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THE EFFECTS OF ROENTGEN RAYS ON ADULT RAINBOW TROUT*

by

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Introduction

The effects of Roentgen rays upon mortality, gross pathology and growth of adult rainbow trout (*Salmo gairdnerii* Richardson) are described. This work is a portion of a program of research evaluating the quantitative and qualitative effects of radiation on various species of animals during different stages of development. The effects of X-radiation on the eggs of a related salmonid, the chinook salmon, have been reported by Welander, et al (1948). Studies on the fingerling of chinook have been reported by Bonham, et al (1948).

Materials and Methods

The rainbow trout used in the experiment had been selectively bred at the School of Fisheries, University of Washington. Their habits and life history were well known. The trout were irradiated at an age of about one year and 9 months, exposure was about three months before the first spawning. An analysis was made of the effects of various doses of X-rays for 64 weeks following exposure.

Between January 11 and 23, 1945, seven of the eight lots of fish were irradiated with single, whole-body doses of 50, 100, 500, 750, 1000, 1500 and 2500 r. Twenty fish were exposed in each treatment lot except for the 1500 and 2500 r doses where 16 and 12 fish respectively were used. A Picker-Waite Shockproof Therapy Unit with a capacity of 25 MA at 200 KV was used. During exposure of the fish the unit was operated at a potential of 200 KV and 20 MA. In addition to the filtration inherent in the Machlett, FCX type oil cooled tube and in the intensimeter (equivalent to about 0.5 mm. of copper and 2.0 mm. of aluminum), 0.5 mm. of copper and 1.0 mm. of aluminum were used. Roentgens were measured in the beam cross section by means of a Victoreen condenser r-meter placed in a canvas sling in the water in which the fish were treated. The distance between the target of the X-ray tube and the near side of the fish was 48 inches. The average intensity of radiation received throughout the body was calculated at 8.25 r per minute. The temperature of the water in which the fish were irradiated varied from 7.1° to 8.1° C.

All of the fish were irradiated during the period January 11 to 23, 1945. Additional details of radiation procedure and measurement are given in Report UWFL-12 (Foster, 1948).

The effect of prolonged retention in the holding jacket under the X-ray tube was tested by similarly immobilizing six of the control fish four or five hours, the maximum time any irradiated fish was confined. No measurable effects were observed.

Immediately following treatment the fish were measured, stage of sexual maturity was estimated, fins were clipped and numbered tags were attached for future identification. The tags were of the "button" type, consisting of two small celluloid discs fastened one on each side of the base of the dorsal fin by a nickle-coated pin inserted through the dorsal musculature. In order to insure against confusion from tag losses one or two fins were removed to identify each irradiation group.

Standard hatchery procedures were followed in handling the fish. Ninety per cent of the trout were spawned artificially between February 6 and April 9, 1945 (Table 1), 20 to 88 days after irradiation. The subsequent fate of these eggs is reported in UWFL-12 (Foster, 1948). Eighty-three per cent of the surviving trout, 59 per cent of the original number, were spawned a second time between February 16 and May 5, 1946. There was no observable correlation between the time of spawning and quantity of radiation given.

Following the exposure to X-rays, length measurements were made January 11 to 22, 1945, June 14 and November 30 of 1945, and at the time of release in April and May, 1946 or at time of death before release. Weights were taken June 14, 1945, November 30, 1945, and weights of some were taken at the time of death or release.

Mortalities

Weekly cumulative percentage mortalities of all the groups are plotted in Figure 1. Table 1 contains mortalities and percentages listed by four-week periods. Considering the number of deaths in the control group as the expected mortality and, calculating chi-square using the four-fold table (Duggar, 1936, Vol.I: 228), the mortalities among fish irradiated with 1000 r were not significantly greater than would be expected from chance variation. Mortalities in fish irradiated with 50, 100, 500 and 750 r were less than mortalities occurring in the controls, but not significantly so.

Doses of 2500 r killed all fish within a period of 13 weeks with the greatest number dying during the eighth week. Exposure to 1500 r killed about 50 per cent of the fish in 12 weeks (highly significant as compared with controls), and 87.5 per cent in 64 weeks. The greatest mortalities occurred during the 10th to 13th week. Some of the fish of the 1500 r group survived for a considerable length of time though obviously not in normal health as evidenced by their behaviour.

Table 1. Summary and averages of mortality and pathology of two (+) year-old rainbow trout.

Treatment	0 r		50 r		100 r		500 r		750 r		1000 r		1500 r		2500 r	
Original Number of Fish	20		20		20		20		20		20		16		12	
	Mort.	Cum.%	Mort.	Cum.%	Mort.	Cum.%	Mort.	Cum.%	Mort.	Cum.%	Mort.	Cum.%	Mort.	Cum.%	Mort.	Cum.%
After 4 weeks					1	5										
After 8 weeks	1	5													9	75
After 12 weeks			1	5			1	5	1	5	2	10	6	37.5	2	91.7
After 16 weeks													3	56.25	1	100
After 20 weeks											1	15	1	62.5		
After 24 weeks							1	10					1	67.75		
After 28 weeks																
After 32 weeks	1	10							1	10						
After 36 weeks											1	20				
After 40 weeks											1	25	1	75		
After 44 weeks	1	15											1	81.25		
After 48 weeks																
After 52 weeks													1	87.5		
After 56 weeks																
After 60 weeks																
After 64 weeks					1	10										
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Total mortalities	3	15	1	5	2	10	2	10	2	10	5	25	14	87.5	12	100
No. killed accidentally	2	10	1	5	1	5			1	5	1	5				
Cause of death unknown	1	5			1	5	2	10								
Killed by radiation*									1	5	4	20	14	87.5	12	100
No. released	17	85	19	95	18	90	18	90	18	90	15	75	2	12.5	0	0
Necrotic tag scar	5	25	6	30	2	10	2	10	5	25	3	15	7	43.75	9	75
Skin fungused	0		1	5	0		1	5	1	5	0		7	43.75	12	100
Gonad hemorrhage	0		0		0		1	5	2	10	2	10	5	31.25	3	25
Peritoneal hemorrhage	0		0		0		0		1	5	2	10	8	50.00	7	58.33
Muscular hemorrhage	0		0		0		0		0		3	15	7	43.75	12	100
Intestine abnormal	0		0		0		0		0		1	5	3	18.75	7	58.33
Air bladder hemorrhage	0		0		0		0		0		0		1	6.25	6	50
Spawning Spring 1945	18	90	18	90	17	85	19	95	20	100	20	100	15	93.7	6	50
Spawning Spring 1946	9	60	14	77.8	17	94.4	16	88.9	15	88.2	13	86.7	3	75	0	0

* Death by radiation is deduced after noting symptoms and eliminating fish which had jumped out of the pond or had died from causes not attributable directly to radiation.

Figure 1. Cumulative percentage distributions of mortalities during the 64 weeks following exposure of adult rainbow trout to various doses of X-rays. See Table 1.

Gross Pathology

The typical radiation syndrome consisting of mass hemorrhage, petechiae and ecchymosis was seen in all heavily irradiated groups, especially in the trout subjected to 1500 to 2500 roentgens. Some abnormalities, symptomatic of radiation damage, were noted in a few specimens irradiated with 1000 and 750 r. Figures 2, 3 and 4 are photographs taken from 35 mm Kodachromes of control and two irradiated trout respectively showing hemorrhage and other abnormalities in the latter.

Figure 5 is a histogram illustrating occurrence and amount of symptoms noted in the experimental groups. In all the fish that were dead, dying or sacrificed for preservation, particular note was made of the condition of the tag scar, skin and internal anatomy. It will be noted in the histogram that a certain percentage in all the groups had unhealed tag scars with the highest percentage in the 1500 and 2500 r groups.

Figure 2.

Figure 3.

Figures 2 and 3. Photographs of rainbow trout reproduced from 35 mm. Kodachromes. The upper photograph is of a female exposed to 50 r and killed March 23, 1945. It is essentially similar to a control specimen in external appearance. The lower photograph is of a female exposed to 2500 r which died March 19, 1945. This specimen illustrates the growth of fungus around the head and sides of the body. About one-half natural size.

1. LIVER 2. STOMACH 3. SPLEEN 4. RIGHT OVARY 5. KIDNEY
6. AIR BLADDER 7. INTESTINE 8. LEFT OVARY

Figure 4. Photograph made from 35 mm. Kodachrome of a rainbow trout several hours after death. The fish had been exposed to 1500 r. The left side of the body cavity was removed to show internal damage. Ecchymosis and other types of hemorrhage are observable.

Figure 5. Composite histogram indicating the percentage of fish in each group showing symptoms of possible irradiation origin. Numbers in histogram refer to the following; (1) tag scar not healing; (2) skin fungused; (3) gonadal hemorrhage; (4) peritoneal hemorrhage; (5) muscular hemorrhage; (6) intestine abnormal; and (7) air bladder hemorrhage.

The experiment seems to substantiate the general hypothesis that extensive growth of *Saprolegnia*, a fungus, found on the skin of trout and salmon, is inversely related to the general health of the fish. Forty-three per cent of the fish irradiated with 1500 r and 100 per cent irradiated with 2500 r had extensive fungus growths over various parts of the body surface area. In the other groups, five per cent of the fish, or less, were fungused.

Autopsies on fish irradiated with 1500 and 2500 r which were dying, had been dead but a short time or had been sacrificed and later preserved for histological purposes, showed considerable hemorrhage either in the musculature, peritoneum or gonads and occasionally in the bladder. In many of the fish irradiated with 2500 r the hemorrhagic condition was noticeable in several systems (Figure 4). The designation "intestine abnormal" in Figure 5 refers to translucent walls, hemorrhage and other abnormal conditions of this organ apparently resulting from irradiation.

The histogram of Figure 5 indicates radiation damage in some fish exposed to 500, 750 and 1000 r. One of the best criteria of damaging exposure due to radiation was hemorrhage or extravasation within an organ. These three groups, 500, 750 and 1000 r, had some individuals which were hemorrhaged in the gonads, peritoneum or musculature.

Growth

Average lengths and weights listed in Table 2 indicate that growth was considerably retarded in fish exposed to 1500 r. Per cent growth increments in Table 2 and 3 and plotted in Figure 6 are based on the gains in length calculated from measurements made at the beginning of the experiment, January 11 to 23, June 14 and September 30, 1945. The per cent increments of weight are based on the two latter dates only. No differences in sensitivity to irradiation that could be attributed to sex were noted between controls and irradiated groups except in the 1500 r group length increment. Here the sample is not adequate to draw conclusions.

/ A detailed analysis of the length and weight increments in per cent is given in Table 3. Actual measurements of length and weight of individual fish are listed in Table 4. Most of the measurements of length are to the nearest 0.5 cm., greater accuracy being difficult to obtain on living fish. A few more accurate measurements that were made on dead specimens are included.

Comparing each irradiated group mean with that of the control using the t test (Snedecor, 1946: 82) reveals that all the irradiated groups of 750 r or more were significantly retarded as compared to controls during the period June 14 to November 30, 1945. This includes the period of rapid summer growth and is in contrast to the period of slow growth, January to June, 1945, during which there were no significant differences in growth increment (Table 2, Figure 6).

It will be noted that the controls were from 2.8 to 8.8 per cent longer and from 16 to 36 per cent heavier than the irradiated groups due to accident or chance in sampling at the beginning of the experiment. In order to determine whether the growth increment in larger fish would be different from that in the smaller specimens each group was divided and the per cent increments of the larger fish of the group were compared with the smaller of the same group using the t test. No significant differences were found and the difference in sizes at the beginning of the experiment between controls and irradiated fish apparently had no effect on subsequent growth rate.

Table 2. Average lengths and weights of two (+) year-old trout.

Date	Sex	Control			50 r			100 r			500 r		
		No.	Ave. spec. lengths (cm)	%* inc.	No.	Ave. spec. lengths (cm)	% inc.	No.	Ave. spec. lengths (cm)	% inc.	No.	Ave. spec. lengths (cm)	% inc.
Jan. 11-23, 1945	F	7	39.8		7	38.2		8	37.9		9	37.2	
" " " "	M	9	41.5		11	39.9		9	40.0		9	39.2	
" " " "	F&M	16	40.8		18	39.3		17	39.0		18	38.2	
June 14, 1945	F	7	43.4	8.3	7	40.7	5.9	8	41.3	8.2	9	39.7	6.3
" " " "	M	9	43.2	4.0	11	41.4	3.6	9	41.6	3.8	9	40.5	3.2
" " " "	F&M	16	43.3	5.7	18	41.2	4.6	17	41.4	5.8	18	40.1	4.7
Nov. 30, 1945	F	7	51.1	22.1	7	46.6	17.8	8	47.0	19.4	9	45.8	18.8
" " " "	M	9	49.8	16.7	11	46.9	14.9	9	47.2	15.3	9	45.7	14.2
" " " "	F&M	16	50.3	18.9	18	46.8	16.1	17	47.1	17.2	18	45.7	16.4
			Ave. weights (gm)			Ave. weights (gm)			Ave. weights (gm)			Ave. weights (gm)	
June 14, 1945	F	7	1042		7	795		8	878		9	788	
" " " "	M	9	960		11	850		9	890		9	804	
" " " "	F&M	16	996		18	829		17	885		18	796	
Nov. 30, 1945	F	7	1879	44.2	7	1364	41.7	8	1337	34.4	9	1260	37.5
" " " "	M	9	1659	42.1	11	1371	38.0	9	1398	36.3	9	1252	35.8
" " " "	F&M	16	1755	43.2	18	1369	39.4	17	1369	35.4	18	1256	36.6

* Refers to per cent increase in length starting January 11-23, 1945, and per cent increase in weight starting June 14, 1945.

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Table 2 continued.

Date	Sex	750 r			1000 r			1500 r			2500 r		
		No.	Ave. spec. lengths (cm)	%* inc.	No.	Ave. spec. lengths (cm)	% inc.	No.	Ave. spec. lengths (cm)	% inc.	No.	Ave. spec. lengths (cm)	% inc.
Jan. 11-23, 1945	F	9	37.8		8	38.0		2	36.3		6	38.7	
" " " "	M	9	40.3		7	39.0		3	40.0		6	39.2	
" " " "	F&M	18	39.0		15	38.5		5	38.6		12	38.9	
June 14, 1945	F	9	40.2	6.0	8	40.9	7.1	2	39.5	8.1			
" " " "	M	9	41.8	3.6	7	40.3	3.2	3	41.0	2.4			
" " " "	F&M	18	41.0	4.9	15	40.6	5.3	5	40.4	4.5			
Nov. 30, 1945	F	9	45.1	16.2	8	45.4	16.3	2	42.2	14.0			
" " " "	M	9	46.2	12.8	7	44.3	12.0	3	42.5	5.9			
" " " "	F&M	18	45.6	14.5	15	44.9	14.3	5	42.4	9.0			
			Ave. weights (gm)			Ave. weights (gm)			Ave. weights (gm)				
June 14, 1945	F	9	761		8	830		2	669				
" " " "	M	9	835		7	754		3	745				
" " " "	F&M	18	798		15	794		5	715				
Nov. 30, 1945	F	9	1199	36.5	8	1192	30.4	2	792	15.5			
" " " "	M	9	1217	31.4	7	1063	29.1	3	873	14.7			
" " " "	F&M	18	1208	34.0	15	1132	29.9	5	841	15.0			

* Refers to per cent increase in length starting January 11-23, 1945, and per cent increase in weight starting June 14, 1945

Table 3. Two (+) year-old rainbow trout length and weight increments in per cent.
Data covering period June 14, to November 30, 1945.

	Control		50 r		100 r		500 r		750 r		1000 r	
	Length	Weight	Length	Weight	Length	Weight	Length	Weight	Length	Weight	Length	Weight
	13.0	42.3	6.4	27.6	12.0	35.5	11.4	34.7	11.6	34.3	7.1	7.7
	12.2	41.3	13.1	40.3	10.9	34.5	12.4	38.7	4.8	14.8	15.2	34.8
	10.4	33.6	18.8	48.0	12.1	34.0	17.0	48.2	15.2	41.4	11.1	30.2
	19.2	45.6	6.7	29.6	15.4	19.5	14.9	15.3	7.1	21.6	4.6	20.9
	12.8	34.4	15.2	49.6	18.8	52.7	11.9	41.1	12.0	40.0	6.0	19.0
	12.5	33.2	6.8	22.3	7.5	17.6	16.3	46.5	11.1	41.7	12.2	35.6
	11.4	29.5	12.4	42.7	7.5	28.1	11.1	30.6	4.3	14.8	11.6	36.2
	12.6	38.1	16.0	46.3	12.2	38.6	16.1	47.4	1.4	4.4	9.3	31.3
	15.6	44.7	15.4	41.7	17.2	51.7	12.5	38.5	13.4	41.3	8.9	28.0
	16.7	56.7	12.6	43.1	16.3	49.0	8.4	20.6	2.2	8.6	3.7	15.1
	14.3	40.0	14.3	45.3	13.1	37.5	9.3	32.4	13.3	34.1	14.8	45.8
	14.8	46.7	8.3	43.3	10.6	32.8	12.4	39.6	10.6	42.5	11.1	32.2
	12.6	41.7	15.7	49.3	7.7	34.5	12.2	40.0	15.8	40.3	12.0	39.0
	13.0	44.2	15.5	40.4	1.3	39.0	13.7	43.4	8.7	32.2	4.4	23.2
	16.0	52.3	2.8	4.6	13.5	29.2	13.0	39.0	16.1	44.9	8.4	19.4
	16.0	50.1	7.0	18.3	11.9	38.8	5.3	21.9	10.0	37.1		
			14.0	35.0	13.2		13.9	37.4	11.1	31.9		
			11.4	38.6			8.9	28.5	10.4	40.6		
n	16	16	18	18	17	16	18	18	18	18	15	15
$\bar{x}$	13.9	42.1	11.8	37.0	11.8	35.8	12.3	35.8	9.9	31.0	9.4	27.9
Sx^2	78.17	816.54	330.46	2505.58	284.50	1458.12	151.55	1486.84	334.27	3341.97	186.66	1449.19
t	Each irradiated group compared		1.75	1.47	1.77	2.02	1.83	2.19	3.24	2.87	4.22	4.49
P	with control		.09	.18	.08	.06	.07	.04	.004	.008	<.001	<.001

Figure 6. Histogram of the length and weight increments (%), males and females combined. The lower sections of length histogram represent increments calculated from January and June, 1945 measurements. The upper sections of the length histogram and the weight histogram represent increments calculated from June and November, 1945 measurements. The percent probabilities have been superimposed on the histograms to indicate relative significance. Data from Table 3.

Table 4. Length (in cms.) and weights (in gms.) of individual rainbow trout at various times during the experiment.

Dose in r	Date	Females										Males												
		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	11	12	
0	Length	a*	44	41	43.5	39.5	41	36	35	43	40													
		b*	47	47	47	42		33	39	49	42													
		c*	54	53.5		52		45	45.5	57.5	50													
		d*				52.5		45.5	46.0															
Weight	b	1344	1300	1385	960		695	660	1800	835														
	c	2344	2215		1766		1266	1100	2814	1673														
	d				1406				2327															
50	Length	a	35	37	39	36	42	43	42	37														
		b	39	39	41	39	44		44	39														
		c	48	46	44	44.5	52		48	44														
		d	49	47.7	44	45.0	52.5		49	46														
Weight	b	780	645	803	700	1040		926	675															
	c	1501	1280	1033	1221	1783		1632	1100															
	d								906															
100	Length	a	37	40	35	39	38	32	39	35	40													
		b	40	44	37	43	41	45	42	37	46													
		c	45.5	52	40	49	49		45.5	42	53													
		d					50.5		55.5	42.5														
Weight	b	719	1067	670	955	770	557	878	622	1346														
	c	1076	1325	613	1555	1510		1341	878	2199														
	d								700															
500	Length	a	34	36	38	36	35	39	36	40	36	39												
		b		39	40	37	39	42	39	43	37	41												
		c		47	47	42	46.5	48	44.5	49	43	45												
		d		47.5	47.5	43	47.5	48.9	45		43.5	44.5												
Weight	b		725	1149	620	690	853	670	980	595	815													
	c		1400	1366	1052	1312	1388	1110	1633	951	1140													
	d					1061																		
750	Length	a	40	36	38	34	38	32	38	39	38													
		b	42	39	40	35	42		40	42	40													
		c	49.5	42	45	35.5	48.5	47		47.5	45	45												
		d	49	41	46	35.5	49			47	47	46												
Weight	b	890	640	695	458	900	885		710	870	805													
	c	1520	816	1192	438	1532	1540		1190	1283	1279													
	d			1073																				
1000	Length	a	36	37	38	33	34	40	41	37	42	36												
		b		40	39	36		44	46	40	44	38												
		c		45	41.5	41		48.5	50.5	45	50	41.5												
		d		45	42.5	40.5		50		46	51.5	41.5												
Weight	b		716	678	515		1060	1252	795	1020	600													
	c		1029	837	800		1542	1739	1172	1673	744													
	d			735			1265																	
1500	Length	a	38	36	36	38	40	36	36	35														
		b		38		40	40			39														
		c				44				40.5														
		d		39		45	41			41.2														
Weight	b		571		675	708			664															
	c				921				664															
	d		564			684			645															
2500	Length	a	36	36	42	38	43	37																
		b																						
		c																						
		d																						

a* - Jan. 11-23, 1945
b* - June 14, 1945
c* - Nov. 30, 1945
d* - Apr.-May, 1945

It should be pointed out that the t and probability values (Table 3, Figure 6) do not indicate that the length increment was retarded strictly proportionally to the graded doses of X-rays. On the other hand, the t and P values for the per cent growth increments of weight show a remarkable proportionality to the amount of irradiation and seem to be a very sensitive measure of radiation damage.

Growth, after single, whole-body irradiation, has revealed similar effects in related species of salmonids. Bonham, et al (1948), working on chinook salmon fingerling (*Oncorhynchus tshawytscha*), observed a significant retardation of growth by doses of 500 r or more. Irradiations of 250 and 100 r apparently had no effect on growth. Mortalities of 100 per cent occurred at 2500 r in 30 days. Welander, et al (1948), investigating radiation effects on the larvae of the same species, noted retardation of growth with 1000 r, but not with 500 and 250 r. Mortalities of 100 per cent occurred at 2500 r in 6 weeks. Corbella (1930) relates of retardation of development of rainbow trout after irradiation during cleavage stages with doses of 95 r, but made no thorough analysis of his data. Theoretically, these early stages should be very sensitive, however, mortalities in the controls were quite high and since the data was not treated statistically the value of his experiment is in doubt.

The time element is a factor in experiments designed to observe the effect of radiation on growth. The experiment on the adult rainbow was carried through a period of more than 64 weeks, several times as long as most experiments of a similar nature. Radiation damage could be detected at lower dosage levels as time progressed.

Summary

Nearly mature adult rainbow trout were subjected to 25 MA, 200 KV, copper and aluminum filtered X-rays of 50, 100, 500, 750, 1000, 1500, and 2500 r at 8.25 r per minute. A total of 148 fish was used in the experiment which lasted 64 weeks. When compared with an unirradiated control group mortalities were significantly higher in fish exposed to 1000 r or more. Doses of 2500 r killed all fish in a period of 13 weeks with the majority dying during the 8th week. Exposures to 1500 r killed 56 per cent in 13 weeks and 87 per cent in 64 weeks. Mortality in the controls was 15 per cent. Injuries symptomatic of radiation were seen in autopsied fish treated with 500 r or more. The injuries, such as hemorrhage, necrosis, growth of fungus and intestinal damage were generally proportional to the amount of X-ray given.

Growth in length and weight was retarded in all irradiated groups as compared with controls. The growth increment during the fastest growing period of the experiment was significantly less in a fish irradiated with 750 r or more and proved to be a sensitive measurement of radiation damage and directly proportional to the amount of radiation given.

LITERATURE CITED

Bonham, K., L. R. Donaldson, R. F. Foster, A. D. Welander and A. H. Seymour.

- 1948 The effect of X-ray on mortality, weight, length and counts of erythrocytes and hematopoietic cells in fingerling chinook, *Oncorhynchus tshawytscha* (Walbaum). Growth, Vol. XII, No. 2, pp 107-121.

Corbella, E.

- 1930 Influsso delle radiazioni Roentgen sullo sviluppo embrionale dei Teleostei (*Salmo lacustris* L., *Salmo irideus* Gibb., *Perca fluviatilis* L.). Riv. Biol. Milano, Vol. XII: pp 93-117.

Duggar, B. M. (editor), et al.

- 1936 Biological effects of radiation. Vol. I: pp 1-676. New York and London, McGraw-Hill Book Co., Inc.

Foster, R. F.

- 1948 Some effects on embryo and young rainbow trout (*Salmo gairdnerii* Richardson) from exposing the parent fish to X-rays. Doctoral Thesis, University of Washington.

Snedecor, G. W.

- 1946 Statistical methods applied to experiments in agriculture and biology. The Iowa State College Press, Ames, Iowa.

Welander, A. D., L. R. Donaldson, R. F. Foster, K. Bonham and A. H. Seymour.

- 1948 The effects of Roentgen rays on the embryos and larvae of the chinook salmon. Growth, Vol. XII, No. 3, pp 203-242.