MANUSCRIPT REPORTS OF THE BIOLOGICAL STATIONS

No. 185.

Report on
The Regeneration of Scales in Atlantic Salmon.

by

A. A. Blair.

FISHERIES RESEARCH BOARD OF CANADA

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April 1937

Introduction

When a fish loses a scale, accidentally or otherwise, a new scale grows in its place which is abnormal in the sense that it has a large focal area without any ridges. Such abnormal scales are usually spoken of as regenerated scales and are frequently encountered in scale studies. An experiment was carried out primarily to determine the rate at which such scales are regenerated.

Methods

The experiment was conducted in fresh water on a single fish, a salmon smolt, 2 + years old, which was obtained on May 20/36 at the St. John Hatchery. On July 17/36 it was anaesthetized in ether solution and the second to the sixth scales dorsad from the lateral line were removed from a row of scales on the right side of the body near the adipose fin (fig.1). This row of empty scale pockets was used as a guide mark in the removal of other scales. From the third antero-posterior row of scales dorsal to the lateral line the fifth scale anterior to the guide mark was also removed on the same date. Later every other scale was removed from this row of scales at intervals of time decreasing from 9 days after the fifth, the ninth scale 8 days after the seventh and so on. (Table 3). The fish was killed one week after the last scale had been removed. The exact position of guide mark scales and the antero-posterior row of scales may be seen in fig. 1.

Growth Rate of Regenerating Scales.

Before removing the regenerated scales from the scale pockets a diagram was made of the appearance of the exposed portion of these scales in relation to the normal scales surrounding them. (fig. 2). The guide mark scales and scale number 5, which have been regenerating for 59 days appear to be of normal size as well as scale number 7 which has been regenerating for 50 days. Scale number 9 regenerating for 42 days as well as all the other scales of less regeneration time are quite noticeably smaller than adjacent scales. Scale number 23 regenerating for 8 days was barely evident while scale number 25 regenerating for 7 days was not exposed at all and incidentally could not even be found in the scale pocket. Of course it is hard to say whether a very small scale was present or not but since there was no difficulty in finding scale number 23 it is quite possible that several days intervene before the formation of a new scale.

In determining the rate of scale growth the dimension most commonly used is the distance from the focus to the anterior edge of the scale. As young regenerating scales do not have any ridges in the centre of the scale to form a definite focus the two diameters were measured, the longitudinal or antero-posterior and the transverse or dorso-ventral. In fig. 3 - 4 the rate of growth of each regenerating scale is compared with the size of the scale that originally occupied the same pocket. The antero-posterior diameter of the regenerating scale increases very rapidly for the first 17 days and from the 17th. to the 59th. day the increase is more or less uniform but not nearly so great. After 50 days the regenerating scale is exactly the same size as the original scale and after 59 days the regenerating scale is larger than the original scale. Thus it is quite obvious that the fish has been growing during the experiment. The dorso-ventral diameter of the regenerating scale increases more rapidly than the antero-posterior diameter as it reaches the size of the original scale in about 35 days. So, if the fish had not grown any during the experiment the rate of scale regeneration would have been 50 days for the antero-posterior diameter and 35 days for the dorso-ventral diameter.

In order to determine the time it takes the regenerating scales to catch up to the normal rate of the fish it is necessary to compare the size of the regenerating scales with the size of scales which had not been removed during the experiment. Obviously normal scales from any part of the body will not do as these vary considerably in size. Two methods have been employed as outlined below.

In the row of scales on the right side of the fish containing the regenerating scales there is a normal scale on either side of each regenerating scale so the average value of the two scales adjacent to each regenerating scale should be a fairly representative value of normal growth with which to compare the size of the regenerating scale. These results are shown in fig. 5 - 6. Both the antero-posterior and the dorso-ventral diameters of the regenerating scales almost reach the normal scale size in 50 days but neither actually reaches the normal even after 59 days. The last part of the curve for normal scale size is somewhat lower than it should be because one of the scales used in averaging the last two points was a regenerating scale and consequently smaller than normal scales. As this is the important part of the curve it would be better to compare the size of the regenerating scales of the right side with the size of corresponding normal scales from the left side. Exactly corresponding scales were easily determined by following the guide mark row of scales of the right side dorsalward over the back of the fish to the left side and in the third row of scales dorsal to the lateral line on the left side the required scales were counted forward from the guide mark. In fig. 7 - 8 are the curves showing the relation between the size of these normal scales of the left side and the size of the regenerating scales. Here again the antero-posterior diameter of the regenerating scales has not reached normal scales size even after 59 days. The dorso-ventral diameter on the other hand reached normal size in 40 days.

So from the above results on the rate of growth of regenerating scales it may be said that the dorso-ventral diameter increases at a faster rate than the antero-posterior diameter and reaches the size of the original scale in about 35 days and the size of normal scales in about 40 days. The antero-posterior diameter does not rëach the size of the original scale until about 50 days and did not reach the size of normal scales even after 59 days; as the experiment lasted only 59 days it cannot be said just how long it would take this diameter to attain normal growth.

On examining regenerating scales from this same fish other than the ones experimented on it was noticed in a large number of them that the exposed posterior field of the scale is much smaller and narrower in relation to the remainder of the scale than is the case in normal scales. Figurell. is a striking example of this condition. As will be noticed also in this figure the posterior field of the scale is distorted from the main longitudinal axis of the scale. This distorted condition, however, does not occur as frequently as does the smallness of the posterior field. The most logical explanation of these facts would seem to be that the exposed portion of the scale pocket (i. e. the part not overlapped by the two scales anterior to it) actually shrinks in size from the time the scale is lost until the new scale fills the scale pocket. The anterior portion of the pocket is situated more deeply in the dermis and overlapped by anterior scales do is not so likely to change in size or shape as readily as the posterior portion. In this way can be explained the fact that the dorso-ventral diameter regenerates at a faster rate than the antero-posterior diameter as the posterior portion of the scale is included in the latter measurement but not in the former.

Formation of Ridges in Regenerating Scales

The number of ridges along the antero-posterior axis of the regenerating scales are recorded in Table 3. There were no ridges on the scale after 8, 10 and 13 days of regeneration time (fig. 12). At 17 days there were 2 ridges and from then on the number of ridges increased fairly regularly up to 8 ridges at 59 days (fig. 13). By referring to fig. 3. the number of ridges on the regenerating scale may be correlated with the regeneration rate of the antero-posterior diameter. From 10 to 17 days the regeneration rate was quite rapid at which time there were no ridges on the scale and from 17 to 59 days the regeneration rate was much slower and the number of ridges gradually increase from 2 to 8.

The spacing of the ridges is similarly determined by the rate of regeneration. The first ridges that are laid down when the scale is growing rapidly are very wide apart and the ridges are closer together as the scale grows more slowly as it approaches the normal size. A check is formed on the regenerating scale when it completely fills the scale pocket and resumes normal scale growth (fig. 10.). The nature of the check varies considerably presumably depending on the rate of growth of the fish at the time. In some cases there are two or more ridges very closely approximated while in other instances the spacing of the ridges grades more or less insensibly into the normal ridge spacing. Such a check might be useful at any time in determining the size of the fish when a particular injury occurred. Figure 10 also shows a transference check formed on the scale when the fish was transferred from the St. John Hatchery to the experimental troughs at St. Andrews. The sudden changes in conditions would upset the normal feeding of the fish for a time and in this way the check in growth would be produced on the scale.

The large focal area of regenerating scales does not possess any ridges but it does have small elevations scattered irregularly over the outer surface. They give this part of the scale a granular appearance and can easily be felt with a fine probe. Therefore the osteoblasts which produce the outer layer of the scale must be irregularly arranged when the regenerating scale is first being laid down. They do not become regularly arranged around the periphery of the scale to form ridges until the rate of growth of the regenerating scale has slowed down somewhat as has been shown above. Also the first few ridges that are laid down are very many and irregular (fig. 10) which is no doubt due to the irregular outline of the young regenerating scale which is quite marked in fig. 12, a scale that has been regenerating for 10 days. This suggests that forking of ridges so often found in normal scales is likely caused by an increased growth rate of that particular part of the scale.

As the osteoblasts, which produce the outer layer of the scale, are found normally only at the periphery of the scale the regeneration of a new scale in the centre of the scale pocket would necessitate either the migration of the osteoblasts to this area or their formation from other cells. Concerning this Neave (1936) states, "It seems likely that the follicle cells play an important part in regenerating scales, for removal of a scale involves also the loss of all or most of the osteoblasts".

Backman (1932) rejects the interpretation of abnormal scales as being those formed to replace scales which have been lost. From one salmon he examined 113 scales from the side and belly of the fish. He says that 53.1%, 30.9% and 11.5% of these scales were laid down in the 1st., 2nd. and 3rd. years respectively in the river and 1.8%, 1.8% and 0.9% were laid down in the 1st. 2nd. and 3rd. years respectively in the sea. He believes that these proportions show that the abnormal scales cannot be regenerated scales but must be new scales intercalated between older ones. All of the scales on a fish are certainly not laid down at the same time but his results do not show this as it is also definitely known that scales are regenerated and he makes no attempt to distinguish between a regenerated scale and one newly formed. Moreover, he states that the widths of the rings surrounding the focal area of these abnormal scales are much greater than are found in normal scales but he is apparently unaware that regenerated scales also possess widely spaced rings before they reach normal scale growth.

Growth of the Fish during the Experiment

The fish showed good growth during the 59 days of the experiment. It grew 5 cm. in length, from 22.6 to 27.6 cm., an increase of 22%; the length was measured to the mid-fork of the tail. It might be mentioned in this connection that the total length is very often unsatisfactory for experimental purposes as the tips of the tail are usually somewhat worm by chaffing against the trough. The growth in weight was from 103. grams to 217. grams, an increase of 111%.

It was fed once daily around 9 A.M. and the food consisted of cross slices of herring (sardine size), each slice weighing around 1 gram. A daily record was kept of the number of slices of herring eaten and the morning and afternoon water temperatures. These records are given in table 1 and plotted in fig. 9. The average daily temperature was 11.9°C with a maximum of 17.5°C (Sept. 10) and a minimum of 6.9°C (Sept. 14). The average daily food consumption was 7.3 slices of herring with a maximum of 14 (Aug. 8) and a minimum of 0 (August 28). The temperature curve shows no definite trend but the food curve shows a steady decrease from Aug. 8th. to the end of the experiment which cannot be correlated with temperature. The dates when the fish was removed from the trough, anaesthetized and a scale removed, are marked on the abscissa in fig. 9. Since the intervals of time between these dates decrease from July 17th. to Sept. 7th., it is quite probable that handling the fish so frequently caused the decreased food consumption from Aug. 8th. to the end of the experiment.

All of the scales removed from this fish at the end of the experiment had one or two indistinct ridges at the edge of the scale which were very often incomplete anteriorly. It was first thought that this was a mild form of scale absorption but as it occurred on all of the scales it is no doubt a slowing down or complete cessation of scale growth coincident with the poor feeding exhibited by the fish during the last week or so of the experiment. Of the various scales removed from the living fish only those removed Sept. 4th. and after possessed these indistinct ridges so they seem to be quite definitely related to poor feeding (see fig. 9).

Summary

An experiment on the regeneration of scales in a 2 + year old smolt gave the following results.

The dorso-ventral diameter of a regenerating scale increases to the size of the original scale from that pocket in 35 days and begins normal growth in 40 days. The antero-posterior diameter grows at a slower rate than the dorso-ventral diameter as it requires 50 days to reach the size of the original scale and in 59 days (the full time of this experiment) had not reached normal scale growth.

The posterior field of a regenerated scale is smaller in relation to the rest of the scale than it is in a normal scale. Therefore, when a scale is removed from its pocket the posterior portion of the pocket must actually shrink in size. This is suggested as the reason for the dorso-ventral diameter increasing to normal scale size at a faster rate than the antero-posterior diameter.

The antero-posterior diameter of regenerating scales increases rapidly up to 17 days and after that time it increases at a slower rate. Correlated with this rate the growth is the number of ridges along the antero-posterior axis of the scale as previous to 17 days there were no ridges and from then on the number increased gradually. A check is formed on a regenerating scale where normal scale growth begins. The contour of a young regenerating scale is very irregular. This, no doubt, is the reason for the irregularity of the ridges first formed on a regenerating scale.

Frequent handling of the fish in removing scales seemed to cause a decrease in daily food consumption and this in turn produced ill-defined ridges at the edge of the scale.

Literature Cited.

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Table 1. N. 1. Ser. 583 Sept. 14/36.

Daily Records of Food and Temperature.

Date 1936	Time	Temp. °C.	Av. Temp.	Daily Food Whole slices of herring
July				
18	4:45	11.6		
19				11.5
20	11:00	10.1		
	4:00	12.6	11.4	7.
21	11:45	11.4		
	4:15			10.
22	9:45	9.5		
	4:45	12.6	11.0	11.
23	10:00	9.5		
	4:00	13.0	11.2	9.
24	9:45	9.4		
	4:00	10.1	9.8	9.
25	9:30	9.7		
	5:00	12.7	11.2	9
26				5.
27	9:45	9.0		
	4:30	13.6	11.3	8.
28	9:30	9.6		
	3:30	14.7	12.2	8.
29	9:45	10.2		
	4:30	13.9	12.0	9.
30	9:30	9.7		
	4:00	14.9	12.3	10.
31	9:45	10.3		
Aug.	4:00	14.4	12.4	11.
1	9:45	10.3		
	4:45	14.9	12.6	10.
2				12.
3				9
4	10:15	10.7		
	3:45	12.8	11.8	7.5
5	9:45	10.2		
	4:00	15.1	12.6	10.
6	10:00	10.1		
	4:15	10.6	10.4	11.
7	9:45	10.6		
	3:45	15.5	1.30	10.
8	9:30			
	11:00			14.
9				9.
10				9.
11				6

Date 1936	Time	Temp. °C.	Av. Temp.	Daily Food Whole slices of herr.
Aug.				
12				11
13	10:30	10.8		
	4:00	15.6	13.2	9
14	9.45	10.9		
	4:15	15.1	13.0	10.5
15	7:00			
	4:00	10.3		8.
16				
17	10:15	12.5		
	4:00	15.0	13.8	5.
18	9:30	8.9		
	4:00	15.3	12.1	10.
19	9:45	11.3		
	4:15	15.5	12.4	7.
20	9:45	10.6		
	4:15	14.8	12.7	11.
	9:45	8.5		
21	4:15	11.2	9.8	5.5
22	9:45	10.3		
	5:30	11.6	10.0	7.
23	1:30	11.1		8.
24	10:45	11.6		
	5:00	13.7	12.6	6.
25	10:45	10.9		
	4:45	14.7	12.8	5.
26	9:45	9.1		
	4:00	15.5	12.3	6.
27	9:30	8.7		
	4:00	13.7	11.2	7.
28				0.
29	9:45	9.6		
	4:30	11.7	10.6	4.
30				7.
31	9:30	10.9		
	4:00	14.1	12.5	3.
Sept.	9:30	10.6		
1	3:45	12.6	11.6	5.
2	9:30	9.6		
	4:00	15.4	12.5	5.
3	10:45	10.3		
	4:30	11.1	10.7	5.
4	9:30	9.6		
	4:15	12.3	11.0	2.
5	9:30	8.2		
	6:15	13.6	10.9	4.

Table 1 (Cont'd)

Daily Records of Food and Temperature Continued

Date 1936	Time	Temp. °C.	Av. Temp.	Daily Food Whole slices of herring.
Sept.				
6				6
7	10:30	11.5		
	6:15	14.8	13.2	3
8	9:45	10.9		
	3:45	13.2	12.0	6
9	10:00	11.6		
	4:30	14.7	13.2	1
10	10:00	11.5		
	4:15	17.5	14.5	4
11	9:45	10.5		
	4:15	15.5	13.0	4
12	9:45	11.9		
	4:45	12.6	12.2	8
13	1:30	12.6		
	6:45	13.6	-	4
14	10:00	6.9		
	2:45	12.9	9.9	
Daily Average		-	11.9	7.3

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Table 2

Weekly Records of Food and Temperature

Date Week Ending	Av. Temp. °C.	Food Record Whole slices of herring
July 25	10.9	9.5
Aug. 1	12.1	8.7
" 8	12.0	10.5
" 15	13.1	8.9
" 22	12.0	7.6
" 29	11.9	5.1
Sept. 5	11.5	4.4
" 12	13.0	4.1

Table 3. N 1.

Time and date of Removal of Scales from Postero-Anterior line of scales of right side, the Regeneration Time of New Scales, and the Number of Ridges on New Scales.

Scale No.	Date of Removal	Time of Removal	Regeneration Time of New Scales in Days	No. of Ridges of New Scales
5	July 17	2:40 p.m.	59.	8
7	" 26	12:45 p.m.	50.	7
9	Aug. 3	3:47 p.m.	42.	5
11	Aug. 10	2:15 p.m.	35.	6
13	" 17	3:45 p.m.	28.	4
15	" 23	1:24 p.m.	22.	3
17	" 28	2:39 p.m.	17.	2
19	Sept. 1	1:57 p.m.	13.	0
21	" 4	2:10 p.m.	10.	0
23	" 6	2:27 p.m.	8.	0
25	" 7	2:16 p.m.	7.	

Killed
Fish Sept. 14 2:15 p.m.

Table 4. N 1.

Diameter of Scales Removed from Postero-Anterior line of scales of right side.

Date 1936	Scale No.	Dorso-ventral Diameter of Scale - m.m.	Antero-posterior Diameter of Scale - m.m.
July 17	5	1.88	2.86
" 26	7	2.21	3.18
Aug. 3	9	2.06	3.42
" 10	11	2.14	3.56
" 17	13	2.36	3.49
" 23	15	2.30	3.82
" 28	17	2.44	3.88
Sept. 1	19	2.29	3.50
" 4	21	2.38	3.88
" 6	23	2.41	3.21
" 7	25	2.41	3.70

Table 5. N. 1 Ser. 583 Sept.14/36

Diameter of Scales of Postero-Anterior line of Scales of right side at end of Experiment.

Scale No.	Dorso-ventral Diameter of Scale - m.m.	Antero-posterior Diameter of Scale - m.m.
2	2.38	3.40
3	2.18	3.38
4	2.35	3.87
5	2.22 (2.32)	3.30 (3.38)#
6	2.29	2.90
7	2.36 (2.40)	3.18 (3.32)
8	2.52	3.74
9	2.18 (2.50)	2.92 (3.71)
10	2.49	3.68
11	2.16 (2.46	2.94 (3.75)
12	2.42	3.82
13	2.04 (2.39)	2.56 (3.84)
14	2.36	3.86
15	1.86 (2.44)	2.47 (3.84)
16	2.51	3.81
17	1.64 (2.49)	2.42 (3.82)
18	2.47	3.84
19	1.14 (2.50)	2.11 (3.92)
20	2.53	4.00
21	1.33 (2.48)	1.44 (3.81)
22	2.42	3.62
23	Broken up - Could not measure	
24	2.46	3.78
25	Could not find any scale	
26	2.58	3.82
27	2.52	3.84
28	2.61	3.81

Diameter in brackets is average of peceding and following diameter.

Table 6. M 1¼ Ser. 583 Sept. 14/36

Diameter of Scales of Postero-Anterior line of scales of left side (comparable to p-a line of right side) at end of experiment.

Scale No.	Dorso-ventral Diameter of Scale - m.m.	Antero-posterior Diameter of Scale - m.m.
2	2.18	3.84
3	2.32	3.78
4	2.19	3.57
5	2.20	3.84
6	2.24	3.60
7	2.19	4.04
8	2.25	3.79
9	2.13	3.76
10	2.25	3.89
11	2.25	3.68
12	2.51	3.59
13	2.36	3.82
14	2.41	4.02
15	2.43	3.74
16	2.33	3.78
17	2.22	3.54
18	2.36	3.72
19	2.29	3.82
20	2.44	3.71
21	2.32	3.66
22	2.61	3.66
23	2.46	3.72
24	2.30	3.60
25	2.29	3.22
26	2.36	3.58
27	2.48	3.74
28	2.45	3.66

Table 7. N 1.

Diameter of Guide Mark Scales of right side at beginning of experiment (July 17/36).

Dorso-ventral Diameter of Scale - mm.	Antero-posterior Diameter of Scale - mm.
1.94	3.24
1.78	3.02
1.95	3.04
1.98	3.08
1.97	3.06
1.99	3.37

Table 8

N 1. Ser. 583 Sept. 14/36.

Diameters of Guide Marks Scales of right side at end of experiment (Sept. 14/36).

Scale No. Dorsad from Lateral Line	Dorso-ventral Diameter of Scale - m.m.	Antero-posterior Diameter of Scale - m.m.
2	2.22	3.32
3	2.26	3.31
4	2.08	3.05
5	2.28	3.36
6	2.26	3.16
7	2.32	3.11

Table 9. N 1. Ser. 583 Sept. 14/36

Diameter of Guide Mark Scales of left side (comparable to Guide Mark Scales of right side) at end of experiment (Sept. 14/36).

Scale No. Dorsad from Lateral Line	Dorso-ventral Diameter of Scale - m.m.	Antero-posterior Diameter of Scale - m.m.
2	2.11	4.41
3	2.43	3.96
4	2.37	3.91
5	2.40	3.88
6	2.45	3.12
7	2.19	3.28