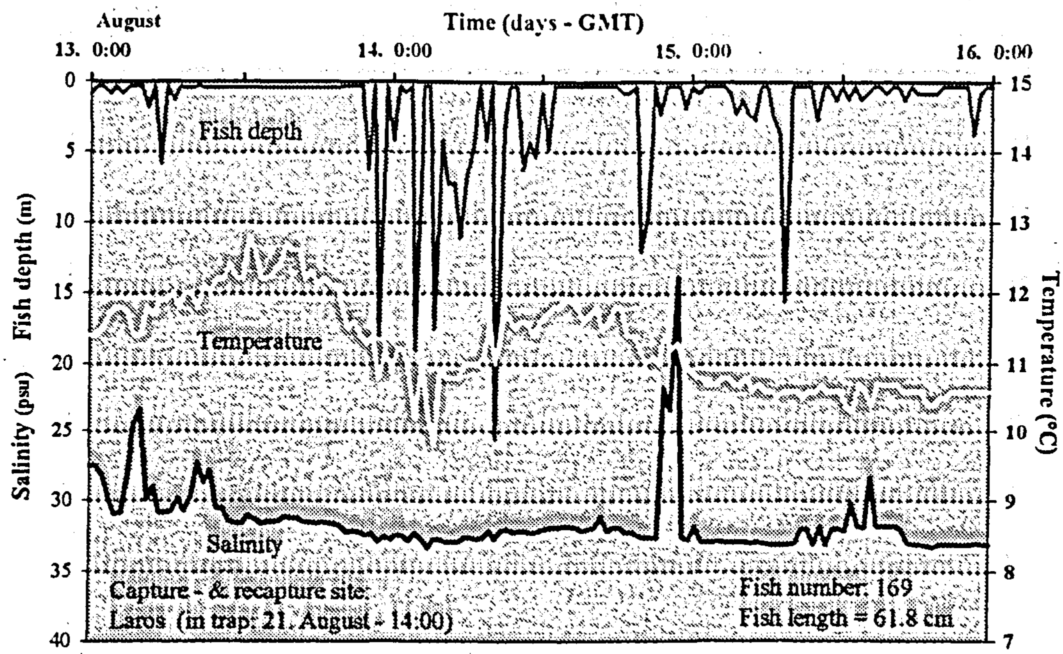

Fig. 17. Depth distribution of homing salmon in waters west of Iceland and corresponding temperature and salinity. The recordings from the migration of salmon 169 shown here show frequent dives in phase between very high sea surface temperature and colder surface temperature after maximum diving activity.

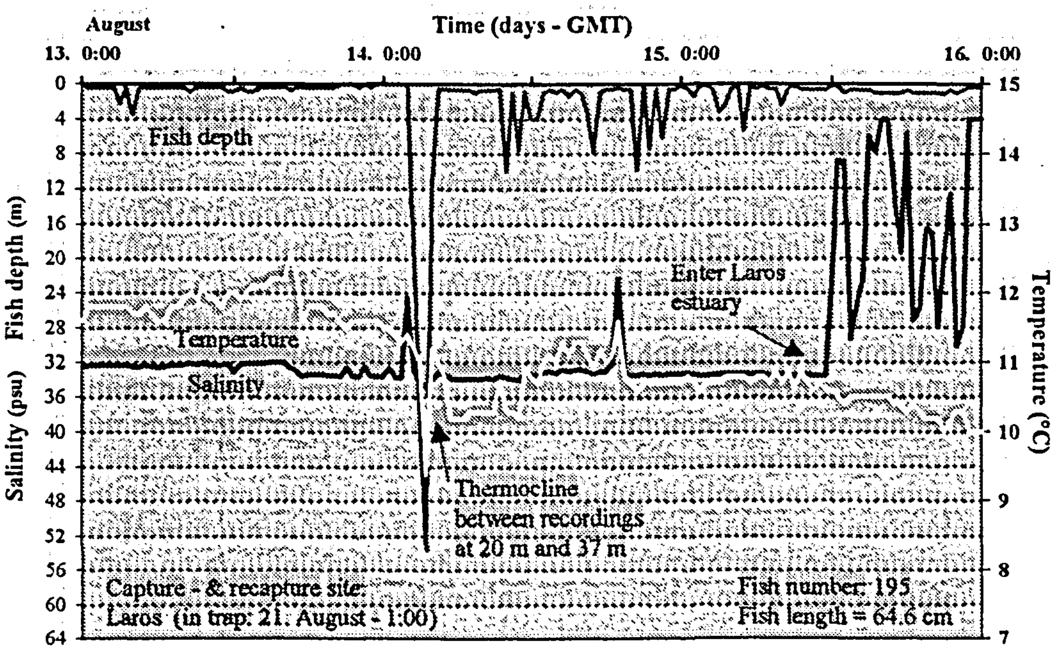

Fig. 18. Depth distribution of homing salmon in waters west of Iceland and corresponding temperature and salinity. The recordings from the migration of salmon 195 shown here show deep dive in the phase during steep decline in temperature shortly after having briefly experienced sea well influenced by freshwater.

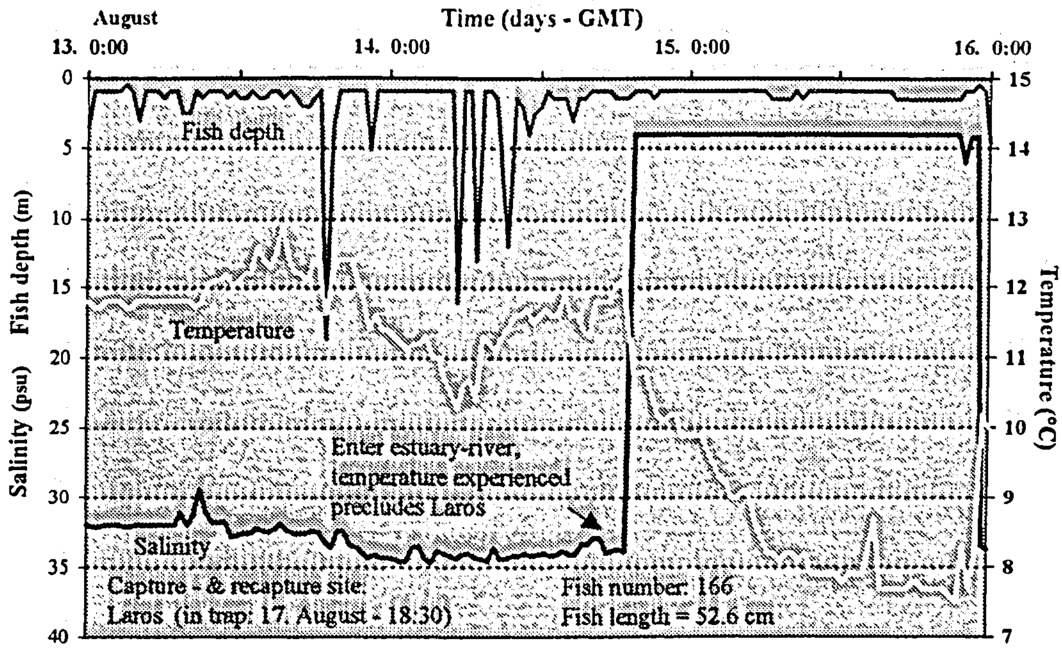

Fig. 19. Depth distribution of homing salmon in waters west of Iceland and corresponding temperature and salinity. The recordings from the migration of salmon 166 shown here show similar diving pattern followed by decline in surface layers temperature. In addition it shows migration into river without any significant preadaption in estuary prior to the freshwater migration. The salmon stayed in the river for roughly a day.

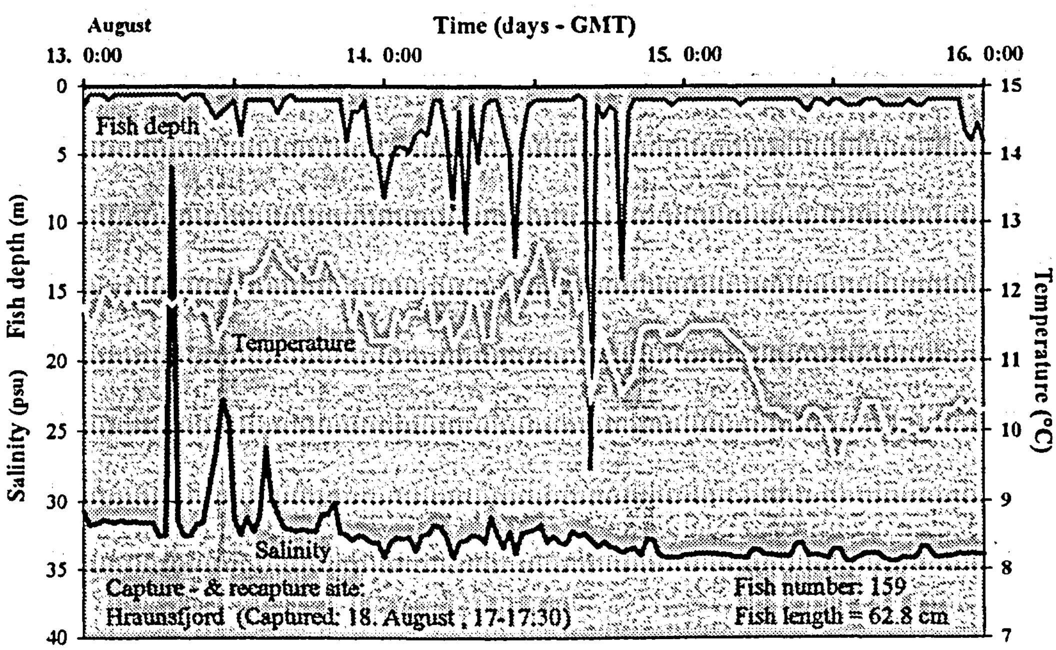

Fig. 20a. Depth distribution of homing salmon in waters west of Iceland and corresponding temperature and salinity. The recordings from the migration of salmon 159 shown here show brief period of decline in salinity related to estuary migration and then the same diving pattern as observed among many other fishes migrating through surface layers where temperature is changing rapidly. (see Fig. 20b. for full scale resolution in relation to recording intervals.)

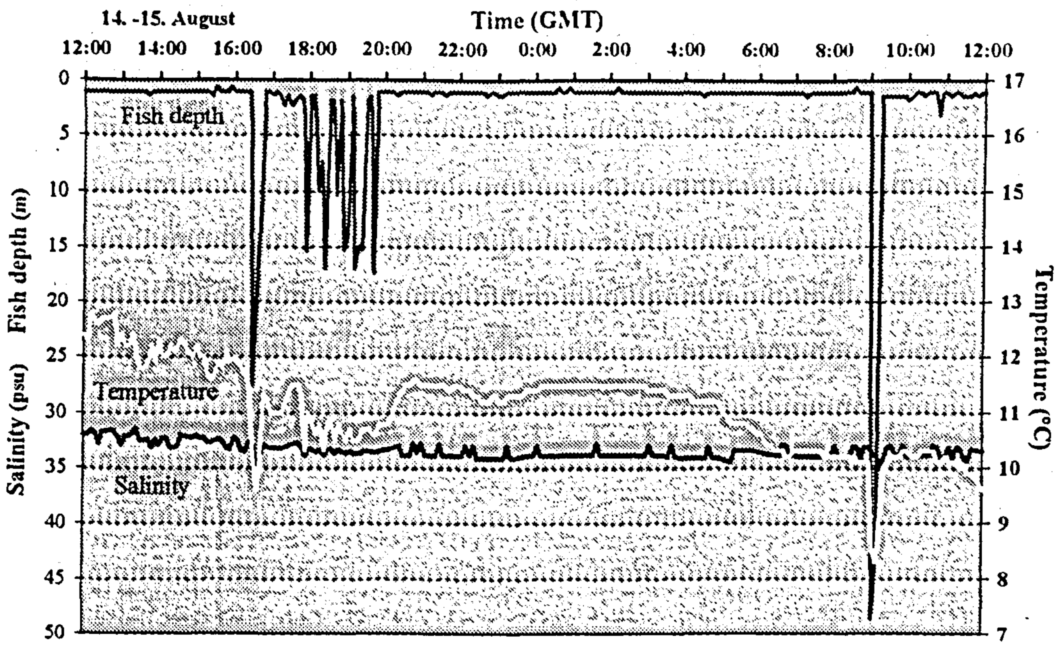

Fig. 20b. Depth distribution of homing salmon in waters west of Iceland and corresponding temperature and salinity. The recordings from the migration of salmon 159 shown here in the scale of 6 min intervals, shows well the common very rapid excursion series from the very uppest meters down to deeper layers. In order of rapid measurements excursion as the deepest dive represent can be detected (not on Fig. 20a - the 30 min subsample). The swimming pattern shown here are also typical in relation to the maximum depth of such dives that are often quite similar to the depths of the thermocline or go little below it, as in the first and last dive on this figure.

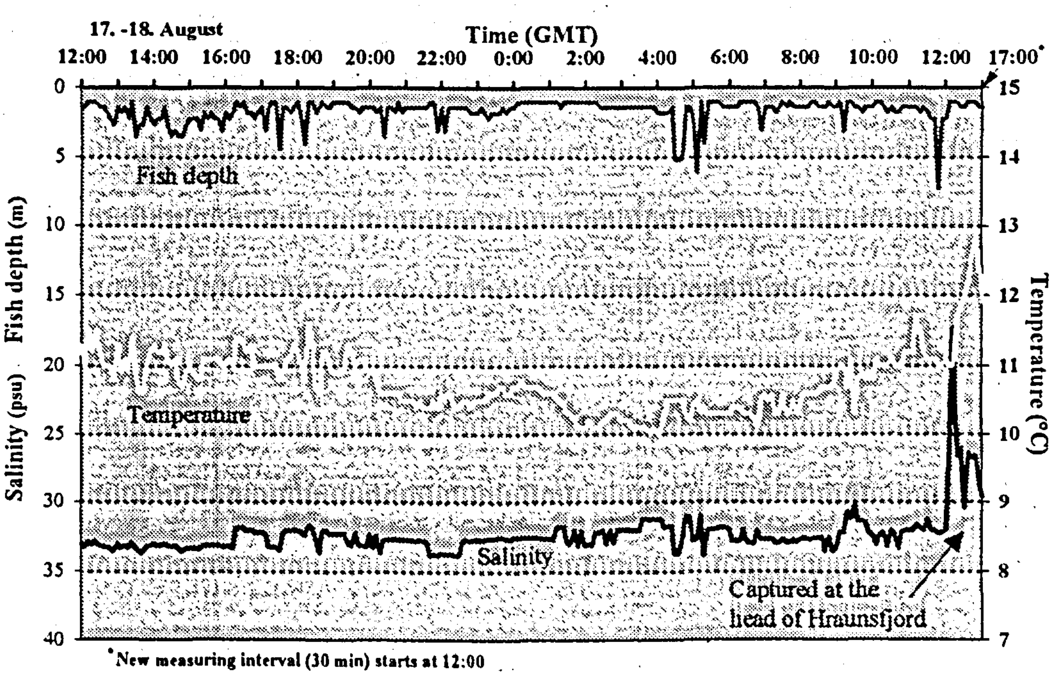

Fig. 20c. Depth distribution of homing salmon (no 159) and corresponding temperature and salinity during the last day before recaptured in home water in Hraunsfjord.

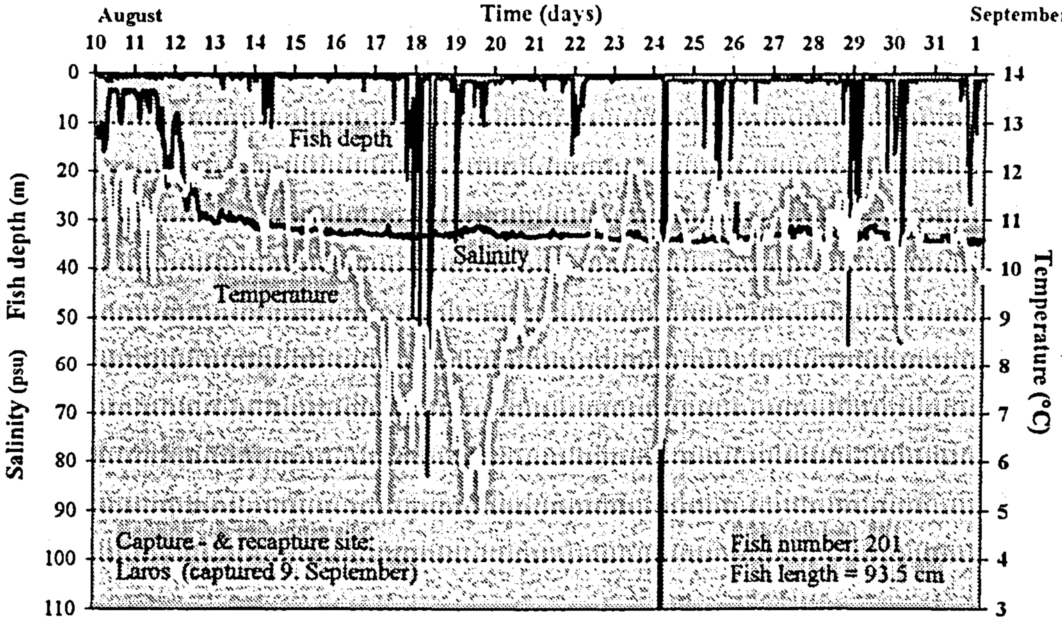

Fig. 21a. Depth distribution of homing salmon in waters west of Iceland and corresponding temperature and salinity. These recordings are the only one from two sea winter old salmon in this migration study and represent quite different pattern compared to the grilse in relation to the sea area migrated trough. The extremely cold surface layers that the salmon experience suggest that he have briefly entered the area where Icelandic waters (Irminger current) and cold northern waters comes together along the sill Iceland - Greenland ridge. This suggestion is based on the sea temperature distribution around Iceland together with known migration speed of salmon and the main current direction and speed west of Iceland.

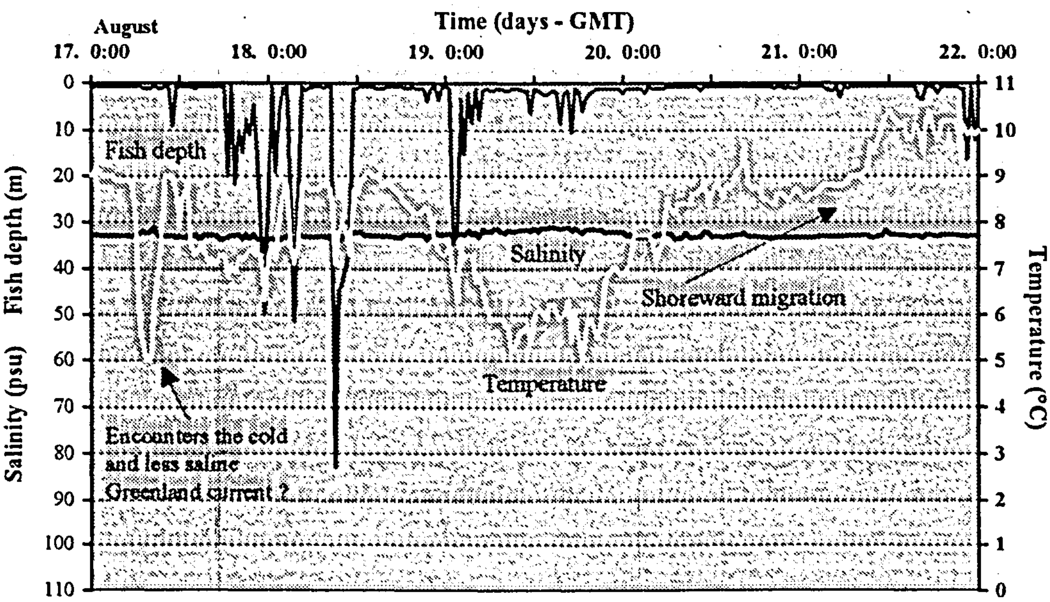

Fig. 21b. Depth distribution of salmon 201, looking closer into the coldest temperature recordings and the diving activity that followed. Increased temperature in the surface layers indicate landward migration.