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USE OF DATA STORAGE TAGS TO STUDY THE SPAWNING MIGRATION OF BALTIC SALMON (*SALMO SALAR* L.) IN THE GULF OF BOTHNIA

by

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Abstract

Most Baltic salmon originate in the Gulf of Bothnia and migrate to the more southerly Main Basin to feed. As spawners they migrate northwards and enter the southerly part of the Gulf of Bothnia in spring or early summer. Catch statistics and conventional tagging have given a good impression of the large scale behaviour of salmon during this period, but detailed information on the behaviour of individual fish is not available. We have started a project to study the spawning migration of Baltic salmon by means of a combination of conventional external tags and data storage tags. Salmon which are tagged in coastal fisheries in the southernmost Gulf of Bothnia may migrate up to 850 km before they enter their home river. In the summer 1995 in total 165 salmon were tagged with dummies or "real" data storage tags. In addition 185 were conventionally tagged. The recovery rate for data storage tags were 47 % as compared to 13.5 % for Carlin tags. Tagged fish migrated northwards after tagging and most of them kept speeds of 25-45 km/day from tagging to recovery. The data storage tags registered temperature and depth. They indicated that most salmon moved at a few meters depth. In spring there are marked temperature gradients in the Gulf of Bothnia with considerably higher temperatures in the coastal, shallow areas than deeper, more central areas. First results from the data storage tags indicate that the fish often avoid the more central areas and migrate along the coasts as also partly indicated by earlier conventional tagging. In 1996 161 salmon were tagged by data storage tags or dummies. A total of 550 salmon were also tagged by Carlin tags, approximately 400 of them in Finland and the remainder in Sweden (Sub-divisions 29 and 30).

Keywords: Baltic salmon, migration, tagging experiments, data storage tag, depth, temperature

Introduction

A majority of all Baltic salmon originate in rivers in the Gulf of Bothnia, but only a few remain in this area for feeding. Instead almost all Baltic salmon migrate to the central and southern parts of the Main Basin for feeding (Carlin 1969). Spawners leave the southern Baltic in April-June (Thurow 1966) and migrate towards their home rivers in the Gulf of Bothnia. The spawners maintain a high speed while swimming towards their rivers in the Gulf of Bothnia and many spawners seem to migrate more along the eastern than the western coastline until coming close to their home river region (Carlin 1969, Karlsson and Karlström 1994).

Many aspects of the migration behaviour of salmon in the Gulf of Bothnia are well known due to intensive fishery, large scale smolt tagging experiments and other experimental studies (Karlsson and Karlström 1994). Nevertheless there is a lack of knowledge of detailed behaviour of individual fish throughout their migration in the Gulf of Bothnia. The newly developed data storage tag technique make it possible to track individual fish in long periods of time (Sturlaugsson 1995). We set out to use this technique to get a better knowledge of the detailed behaviour of individual fish. If the number of experimental fish is sufficient it will also be possible to get estimates of population features such as migration timing and possible differences in behaviour among wild and reared fish. Such features are of interest for the commercial exploitaiton of salmon in the intense fishery in this region.

Temperature data from data storage are compared with SST:s from in situ measurements and satellite recordings. The temperature structure in the Gulf of Bothnia is dominated by large scale fronts aligned to the coast and isobaths, and occur predominantly in areas of straight and uniformly sloping bottom topography. The major frontal areas are along the eastern coast of the Gulf (Kahru, Håkansson and Rud 1995). In the spring there are marked temperature gradients in the area with considerably higher temperatures in the coastal, shallow areas than deeper, more central areas. This may make it possible to track salmon migration routes along isothermes if the data storage records keep in narrow limits.

In this paper we describe the first results from the first year of a three-year tagging project of spawners entering the Gulf of Bothnia. Both data storage tags and conventional tags (Carlin tags) are used in the study.

Material and methods

Fish and tagging

The experiments described in this paper took place in 1995. Salmon spawners were trapped in coastal trapnets at the sites shown in Fig. 1 in the period of May 30-September 18. The majority, 264 fish, were tagged before the end of June. All tagging places were selected to be far off from salmon rivers and at an early part of the spawning migration. Both conventional tags, a dummy of data storage tags (DST) and real data storage tags were used. Unimpaired fish were released from the trapnet and tagged externally below the dorsal fin using a 0.5 mm steel thread to attach the DST. Carlin tags were attached with a 0.3 mm thread. Salmon length was recorded and in many cases also the weight. A scale sample was taken to determine age and origin (wild/reared) according to the method of Antere and Ikonen (1983). To minimize handling time fish were normally released immediately after tagging. To increase recovery rates dummy tags and DST:s were labeled with a fluorescent red label announcing a 300 SEC or 200 FM reward for the dummy and DST tags. In addition there were information in newspapers about the project and local and regional fisheries officers were informed of the tagging.

Data storage tags

The data storage tags used in the experiments were manufactured by Star Oddi Hf, Iceland, and fitted with temperature and pressure sensors. The tags were set to a 1 hour sampling interval which gave a total logging time of 990 hours. The cylindrical housing was 60*18 mm and the weight in water was less than 1 gram. The dummy tags were similar in all respects except for having a slightly positive buoyancy. The temperature and pressure range was -2 to 18 °C and 0 to 70 m respectively. The nominal accuracy for temperature was ±0.2 deg and for pressure ±0.5 m. A number of tags were tested to study the effect of temperature on the pressure calibration, the time constant and hysteresis of the sensors etc. The results are given in Appendix I.

Satellite data

Sea surface temperature (SST) data from NOAA AVHRR satellite pictures covering the Baltic north of 59° N were used to analyse the DST temperature time series. The best available scenes at 2-3 days intervals during the period June to September 1995 were obtained from Tromsø Satellite Station in digital format. Basically the reconstruction of the trajectory of the fish carrying DST:s was made by comparing the temperatures recorded at the fish while it was within 4 m from the surface during the hours before and after a particular SST scene with the areas available within this temperature interval. This comparison was facilitated by an IDL (Research Systems Ltd) application that could highlight the temperature range of interest on the computer screen. The probable location(s) of the fish was then determined by combining the temperature information and a simple dead reckoning of the distance and time from the point of release to the capture site. Additional SST data was taken from analysed quasi-synoptic temperature charts of the Baltic that combines satellite data and ship observations and are released twice weekly by the Swedish Meteorological and Hydrological Institute.

Results and discussion

Recoveries

The number of tagged and recovered salmon originating from nine different tagging sites is shown in Table 1. In total 350 fish were tagged and until now a total of 114 recoveries were recorded. The recovery rate for dummy and data storage tags was 49.7 % while the recovery rate for Carlin tagged fish was 17.3 %. The lower recovery rate of Carlin tagged fish ($p<0.001$) may be attributed to at least two different factors. Firstly, two of the sites, A and B, dominate the tagging and almost all dummy and DST tags were also used there. Secondly, the highly visible large DST having a high reward stimulated people in reporting tagged fish. Because of the probable multifactorial causes of the difference between tagging categories, we haven't compared results from Carlin tagged and DST salmon at this stage.

Almost all fish migrated northwards after tagging and were recovered in a coastal fishery, Fig 1. Eight recoveries were made outside the Gulf of Bothnia, indicating that these fish were probably not prespawners on their way to rivers in the Gulf of Bothnia. Salmon tagged with dummy or DST:s normally kept a swimming speed of 20-50 km/day counted along the shortest distance from release to recovery site, Fig. 2. The fish having speeds below 10 km/day were normally recovered more than 50 days after tagging or at a short distance (<100 km) from the tagging site. Because of the choice of tagging sites far from rivers, most (67.5%) recovered salmon had migrated at least 200 km, the maximum being 830 km, Fig. 3. Most fish were recovered within 30 days, Fig. 4, and only 8.8% of the salmon were recovered more than 41 days after tagging indicating that the 41.25 day recording time of DST:s was sufficient. At least three dummy recoveries after longer time intervals were reported as tags found at shore or in water, showing the potential value of the positive buoyancy of the tag. One of these tags was found at the river mouth of the northerly River Ume in May, possibly indicating that the tagged salmon had ascended this river in the preceeding summer and that the tag had drifted down after the salmon had died.

Scale reading indicated that a surprisingly high proportion of the tagged fish was of wild origin. Out of in total 236 sampled fish, 22 were undetermined, 125 of reared origin and 89 (41.6%) were of wild origin. The age distribution was as follows: A.1+,30.3%; A.2+ 57.1% and A.3+ 8.4%. Six river recoveries had their origin independently determined from scale samples taken at tagging. The origin predicted from scale reading fitted in with the salmon population present in the river for four "reared" fish as well as for two "wild" salmon.

DST-data

The swimming depth, as seen from the DST time series, was in general close to the surface. Fig. 5a gives the frequency distribution in 2 m intervals averaged for all inidviduals and the whole tracks. It is seen that the salmon spent almost 40 % of the time within the uppermost 2 m. There is some individual variation to this, Fig. 5 b and c give examples of both extreme preference for the surface layer and individuals that spent more time at larger depth. The uncertainty about the offset and absolute calibration of the pressure data makes it impossible to resolve the preferences within the uppermost 2 m.

The diving activity of the salmon is indicated by maximum depth recordings down to typically 25 m, for two individuals down to 35-40 m. The duration of a dive is usually brief so the instantaneous samplings with 1 hour intervals don't allow any detailed analysis. The thermocline in the Gulf of Bothnia extends down to 20 to 30 m during the months June and July so this means that the vertical excursions of the salmon is through the thermocline and in some cases deeper. There was no diurnal pattern in the mean depth preference. For some salmon, T12, T20, T21, T29 there is a tendency that the deepest records are clustered around dawn and dusk, but this is not a very persistent pattern. Other individuals, T40 and T11, showed their deepest dives during the middle of the day.

Three factors dominate the temperature records - the gradual heating of the surface layer, occasional low temperatures connected to dives into the thermocline and short or medium scale variations due to the movements through the surface thermal field. The latter variations are used for the reconstruction of the individual tracks. By looking at the temperature and corresponding depth records over a limited part of the time series a vertical temperature profile for the position of the salmon could, in principle, be constructed. This was tried with the hope that the transition past the Kvarken sill could be detected. In practice there is a large uncertainty due to the 3-4 min time lag of the DST however and this in combination with only a few hydrographic depth proof.

The comparison of temperature data from DST:s and satellites (SST) showed in some instances that the salmon migration routes culd only be located in narrow areas, Fig. 6. This figure describes the probable migration route of a fish tagged at site A (see Fig. 1) in the southern part of Gulf of Bothnia on June 2 and recovered in the northernmost part of the Gulf of Bothnia at June 22. It seems likely that this salmon migrated closely along the eastern, Finnish coast at least until it came close to the Kvarken area in the middle of the Gulf. After passing this area it once again seems as if it migrated closely along the eastern part of the Gulf in the northernmost part of the Gulf, but this is more doubtful because of a lack of satellite data corroborating this route.

For one salmon (T40) there was a period of the recording immediately before the recovery where the temperature record indicated a water temperature which was too high compared to the satellite SST data for the area. This gave rise to the suspicion that there might be a solar heating of the tag, an effect that was demonstrated in later experiments (Appendix I).

Concluding remarks

The analysis of the temperature and depth time series has not been very exhaustive as the 1995 recoveries is the first part of a larger and more comprehensive data set that will be analysed in its entirety later. The difficulty in interpreting the diving activity and reconstruction of the vertical temperature profile has been used in designing the 1996 tagging; this year the tags are programmed to sample in alternating 5 and 9 hours periods with 10 and 60 minutes intervals respectively.

In general the tracking of the spawning migration routes via SST data comparisons, suggested that this method can be used to give approximate migration trails of fishes that migrate close to the sea surface over large distances. The long series of DST recordings over the salmon behaviour versus their environment have already given us new information. We think that this technique in combination with results from conventional tagging will enable more precise mapping of the salmon spawning migration routes in the Gulf of Bothnia. This is of relevance both to the basic question of migration and orientation of salmon as well as to management of the fisheries and conservation of salmon of different origin.

Acknowledgement

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Table 1. Number of tagged and recovered salmon originating from different tagging sites, see Fig. 1.

Place	Tagged Carlin	Recovery Carlin	Tagged Dummy	Recovery Dummy	Tagged DST	Recovery DST	Tagged Total	Recovery Total
A	16	4	86	44	22	8	124	56
B	100	17	20	15	5	4	125	36
C	15	5	14	4	5	1	34	10
D	1	0	0	0	0	0	1	0
E	0	0	5	1	0	0	5	1
F	1	0	5	4	3	1	9	5
G	34	4	0	0	0	0	34	4
H	16	1	0	0	0	0	16	1
I	2	1	0	0	0	0	2	1
Total	185	32	130	68	35	14	350	114

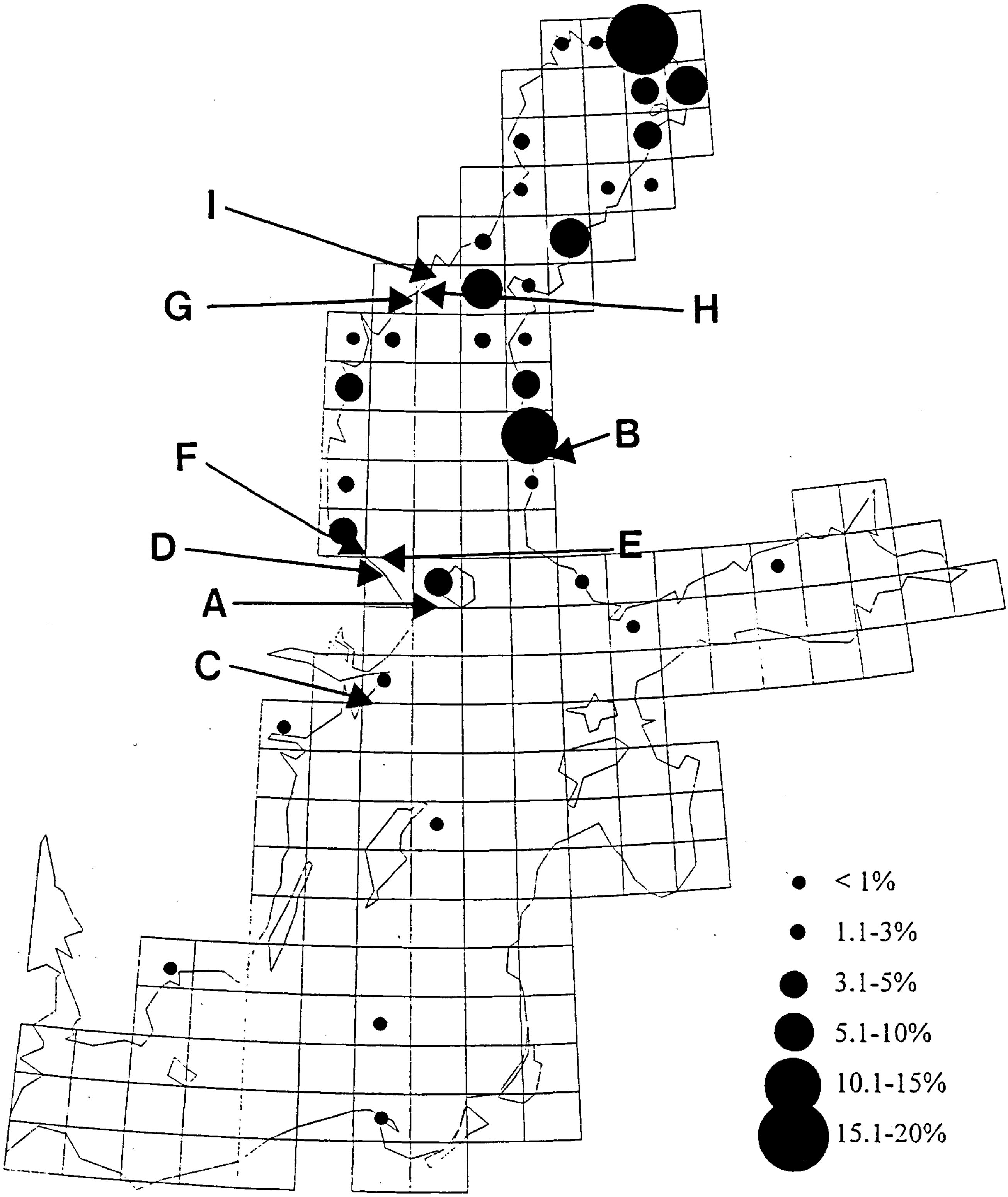


Figure 1. Tagging in 1995 (sites A-I) and distribution of recoveries (dots) by area.

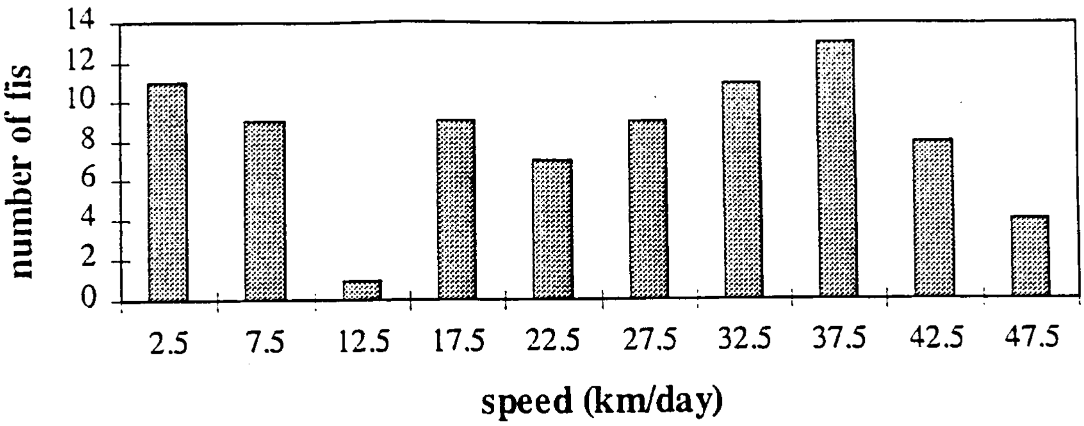


Figure 2. Swimming speed from release to recovery of salmon tagged with dummy or data storage tags.

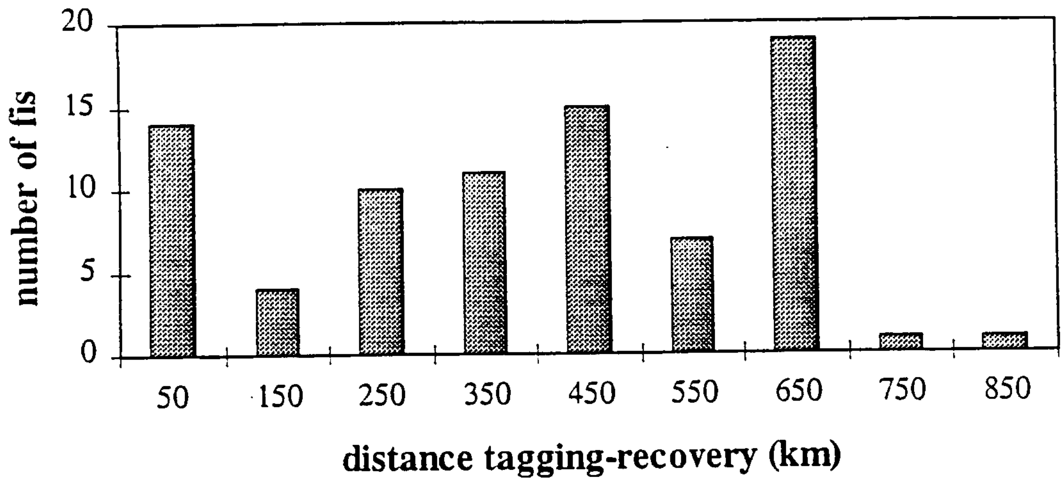


Figure 3. Distance covered from release to recovery of salmon tagged carrying dummy or data storage tags.

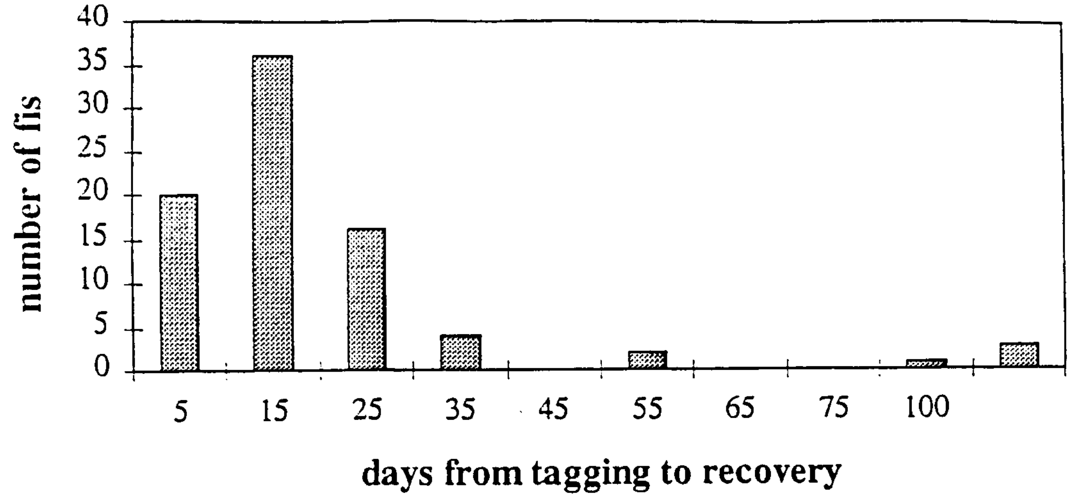


Figure 4. Number of days from tagging to recovery of salmon tagged with dummy or data storage tags.

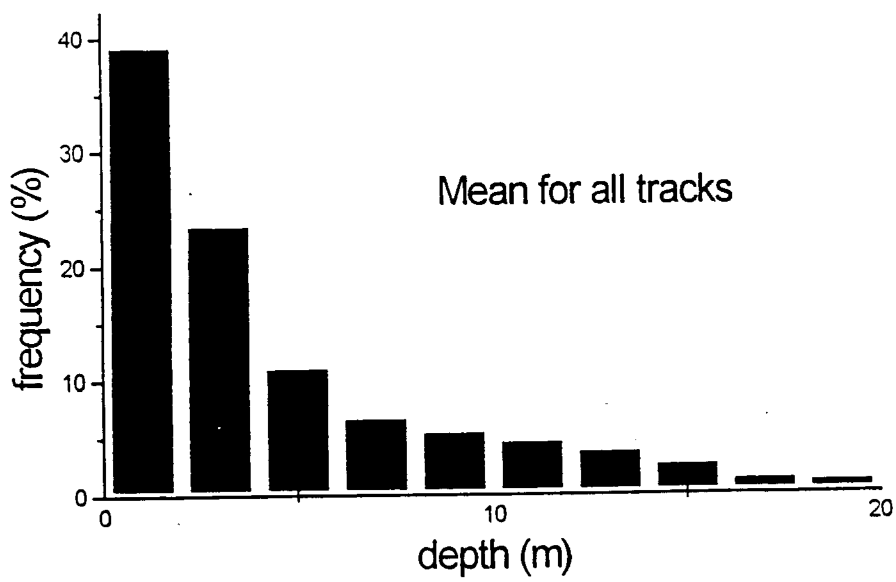


Figure 5a. Depth preferences as a mean for all DST-tagged salmon.

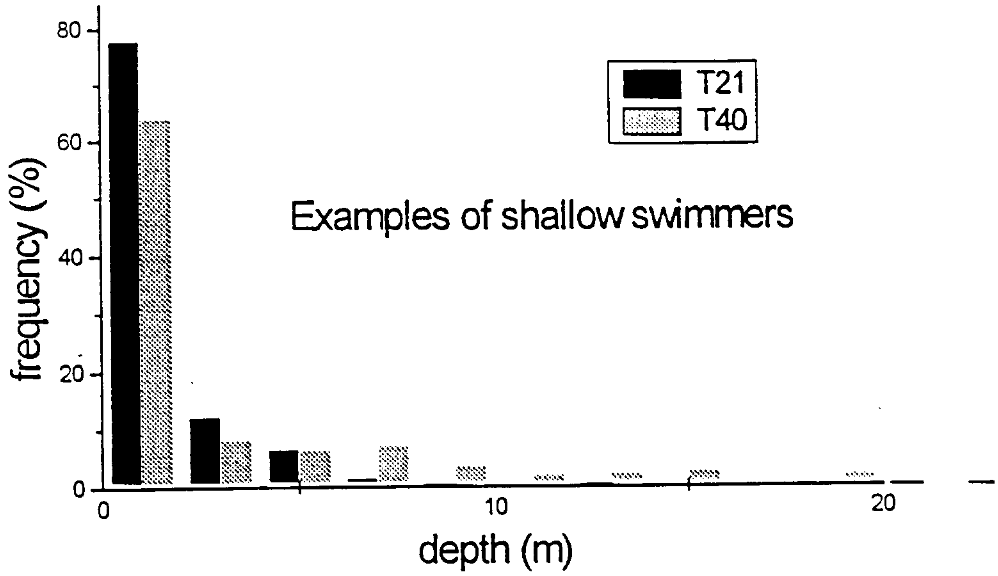


Figure 5b. Depth frequency distribution of two salmon that had a shallow depth range.

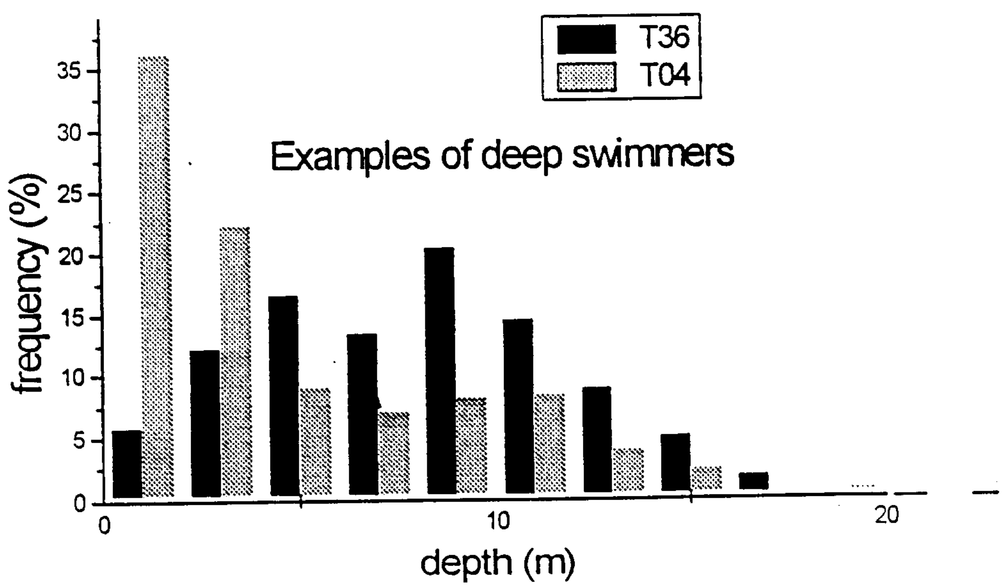


Figure 5c. Depth frequency distribution of two salmon that had a relatively deep vertical distribution.

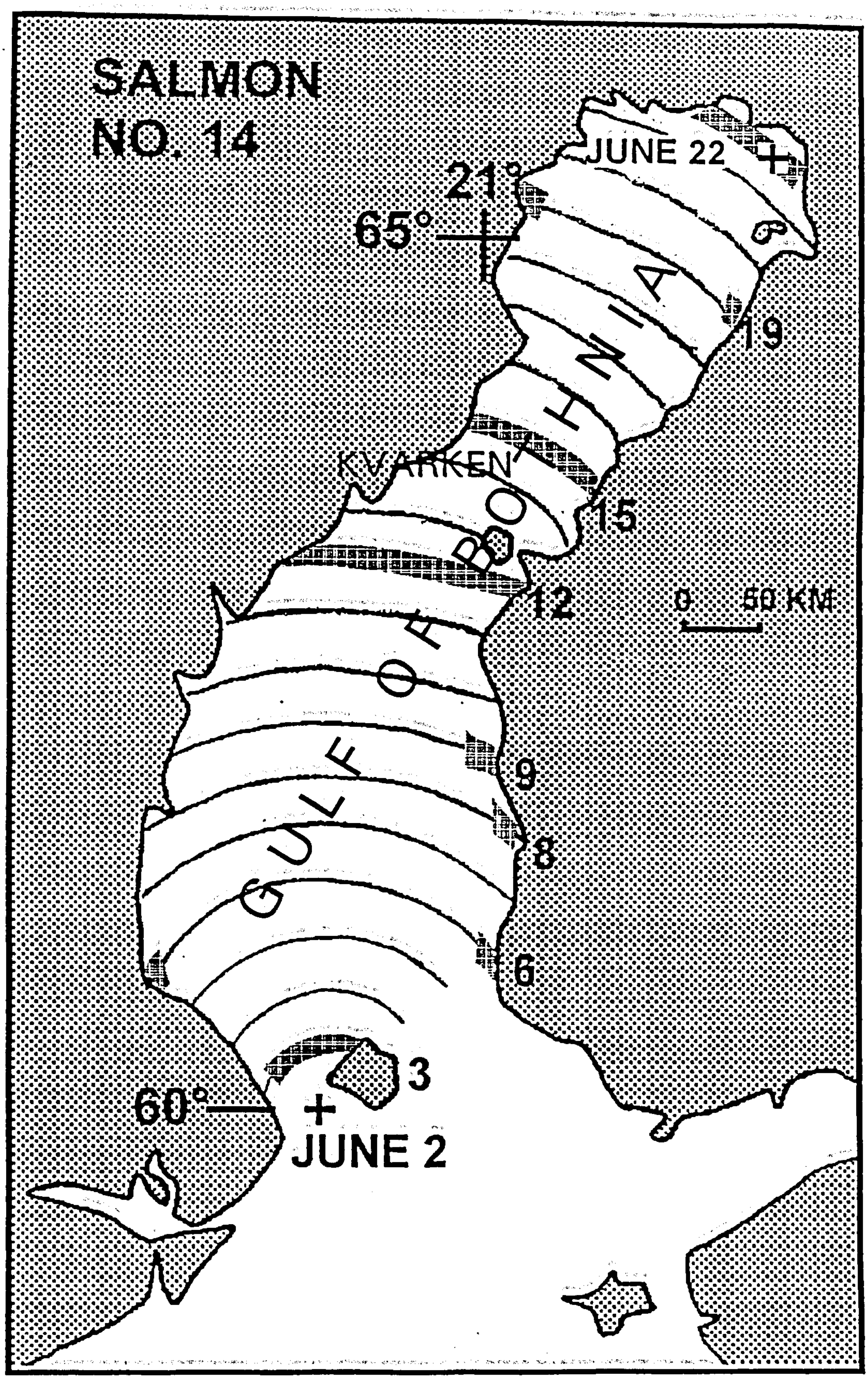


Figure 6. Tracking of the migration route of salmon no. T14, from June 2 when it was tagged in the southerly Gulf of Bothnia (+ tagging and release) to June 22 when it was recovered in the northernmost part of the Gulf (+ recovery). Possible locations are shown, based on areas where SST:s from the DST and satellites were overlapping. Distribution of these areas are shown as shaded areas on the daily gridlines for those days when high qualitative satellite SST data were available. Mean migration speed =33.0 km/day.

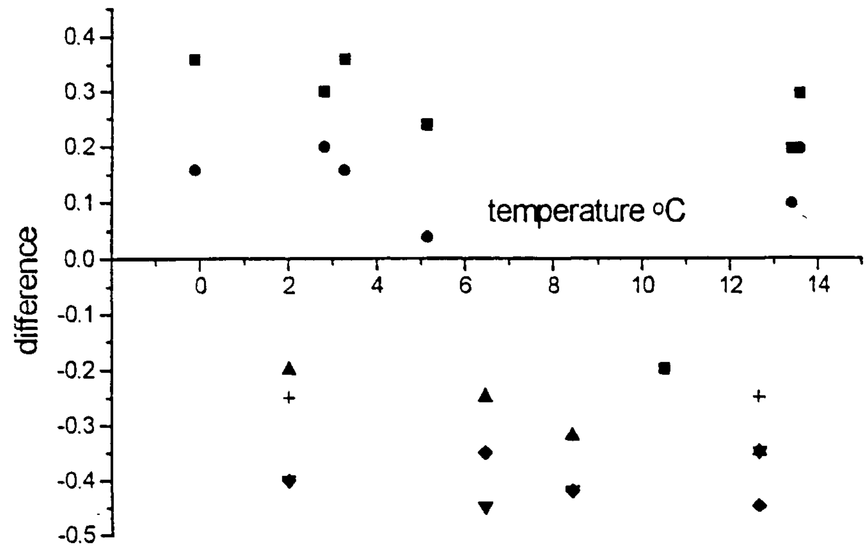
APPENDIX I

Six StarOddi data storage tags of the kind used for the 1995 and 1996 taggings have been subjected to various laboratory performance tests. Pressure calibrations were made in a small, brass pressure chamber submerged in a thermostated bath. The pressure was measured with a "Druck Ltd" type 601 digital pressure indicator which was calibrated to within ±0.005 bar absolute pressure. To convert the absolute pressure reading to depth in meter the atmospheric pressure was subtracted from the reading and the remainder was converted to m water column using the standard value of g and the density of fresh water at 4°C. Temperature was measured with calibrated mercury thermometers with a 0.01 deg resolution.

The temperature deviations for all tags and calibration points are shown in Fig A1. The observed errors are somewhat higher than the nominal value, approximately ±0.4 deg. The linearity errors are however less - usually better than 0.2 deg. Pressure had no effect on the temperature calibration. The time constant of the tag was determined by rapidly transferring two tags between stirred water baths of different temperature. The sampling period of the tags was 1 minute. The recorded response is shown in Fig. A2. The 1/e time constant was approximately 4 minutes.

The housing of the tag is transparent and close to the surface sunlight can be absorbed by the circuit boards and heat up the temperature sensor. This effect was tested by placing two tags in the same stirred water basin and exposing them to the sun during a relatively cloudfree sky. The tags were covered by 1 cm of water and were shaded alternatively one or the other during 30 minutes periods. As seen in Fig. A3 the heating of the sun gave a false reading whith errors in excess of 1 deg. The test was made in the end of August during the afternoon and with a beginning cirrostratus cover, which dulled the radiation from the sun, thus even larger errors could be expected in other conditions. This effect should be further investigated looking at the dependence on the thickness of the water column, the change with sun altitude etc.

The pressure calibrations were made at different temperatures and were spread in time over the whole active recording time of the tags. The individual differences between four tags tested at the same time are shown in Fig. A4. The spread between the tags amounted to approximately 1 m and the maximum deviation is up to 2.5 m. There seemed to be an offset of roughly 1 m which also can be seen in another tag which was tested repetedly at different temperatures, Fig. A5. There was no measurable difference in the calibration slope with temperature. The possible effect on the offset can as well be attributed to that the calibration runs were made at different times and that the battery voltage has changed. The hysteresis of the pressure sensor was insignificant - at most 0.2 m.



Figur A1. Temperature deviations for six different DST:s calibrated at different temperatures.

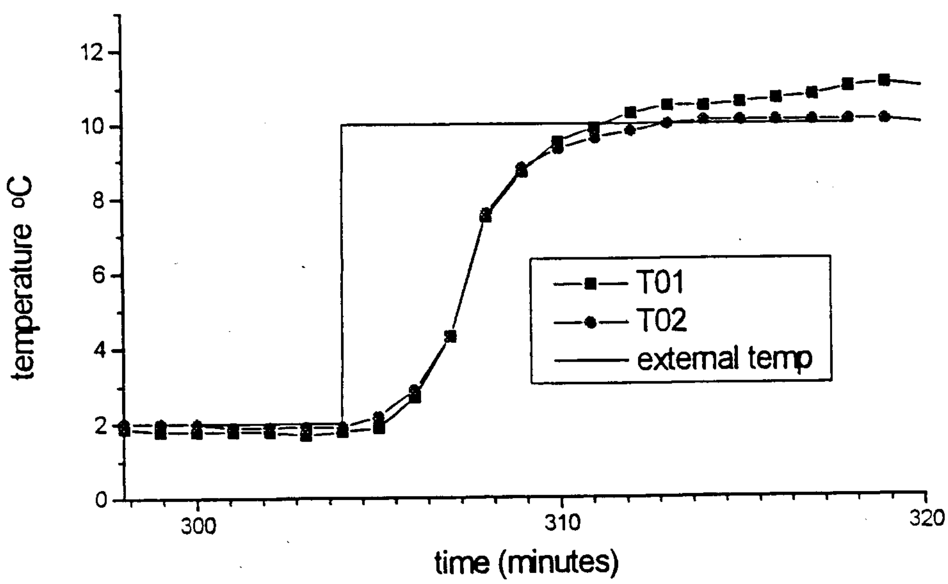


Figure A2. Response time of two DST:s to a step change of temperature.

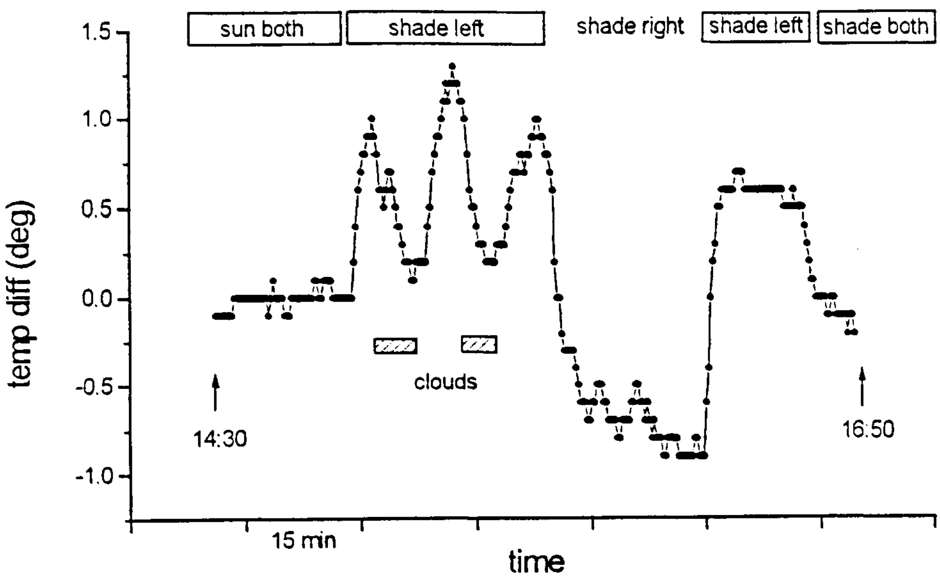


Figure A3. Temperature difference between tags exposed or shaded from the sun.

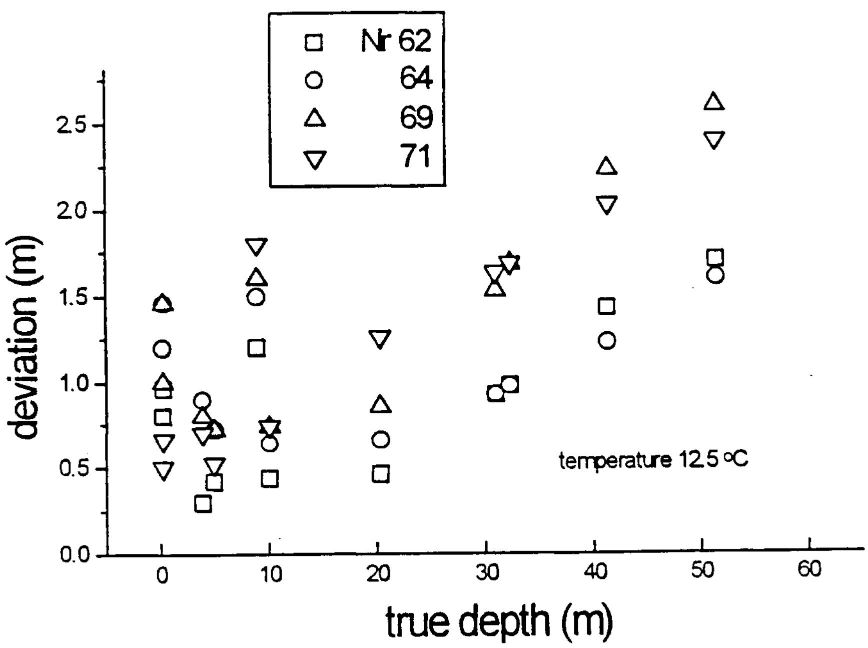


Figure A4. Pressure calibration of four DST tags at the same temperature.

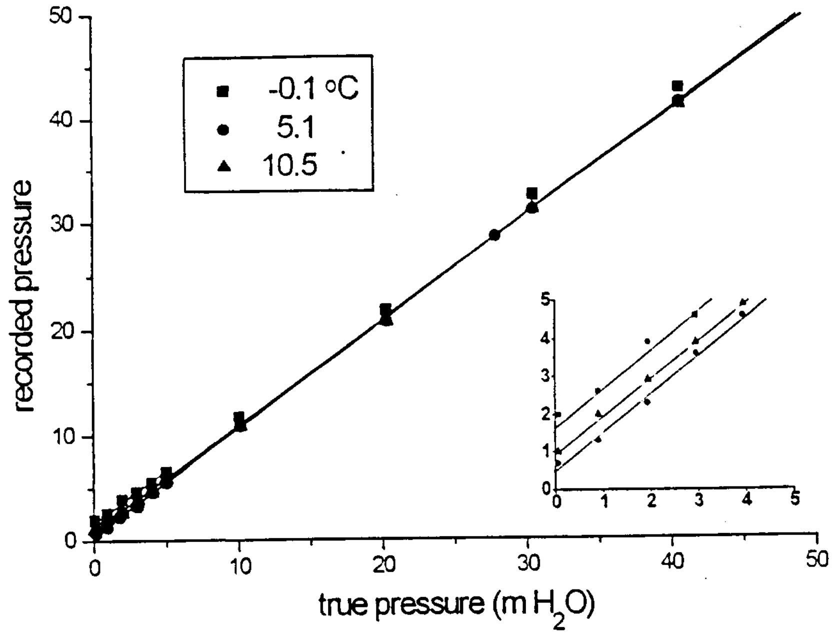


Figure A5. Pressure calibrations at different temperatures.