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Beyond geolocation

ORIENTATION OF HOMING ATLANTIC SALMON (*Salmo salar* L.) MAPPED IN RELATION TO GEOMAGNETIC FIELD

by

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Abstract

A migration study on the homing of Atlantic salmon was carried out in waters off SW – Iceland. Data was sampled on the salmon behaviour and environment during spawning migration in sea. New type of data storage tag was used to measure the earth's magnetic field and the tilt (in 3 directions) and paired information on fish depth (pressure) and correspondingly the temperature experienced. By taking advantage of this new research tool we have managed in this study to bring forward new information on salmon orientation. The study involves new approach in mapping information on behaviour and positioning of free ranging fish.

Information already available from the study is showing that salmon migration behaviour changes when moving from offshore to inshore waters. We conclude that this stands for changes in the orientation behaviour of the salmon due to the increased use of olfactory sense in the inshore area. Based on that we recommend to divide the spawning migration in sea into three phases in relation to the different migration (orientation) behaviour in different sea area (offshore; inshore; estuary). Parallel to this finding is the fact that the directional geomagnetic recordings sampled during the migration of the salmon from release offshore to entry to their home river showed that fixed direction all the way from offshore to the home fjord area or home estuary could not explain their migration. Therefore we make that assumption that shoreline orientation is important in finding the way once the shore has been approached. The study setup has brought to shore many interesting recordings of new parameters on behaviour and environmental patterns that will be examined further later.

Keywords: Atlantic salmon, migration, homing, orientation, navigation, data storage tags

Introduction

Atlantic salmon (*Salmo salar* L.) usually travel distances that span hundreds to thousands of kilometre in the N-Atlantic. During feeding migration as post-smolts and adults that is followed by the spawning migration of adults, either after staying close to 1 year in sea (grilse) or two or more years (salmon). The spawning migration in sea usually starts in the oceanic area where the main feeding grounds are located and ends in the home estuary of the salmon, where freshwater phase of the spawning migration starts. The homing behaviour of salmon during spawning migration towards their river of origin that they left as smolts is from a navigational perspective one of the most remarkable migration in marine environment. In this field study we use new technology together with transplant release of salmon to gather new information on the orientation of homing salmon. Here we put forward the first results from the study. Due to changes in study time according to plans we just had few days available to analyse data and put forward in paper to be presented the ICES annual science conference in 2009. This means that we just touched the surface of the data sampled and that together with expected further recapture of tagged salmon, is giving us reason to look forward to exciting work on further analysing and representing of the data.

The tagging was planned to be carried out in mid summer 2009 but situation came up that could not be foreseen that delayed manufacturing of the DST magnetic for the study. When DSTs were available, salmon were tagged and released right away. Due to the delay of tagging and therefore correspondingly the total recaptures. The results discussed in this paper do not manage to look into all those matters that the study as whole will give information on. The possible use of magnetic recordings as geolocation reference will just briefly be revealed in this paper, but will be analysed further later. An important part of that work includes post-calibration of geomagnetic parameters that will be carried out in facilities in Norway. That will give us the opportunity to look all the measurements as “absolute” values, e.g. in nanotesla (nT). Based on the experienced gained from that work and parallel work, it will be possible to improve the DST magnetic by including the calculations needed for absolute values into the DSTs onboard functions and into the DST software used for retrieving and handling data. Absolute geomagnetic data are believed to be important additional geological reference for long migrating species. Addition that in some instances will when added to data on temperature from the trail of the fish versus temperature distribution and fish depth from the migration versus bottom topography give the extra information that enables to delimit the area of migration.

This paper focus on the possible use of geomagnetic data to analyse the migration behaviour of the salmon. We use that data in conjunction with paired data from other measurements of the salmon DSTs. To some extend we also refer to documented general trends in environment and salmon behaviour in the study area or elsewhere that can be of use in our attempt to explain the nature and underlying factors of the behaviour recorded in the study.

Material and methods

Study area, tagging and releases

Figure 1 shows the study area, the sea off W-Iceland, including the release sites and the estuary of River Hafnara in Borgarfjord W-Iceland. Tagging was carried out in the evening of 19th of August 2009 when 9 salmon (grilse) were tagged with DST magnetic from Star-Oddi (Table 1). These fish were from school of homing salmon that were caught in trap facility when entering their home water after approximately 1 year in sea. At tagging the fork length and weight of salmon were measured. DSTs were fastened externally adjacent to the dorsal fin by modified Carlin method using stainless steel wire and holding plastic plates.

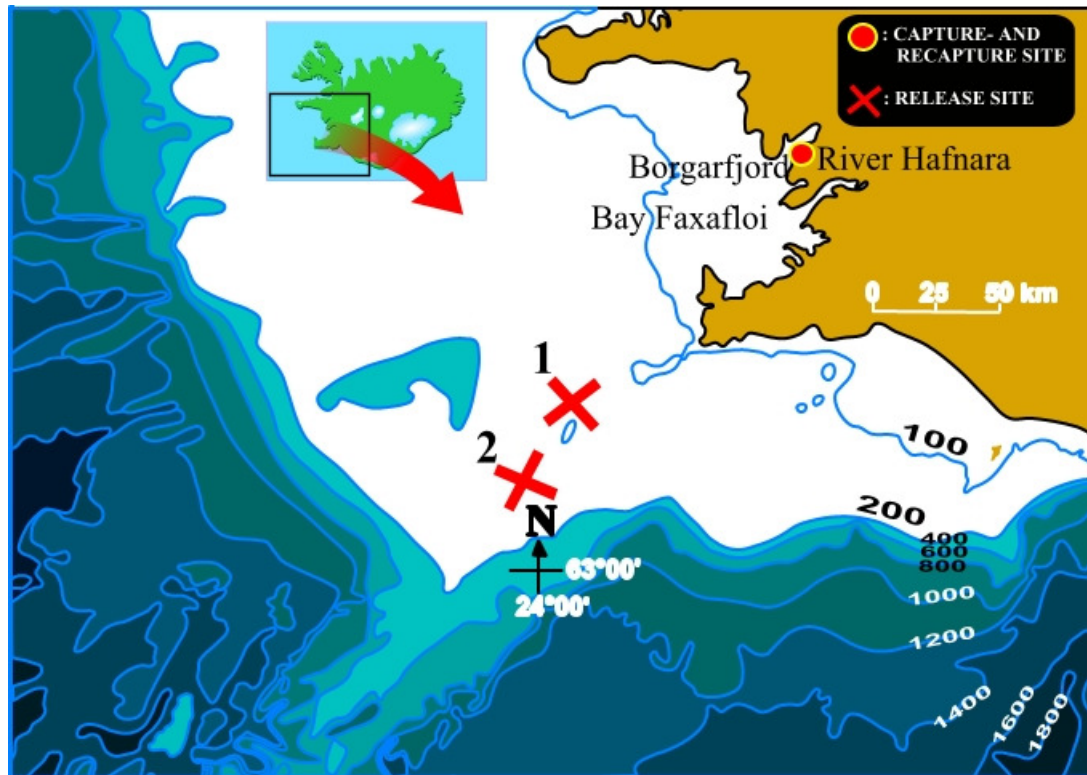


Fig. 1. Map of the coast of SW- Iceland, showing the area that the DST tagged Atlantic salmon migrated through. Locations are shown for the release sites (X) and the capture- and recapture site (circle) River Hafnara that runs into Borgarfjörður. Water depth intervals are shown by bottom depth isolines (100m, 200m etc.).

Following tagging 19th of August 2009 the salmon were transferred for few hours in seawater, first in a tank on a truck and then in tanks onboard a vessel. Following the transferring to off shore area the fish were released in two groups in 20 August within the time interval 4:00 – 5:50 (Table 1). By this transplanting setup it was possible to map the sea migration behaviour of salmon within homing phase by recording their behaviour and the corresponding environment experienced at given time while they found their way back to their home river.

Table 1. Information on sites of capture and release are listed and information on corresponding recapture rate the first week following release.

Capture site		Release sites			Number	Recapture rates	
Capture- and recapture site (tagging site/ home river)	Position	Position	Bottom depth (m)	Shortest way to shore (Reykjanes peninsula) (km)	Shortest way to home river (capture site) (km)	Number of DST tagged salmon	Total ¹⁾ recapture rate (%)
River Hafnara	64°27,6' N 21°59,1' V	63°37,4' N 23°39,8' V	180	52	123	4	50
River Hafnara	64°27,6' N 21°59,1' V	63°21,4' N 24°06,0' V	180	83	165	5	

¹⁾The recapture rates are not final as the paper is made shortly after the study started so it reasonable that more of the DST equipped salmon will be recaptured

Tag types and programming

The DSTs used were of new type that has being developed and manufactured by Star-Oddi (DST magnetic). The development has been carried out in co-operation with the Institute of Marine Research in Norway and the first results from laboratory tests have been described (Stockhausen and Gudbjornsson 2009). The new tag is a magnetic recording device, a tag with build in eight sensors. It measures the earth's magnetic field (in 3 axis) and the corresponding information on fish depth (0-800m measuring range) and the fish position, both pitch and roll (in 3 axis) as well as recording the sea temperature. The detailed

description of the DST magnetic function and technical specification is listed on Star-Oddi web site (<http://www.star-oddi.com/>). The DST magnetic used has memory storing roughly 17 thousand paired measurements. DSTs were programmed to optimize the use of the memory. The DSTs of the two fish recaptured, recorded at 30 second intervals their migration from release to home estuary, a travel that took them roughly 4 days to finish.

Comparative environmental data

Hydrographical data were sampled continuously during the transport to release site for comparison. For further data analysis additional hydrographical data from outer areas will be received from the Marine Research Institute in Iceland and from satellite measurements of both sea surface temperature (SST) and International Geomagnetic Reference Field (IGRF). Tidal stream data and data on weather (wind) and sea conditions (waves) will also be received and used for comparison, e.g. in relation to DSTs data on the depth of the migrating salmon and the geomagnetic values recorded during their homing. Although we do not have change here to analyse the possible use of the geomagnetic factors sampled for geolocation, e.g. in relation to SST. It is of interest to show the variance found among some of the geomagnetic field values for the study area that itself span only fraction of the area that the total sea migration of salmon includes at average (Table 2).

Table 2. Geomagnetic field values from sites of release and capture to give insight into the variation of geomagnetic field in the study area. The data is derived from database operated by NOAA.

Geomagnetic field values 20 August 2009 (from NOAA database)

Capture- and release site	Declination - West + East	Inclination + Down - Up	Horizontal intensity	North component + North - South	East component + East - West	Vertical component + Down - Up	Total field
Estuary of River Hafnara (capture site)	-16°15'	75°44'	12,938.4 nT	12,421.1 nT	-3621.9 nT	50,852.1 nT	52,472.3 nT
Release site 1 (closer to shore)	-16°45'	75°20'	13,274.4 nT	12,711.5 nT	-3824.7 nT	50,711.8 nT	52,420.4 nT
Release site 2 (off shore)	-16°51'	75°12'	13,385.5 nT	12,810.9 nT	-3879.6 nT	50,660.3 nT	52,398.8 nT

Data handling

In this paper the DSTs data handling is based on two salmon that migrated just in time, i.e. in order for this paper to be prepared for the annual conference of ICES. Due to two recaptures it was though possible to check whether obvious trends were found and such examples are shown, but large part of the data presented is given on individual basis.

Results and discussion

Recaptures

Salmon of sizes ranging between 55.5 – 72.5 cm in fork length and 1830 - 3435 g in weight were tagged. Of the 9 fish released at the two sites, two fish from the release site closer to the home river have being recaptured (Table 1). Transplant release was used as we knew based on great experience of such setup in both coastal and oceanic waters that it would be good way to receive detailed information on homing behaviour of salmon in sea in short time (Sturlaugsson 1995 and Sturlaugsson and Thorisson 1997, Sturlaugsson unpublished). Based on results from these earlier migration studies including transplants of salmon in oceanic and coastal waters off W-Iceland, additional recaptures are expected. Both the salmon that have been recaptured returned DSTs that gave roughly 12 thousand recordings of paired data, i.e. on geomagnetic vectors, fish depth (pressure) and position (pitch and roll) and on temperature.

Migration speed

The overall mean migration speed of the two recaptured salmon was 1.2 km/hour. Based on the time between the release of the salmon until they entered their home estuary.

Migration depth - Circadian rhythm

In relation to the depth it was also interesting to see how similar the depth distribution was for both these fish during their homing. Figure 2 shows that the overall depth preference was highly pelagic as was expected according to earlier DST studies on salmon (Sturlaugsson 1995; Sturlaugsson and Thorisson 1997).

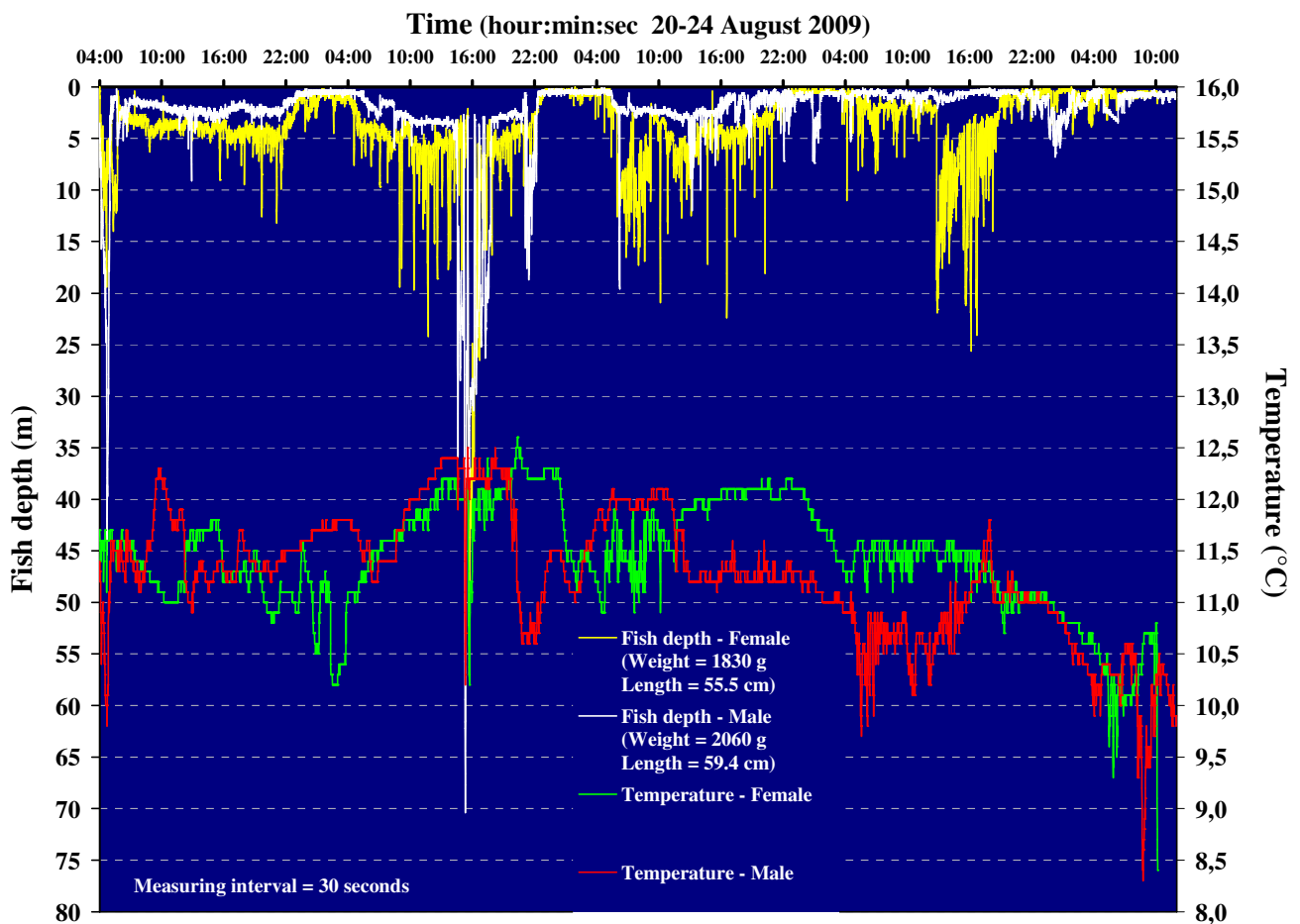


Fig. 2. Depth distribution of 2 homing salmon in coastal waters in the area SW off Iceland and corresponding temperature. The profiles range over area in South from off Reykjanes peninsula near Reykjanes ridge, into Bay of Faxafloi and finally in North into Borgarfjord and the estuary of River Hafnara. Size of the salmon and their sex are given.

When observing the depth pattern for these two salmon it is obvious that there is highly significant link between light condition and the overall depth that they prefer. This is shown by the high tendency of migrating just below the surface when sun is below the horizon, i.e. during light condition of dusk/dawn and darkness, that on daily basis ranged in time from close to ten in the evening towards six in the morning (Fig. 3.).

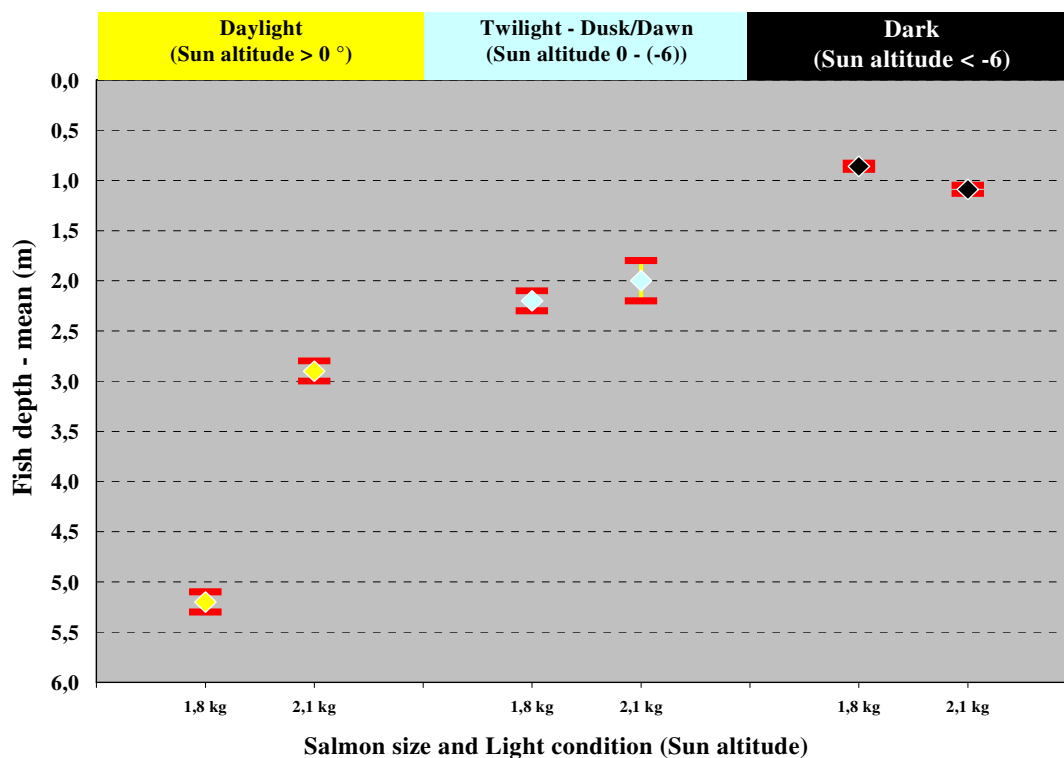


Fig. 3. Mean values for fish depth along with 95% confidence limits for two salmon during their homing migration 20-24 of August 2009 in relation to light conditions. The light conditions are given and the corresponding altitude of the sun. Means of each fish is listed with the size of the fish.

When preparing this paper we did not have time to check on the possible relationship between the depth patterns (steady depth; rapid depth changes etc) and the corresponding heading recorded at same time by the DST tagged salmon. That will be interesting task not the least when more fish have being recaptured from the releases. Such work will include a check up on the diving pattern that occurs when the sun is going below the horizon and via versa as well as the diving of salmon that are often started when they encounter rapid environmental changes during homing migration (rapid changes in sea temperature, salinity, etc). Those diving patterns were also shown in earlier DSTs studies on homing salmon in Icelandic waters (Sturlaugsson 1995; Sturlaugsson and Thorisson 1997 and Sturlaugsson unpublished). But due to the geomagnetic data sampled here we have new possibilities to examine the underlying mechanism.

The overall migration strategy of homing salmon – summing up the geomagnetic directional recordings

The data sampled on geomagnetic field gives many interesting changes to check on the nature of salmon migration behaviour. The use of the geomagnetic compass data in relation to other data sampled such on fish depth and sea temperature is especially interesting. One thing there is to use the overall changes in heading e.g. on daily basis as done here to get the main progress in the directional horizontal distribution of salmon during the migration (Fig. 4) Such simplifying of the directional data as compiling data into 45° directional sectors as done here can by itself point visually towards migration patterns worthwhile to check on further. But at same time such compilation of 45°sectors can also oversimplify things as when the directional values are clustered close to outer limits of these sectors, so maybe such use of sectors would be better off by using 22.5°sectors. Here we had example of such clustering for part of the geomagnetic directional data that fell into the East sector, as it were close to the N-East sector. Here it is also necessary to remember that we are dealing with geomagnetic compass data, that in the given study area involves declination of 16-17° compared to absolute compass values. So in order to get the absolute compass value we have to take 16-17° from the recorded geocompass value. From the proportional compass

directional data represented by the directional sectors in Figure 4. We can visually verify that the directional data from the salmon migration does not indicate that throughout the total migration the fish had more or less fixed compass heading towards the home river or the fjord it runs into (Borgarfjord). So the directional information sampled during the given homing migration does not support that the migration from offshore area returns the salmon directly to inshore area very close to the estuary of their home river. At the same time the orientation trends from that migration, indicate for the latter part of that journey that the fish overall directional pattern is in broad aspect reflecting migration along shores better for latter part of their spawning migration, than direct heading from release site to the home river. The increased heading variation in the latter part of the migration discussed in next section does in fact point towards the same conclusion.

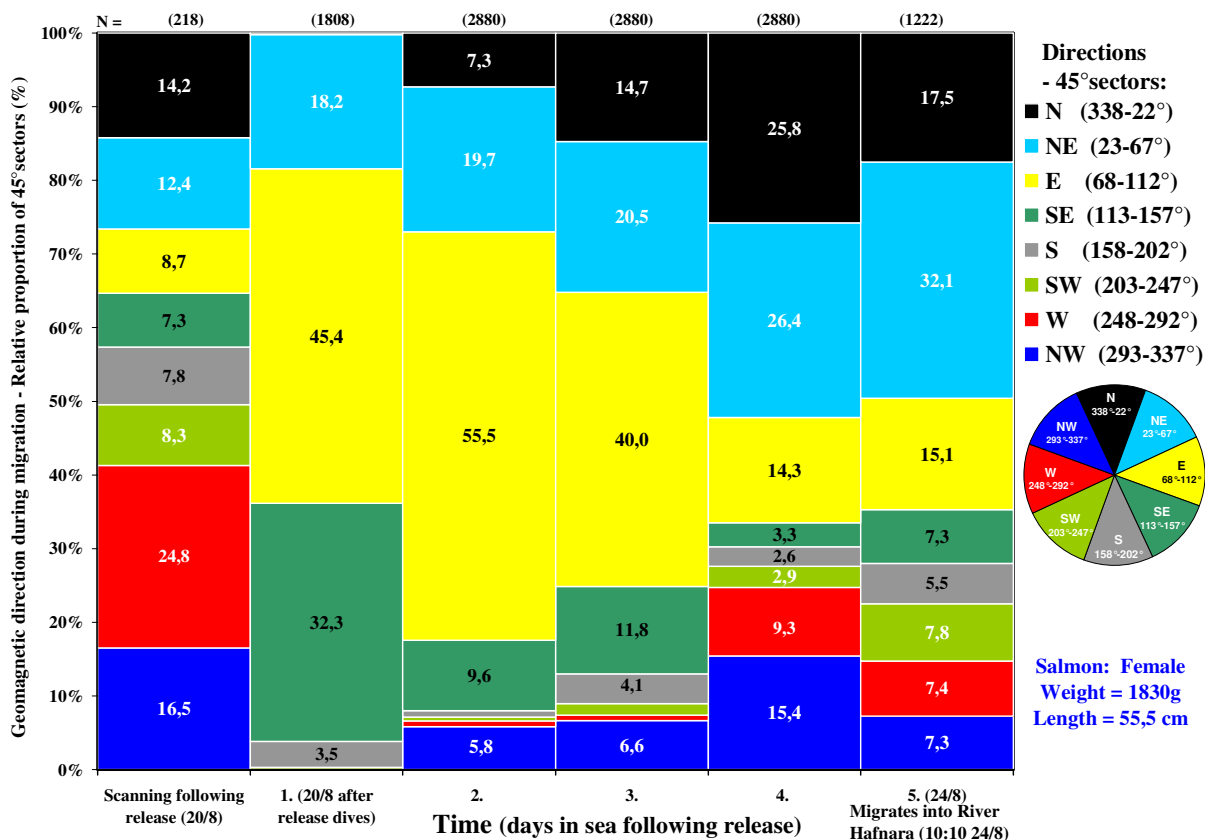


Fig. 4. Geomagnetic values presented as 45° geomagnetic compass sectors throughout migration of salmon in sea from release 20 August until entering home river 24th of August. The time that the salmon spent within each directional sectors each day is presented as relative proportion (%) of the total recordings that day. Classification of sectors are shown beside their legend. Number of total observations for each day of the migration as well as for the scanning period in the start are shown at the top of these sections. Size and sex of the fish is shown.

Due to effects of the transplant release in the very beginning of the migration, the scanning part in the very beginning of the migration is put forward separately in figure 4. At the same time the presentation of exactly that part shows us how seeking the salmon is in its movements at first. This gives the opportunity to put forward the assumption that after transplant the salmon use horizontal scanning along with vertical scanning to fulfil its need for oriental cues that enables it to make the navigational decision. In next sections we will look further into how the geomagnetic compass data reflects different migration behaviour.

Orientating behaviour in beginning of homing migration (following release)

– The vertical and horizontal scanning for orientation cues.

The DST tagged salmon discussed here showed migration pattern the first 1–2 hours following the release, that was different to what followed. Both the salmon diving pattern as well as large directional variation in relation to their horizontal movements. Based on numerous homing studies where DST tagged salmon were transferred to various circumstances in sea, the diving pattern in beginning of migration is known to play role when the salmon tunes their orientation in unfamiliar environment (Sturlaugsson 1995; Sturlaugsson and Thorisson 1997; Sturlaugsson and Gudbjornsson 1997). This ability to navigate was examined further when first DST compass tags (measuring geomagnetic in 2 axis) from Star-Oddi were used to study homing of salmon in sea off W-Iceland in 2006 along with use of DST-pitch and roll and DST with salinity sensor (Sturlaugsson unpublished). The findings here shows the same pattern, i.e. the transferred salmon are following release not simply scanning vertical layers by swimming up and down in beginning of their home migration. As the horizontal movements shows pattern that we conclude is of similar nature as the vertical scanning behaviour, i.e. standing for scanning of orientation cues to use for navigation (Fig. 5).

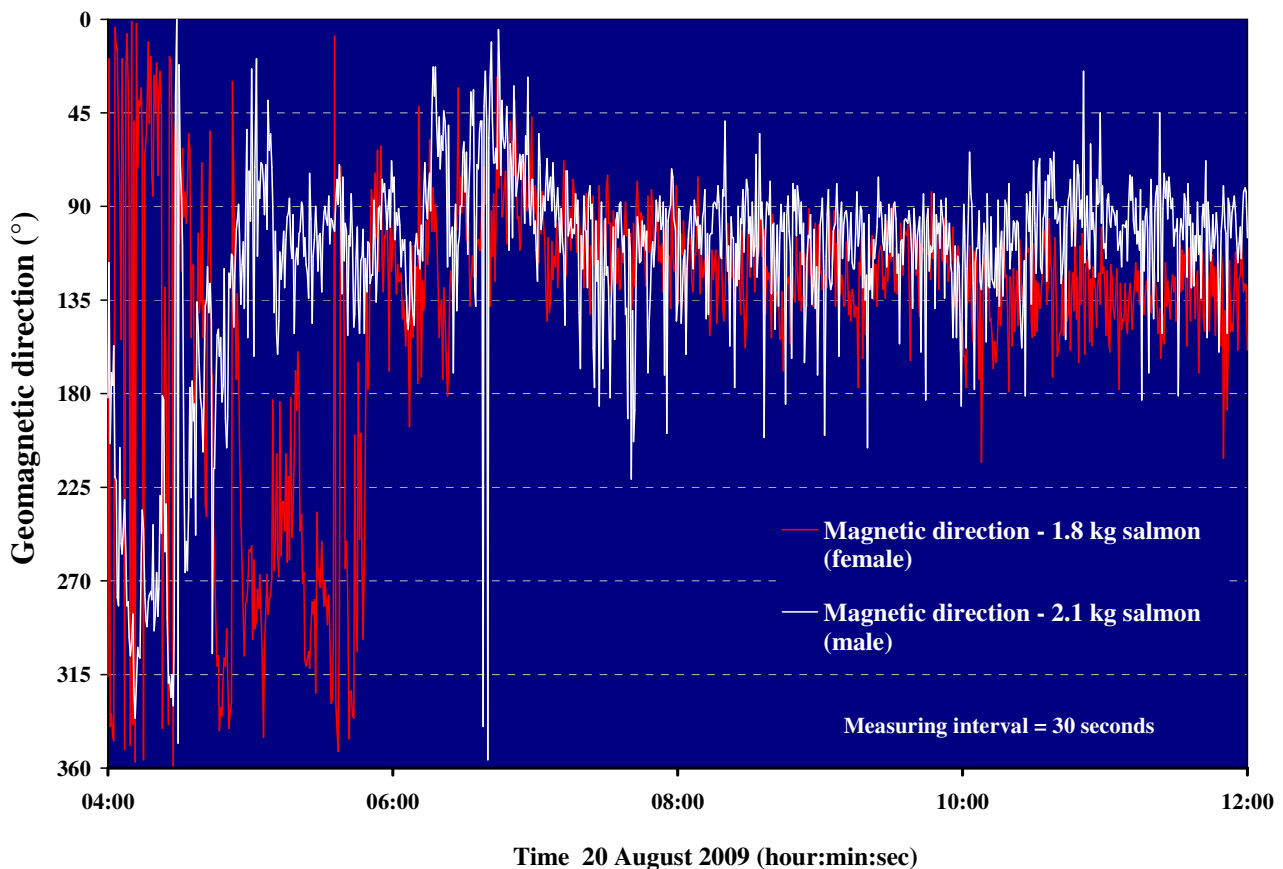


Fig. 5. The geomagnetic compass direction recorded in the beginning of migration of 2 homing salmon SW off Iceland.

In figure 5 the profiles presenting the geocompass recordings shows well the highly variable movements of salmon during the first 1- 2 hours of the salmon movements following release. Following that they start both relatively steady course in similar direction. In figure 6, is shown in more detail this variance of the salmon migration heading and in figure 7 the horizontal directional variance is shown for the same period of the day one day later for comparison. Then this variance is much less. But in both instances the main pattern of variance is though a row of values where the variance shifts from being clockwise to counterclockwise. That main pattern by itself shows that the fish is relatively sure where it is heading. Although representing the migration with one way or another, the directional

variation shown in figure 6 and 7 could partly been a result from other reason than active directional movements of the salmon. Such influencing factors can be derived from the fish itself or from environmental changes confronted during the migration as difference in the directional variations could reflect variations in currents, topography of shores and bottom etc.

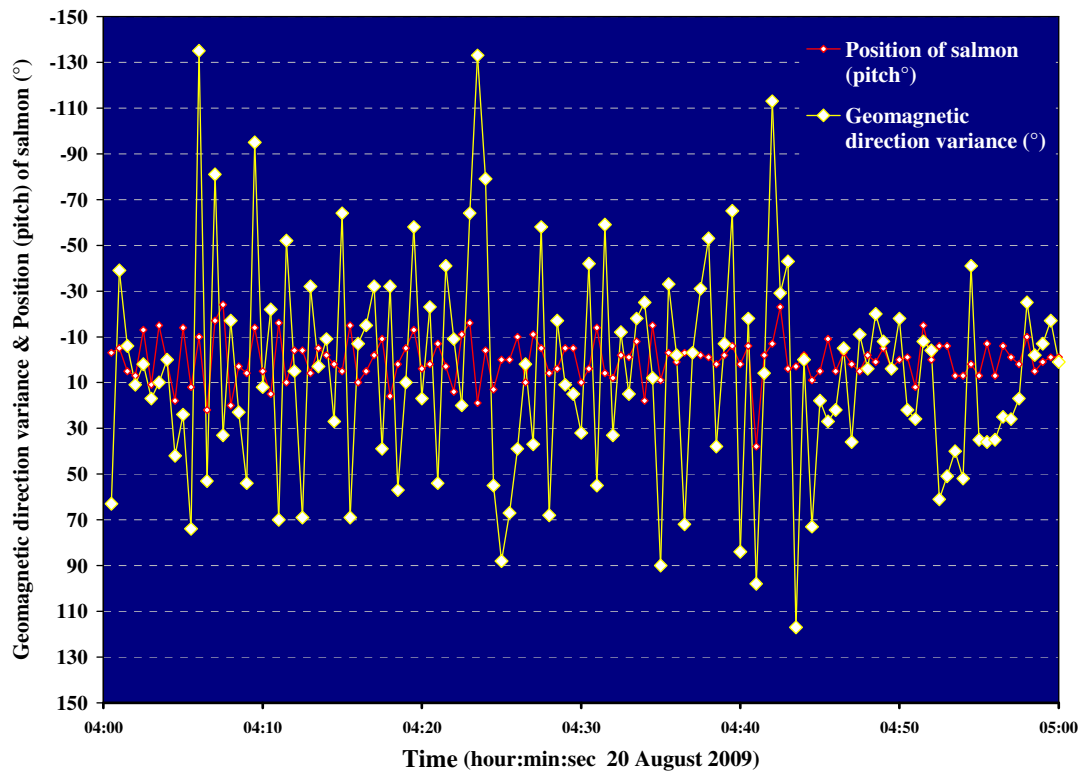


Fig. 6. The geomagnetic direction variance between adjacent recordings of DST of 1,8 kg salmon in the beginning of the migration following release. The pitch positioning recordings are shown for comparison.

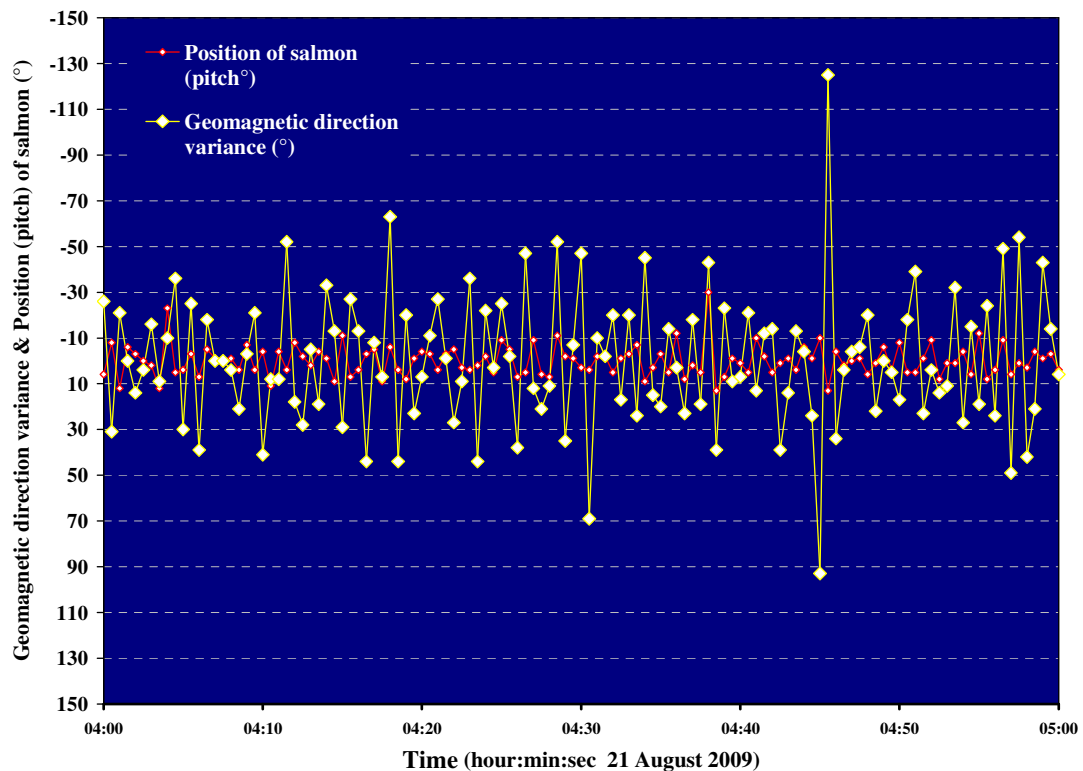


Fig. 7. The geomagnetic direction variance between adjacent recordings of DST of 1,8 kg salmon during second day of homing migration following release. The pitch positioning recordings are shown for comparison.

The third possibility is an inbuilt disturbance “noise” from the tag itself towards the recordings, but that explanation is not of concern as significant measurement value effect, according to testing of prototypes and improvements following that (Stockhausen and Gudbjornsson). When looking at the fish as possible source of recorded directional variation it could to some extent be derived from the swimming activity of the fish itself although the tag is located in the mid fish body where the movement is little. Although such possible influence would not be enough to change the overall pattern of recordings it is necessary to test the geomagnetic directional recordings in monotone environment as in river in order to get comparative data from fixed conditions. In this context it would also be interesting to see if DST magnetic tag placed on the tail or close to it could give useful estimation of swimming speed that could then be used to study activity within different periods of fish migration.

In next section we will look further into how we can use the directional variance to learn more about the homing migration of salmon in sea.

Geomagnetic recordings reveals difference in salmon orientation behaviour in offshore area versus inshore area

When working on the data from the two salmon from the first recaptures we looked especially on how variable the heading of the migrating homing salmon was, as reflected by the geomagnetic recordings. Due to the fact that the heading data is sampled in range from 0 to 360° then special data handling have to be done to get all the variation between adjacent measurements (recordings) in same format. With reference to temperature data from sea surface layers sampled during the vessel cruise when transferring the salmon to the offshore release sites and with reference to other data including the temperature data onboard the fish DST. It is possible to see that the salmon discussed here had on 3rd day moved from the offshore area into the inshore area (inner coastal area), i.e. they entered the Bay of Faxafloi (Figure 1). When the salmon enters the inshore area their swimming behaviour changed according to the geomagnetic values recorded onboard the DSTs. That changes reflected that the salmon horizontal movements became less direct compared to the offshore migration in beginning of their homing migration (Fig. 8).

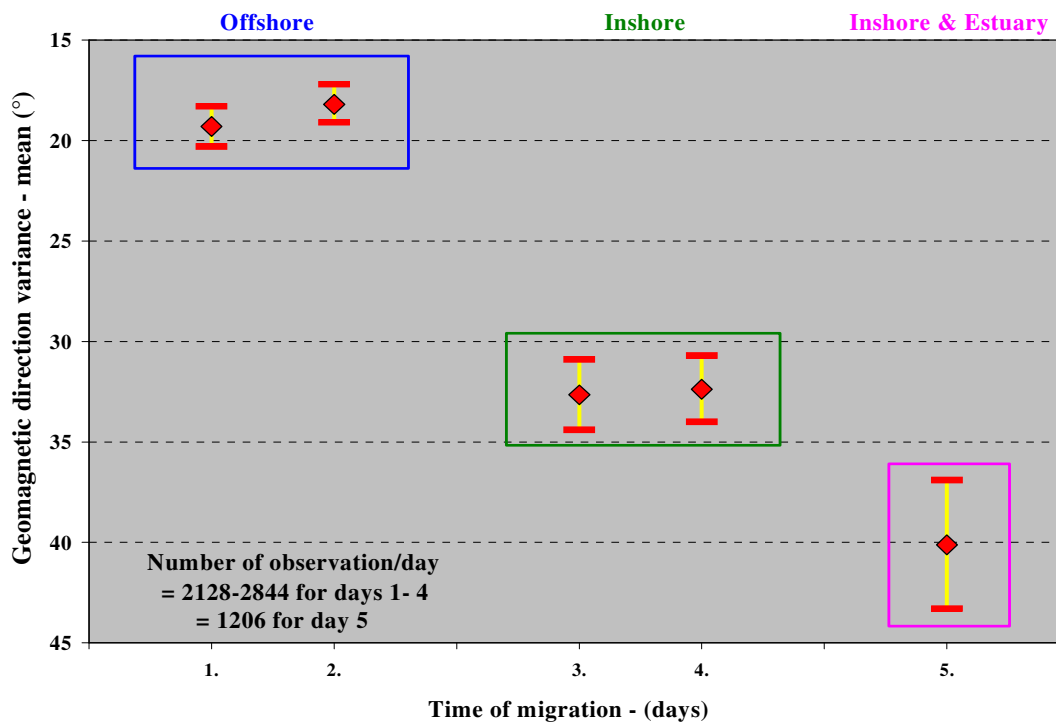


Fig. 8. The geomagnetic direction variance at average between adjacent recordings of DST of 1,8 kg salmon during the homing migration following release until it migrated into the home river. The mean values along with 95% confidence limits are given for the days of the migration (scanning phase following release the 1. day is excluded). The estimated approximate area migrated trough area shown.

This difference between offshore and nearshore area is clearly shown in figure 8. By comparing the mean variation of the fish heading based on the geomagnetic directions recorded and the corresponding confidence limits. The difference is highly significant which underlines the overall changes in swimming behaviour. We conclude that our data is for the first time giving the possibility to discriminate the different migration behaviour of Atlantic salmon in detailed manner with directional references for same fish in both offshore waters and inshore waters. The changes that we observed between area we believe are predominately driven by behavioural changes of the salmon corresponding to increased use of olfactory for orientation in inshore area due to the effort that is carried out to discriminate the olfactory cues. If the landward migration would be fixed on the mouth of the fjord or the river mouth itself and be functional without the fish using the olfactory sense then no significant changes would occur in migration behaviour between area.. The result of this migration study is showing in clear way that the changes occur. Then it is the question what underlying factors are influencing these changes. Firstly it is reasonable to believe that the salmon starts at least partly to use additional orientation skills in the inner coastal area. The results would be expected to reflect that the salmon is already in inner coastal area taking more advantage of the olfactory sense to discriminate olfactory cues in bays, fjords and along the coast. In relation to this it is worth mentioning that at given site short distance (ca 30 km) outward from the river used for capture and re-capture in this study (River Hafnara) fishing on homing salmon was carried out in earlier years in 30 m long net laid out from shore. In this single net fish originated from all over Iceland were captured (Sturlaugsson 2000). That along with extreme high capture rate of both 1 sea winter and 2 sea winter old salmon at that fishing site during the best summers (thousands of salmon) in just one net. Is showing how closely to the shore the salmon is migrating when homing. Such shoreline orientation points directly to the use of olfactory cues by the salmon while navigating the last part of the sea migration when inshore on their way towards their home river. Based on our findings we believe that shoreline orientation is important part of salmon orientation during the end of the sea migration, i.e. once the shore has been approached.

As mentioned the re-calibration of the DST data sampled on the magnetic field as the salmon migrated through it will give us interesting absolute values to work with. In figure 9.

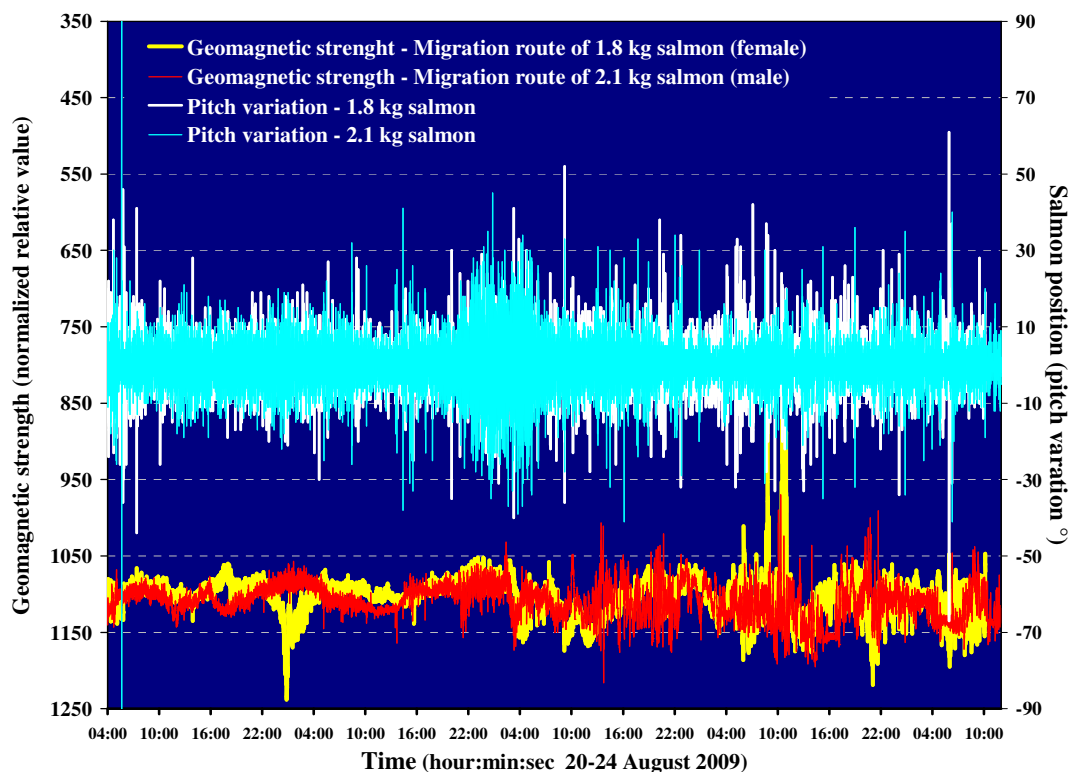


Fig. 9. Measured values for geomagnetic axis during migration of 2 homing salmon in coastal waters in the area SW off Iceland and corresponding position of those salmon measured parallel as pitch ($^{\circ}$).

measurements on the strength of one of the geomagnetic axis measured in the study during the spawning migration of salmon, are shown as profiles for both the fish. For comparison the position of these salmon is given parallel as pitch values ($^{\circ}$). In figure 9, one of the salmon (2.1 kg male) is recording two sharp variances. That could reflect local magnetic anomaly even one that is already documented (Jonsson, G. and Kristjansson, L. 2002). These two variations could possibly be anomaly at the Reykjanes ridge during the first day and another experienced off Kjalarnes 24 hours before entering the home estuary. In addition to such speculations it is notable that although the two fish went not the same route from release to home river the geomagnetic recordings are in main terms giving similar values as expected, something that will be interesting to look closer into after re-calibration of that data, not the least the corresponding transformed absolute values.

The salmon are very focused on homing during their spawning migration in sea as is reflected in the fact that they have usually stopped feeding during that phase although inactive feeding have been observed (Sturlaugsson 1995 and Sturlaugsson 2000). Because of this the main pattern of their migration during this phase observed by use of DST gives us detailed information on how the salmon behave towards the environment migrated through when homing, as well as giving us information on many of the landmarks that the salmon use during his migration along that route.

The new information on the orientation behaviour received here are important addition to the detailed information we have been sampling on salmon homing behaviour since we started using DSTs for that purpose in 1993. (Sturlaugsson 1995; Sturlaugsson & Thorisson 1997, Sturlaugsson unpublished). With reference to that foundation of detailed information on homing salmon from the mentioned DST studies and the new important additional information received here. It is appropriate based on the new migration patterns found to suggest classification of the spawning migration of salmon in sea into three phases. The first part would be the off-shore part that includes the migration toward shores from the ocean area into the outer shelf (coastal) area. This first part is characterized by migration behaviour that directionally is relatively stable. The second part of the spawning migration in sea that follows involves migration of the salmon in inshore area both inner coastal areas as well as into the innermost area along shores. In this area the movements of salmon are less directional. This is partly explained by their increasing use of olfactory sense that studies has shown that involves active discrimination of such cues (Westerberg 1982; Døving, *et al.* 1985). The second explanation for increased directional variation in the migration behaviour during this second part of the spawning migration in sea is at least partly involved. Here we are referring to the more diverse environment the salmon confront in these inner sea area because of increased complexity of sea layers due to variable currents, temperature, salinity etc, as well as diverse topography of bottom and shorelines. This increased diversity is something that the salmon have to react towards during its migration both without any relation to orientation matters as well as directly due to the influence of these factors on their orientation cues.

Important progress has been made the last years in studies on salmon migration in sea, using DST technology to sample information from the vast area of the N-Atlantic. Salmon and Trout Research has in later years in addition to earlier homing studies of Sturlaugsson carried out DST taggings on salmon kelts and smolts in order to sample detailed information from the whole sea migration of salmon to investigate their temporal and spatial distribution. Those studies gave in 2005 both for kelts and smolts the first depth data sampled throughout the whole sea migration of Atlantic salmon as well as data on temperature sampled parallel. Giving total recordings on the behaviour and environment of salmon from their home estuary to the feeding grounds in the ocean and on their way back home to spawn. This was followed later with additional recaptures were additional parameters (salinity) were also recorded for the total sea round trip of salmon. When referring to DST studies on Atlantic salmon it is also appropriate to mention the extensive Nordic co-operation that was carried out for years in order to gather information on salmon

migration, both in the Baltic (Karlsson *et al.* 1996 and 1999; Westerberg *et al.* 1999) and in the N-Atlantic (Sturlaugsson 2003; Holm *et al.* 2005).

It is always both useful and exciting when new research approach can add some piece of information that enables to understand better the mysterious and most often long homing migration of salmon from their feeding area in the oceanic area to their home river to spawn. The DST magnetic is an example of research equipment that has already given us new interesting recordings on salmon spawning migration that are giving a kind of panorama view from offshore area to inshore area. The new information on the different orientation behaviour of the salmon brings us one step closer to the understanding of the salmon navigation. Further progress will be done by taking into consideration the new information that researchers have in last years brought forward on various animal migration and the underlying mechanism (Dittman *et al.* 1996; Wiltschko & Wiltschko 2003; Lohmann *et al.* 2007 and 2008) One of the new interesting hypothesis is that salmon as well as turtles and other long migrating animals are using geomagnetic fields as maps to orient along through vast distances in the ocean.

Concluding remarks

The study enabled to give new insight into the orientation behaviour of salmon. This first experience with three dimensional magnetic data storage tags in salmon studies has given valuable information on orientation of salmon and other aspects of their migration behaviour.

Acknowledgments

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