DST-compass: the new research tool from Star-Oddi

DST-compass measures and stores information on compass directions (earth magnetic field) in addition to temperature and fish depth (pressure). This tag opens up interesting possibilities to access directions in movements of aquatic animals. The tag can cast extra light on various parts of their activity below the surface and how they orientate and navigate during migration. The directional information reflects in an educating way how the animals in given areas position themselves in relation to environmental circumstances e.g. light and tidal condition. Such extra information can increase our understanding on how these animals utilize area studied for feeding, resting etc. One of the major inspiration for the development of DST-compass was the magic of the salmon precise navigation when migrating to their home rivers to spawn after hundreds - thousands of kilometres migration in the ocean during feeding. It is appropriate that the first study using these tags focuses on salmon migration in sea. Here follows a summary from Sturlaugsson giving examples of first results from use of DST-compass in that study. Together with another section summing up the salmon studies using DSTs that lead to that work.

Orientation and navigation of salmon in sea studied by use of DSTs – Preliminary data

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Orientation and navigation of salmon in sea

In 2006 DST-Compass was used for the first time by Salmon and Trout Research in Iceland and collaborating partners. The aim was to study orientation and navigation of salmon at sea. Sturlaugsson is leading this work at Salmon and Trout Research (Laxfiskar in Icelandic). The very beginning of this work goes way back and that history of salmon research in sea with DSTs is revealed here in the end.

In 2006 the DST-compass were used in Icelandic waters to record the homing behaviour of Atlantic salmon and the corresponding environment during their sea journey. These studies were continued in 2007 and in addition salmon kelts were tagged prior to sea migration in order to record the earth magnetic fields (compass directions) for the total sea migration of salmon (Figure 1).

Figure 1. Small salmon kelt female tagged with DSTcompass in River Botnsa in spring 2007

During studies using DST-compass, part of the salmon were double tagged with DSTs of different types enabling sampling of additional information on the fish body position parallel for comparison, using pitch and roll (DST-P&R) as well on the salinity (DST-CTD) during migration through fully saline sea to estuaries and rivers. The sampled information and data from other resources for comparison (e.g. on sun position and on horizontal and vertical distribution of sea temperature) enables new insight to the mechanism involved in orientation and navigation of salmon in the sea.

The analysis of the data from recovered DST-compass and other DSTs used in the double DST tagging are ongoing and have already given very interesting information on orientation patterns for salmon in sea and relevant behaviour with a sampling rate as frequent as 2 seconds for selected intervals. When salmon were homing in coastal waters they were shown to swim at considerably steady course. At the end of this phase of their sea migration when entering fjords and shores the recorded direction patterns of the salmon got more complex (Figure 2).

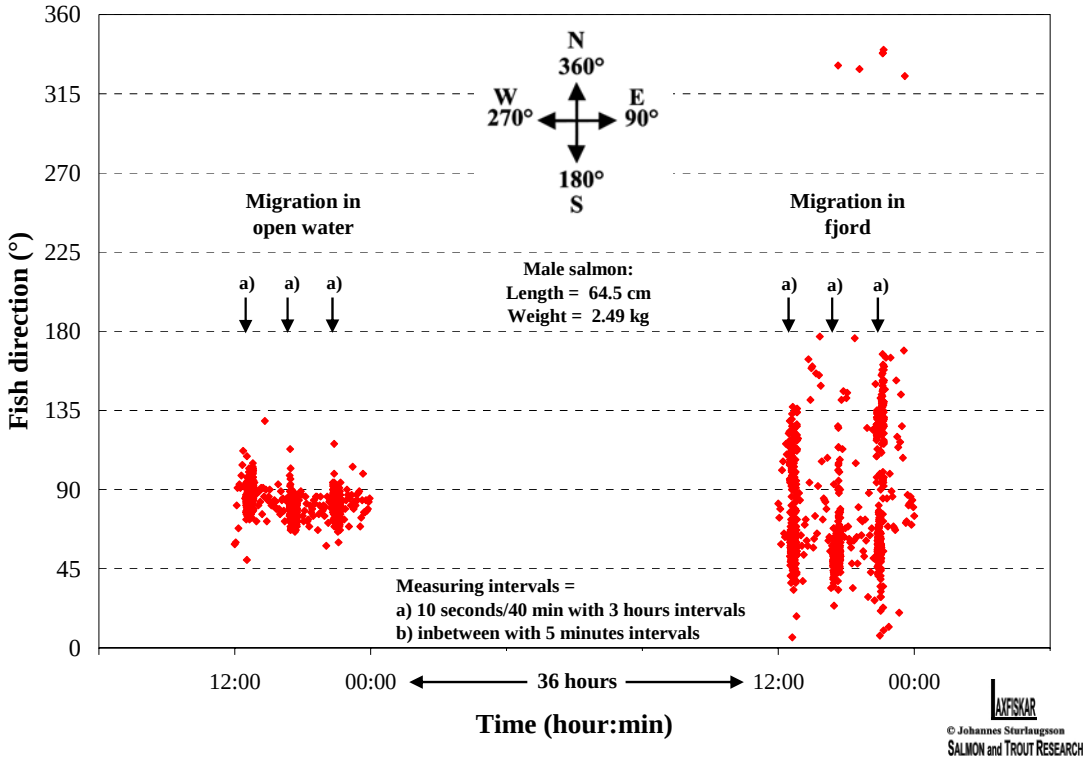

Figure 2. The direction of salmon during homing migration through surface layers recorded by DST-compass. Two measuring periods from the continuous recordings of the migration are shown. Both periods are lasting for 12 hours in relation to time of the day (12:00-00:00). The first period is while the salmon is still migrating through open water but the latter period is during migration in fjord as reflected by both the temperature and the salinity recorded separately by DST-CTD on the same fish. Recording intervals are two, 10 seconds reflected by dense cluster of measurements (240 recordings/40 minutes) and 5 minutes intervals. Depth recorded during these periods was ranging from surface down to 16 m depth. Directions are given and also size of the salmon observed.

The fact that salmon were shown to maintain a steady heading continuously for hours while swimming in open waters shows well their orientation skills. The more complex near-shore directional patterns in the salmon movements is now being analysed, to see what part of the behaviour can be linked to local environmental conditions (tidal movements, diurnal rhythms, home river discharge etc). Because off-shore orientation and near-shore orientation of salmon can differ e.g. in relation to

use of orientating cues, such directional comparison of the salmon migration behaviour between areas during homing is very interesting.

During the homing of salmon the studies showed examples of what could be called a vertical scanning of sea layers among the homing salmon down to hundreds of meters. In figure 3 there is given example of this behaviour from the surface layers. This behaviour has been reported before (Sturlaugsson 1995; Sturlaugsson and Thorisson 1997) but in ongoing studies it was possible to record how fast this happens in relation to body position of the salmon.

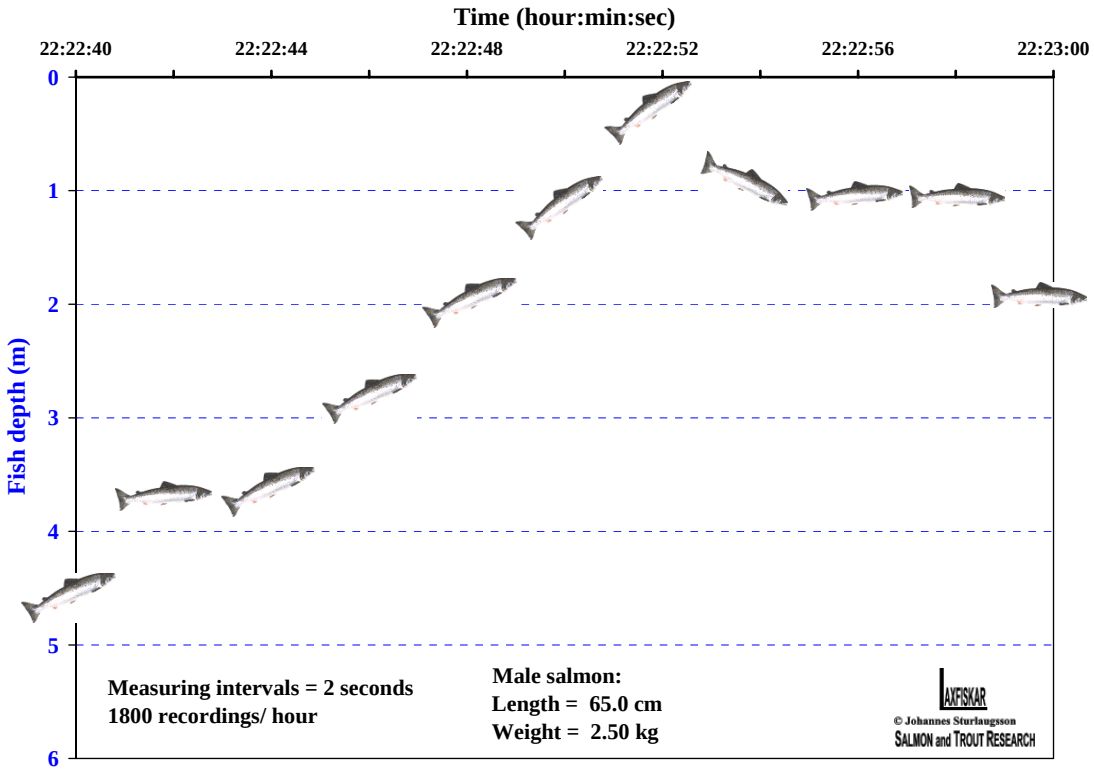

Figure 3. One "scanning" movement from a serie of such vertical movements of homing salmon. Recordings of salmon depth are shown taken with 2 second intervals by DST Pitch and Roll given as salmon symbol in relation to the pitch body position of the fish (°) shown by corresponding pitch (tilt) of the salmon symbol at given time. Size of salmon is given.

Directional data from DSTs on salmon migration through coastal and oceanic areas together with other sampled information on salmon behaviour data and corresponding environmental data is giving new possibilities to study orientation of salmon and the navigation mechanism involved. In next section the history of studies on salmon in sea using DSTs that lead to this point is revealed.

Salmon under surveillance in sea by DSTs

The salmon orientation and navigation study started in 2006 by Salmon and Trout Research can be tracked back to 1993 when Sturlaugsson started co-operation with Star-Oddi in developing DSTs and appropriate research setup to study salmon in sea. At that time, DST-compass was on the "wish-list", but first now over a decade later, it is a part of the DST product range at Star-Oddi. In the meantime, salmon studies in sea using DSTs have progressed and new types, sensors and tags have been

developed, that played important role in salmon research in sea during this period (Sturlaugsson and Gudbjornsson 1997).

Following the prototype phase in 1993, the first actual sampling on fish depth and corresponding temperature of salmon migrating in sea was carried out with DSTs in 1994 (Sturlaugsson 1995). That study showed already the pelagic characters and some of the diving patterns involved (down to 123 m depth) in the homing migration of salmon. This part of the sea migration was further studied in 1995 by Sturlaugsson and Thorisson (1996) e.g. by using higher sampling rate (90 second intervals in between) showing salmon diving down to 153 m depth. In 1996 the progress continued when the first DSTs equipped with salinity sensors were used to get additional information on coastal migration of salmon, also showing that their migrating speed was up to 4 km/hour (Sturlaugsson and Thorisson 1997). In the next following years further salmon studies in small scale were conducted by Sturlaugsson in Icelandic waters. Including successive mapping of homing behaviour of salmon transplanted 400 km from their home estuary (shortest way to shore 260 km), reflecting well the special navigational ability of salmon.

In addition to these Icelandic studies, Star-Oddi DSTs were used successfully to study homing salmon in the Baltic during 1995-1997 (Karlsson *et al.* 1996, 1999; Westerberg *et al.* 1999) and to study sea migration of salmon in the NE-Atlantic 2002-2004 by using special salmon trawl to capture salmon for DST tagging in oceanic areas (Sturlaugsson *et al.* 2003; Holm *et al.* 2006).

In 2005 there was major progress when Salmon and Trout Research recovered the first DSTs that stored continuous recordings for the whole sea migration (round trip) of Atlantic salmon on fish depth and corresponding temperature from the estuary to the feeding grounds in the oceanic areas and back into estuary again. This mapping of the total migration of the salmon in sea conducted by Sturlaugsson was based on tagging of both kelts (with DST centi and DST milli) and smolts (with DST micro) prior to sea migration. These first recorded round trips of salmon in sea included partly data recorded with high sampling rate, down to 1 minute for post-smolts and down to 30 seconds for recovered kelts, showing that vertical movements of salmon was sometimes fast. When the DST data was compared to sea surface temperature (SST) data from satellites and sea temperature data from surveys it was shown that the feeding migration of the DST tagged Icelandic salmon occurred in oceanic areas South and West off Iceland.

In 2006 further such data from the total sea migration of salmon emerged in studies carried out by Salmon and Trout Research with additional information from salinity measurements and examples of deeper dives than had been recorded in earlier studies, all the way down to 600 m depth. Same year Salmon and Trout Research used the first DST-compass tags in study on salmon migration carried out in co-operation with the Marine Research Institute, Star-Oddi, Nordlingur, river owners and Hakan Westerberg (Fiskeriverket, Sweden).

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