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Migration of Atlantic salmon kelts (*Salmo salar* L.) in relation to sea water temperature in Newfoundland, 1998

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Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au secrétariat.

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Abstract

Data storage tags (DST) manufactured by Kiwi Inc. were applied to 139 Atlantic salmon kelts at enumeration facilities on Western Arm Brook, Humber, Campbellton and Highlands rivers, Newfoundland in 1998. In total, 12 of these Kiwi DSTs were subsequently recaptured and water temperatures downloaded from 11 of them (data from tag 12 was lost in transit). Control DSTs for verification purposes were applied to kelts held in a freshwater fluvarium and indicated that water temperatures recorded by the DSTs were accurate. Results from 11 recaptured tags indicated differences between rivers and among fish within a river. Water temperature profiles are useful for indicating water temperatures encountered by salmon in freshwater and in the sea and may prove useful for determining temperature preferences. This information is important for marine climate change models and water temperature protocols for opening/closing angling fisheries in freshwater due to high water temperatures. Unlike some Pacific salmon, no diurnal movements could be inferred from the temperature profiles on the tags. The Kiwi tagged salmon spent most of their time in water from 4.7 to 16.8 °C.

Résumé

En 1998, on a marqué 139 saumons charognards de l'Atlantique au moyen d'étiquettes de mémorisation de données (EMD), fabriquées par Kiwi, inc., à des installations de dénombrement dans les rivières Western Arm Brook, Humber, Campbellton et Highlands à Terre-Neuve. En tout, 12 EMD de Kiwi ont été récupérées en conséquences. Les données sur la température de l'eau ont été téléchargées à partir de 11 étiquettes, celles de la douzième ayant été perdues lors du transfert. Des EMD pour fins de vérification ont été témoins, appliquées à des saumons charognards maintenus dans un fluvarium d'eau douce et ont confirmé l'exactitude des températures enregistrées par les EMD. Les données récupérées des 11 étiquettes ont fait ressortir des différences entre les cours d'eau et entre les poissons d'un même cours d'eau. Les profils de températures de l'eau sont un bon moyen de connaître les températures auxquelles les saumons sont soumis en eau douce et dans la mer. Ils pourraient aussi se révéler utiles pour indiquer leurs préférences à cet égard. Ces renseignements sont importants pour la modélisation du changement climatique marin et l'élaboration de protocoles d'ouverture et de fermeture de la pêche sportive à la ligne en eau douce lorsque la température de l'eau est trop élevée. Contrairement à certains saumons du Pacifique, aucun mouvement diurne n'a pu être déduit des profils de température enregistrés par les étiquettes. Les saumons portant des étiquettes Kiwi ont passé la plupart du temps dans des eaux dont les températures se situaient entre 4,7 et 16,8 ^{o}C.

Introduction

Many authors have noted the lack of information on the sea life of Atlantic salmon (*Salmo salar* L.) (Huntsman 1938; Menzies 1949; Mills 1989; Nickson 1991; Reddin and Friedland 1993). Understanding the factors in the sea that influence survival has become increasingly important as survival rates of salmon back to many enumeration facilities on both sides of the Atlantic have declined considerably in recent years (Anon. 1997a; Dempson et al. 1998). Up to the present, research vessels specifically designed for marine investigations and information from commercial catches have been mainly used to examine and collect life history traits of salmon at sea. Recently, more technologically complex methods have begun to come into use such as earth observation satellites that can collect data remotely. Other researchers have noted the possibility of using data storage tags (DSTs) or tracking tags to obtain information on salmon at sea. Several groups although noting that the use of DSTs is in its infancy have suggested that DSTs are probably one of the least expensive methods of answering questions posed on sea life of salmon (Anon. 1997b, 1998b; Boehlert 1997). In 1997, the record low returns to rivers in North America has focused attention on how little we know of salmon marine life including movements and habitat utilization at various stages (Anon. 1998a).

Most of our current knowledge about salmon marine life has come from experimental net capture using research vessels, traditional tagging studies using external tags and coded-wire tags, and acoustic tracking studies (Boehlert 1997). One early use of DST technology has been on salmon and sea trout returning to Icelandic rivers (Sturlaugsson 1995). DST technology is improving very quickly as tags become smaller, more reliable and include more functions. DSTs can also provide information on migration when coupled with information from earth observation satellites (Anon. 1997b, 1998b). While the size and weight of DSTs restricts use to salmon after the early postsmolt stage; miniaturization may soon allow for tagging of smolts as they exit freshwater in the spring.

This paper describes the results of the migration of salmon kelts in relation to sea water temperature from three rivers in Newfoundland. The study was conducted with salmon kelts as they migrated past fish counting sites and into the sea. Recovery of the DSTs required the return of the tag from commercial fishers, anglers, or to the enumeration facility where it was originally tagged. Because counting facilities are usually placed a short distance upstream from the sea, the temperature record will contain freshwater, estuarine and sea events.

METHODS

Experimental sites were chosen from amongst the enumeration facilities in insular Newfoundland where smolt counts were carried out because of the presence of downstream migrating kelt or where high numbers of kelts could be accessed for tagging (O'Connell et al. 1998). Also, there had to be a strong possibility of physically recapturing the tagged salmon as it re-entered the river to spawn for a subsequent time. Consequently, sites chosen were Western Arm Brook, Campbellton River, Highlands River, and Humber River (Fig. 1). Smolt and adult salmon counts at Western Arm Brook and Highlands and Campbellton rivers utilized full upstream and downstream counting fences whereas returns to Humber River were enumerated by mark-recapture. Full descriptions of each site and gear used to count and capture salmon are described by: Mullins (1998) for Western Arm Brook, Downton & Reddin (1998) for Campbellton River, Reddin & Whalen (1998) for Highlands River, and Mullins & Caines (1998) for Humber River. Approximately, 50 Kiwi tags were assigned to each river. However, due to availability of kelt for tagging, the numbers of tags used at each river differed from those assigned and were as follows: Western Arm Brook – 30 tags, Campbellton River – 52 tags, Highlands River – 26 tags, and Humber River – 31 tags.

The DSTS used in this study were manufactured by Kiwi Minitag Inc., Woods Hole, MA, USA. The Kiwi DST records date and temperature. Kiwi DSTs will store up to 8,000 readings over a five-year period from date of manufacture (Nov. 1997) at which time the batteries will expire. The temperature range is –5 °C to 30 °C with a sensitivity of 0.1 °C. The tag weighs 9.3 g in air and less than 3.3 g in water and is approximately 40 mm by 23 mm by 9 mm (Appendix 1). Data acquisition and downloading are magnetically activated by an internal switch. Each tag has an identifying number on the bottom right corner of the upper surface of the tag, a return address and a reward. Tags were attached to salmon kelt using a double-wire bridal through the dorsal musculature with a backing plate on the opposite side of the fish to anchor the tag in place. Wire was 0.32 mm stainless steel. A reward of $50 US was offered for the return of the tag (Appendix 1).

As recommended by Boehlert (1997) and Anon. (1998b) the reliability of the attachment technique and the temperature recorded by the DST were tested in a known environment. The site chosen for DST testing was a stream tank at the Fluvarium in St. John's, NF. A Hugrun automatic recording thermometer was placed in the tank with six Kiwi tagged fish. The salmon in the tank were mobile and could move freely anywhere in the tank; whereas, the Hugrun was fixed in position near to the surface of the tank. Thus, there was no guarantee that the fish would remain at the same depth as the Hugrun which was near to the surface. Fish were inspected visually on a daily basis for the presence of the Kiwi tag. The length of time that tags remained attached to fish was used as an index of time to tag loss.

Data analysis after downloading data from the tank proceeded by comparing temperatures from test tags and Hugrun automated recorders placed in tanks at the Fluvarium, comparison of temperatures from salmon within a river, amongst rivers and by individual weeks. Standard weeks were assigned based on week 1 from January 1 to 7, week 2 from January 8 to 14, etc. Analysis of variance model used was PROC MIXED of SAS (1988). PROC MEANS and UNIVARIATE were used to summarise distributions and statistics. PROC SUMMARY was used to produce mean temperatures per day which were used for all subsequent analyses. This was done because of the unbalanced nature of the data where different numbers of observations were stored each day from different times.

RESULTS

Calibration study

Of the six DST tagged salmon placed in the fluvarium, there were four Kiwi tags recovered from the Fluvarium tank with temperature data that could be compared. One fish had non-comparable data to the other four and one fish retained the Kiwi tag up to December, 1998 when the experiment ended (Table 1). The tag with non-comparable temperature data had recording times that were miss-matched with the recording times on the other four tags as the tag had not been properly restarted before deployment. Although the tag did record useful temperatures it was not used in the analysis since the recorded temperatures were not directly comparable to those of the other four tags due to the miss-matched start times. In total, five of the six salmon placed in the tank had shed their tags; most of these were shed in early June. The tags were shed by the wire attachment bridle cutting through the flesh of the salmon. Tag shedding may be reduced by using a thicker wire. Thus, it can be expected that after 4 or 5 months about 80% of the salmon released bearing tags may have shed them. The relatively short length of time that most of the tags remained on the fish suggests that the probability of recapturing in 1999 a salmon tagged in 1998 is somewhat slim.

The comparison of temperatures from the four Kiwi tags held in the Fluvarium tanks from 29 January to 7 November, 1998, indicates strong concurrence between the temperatures recorded by the four tags (Fig. 2a). Overall means for temperatures from the four tags were 13.3 °C, 13.0 °C, 13.3 °C and 13.3 °C. While average temperatures among tags were not statistically different at the 5% level of significance ($F_{3,496}$= 1.95, P= 0.12), some of the few minor differences in temperature discernible on the profiles from the tags may have occurred due to differences in position in the tank or removal of the fish from the tank for cleaning. Comparison of average water temperatures from the four Kiwi tags and the Hugrun held in Fluvarium tanks from 4 February to 6 April, 1998 indicates a very close concurrence of temperatures between the Kiwi tags and Hugrun (Fig. 2b). Mean temperatures were 4.6 °C for the Hugrun and 4.5 °C for the four Kiwi tags during the same time as the Hugrun. The slight differences observed maybe be due to a slight stratification of temperatures in the tank. The tank is about 2 m in depth and due to solar heating may have been warmer near the surface where the Hugrun was stationed; whereas, the tagged salmon were free to move around in the tank. The overall conclusion is that temperatures recorded by the Kiwi tags are reasonably accurate as shown in comparison to Hugrun temperatures and by comparison of temperatures among Kiwi tags.

Wild fish study

In total, there were twelve Kiwi tags recovered from the 139 tagged salmon kelts released (Table 2). The information from one tag was lost when it reset during transit and so there is information from eleven DSTs available for analysis. There were two recovered from the counting fence at

Campbellton River where 52 were tagged and released. There were three recovered from the 30 tagged and released at the counting fence at Western Arm Brook. Of the three, one was caught in a herring trap and two were from a sentinel cod trap. There were none recovered from the 31 tagged and released at the Humber River mark-recapture trap. There were six recovered from the 26 tagged and released at the counting fence on Highlands River. Of the six, four were recovered at the counting fence, one in a nearby sentinel cod tap and one in the Quebec commercial salmon fishery (Table 2). The longest time between release and recapture was 112 days while the shortest was 34 days.

Water temperature profiles from individual Kiwi DSTs show three factors: 1 - considerable variability from day to day and river to river; 2 - there is a distinct trend to increasing temperatures as the summer progresses due to gradual heating of the surface layer; 3 – a series of abrupt changes in water temperature sometimes ranging as much as 14°C; and 4 – a series of steady temperatures near the beginning and end of the track from temperatures in freshwater (Fig. 3). The very abrupt decreases and increases are thought to arise as the salmon dives while foraging for prey and then returning to near surface waters where the majority of time seems to be spent. The high temperatures at the beginning of the some graphs are from tag start-up until the salmon bearing tags were returned to the water at which time the temperature declines considerably. Presumably, as many other studies have found, salmon spend most of the time on the surface but do make frequent deep dives and from the frequency must be feeding heavily. The frequency of these abrupt changes in temperature provide some information on the number of dives per day and may be a proxy for the length of time spent feeding.

The frequency distributions of water temperatures for individual fish show a wide range of temperatures from below 0 to above 20°C; although the patterns for fish from the same river were remarkably similar to each other (Fig. 4). The pattern for each fish presumably reflects a combination of individual preferences and availability of specific water temperatures. Mean water temperatures ranged from a low of about 10.5°C to 12.5°C (Fig.5). This may in part be due to the time in the season of departure from the river and the time of recapture, especially for those fish caught in commercial or sentinel fisheries. Since consecutive year spawning is the dominant life history pattern for salmon in these three rivers, the distance that can be potentially travelled will be somewhat restricted to that possible by an adult salmon at sea for only a couple of months or less. The length of time at sea and the time of entry would also control the opportunities for achieving certain temperatures.

A mixed-effects model analysis of variance (ANOVA) was used to examine the relationship between water temperature and week, river and tag nested within river. Tag was treated as a random rather than fixed effects variable. Type III sum of squares indicated F-values were significant at the 5% level for week (($F_{1,142} = 246.60$, $P < 0.0001$) and river ($F_{2,8} = 5.89$, $P = 0.0268$) (Table 3). This suggests that different fish especially those from different rivers are not necessarily found in the same temperature water. The profile of cumulative percent for data from all tags indicates that about 95% of the fish remained in water temperatures ranging from slightly less than 5°C to about 15°C (Fig. 6).

Some species of Pacific salmon are noted for their strong diurnal movements. While some tracking studies have documented diving activities in Atlantic salmon the frequency of such acts and whether such activity occurs more frequently at night or during the day is unknown. Analysis of variance was used to compare daytime temperatures with night temperatures hypothesizing that any diurnal movements would be reflected in sudden changes in temperatures. Overall, mean temperature for day activities was 9.97 °C and for night it was 9.99°C. There was no difference between mean day and night temperatures at the 5% level of signficance ($F_{1,42049}$=0.18, P=0.67).

DISCUSSION

The first studies using data storage tags (DSTs) on Atlantic salmon were carried out in coastal waters in Iceland in 1993 and in several of the following years (Sturlaugsson 1995; Sturlaugsson and Thorisson 1996). DST studies on salmon have also been carried out in the Baltic (Karlsson et al. 1996) and in Japan on Pacific salmon (Tanaka et al. 1996; Ogura 1997). Furthermore, DSTs have been used in Iceland to track coastal migrations of sea trout (*Salmo trutta* L.) and other species have also been tracked (Metcalfe et al. 1994 Sturlaugsson and Jóhannsson 1997). However, in spite of these recent achievements with DSTs, there are still relatively few studies of individual fish and records of the water temperatures they encountered during their migrations in the sea but if the current rate of DST tagging continues this will not long be the case (Anon. 1997b & 1998b). In addition, information other than temperature has also been collected.

In our study, we show the temperature profiles encountered by ten salmon from three rivers in Newfoundland as they migrate as kelts into the sea and on their subsequent return to freshwater. Various telemetry studies mainly on smolt as they leave freshwater into the coastal marine environment have shown the importance of tidal transport and that a mixture of active and passive transport mechanisms were utilised. Also, differences in physical characteristics of the estuary through which they migrated seemed to influence their behaviour. In our case, while the transport mechanisms are unknown the frequent and rapid change in temperature is consistent with diving behaviour perhaps seeking prey. The dives seem to be of relatively short duration and most of the time seems to be spent in the warmer surface waters (Westerberg 1982). Somewhat infrequent diving behaviour was noted in the case of Baltic salmon (Karlsson et al. 1996) and Atlantic salmon in Iceland (Sturlaugsson 1995).

Sea temperatures encountered by salmon migrating to their home river in Iceland indicates a temperature range of about 7°C to about 13°C with relatively few deep dives (Sturlaugsson 1995). Also, not all the salmon behaved in the same way and the frequency of deep dives varied considerably from salmon to salmon. Salmon movements in relation to temperature have also been examined in the Baltic Karlsson et al. (1996) who reported that salmon migrated through fairly narrow temperature corridors along coastal areas. Reddin and Friedland (1993) reported temperature ranges for salmon in the northwest Atlantic ranged from about 1°C to 13°C with 80% of the salmon being found from 4 to 10°C. These of course are mainly non-maturing salmon and the higher range of temperatures encountered by the DST tagged salmon were on salmon that were maturing in the same year as tagged. Perhaps the maturation state also influences the temperature preferences.

ACKNOWLEDGEMENTS

The assistance of the counting fence staff of Western Arm Brook, Humber, Campbellton, and Highlands rivers, Newfoundland is gratefully acknowledged. Dr. C. Schwarz provided statistical advice on the proper method of analysis for unbalanced data.

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Table 1. Application and recovery information for six Kiwi DSTs applied to salmon kelt at the Fluvarium, St. John's, Newfoundland.

Tag No.	**Date applied**	**Date recovered**	**No of days at large**	**Sampling frequency**	**Start time (interval min)**
563	29 January 98	8 June 98	130	6768	11:01 (1 hr)
564	29 January 98	8 June 98	130	3384	10:33 (2 hr)
566	29 January 98	10 June 98	132	6768	10:50 (1 hr)
567	29 January 98	17 June 98	139	6768	11:00 (1 hr)
569	29 January 98	17 June 98	139	6768	10:59 (1 hr)
570	29 January 98	December 98			

Table 2. Tagging and recapture details for Kiwi DSTs applied to salmon at four sites in Newfoundland, 1998.

Tag No.	**Date applied**	**Location**	**Fork length (cm)**	**Date recaptured**	**Location of capture**	**Gear**	**No. of days at large(week)**	**Sampling frequency**	**Start time & (interval min)**
446	31 May	Campbellton	65.0	21 July	Campbellton	Counting fence	52 (22-29)	4609	10:37 (15)
448	27 May	WAB	50.8	13 July	Nameless Cove	Herring trap	48(21-28)	4550	10:55 (15)
461	28 May	WAB	56.5	24 July	Flowers Cove	Sentinel cod trap	59(22-28)	2007	9:43 (30)
469	28 May	WAB	56.5	9 July	Lower Cove	Sentinel cod trap	43(22-28)	4075	9:58 (15)
535	2 June	Campbellton	67.0	22 July	Campbellton	Counting fence	51(22-29)	4738	10:36 (15)
573	18 May	Highlands	97.0	6 Sept	Highlands	Counting fence	112(20-30)	3440	6:27 (30)
574	18 May	Highlands	67.0	20 June	Port au Port	Sentinel cod trap	34(20-25)	3016	6:23 (5)
576	18 May	Highlands	62.5	20 August	Highlands	Counting fence	95(20-34)	4416	8:15 (30)
578	18 May	Highlands	79.0	20 August	Highlands	Counting fence	95(20-34)	4515	6:31 (30)
580	18 May	Highlands	78.5	7 July	Quebec	Quebec commercial fishery	51(20-27)	2404	6:24 (30)
599	26 May	Highlands	74.5	23 August	Highlands	Counting fence	90(21-34)	4284	8:54 (30)

Table 3. Results of a mixed model with 'Satterthwaite approximation' for water temperatures from 11 Kiwi DSTs. Data has been reduced to weeks 22 to 23 which is period of time of complete data for each tag.

REML Estimation Iteration History

Iteration	Evaluations	Objective	Criterion
0	1	164.86582924	
1	1	152.92794519	0.00000000

Convergence criteria met.

Covariance Parameter Estimates (REML)

Cov Parm	Estimate
TAG(RIVER)	0.19309780
Residual	0.85662026

Model Fitting Information for TEMP

Description	Value
Observations	154.0000
Res Log Likelihood	-214.305
Akaike's Information Criterion	-216.305
Schwarz's Bayesian Criterion	-219.315
-2 Res Log Likelihood	428.6095

Tests of Fixed Effects

Source	NDF	DDF	Type III F	Pr > F
RIVER	2	8	5.89	0.0268
WEEK	1	142	246.60	0.0001

Fig. 1 Sites in Newfoundland where Kiwi tags were applied in 1998. 1 - Western Arm Brook, 2 - Campbellton River, 3 - Highlands River, and 4 - Humber River.

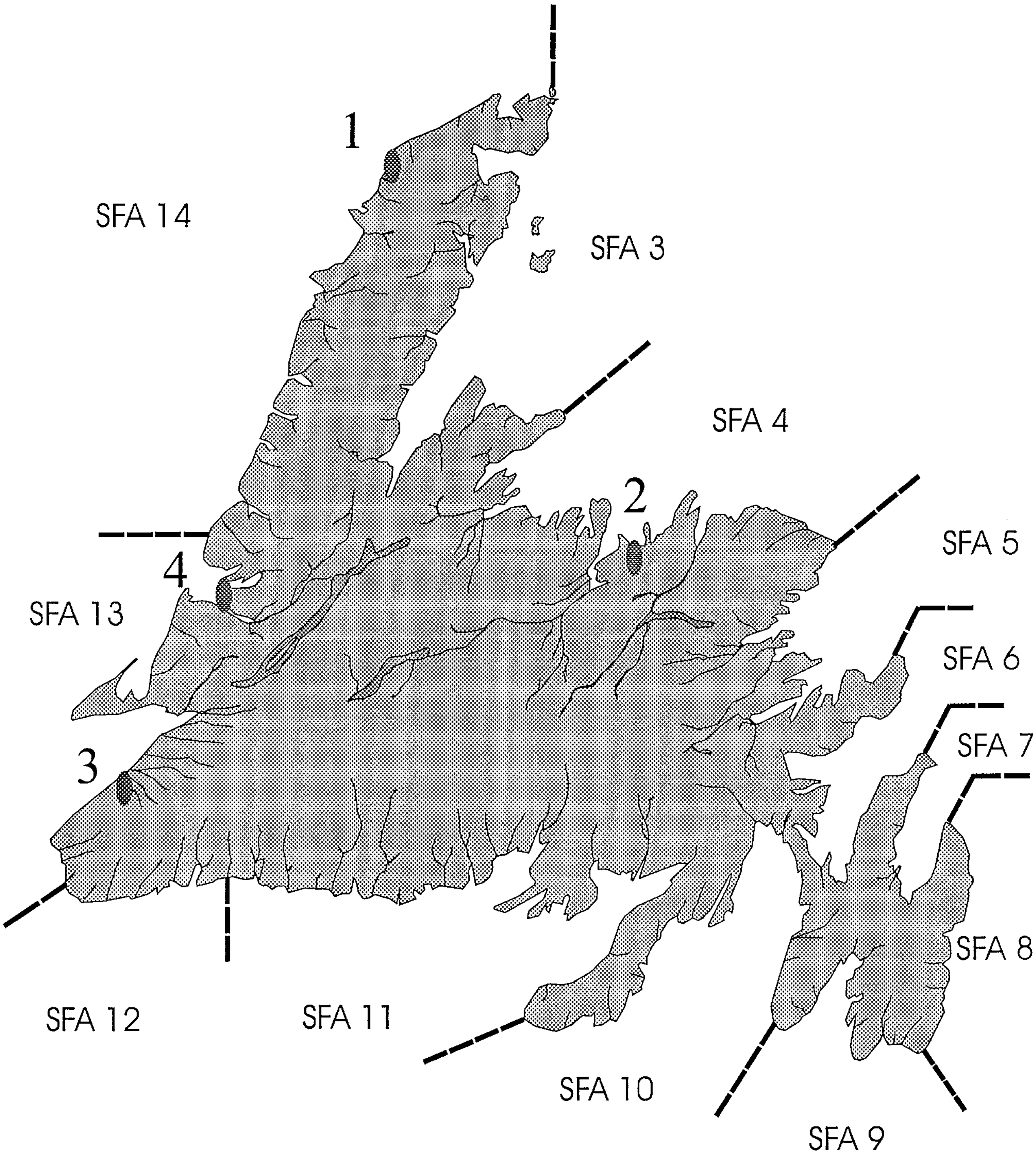


Fig. 2a. Comparison of temperatures from 4 Kiwi tags held on salmon kelt at Fluvarium, St. John's, NF.

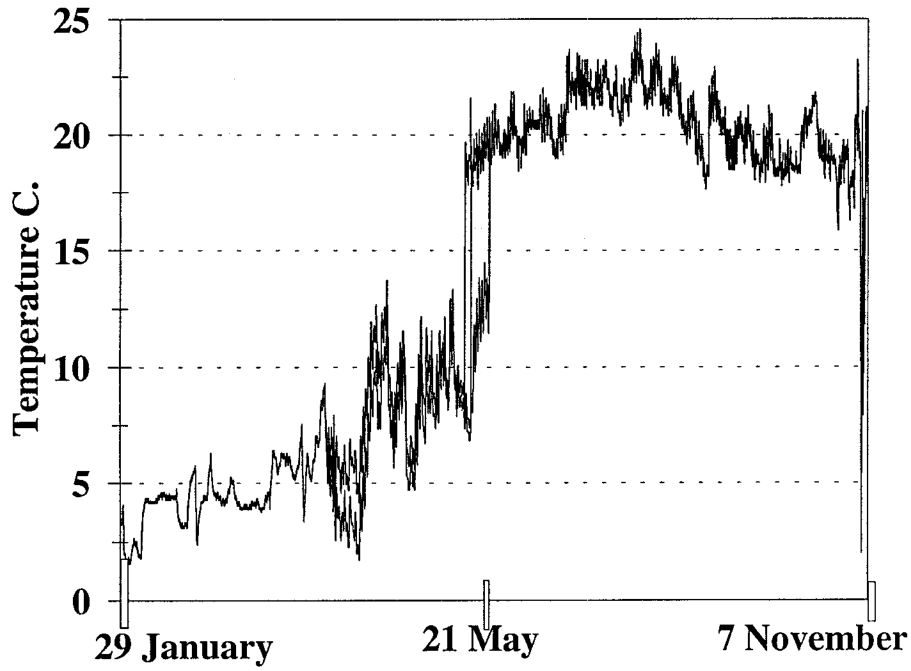


Fig. 2b. Comparison of average temperature from 4 Kiwi tags and Hugrun held on salmon kelt at Fluvarium, St. John's, NF.

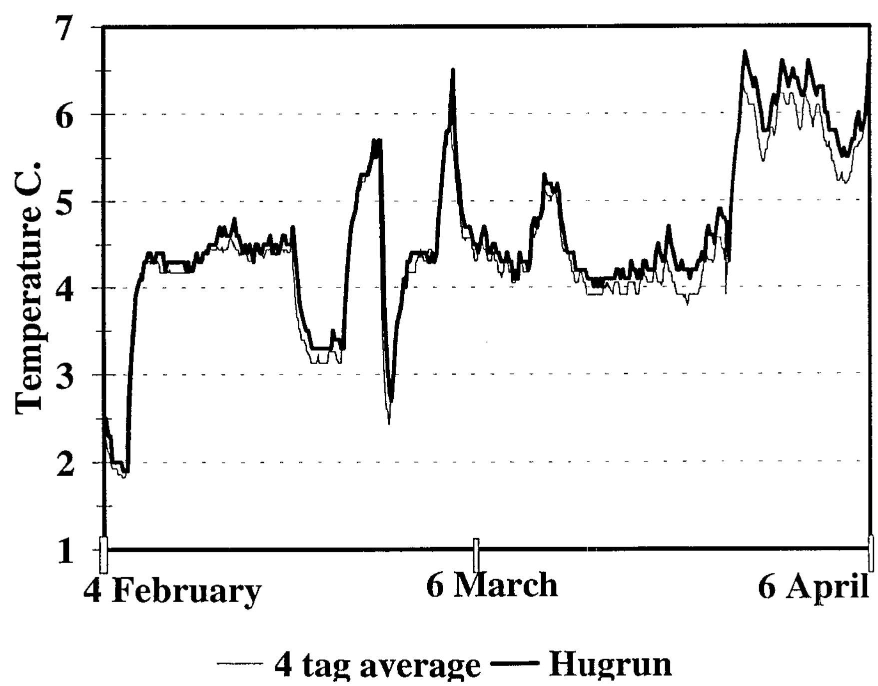


Fig. 3. Temperature profiles recovered from Kiwi tags applied to kelt at Campbellton, Highlands, and Humber rivers and Western Arm Brook, Newfoundland, 1998.

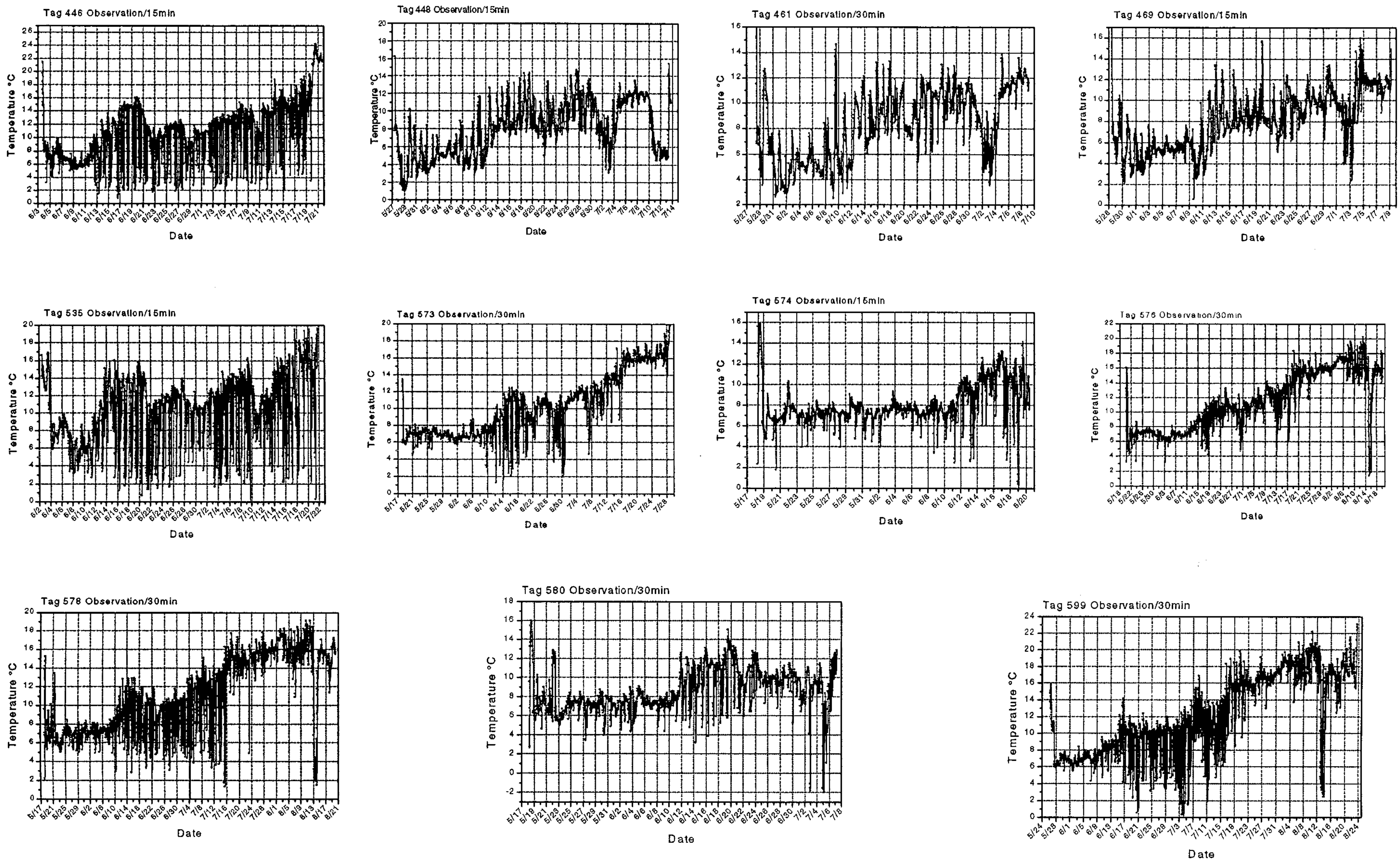
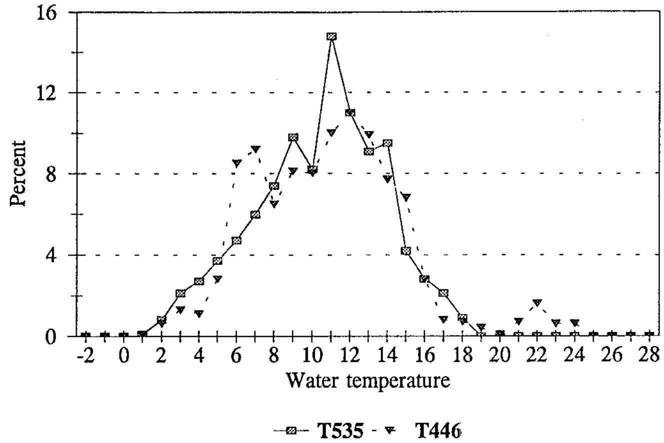
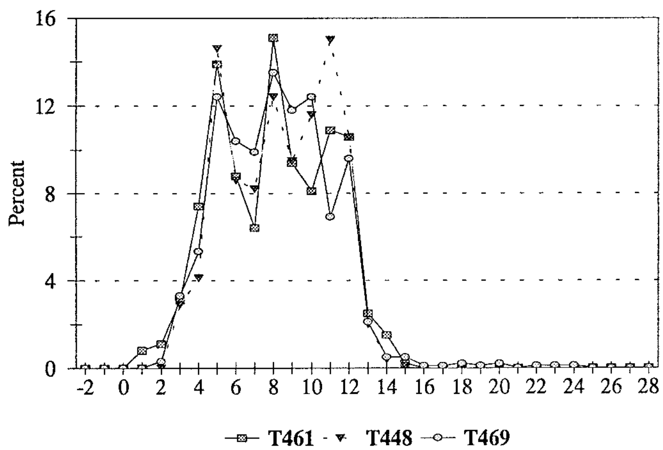


Fig. 4. Frequency distribution of temperature recorded by DST applied to kelt.

Campbellton River



Western Arm Brook



Highlands River

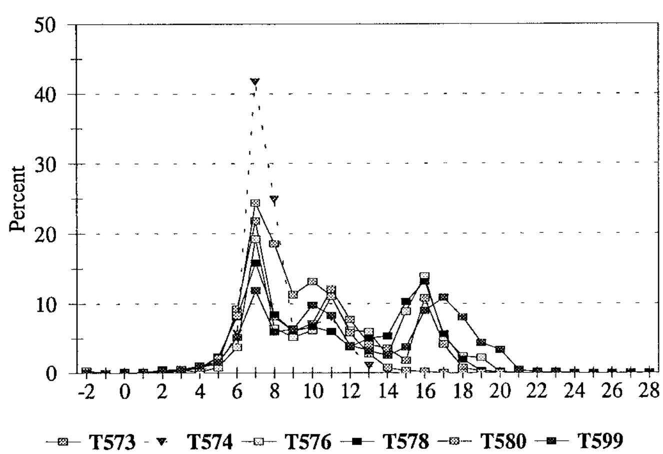


Fig 5. LS mean water temperatures and 95% confidence intervals for Kiwi DSTs. C - Campbellton R, W - Western Arm Br, & H - Highlands R.

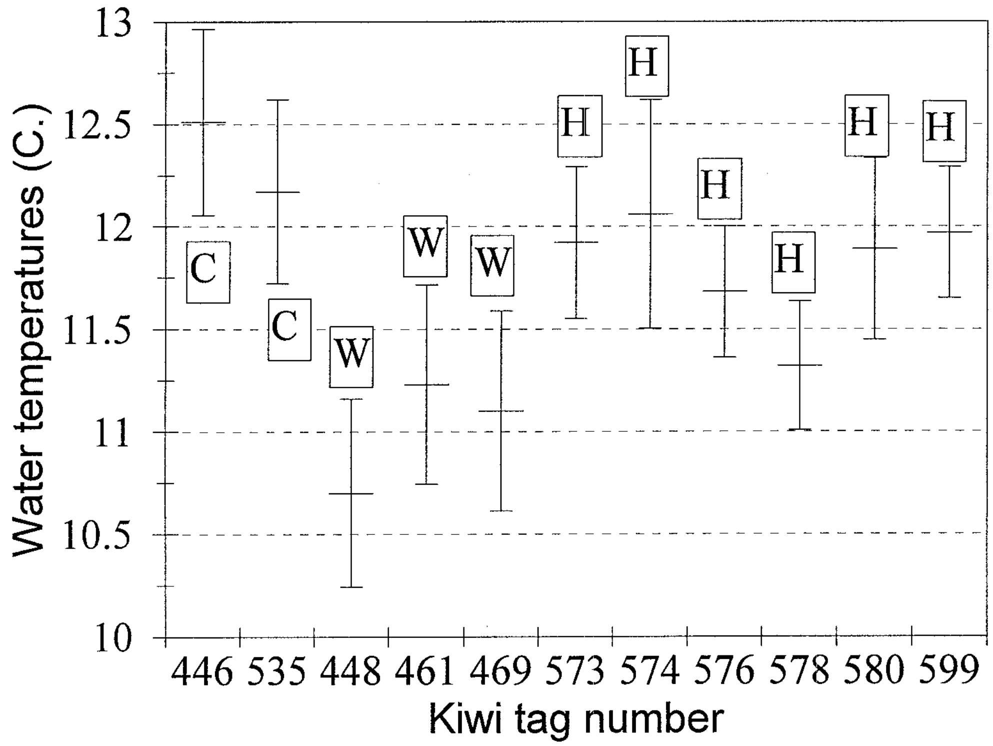
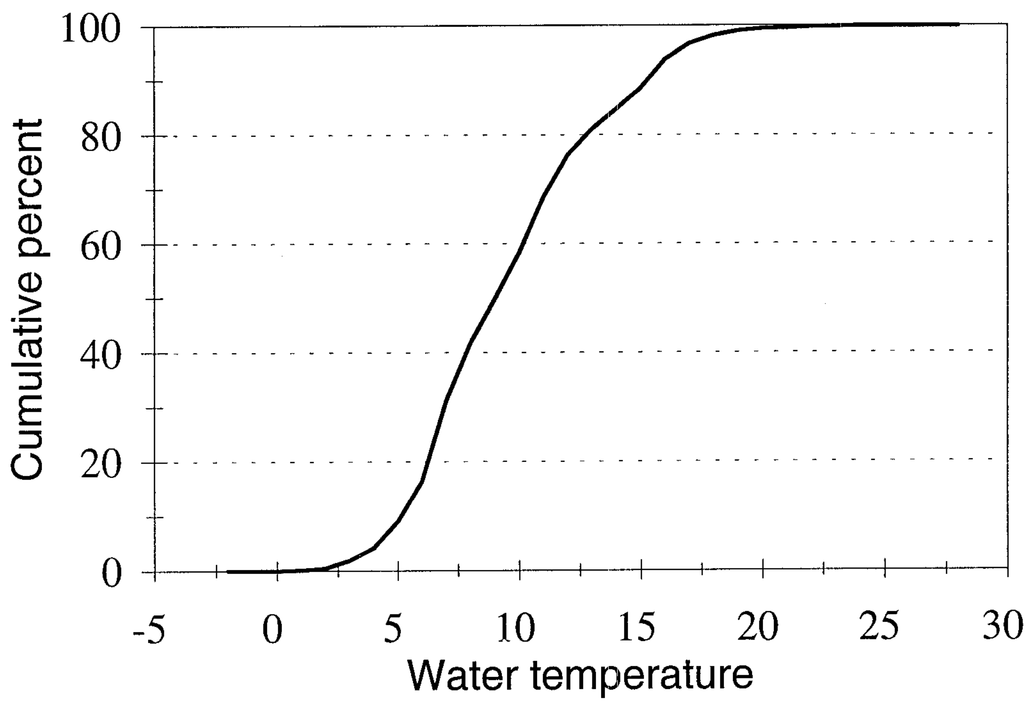


Fig. 6. Cumulative frequency distribution for all tags from Western Arm Brook, Campbellton River and Highlands River.



Appendix 1. Atlantic salmon KIWI Data Storage Tags

KIWI DST Specifications

Archival tag for date and temperature

Sensitivity 0.1 C

Weight 9.3 grams in air (displaces 6 ml of water) < 3.3 grams in water.

Range -5 to 30 Centigrade.

Battery life 5 years from manufacture date (mid Nov. 1997).

8000 readings during the 5 year period.

Data acquisition and down loading done by internal switch which is activated by external magnetic field.

Temperature acquisition is indicated by internal blinking light duration between reading increases as a factor of time.

Each tag has an identifying number on the bottom right.

KIWI DST attached to backing plate with 0.32 mm SS wire.