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MIGRATION STUDY OF WILD SEA TROUT (Salmo trutta L.) IN SE-ICELAND:

Depth movements and water temperatures recorded by data storage tags in freshwater and marine environment

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Abstract

Sea trout (Salmo trutta L.) were equipped externally and internally with data storage tags (DSTs) and conventional tags in the Grenlaekur River, SE- Iceland in early May 1995. The data storage tags measured both pressure (depth) and temperature at 4 hour intervals for periods up to 5 months. Tagged sea trout were recaptured by anglers in the Grenlaekur River (May-October). The total recapture rate of trout tagged with DSTs in 1995, during the 2 following fishing season (1995 and 1996) was 54 %.

Data storage tagged sea trout showed a strong negative relationship between length at tagging (39-65 cm) and the cumulative temperature experienced in freshwater until sea migration. The recordings showed that fish predominantly migrated nocturnally into sea water.

During sea migration the sea trout spent 91% of their time in the uppermost 7 meters, but deeper dives were taken down to 26 meters. The depth distribution indicated a stepward increase in migration distance outward from the shore, during the first 3-5 weeks of the sea migration. Occasional high temperature recordings from sea trout while feeding at sea are likely to be related to brief migrations into an estuary. The growth rate of sea trout in the sea was negatively related to their length at tagging.

After a period of 33 to 93 days in the sea, sea trout entered fresh water for spawning and/or overwintering. In freshwater, the fish showed diurnal rhythm in depth, staying deeper in the daytime.

Key words: anadromous species, sea trout, behaviour, migration, tagging, telemetry, data storage tags, growth, stock assessment.

Introduction

The migration study was based on tagging of anadromous brown trout (Salmo trutta L.) in the Grenlaekur River SE-Iceland, with Icelandic data storage tags (DST). These tags, are manufactured by Star-Oddi Ltd in Iceland, record a series of measurements from the environment of the fish and have been used in pioneer research in this field of telemetry since May 1993 (Sturlaugsson 1995; Sturlaugsson and Gudbjornsson 1996; Thorsteinsson 1995). The tag used in this study (DST 100) measured both pressure (depth) and temperature. The small size, low weight and cylindrical shape of these data storage tags enabled us to use them on relatively small migrants. This study was the first instance of DSTs used in research on trout.

The Grenlaekur River was chosen as a study area because its sea trout stock varies in life history parameters and is harvested by angling, which also ensures recovery of DSTs. This sea trout stock is the largest in number in Iceland, with a mean annual rod catch for the last couple of years around 3500 sea trout or 5 tonnes (Gudbergsson 1996).

Anadromous brown trout are found in all parts of Iceland and are the most common salmonid species in SE-Iceland. Studies on sea trout are few in Iceland, the majority of them being juvenile studies and studies on age composition and growth by analysing scales (see Johannsson & Einarsson 1993 for a review). While migrating at sea, the sea trout utilize mostly nearshore areas relatively close to the estuary of their home rivers. The recaptures of sea trout in sea decrease with increased distance from the river's mouth, and their distribution is usually limited to a range of few tens of kilometers from the home river (e.g. Jensen 1968).

The main aim of the research was to improve the knowledge of anadromous brown trout biology in Iceland. The research work focused on the sea migration. The new DST telemetry enables sampling data directly from the fish's environment, and over longer periods of time in the sea than previously possible. This method provides unique information about the timing of the anadromous migration and the spatial and temporal distribution of these migrants at sea (Sturlaugsson & Gudbjornsson 1996).

Material and methods

Study area

In 1995 a migration study on sea trout was carried out in Grenlaekur SE-Iceland (Fig. 1). The Grenlaekur River is mainly spring fed and the discharge in the upper part of the river system is about 1.9m3× sec-1. The spawning grounds are in the upper area of the river, but the lower area is predominantly very shallow (<50 cm) and also characterized by a sandy bottom (Fig. 1). The Grenlaekur River has a joint estuary with a large glacial river (River Skafta) with a mean discharge of about 120 m3× sec-1 (Rist 1990).

The river temperature in the Grenlaekur River was measured throughout the summer with DST.Also a river level-meter was operated in the upper part of the river giving information about the discharge.Air temperature data, for comparison were received from a weather station at land, 20 km from the estuary of Grenlaekur.

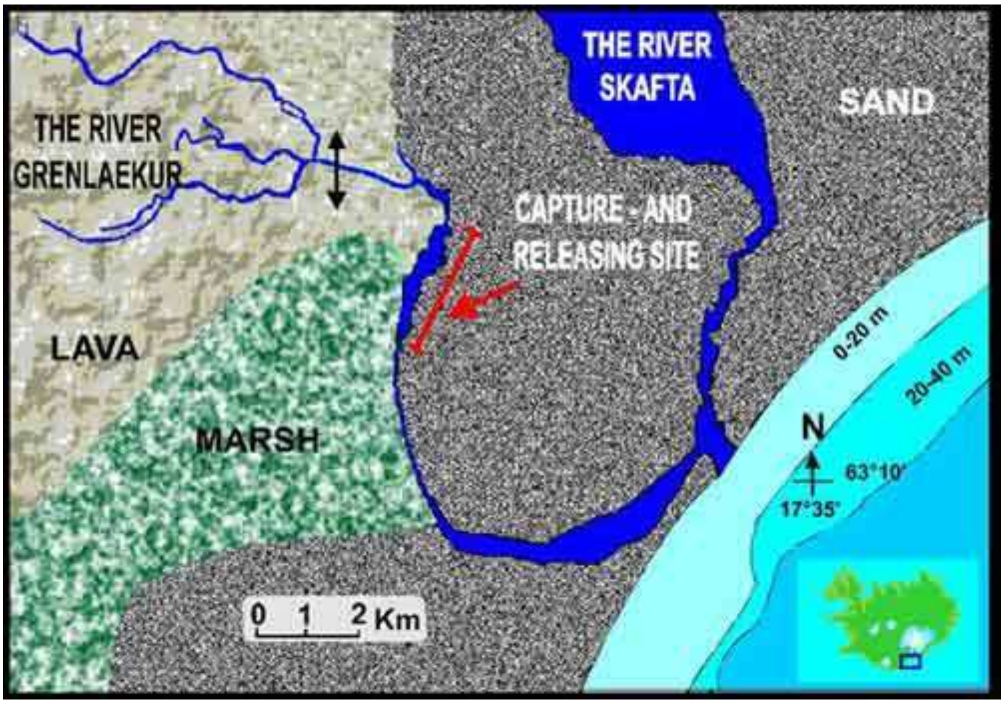

Fig. 1. Area map of Grenlaekur River SE-Iceland and Skafta River and sea in the vicinity of their estuary. These area are involved in the migration study on wild sea trout from the River Grenlaekur. The capture and release site included in the tagging of sea trout are shown within the river. Also shown are the boundary («) between lower area of the Grenlaekur River (0-20 m above sea level) and the upper area of the river (> 20 m above sea level).

Daylight was predominant during the study. Most of the sea migration took place when there were just 3-5 hours (hrs 23-04) of dusk daily during May 19 - July 23. Outside that period of the study, the trout experienced darkness daily, that increased to 4 hours in early May and 8 hours in late September.

The topography of the coastal waters in this part of Iceland is characterized by sandy beaches, without any shelter from the open Atlantic Ocean. Next to land are sandy bottom and shallow waters, with a depth of 20 m or less the first 1-2 km from shore.

The coastal waters are dominated by Atlantic water from the Gulf Stream but also characterized nearshore by outlets of many glacier rivers. Hydrographical data were received from the Marine Research Institute for comparison to DSTs recordings.

These temperature and salinity profiles from 2 - 27 km from shore, from the hydrographical section (Ingolfshofdi) that was the nearest to the estuary of the Grenlaekur River, showed that the main variation in these parameters on June 1 and August 10 in 1995 were in the depth intervals of 12-25 m and 5-25 m respectively. A satellite image of sea surface temperature (SST) covering a 100 km range from the Grenlaekur estuary at June 20 in 1995 was received for comparison with the DST temperature recordings (see Sturlaugsson 1995; Karlsson et al. 1996).

Tagging

On May 6-7 1995, we tagged a total of 170 sea trout in the lower area of Grenlaekur, about 6 km above the estuary (Fig. 1). All of them were tagged with conventional tags (Floy), but 44 of the fish were also tagged with DSTs (double tagging). The trout tagged were caught by fly fishing and released the same day following tagging. The length distribution of tagged sea trout was 28-76 cm, whereof the DST tagged trout were 36.6-66.0 cm in length and weighed between 0.40 -3.10 kg at tagging. The sea trout were both tagged externally (26 fish, 36.6-54 cm in length) and internally (18 fish, 45.5-66 cm in length). Half of each group were injected with antibiotics (Baytril) and wounds from implanting or attachment were covered with a fungicide (Aureomycin). Fish were anaesthetized using MS 222 (Tricane Methane Sulfonate) while tagged and measured (fork length and weight). For determination of age and previous spawning, 3-5 scales were sampled from each fish.

Internal tagging was done by surgical implantation. After placement of the tag into the body cavity the incision was closed by a synthetic absorbable suture (3 stiches) that disappears in a few weeks (Ethicon -vicryl no. 9321). The incision was closed letting the indentification plastic tube of the DST hang out through the body wall. Externally the DST were fastened adjacent to the dorsal fin (Carlin method) by 0.6 mm stainless steel threading.

The DSTs used were 2 Kbyte and programmed to measure both depth and temperature at an interval of 4 hours, recording each day at hours 12:30, 16:30, etc. The data were preserved in the memory without battery backup. The DSTs (56x17 mm) weighed less than 1 gram in water. The temperature and pressure range were -3 to 17 °C and 0 to 70 m respectively. The accuracy for the temperature was +/- 0.2 °C and +/- 0.5 m for pressure.

Recaptures

In the coastal waters of SE-Iceland, there is insignificant fishing of sea trout. Recaptures were based on sea trout captured by anglers throughout the fishing season, from early May to late October. Fishing guards controlled the logging of information from all recaptured fish (length, weight and sex) and scale sampling from tagged fish and from subsamples of untagged fish. Recaptured fish tagged with DSTs were sent to The Institute of Freshwater Fisheries for further examination. Returns of tags were rewarded.

Results

Size, maturation and age composition

Fish that had matured the previous autumn were 21% of the total number observed, indicating a high survival rate. Most of them had spawned once but instances of individuals spawning 4 times were seen. The age of tagged fish was 4-8 years. Sea trout spent 3-5 years in the river before their first sea migration. After that, they migrated every year into the sea and instances of 6 sea migrations were seen. The sea trout first participated in spawning after the second, or more commonly the third, sea migration and then each year following sea migration. Back calculations of length from scales indicated that the sea trout averaged 26 cm in length when starting their first sea migration.

Recaptures

The DST equipped sea trout that were recaptured after sea migration were 38.5- 65.0 cm in length at tagging. Recaptured DSTs included up to 5 month long series of vertical movements and corresponding water temperatures.

Total recaptures the first 2 fishing seasons after tagging (1995 and 1996) were 54%. During upstream migration, following sea migration then the recapture rates of DST tagged sea trout were 25% and additionally 29% were caught in the river before migrating into the sea. No significant difference in recapture rate was found between internally and externally tagged fish or between those that were injected with antibiotics and the untreated ones. Recapture rates of conventionally tagged sea trout were 13 % in 1995. These recaptures showed that a fraction (0.6%) of the immature fish tagged in Grenlaekur entered tributaries of the River Skafta.

In 1996 the recaptures from the DST taggings in 1995 were 7%. Thereof we received 2 DST from internally tagged fish and one sea trout that had lost the externally fastened DST along with the wire.

Tag attachment

The incisions of internally tagged fish healed perfectly within the 1st month after tagging and more than a year after tagging the fish was without any erosion around the identification tube. The wire of externally tagged fish caused minimal erosion of the flesh where it came out through the epidermis, with one exception of a 4 mm gap. The double tagging showed that sea trout showed no loss of DSTs in the angling season following the tagging. In the following season in 1996, on the other hand, we had DST loss in one case of externally tagged sea trout, as expected. This verified that the DST can be used externally without taking the possible risk of harming the fish later on due to the tagging.

Sea migration – timing

The beginning of the sea migration was detected from a drop in the water temperature and the subsequent depth recordings, showing depths not found within the river (Fig. 2). The difference between the freshwater - seawater phase is also detectable by the fluctating water temperatures in the river wich are not found in the sea.

The DST tagged sea trout started their feeding migration in the sea in the period from May 27 to June 17 and were running back into the freshwater between July 18 and September 18 (Fig.3). The duration of the sea migration was 33 to 93 days, and most of them corresponded to the maximum daylength period.

The timing of sea entry was significantly negatively related to fish size, also reflecting the different cumulative water temperatures experienced before entering the sea. This cumulative temperature experienced by the sea trout (May 8 to sea entry) ranged from 158 - 421 degree-days. The mean water temperature the day prior to sea entry was 8.8°C in the beginning of the period and 10.3°C when the last trout descended the river. The migrants entered the sea predominantly nocturnally and during high waters of spring tide, corresponding to the lunar cycle around new or full moon (Fig 3.).

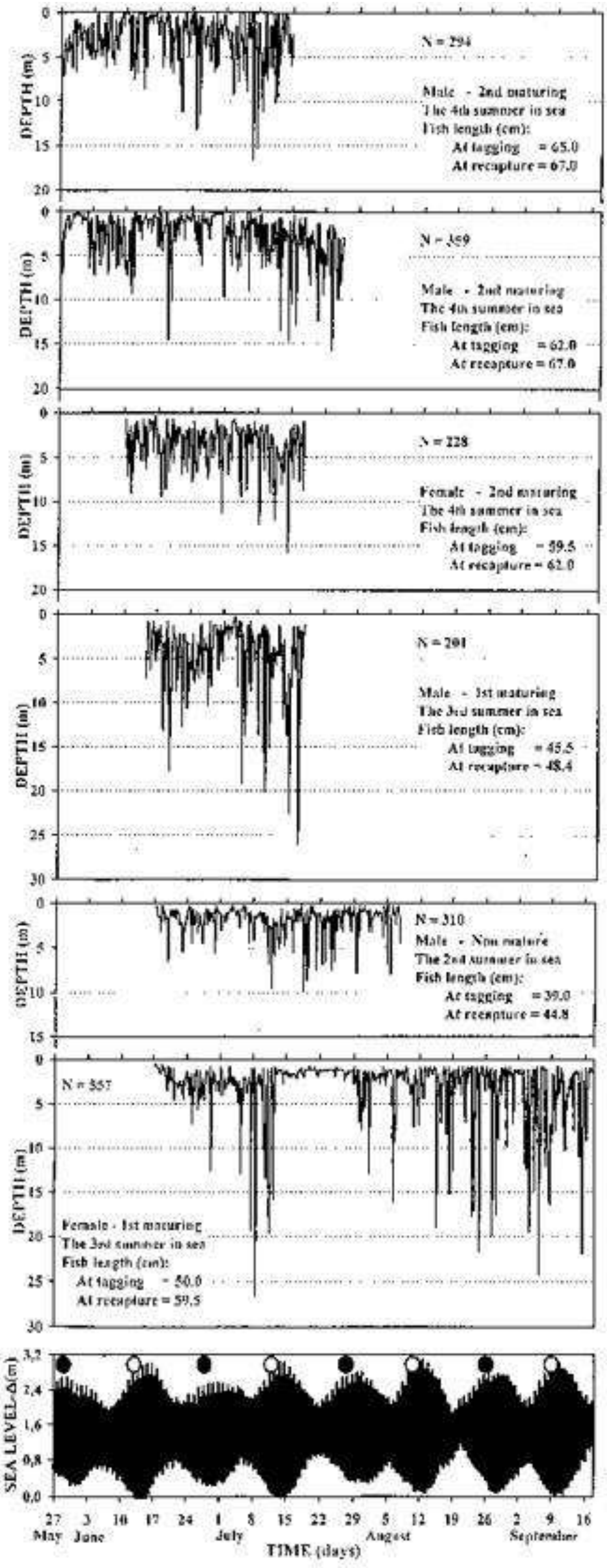
N = 294
Male - 2nd maturing
The 4th summer in sea
Fish length (cm):
At tagging = 65.0
At recapture = 67.0
N = 359
Male - 2nd maturing
The 4th summer in sea
Fish length (cm):
At tagging = 62.0
At recapture = 67.0
N = 228
Female - 2nd maturing
The 4th summer in sea
Fish length (cm):
At tagging = 59.5
At recapture = 62.0
N = 201
Male - 1st maturing
The 3rd summer in sea
Fish length (cm):
At tagging = 45.5
At recapture = 48.4
N = 310
Male - Non mature
The 2nd summer in sea
Fish length (cm):
At tagging = 39.0
At recapture = 44.8
N = 557
Female - 1st maturing
The 3rd summer in sea
Fish length (cm):
At tagging = 50.0
At recapture = 59.5
DEPTH (m)
SEA LEVEL (m)
27 May
3 June
10
17
24
1 July
8
15
22
29
5 August
12
19
26
2 September
9
16
TIME (days)

Fig. 3.

Fig. 3. Depth distribution of DST equipped sea trout from the River Grenlaekur during their sea migration, in relation to time, lunar cycle and tides (variable sea levels). The profiles given show the total duration of these sea migrations and present the total number of depth recordings (N) included. Presented for each fish are information about the sex, maturing status, the number of sea migrations and the length of the fish, both at tagging and recapture. The strength of tides are indicated by the difference between low and high tide, expressed in meters above ebb level of the mean spring tide. The timing of new (M) and full moon (F) are shown.

Sea migration - vertical distribution

The depth recordings showed that the sea trout spent 91% of their time in the uppermost 7 m of the sea (Fig. 3 & 4). The recordings also showed that the trout were swimming through deeper layers, down to depths of 26 m, but they only stayed 1.5 % of their time beneath 15 m depth (Fig. 3).

The depth pattern recorded by the trout in sea showed in all cases a stepward increase of maximum depth the first 3-5 weeks. The maximum depths were in general close to the end of the sea migration (Fig. 3).

Diurnal patterns were observed for some fish, that stayed closer to the sea surface at night (Fig. 4).

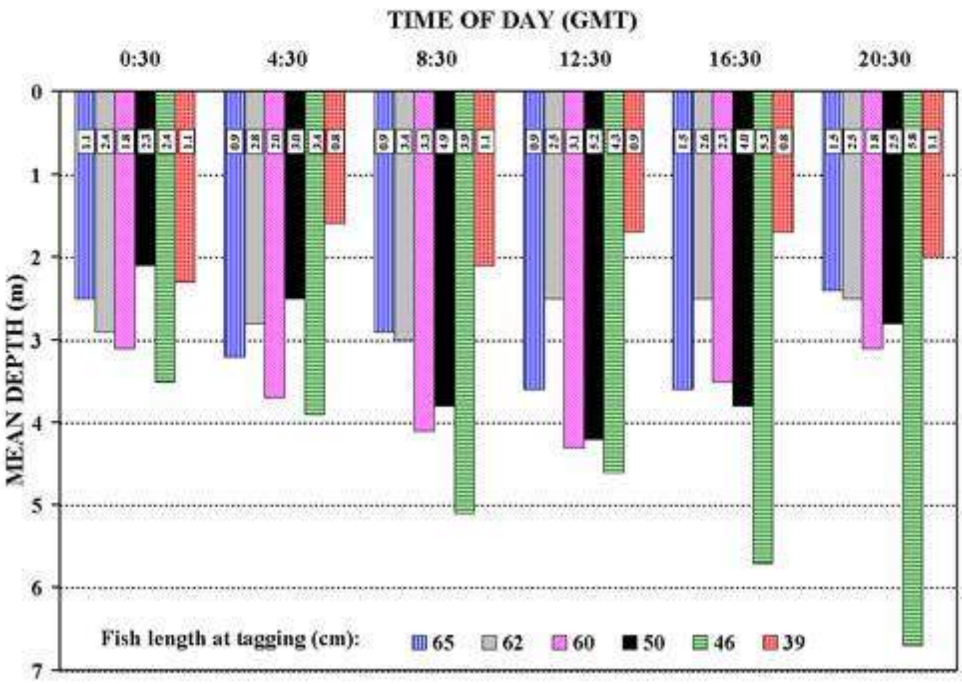

Fig. 4. Mean depth of DST tagged sea trout at sea from the River Grenlaekur, in relation to their length and time of day. The standard deviations for mean depth are given in the corresponding columns.

Sea migration - horizontal distribution

The trout showed a stepward increase in maximum migration depth during the first weeks in the sea, but the fish did not decrease their maximum depth as gradually at the end of the sea migration prior to river migration. The sea trout, while in the sea, experienced variable temperatures and occasionally there were large variations in a short time, most often related to high temperatures recorded in the evening or nocturnally. The SST data that were received showed considerable difference of sea surface temperature between the estuary of the River Grenlaekur and the River Skafta where it ranged from 10.2-13.1°C, and the outer areas that had lower temperatures. These freshwater of the estuary extended 1 km2 outward from the river´s mouth into the coastal waters and additionally in a 2 km long narrower zone along the coast westward due to the coastal current. Comparison of the SST data and corresponding DST temperature data from 6 trout (0.5-2 m depth) ranging from 8.1-8.3 °C showed that the trout were at that time not within the home estuary or any other big estuaries within a 100 km range. Comparision between the outer sea areas within that range was not possible because parts of that area had cloud coverage.

Body growth

The body growth of the sea trout in the sea was negatively related to their length at tagging. The DST tagged sea trout increased their weight during the sea migration by 160-650 g, equal to a weight increase of 0.39-0.89 % × day-1. These sea trout increased their length during the sea migration by 1-9.5 cm, equal to a length increase of 0.02-0.27 % × day-1.

River migration - Vertical distribution

The depth recordings showed that the swimming behaviour of sea trout had a diurnal variation within the river, as the sea trout were closer to the surface nocturnally. The water discharge in the river was compared to the vertical distribution of the sea trout for some periods, but no significant relationship was found between these parameters for those periods. As the temperature pattern in the river reflects the air temperature and other weather conditions, the sea trout experience large temperature fluctations both diurnally and over longer periods, especially in spring and autumn.

Discussion

As a large majority of the sea trout in the Grenlaekur River were recaptured in the year of tagging, convenient external tagging ensured results. The more arduous internal tagging also gave some additional recaptures in later years. The high recapture rates of DST tagged fish, their growth rate and good status in relation to tag attachment, shows well how little effect the DSTs have on them. The observed higher recaptures of DST tagged sea trout compared to conventionally tagged sea trout is likely related to many reasons. Two of these reason being the more prominent DSTs, and a biased positive attitude of anglers towards the DSTs.

The total recaptures showed well the precise migration of spawners to their home river, but also showed examples of the tendency of immature sea trouts to overwinter in other rivers than their home river.

The data series from the DSTs are the first instances of such measurements that include all the sea phase. In addition these series of measurements included a freshwater phase before and after the sea migration. These continuous series of measurements gave new information about the vertical distribution and the timing of the runs into and out of the sea, with reference to measured environmental factors.

The timing of the beginning of sea migrations of trout, and also the cumulative water temperature experienced by them from tagging until entry into the sea, were significantly negatively related to their size. Such behaviour can be used for management purposes, e.g. by specifying the start of the angling period in relation to the status of the stock.

It was not possible to analyse short term vertical distribution of trout because of the measuring intervals of the DSTs used. Instead we gained very good overview of the average depth preferred over long time intervals from variable periods of their migration.

In the river, the diurnal rhythm of vertical distribution of the trout is likely to involve increased utilization of shallower parts of the river during the night, probably in relation to increased migration activity. The nocturnal outward migration is also likely to reflect avoidance of predators, especially in the lowest 4 km of the river and the estuary. In that area the great skua (Stercorarius skua) preys on sea trout when migrating through the extremely shallow sandy areas and seals (Phoca vitulina) prey on them in the estuary and near shore. Nocturnal outward migration through estuaries has also been observed among sea trout smolts (Moore and Potter 1994). High temperature in the afternoon and evening may influence the migration of the sea trout negatively for energy budget reasons, especially in the shallow lower areas prior to sea migration when spawners are very thin.

In the sea, the sea trout mostly uses uppermost meters. This reflects the depth preference of the sea trouts and/or their prey, in relation to factors such as hydrography and/or bottom depth near shore. Information from experimental fishing of sea trout in the study area (Sturlaugsson and Magnusson unpublished) shows that sea trout captured at the shore 5-15 m from the tidal line up to 3 km eastward of the estuary were preying on sand eels. (Ammodytidae). This shows both that sea trouts, at least up to 4 kg, are feeding that close to shore in appropriate weather conditions and also that sand eels are an important prey for them in this area. The sand eel utilizes mainly coastal waters with a sandy bottom, not the least the shallower areas (Jónsson 1983). When depth recordings were compared to hydrographical data they showed that the trout used mainly the depths above the thermocline, and even within that zone they stayed principally at depths with the lowest salinity and highest temperature. The examples from the sea phase of diurnal rhythm in the vertical distribution of trout are likely linked to their increased feeding utilization of upper layers during the night that probably reflects changes in vertical movements of their prey.

During the sea migration the occasional large temperature variation recorded by the sea trout DSTs along with corresponding migration close to the surface together with SST data indicate brief migrations into estuaries. These migrations into estuaries were most apparent nocturnally. A horizontal location relative to the shore was also inferred from the maximum depth pattern of the trout in the sea. This is based on the fact that the sea trout all showed a similar stepwise increase in their maximum depth during their first 3-5 weeks in the sea, despite differences in timing of their outward migration accompanied by differences in environmental conditions, such as feeding conditions. Therefore we assume that the maximum depth pattern recorded by the trout approximately reflects changes in the bottom depth in the area migrated through. Another possibility is that this depth pattern is partly related to changes in the vertical distribution of salinity and temperature and/or changes in the salinity tolerance of the trout during the sea migration. The observed maximum depth pattern of the trout would in order to both this options indicate increased tendency by the trout to migrate oceanward during the 3-5 first week in the sea. Despite the maximum migration depth of trout increased stepwise during this period of the sea migration, that increase was not continuous. This were shown by excursions into estuaries, that also indicates the migration in and out from the shore. The increase in maximum migration depths during their first weeks of sea migration therefore indicates that the trout moves out from the area closest to shore for period ranging in time from less than a day to some day´s. The distance of these offshore migration does not have to be long when considering that the maximum depths migrated through by the trout in the sea could be within area very close to the shore e.g. 1-4 km from shore in the sea area adjacent to their home estuary. In short, it appears that the sea trouts are utilizing coastal waters the whole sea migration, especially the areas near shore.

In order to look more closely into the sea migration of sea trout's, we will carry out tagging experiments in 1997. Then we will use new and smaller type of DSTs that in addition to pressure and temperature sensors have a salinity sensor, a four times bigger memory and two different sampling interval possibilities. Such DSTs were tested for the first time in the summer of 1996 on salmon migrating in coastal waters giving very interesting results (Sturlaugsson et al. unpublished data).

The DSTs greatly increase our understanding of the factors involved in the migration and distribution of anadromous brown trout. Some of the new information, such as the timing of the sea migration, will have practical importance right away regarding stock assessment and conservation of sea trout in the area.

The data storage tags open up new dimensions in fish research that adds valuable information to our understanding of fish behaviour and their reactions to their environment. The data storage tags will because of this be a very useful research tool in this field in the future.

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