The Marine Migration & Swimming Depth of Sea Trout (*Salmo trutta L.*) in Icelandic Waters

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ABSTRACT

Information on the life history and migratory behaviour of sea trout (*Salmo trutta* L.) in Icelandic waters is scarce. This paper summarises the results of 11 years of detailed observations on the swimming depth and timing of marine residency of adult sea trout during their annual feeding migration in the sea. Over this period, 41 fish were fitted with data storage tags to monitor the timing of their marine migration and their movements in relation to swimming depth, ambient water temperature and, in three years, salinity. The typical sea migration period started in May-June and finished in July-September. The duration of the annual sea feeding migration period monitored for all 46 round-trips by fish aged from 4 – 11 years varied from 23-183 days for individual fish and averaged 59 days overall. In addition, one 12 year old fish was captured after 188 days at sea. The main sea residence period corresponded closely with the non-darkness period in this area from 20th May to 23rd July. Similar patterns of swimming behaviour during the period of sea residence were observed across all years: with swimming at depths at 0 – 5 metres for 72 – 93% of the time, at 5.1 – 10.0 metres for 6 – 25% of the time and at 10.1 – 15.0 metres for 0.4 – 2.2% of the time. Very limited time (an average of less than 0.5%) was spent at depths greater than 15 metres. The aggregated annual mean depth recorded from all fish ranged from 2.0 – 3.8 metres, confirming the pelagic nature of their feeding behaviour. Measurement of temperature and salinity indicated that the fish moved in close proximity to the coast, where lower salinities and higher temperatures occurred. A maximum depth recorded from any one fish was 70 metres. Some of the depth profiles for individual fish showed sudden rapid dives into deeper water and occasional fast upward movements from the bottom in shallow water close to the shoreline. A comparison of swimming depth in relation to fish length and maturity status showed no major variation in mean swimming depth between individual fish with regard to those parameters. Fastest recorded vertical movement of sea trout were 2.2 body length/sec.

***Keywords**:* sea trout; Iceland; sea migration; swimming depth; risk assessment: marine residence.

INTRODUCTION

The first study using Data Storage Tags (DSTs) to obtain a continuous record of the behaviour of sea trout during their feeding migrations in the sea was undertaken in 1995 (Sturlaugsson & Johannsson 1996). Since then, the same methodology was used by Sturlaugsson in various investigations to obtain a detailed record of swimming depth and related biological and environmental data in the coastal waters of South Iceland. This paper provides a summary of the results of those investigations over the period 1996-2011, on swimming depth, marine residence time and on the life history features of the tagged fish. The principal findings presented here are abstracted from the detailed analysis of the raw data on the swimming depth of individual sea trout between 1996–2008 requested by the Scottish Government for use in risk assessment models for future tidal power schemes to generate marine renewable energy in Scotland (Sturlaugsson, 2016).

METHOD & MATERIALS

STUDY AREA

The investigation was centred on two rivers, the Tungulaekur and Grenlaekur in South Iceland (Figure 1). This is an area where the sea trout is the most abundant salmonid and both rivers are noted for their strong runs of sea trout (Antonsson & Johannsson, 2012). The rivers are mainly spring-fed and discharge at a mean rate of about 2 m^3s^{-1} during the summer months. The Tungulaekur feeds into a large glacial river (the Skafta) with a mean discharge of 120 m^3s^{-1}, while the Grenlaekur shares a common estuary with the river Skafta. The coastline is unsheltered and has extensive areas of sand that extend well out into the sea from the shoreline.

Hydrographical data from the Marine Research Institute, Reykjavik (http://www.hafro.is) shows that there is a thermocline in this area that is approximately 20 m deep during the summer that extends 2–27 km from the shore. This coastal area is influenced by a massive input of fresh water from glacial rivers in the summer for several hundred kilometres along the coast. Consequently, it is probable that sea trout experience low salinities close to the shore without entering brackish estuarine waters to feed. There is some limited information on the prey species of sea feeding sea trout (Antonsson & Johansson, 2012; Sturlaugsson & Agustsson, 2012; Sturlaugsson, *unpublished data*). Sand eels are the predominant prey with herring and capelin becoming important when available. Smaller prey species, such as amphipods and polychaetes, also occur in the diet but are quantitatively less important.

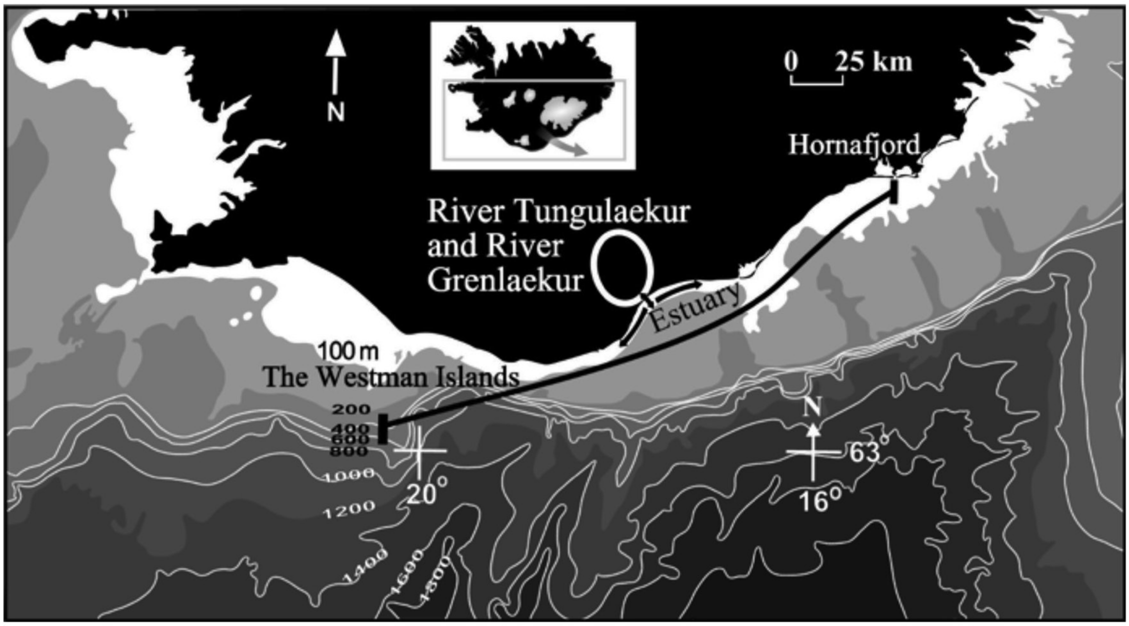

Figure 1. Map of the coast of South Iceland, showing the area that the DST tagged sea trout migrated through during the monitoring in 1996-2011. The white circle shows the area where the two home rivers of the monitored sea trout are located (Tungulaekur and Grenlaekur). Also marked is the estuary Veidios where River Grenlaekur enters the sea as well as River Skafta, the glacial river into which River Tungulaekur flows. Black arrows indicate the feeding area of the sea trout closest to the estuary. The black line stretching from Hornafjord to Westman Islands shows the coastal area used by foraging sea trout from the two rivers. These known outer limits of their distribution during sea migration are of approximately 160 km east and west of their home estuary, Veidios. The map also shows water depth intervals by bottom depth isolines (100 m, 200 m etc.). The waters are relatively shallow along the coast with water of depth 20 m or less extending 1-2 km out from shore.

SOURCE OF FISH

The adult sea trout monitored in this study were captured initially in the two rivers and generally tagged and released the same day. Most of the fish were caught by anglers in the spring prior to their annual seaward migration, although some were tagged and released on their spawning grounds in the autumn after being captured at night with a dip net. Since the behaviour of the fish could be influenced by differences in their life history features, the following biological details were obtained as an aid in identifying and interpreting any apparent aberrant or atypical behaviour exhibited by individual fish: a) length and weight at capture and recapture, b) sex (where possible), c) maturity status and d) smolt-age, sea-age and previous spawning history from scales samples taken at time of first tagging or recapture.

DATA STORAGE TAGS

The investigation used data storage tags (DSTs) manufactured by Star-Oddi (http://www.star-oddi.com/). The tags were pre-programmed to log information at different recording frequencies ranging from 5 seconds to 2 hours on the depth and ambient water temperature experienced by each fish throughout the duration of their residence in the sea during the 11 year period. Some tags were also equipped with salinity (conductivity) sensors in three of the years.

The programmed frequency of sampling for individual fish varied within and between years depending on tag type, tag memory and the specific aim of the annual sampling programme. The most detailed measurements (with the highest recording frequency) were collected over short periods during summer months, when recording intervals as frequent as every 5 – 10 seconds were used to obtain highly detailed information on vertical distribution and swimming movements between different depth layers. Table 1 gives the number of fish tagged in each year and the frequency of the uniform recording intervals throughout the sea migration period for a given year and the number of recordings obtained from that uniform sampling.

Although most of the DST tags were attached externally (modified Carlin method), a few were implanted into the peritoneal cavity. The manufacturers declared accuracy for the depth measurements of the tags was +/- 0.4% of the selected depth range – which was 50 m in all years. The accuracy for the temperature and salinity measurements was +/- 0.1^{0}C and +/- 1 psu respectively.

It should be noted that it was essential to recover each fish to retrieve the tag and access the stored data. This depended on their recapture during their subsequent return the rivers; either by anglers or on the spawning grounds. Consequently, not all the fish originally tagged were recovered.

Table 1. Overall mean swimming depth of sea trout in each year of the study period showing mean, SD and maximum recorded depth. The number of fish monitored in each year, the recording interval and the total number of uniform annual recordings for determining mean depth are also given.

Study Year	*Fish Depth (uniform measurements during sea migration period)*			*Fish monitored in year*	*Recording Interval & number of recordings in year*	
	Mean	*SD*	*Max*	*No.*	*Intervals*	*No.*
1996	2.6	2.73	46.5	14	1 hour	18,228
1997	3.4	2.60	21.5	10	2 hours	6,878
1998	3.3	2,41	17.0	5	2 hours	3,123
1999	3.8	2,59	26.9	7	30 min	19,676
2004	3.4	2.11	32.8	1	5 min	19,262
2006	2.5	2.57	45.2	2	1 hour	2,925
2007	2.5	1.97	13.4	2	2 hours	1,107
2008	2.6	3.25	38.3	3	30 min	7,476
2009	2.5	2.10	20.6	1	1 hour	2,024
2010	2.5	4.72	70.4	1	2 hours	2,190
2011	2.0	3.28	70.2	1	2 hours	2,259

RESULTS

Sturlaugsson (2016) provided comprehensive information on the temperature, salinity and depth profiles of individual fish in relation to their sexual maturity, size, different life history features and biological characteristics for different years. [Appendix Figure A/1 illustrates an example of the highly detailed nature of the information on depth, temperature and salinity retrieved from the DST from a single fish over one complete return migration between fresh water and the sea. Appendix Figure A/2 is an example of an occasional sudden rapid dive into deeper water obtained from high frequency recording intervals of 5-10 seconds.]

DATABASE

A total of 41 sea trout were tagged and monitored during their sea feeding migration periods. Of these, three fish made either 2 or 3 return visits between fresh water and the sea to spawn and/or over winter in the rivers. Some fish were subsequently recaptured, retagged and monitored for a second migration period. This gave continuous datasets for 47 completed marine migration periods: with a total of 85,149 separate recordings of individual fish depth and ambient water temperature at uniform recording intervals throughout the sea migration for any given year. In addition, monitoring the same parameters included 176,378 separate recordings from sub-sampling of the same tags at a more frequent measuring interval: providing a grand total of 261,527 separate recordings for the entire 11 year monitoring programme.

LIFE HISTORY FEATURES

The age of fish at tagging ranged from 4 – 10 years and their lengths ranged from 32-76 cm when captured and 47-81 cm when recaptured. Of these, 17 fish were immature 'maiden' fish and 24 had matured and spawned previously on 1-3 separate occasions before tagging. Of the 36 fish where sex could be determined when tagged or recaptured, 16 were females and 20 males. Life histories shown from scale reading established that the fish spent 2 – 5 years in fresh water before their first migration into the sea to feed and grow. They then made repeated annual return migrations between the river and the sea, with up to 8 separate sea migrations observed. Scale reading established that first spawning occurred after the second or, more commonly, the third return migration, with one example of four return migrations before first spawning. The total number of spawning occasions observed among monitored individuals ranged from 1 – 5 years. Sturlaugsson (2016) provides more detailed life history information for each individual fish. They broadly reflected the typical life history pattern of sea trout in the local area (Antonsson & Johannsson, 2012).

SEA RESIDENCE

The DST monitoring programme generated detailed information on the actual sea residence periods for adult fish; with resolution frequencies between entering the sea and returning to the river ranging from 5 minutes to 2 hours (Figure 2). Based on all 46 completed round trips for 1996 – 2010, the aggregated mean proportions of fish entering the sea to start their marine residence period were – 41.3% in May, 54.3% in June, 2.2% in July, and 2.2% % in August. Likewise, the monthly pattern of return to the river at the end of the sea residence period was: 2.2% in June, 56.5% in July, 32.6% in August, 6.5% in September and 2.2% in November. The average duration of the annual period of marine residence for all sea trout monitored throughout whole sea migration period (1996–2010) was 59 days (SD = 14.3 days) and ranged from 23-183 days. In addition, one fish monitored in 2011 was captured in sea after 188 days of sea migration. Sea trout that finished their sea migration showed that 76% of the fish started their period of sea residence within the 4 weeks from 20th May to 16th June and returned to fresh water within the 4 weeks from 15th July to 11th August (Figure 2). The main sea residence periods corresponds closely with the non-darkness period (sun altitude $\geq$ -6°) in this area from 20th May to 23rd July.

A large male sea trout monitored over 3 seasons (2009 – 2011) was the oldest fish studied. The results on this fish suggested that older fish may exhibit different patterns of behaviour in different years. It was first tagged in spring 2009 when aged 10 years. Its period of sea residence was 23rd May–28th August in the first year and 19th May–17th November in the second year. It then remained in fresh water until 29th December before returning to sea for the third monitored migration. This was the eighth migration between fresh water and the sea for this fish. It was finally recaptured at sea on 5th July after 188 days at sea by a trawl net used in fishing for mackerel some 35 km southeast of Surtsey Island (a distance of about 160 km west of its home estuary) when twelve years old.

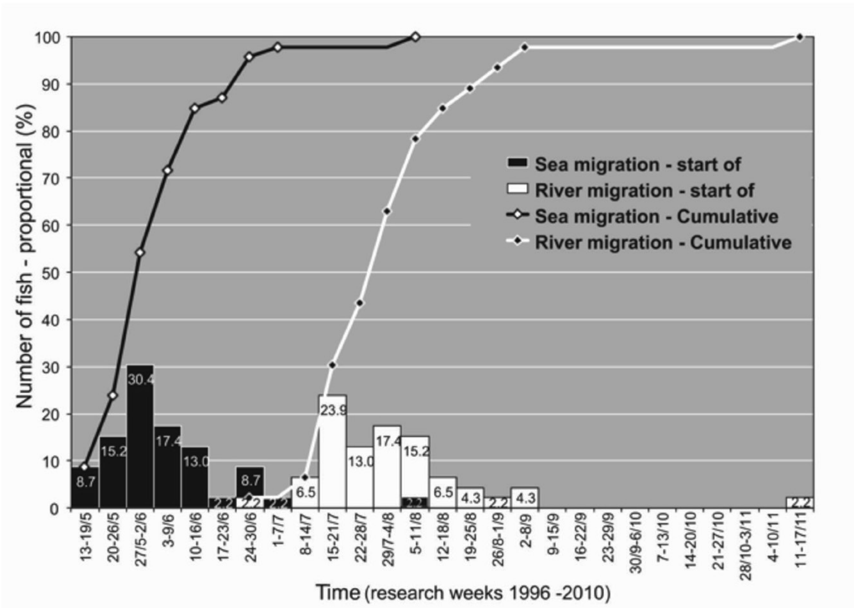

Figure 2. The mean weekly and cumulative proportions of sea trout starting and ending their period of marine residence in each research week based on 46 completed return migrations (1996 – 2010).

SWIMMING DEPTH AT SEA

The aggregated data on swimming depth from the main set of 85,149 recordings for 1996 – 2011 is summarised in Table 2. This information is transposed in Figure 3 to show the annual proportion of time that the monitored fish spent at each 5 metre depth interval between the sea surface and 70m depth. On average, the proportion of time spent at different depths was: 85% at 0–5 metres, 13.09% at 5.1–10 metres, 1.3% at 10.1–15 metres and only 0.52% of the time at depths below 15 metres. Although there was some variability in the general patterns of depths observed in different years, the time spent below 20 m was 1.1% or less in all years.

The mean values and 95% CL for overall depth in each of the 11 years of the study period are shown in Figure 4. Although the variation is significant between some years, the absolute difference is small.

The highly detailed information obtained by sub-sampling high frequency recordings (Sturlaugsson 2016) showed the same general distribution pattern given in Figure 3. Although the recording periods were usually for very short periods and highly clustered at different times in the summer, they were consistent with a generally uniform pattern of swimming depth. The most frequent measurements allowed approximate observations of the actual recorded vertical movement of sea trout, where the fastest vertical movements were 1.56 m/sec (2.2 body-length/sec).

Table 2. Aggregated proportions of sea residence time spent at given depth intervals in each year over the 11-year study period.

Depth Interval (metres)	*Proportion of time at each depth interval in each year over the period of marine residence*											*% Mean Time*
	1996	*1997*	*1998*	*1999*	*2004*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	
0 – 5.0	85.44	78.24	80.37	72.21	81.5	85.58	88.98	87.68	89.58	90.19	93.23	85.10
5.1 -10	12.54	19.34	17.64	25.37	17.6	9.33	10.57	9,03	9.19	7.75	5.53	13.09
10.1 - 15	1.45	2.22	1.83	2.19	0.56	1.64	0.45	1.67	1.09	0.73	0.40	1.29
15.1 - 20	0.43	0.22	0.16	0.21,	0.09	0.31	*	0.95	0.10	0.32	0.44	0.29
20.1 - 25	0.07	0.03	*	0.01	0.03	0.10	*	0.40	0.05	*	0.18	0.08
25.1 - 30	0.02	*	*	0.01	0.07	*	*	0.17	*	0.27	0.04	0.05
30.1 - 35	0.02	*	*	*	0.02	*	*	0.07	*	0.18	*	0.03
35.1 - 40	*	*	*	*	*	*	*	0.03	*	0.05	0.04	0.01
40.1 - 45	0.02	*	*	*	*	*	*	*	*	0.14	*	0.01
45.1 - 50	0.01	*	*	*	*	*	*	*	*	0.09	0.04	0.02
50 - 70	*	*	*	*	*	*	*	*	*	0.27	0.09	0.18

* = *No records*

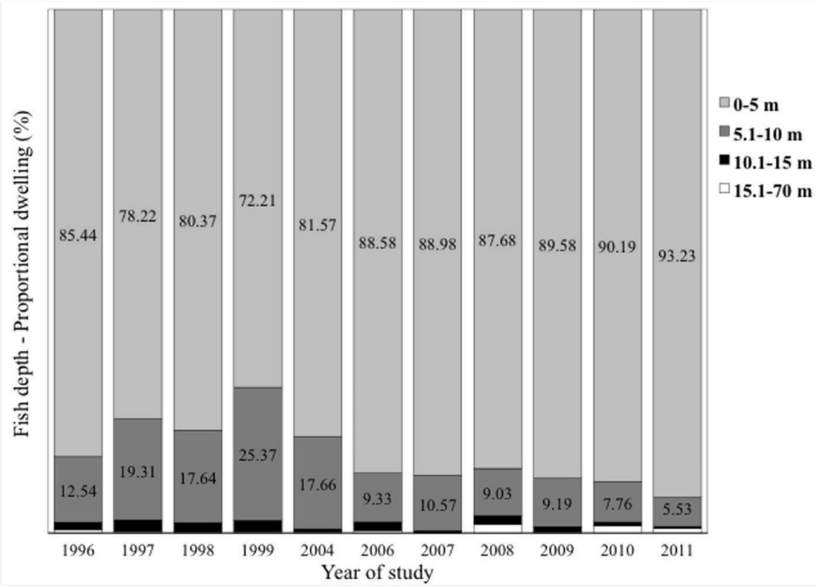

Figure 3. The aggregated mean proportion of time that sea trout spent within 5 m depth intervals during their sea residence period in each year

The aggregated data on swimming depth for all fish in all years showed that sea trout spent between 72–93% of their marine residence time in the upper 5 metres of the water column layer. They occupied the next 5 – 10 metre depth zone for 6 – 25% of their time and spent very little time in deeper water. The time spent at depths below 20 metres was 1.1% or less over the entire study period. Although some fish were recorded at a depth of 70 metres in deeper waters, such movements were very rare.

DISCUSSION

Comparable investigations into the marine feeding migrations of sea trout from other geographical regions are scarce. Rikardsen *et al.* (2007) monitored eight sea trout fitted with DSTs in Alta Fjord in Northern Norway in 2002. The fish were recaptured after 1 – 40 days and had spent 50% of the time at depths of 1 – 2 metres and more than 90% of time in water no deeper than 3 m. However, deeper dives down to 28 m were also recorded, usually at the end of the sea residence period. Hantke *et al*. (2011) monitored the swimming depth of sea trout in the coastal waters of the Baltic Sea in Germany. They observed that 64% of the fish migrated in the upper water layer at a depth of about 1.5 m, but with occasional dives to a depth of 13 metres. Davidsen *et al*. (2014) studied sea trout in a fjord in central Norway and concluded that the average swimming depth of 1.87 m in the period from April to September varied significantly in different types of coastal habitat. The mean swimming depth in littoral habitats (2.11 m) and in cliff habitats (2.53 m) was significantly deeper than in pelagic areas (1.28 m)

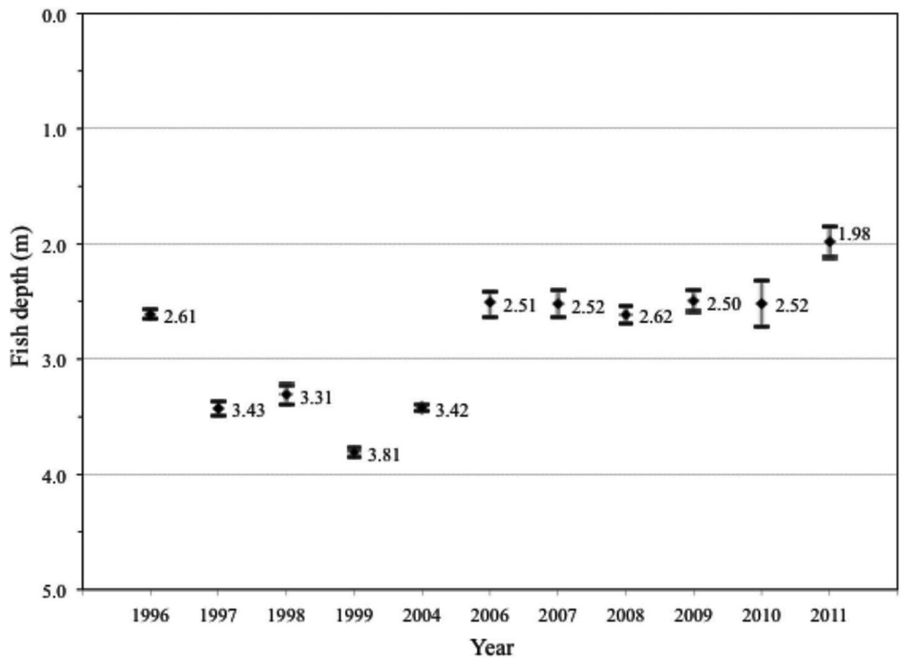

Figure 4. Aggregated annual mean values for swimming depth (with 95% CL) during marine migration within the overall study period 1996-2011. The values are based on all sea trout monitored in each year from measurements that were recorded with same uniform interval throughout the sea migration period by all the fish.

and that the average swimming depth was significantly deeper during the day (1.98 m) than at night (1.28 m). The progressively deeper swimming pattern from April into late summer was positively correlated with water temperature, suggesting that sea trout actively sought cooler, deeper water.

These studies all support the general conclusion from this investigations that sea trout feed close to the surface for most of time during their period of marine residence and that differences in the local environment or in the age, length and maturity status of individual sea trout do not materially influence this typical pattern of pelagic feeding behaviour. Although feeding fish were observed to remain close to the surface for most of the time, this could imply that they were also feeding close to the seabed when in shallow water.

Information on the swimming depths of sea trout during their marine feeding migrations has practical application for risk assessment. As noted in the introduction, one important use for such information is to serve as a basis for informing decisions on tidal stream electricity generating turbines in coastal waters. Another, more general application, would be in informing decisions for the regulation of commercial fishing with pelagic nets for marine fish species in coastal waters used as feeding areas and as migration pathways for sea trout and other diadromous fishes.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of river owners, anglers and colleagues. Monitoring was partly supported by grants received from the Research Council of Iceland, the Icelandic Salmonid Enhancement Fund and the Republic Fund of Iceland. The Scottish Government funded analysis of the raw data on swimming depth of sea trout for the period 1996-2008.

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APPENDIX

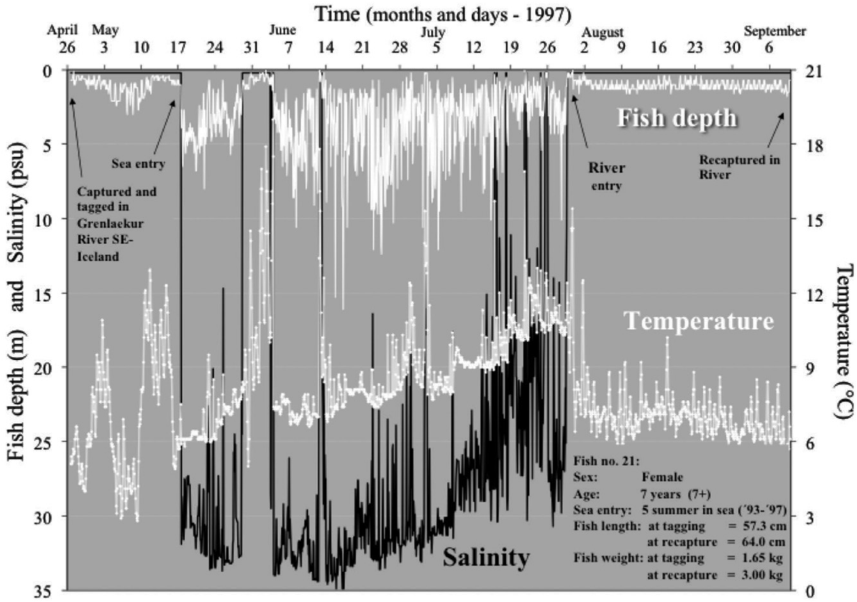


Figure A/1. Individual pattern of riverine and marine movements of sea trout No.21 in relation to swimming depth and ambient water temperature and salinity shown for measurements taken every 2 hours from April to September 1997. Salinity values lower than 5 psu are not real values, but are within the interval 0 – 5 psu. Information on the fish is given.

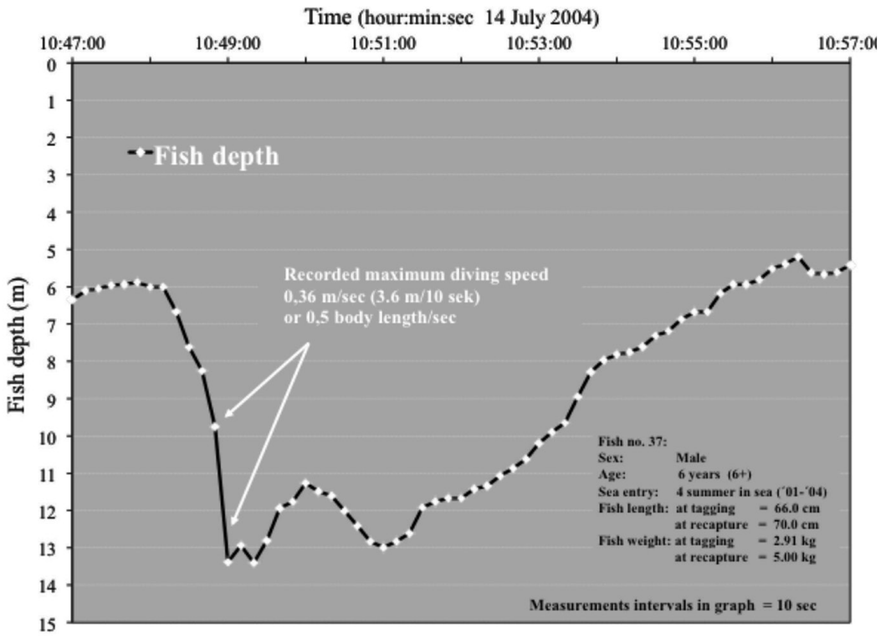
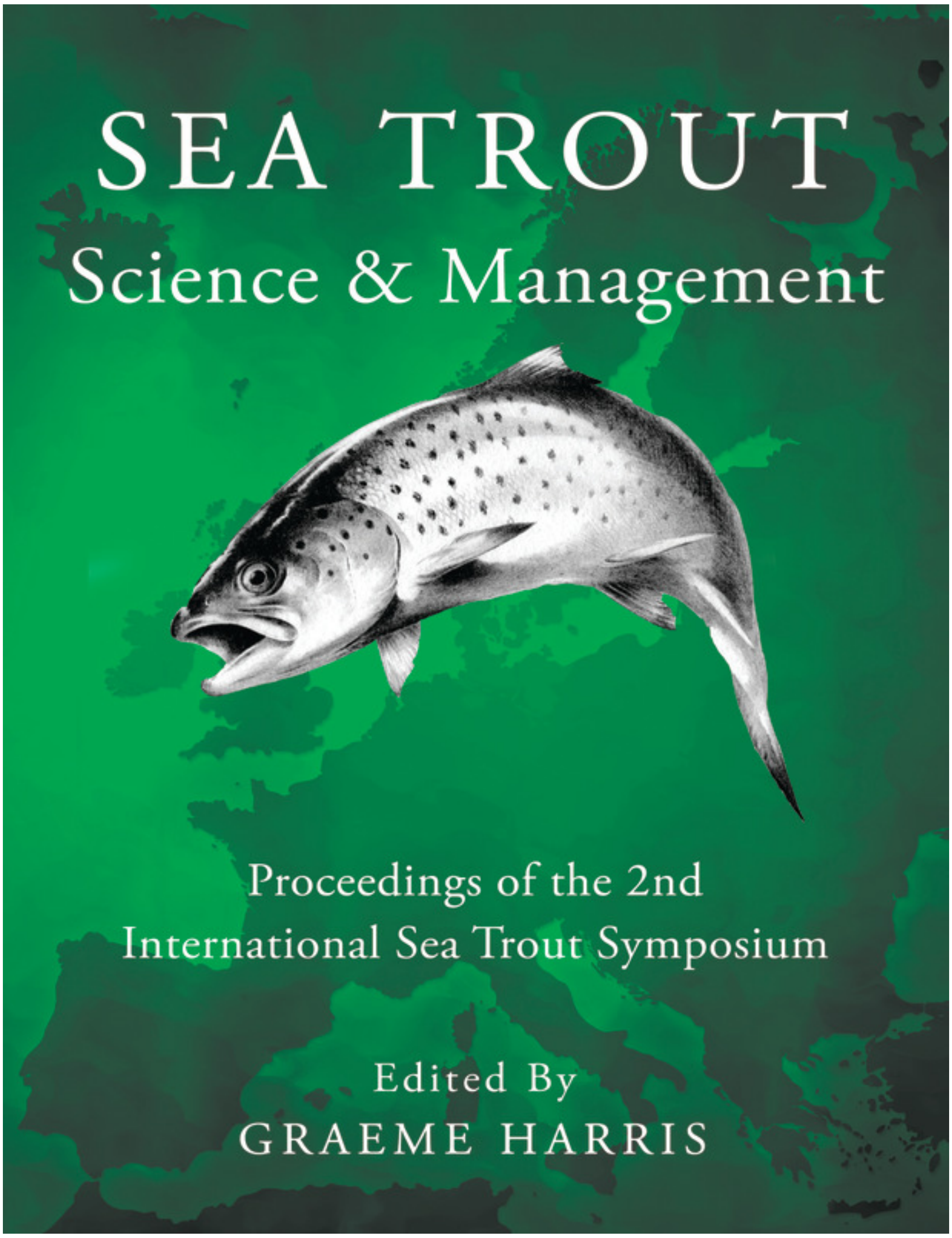


Figure A/2. 'Snapshot' of a sudden depth change of sea trout No.37 monitored at 10 second intervals over a 10 minute period on 14th July 2004.

Greinin "The marine migration and swimming depth of sea trout (*Salmo trutta* L.) in Icelandic waters" birtist í bókinni *Sea Trout: Science and management*, sem gefin var út í árslok 2017.

The paper "The marine migration and swimming depth of sea trout (*Salmo trutta* L.) in Icelandic waters" was published in the book *Sea Trout: Science and management*, that was published in 2017.



Vitnað skal í greinina á eftirfarandi máta:

Jóhannes Sturlaugsson. (2017). The marine migration and swimming depth of sea trout (*Salmo trutta* L.) in Icelandic waters. In: *Sea Trout: Science and management*. (Graeme Harris. *Ed*.) Proceedings of the 2nd International Sea Trout Symposium, 20-22 October 2015, Dundalk, Ireland. Troubador, 328-338.

Citation:

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