Informational Leaflet 43

EFFECT OF THE MARCH 27, 1964 EARTHQUAKE ON PINK SALMON ALEVIN SURVIVAL IN PRINCE WILLIAM SOUND SPAWNING STREAMS

By:

Wallace H. Noerenberg
Frank J. Ossiander

August 28, 1964

STATE OF ALASKA
WILLIAM A. EGAN - GOVERNOR

DEPARTMENT OF
FISH AND GAME
WALTER KIRKNESS - COMMISSIONER
SUBPORT BUILDING, JUNEAU

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INTRODUCTION

An earthquake of great intensity struck the state of Alaska on March 27, 1964.

Although the impact of the damage by the earthquake, seismic waves, and subsequent tidal waves on salmon stocks may not be fully known for many years, some of its immediate damages are now readily discernable.

The earthquake caused drastic changes to the topography. Many of the normal pink salmon spawning beds were damaged or destroyed with a possible resulting increased mortality of the salmon alevins occupying these beds. If this is true, future salmon populations may be drastically and adversely altered. It is desirable to determine whether the salmon alevins occupying gravel beds at the time of the earthquake suffered a significant increase in mortality.

I. AVAILABLE SURVEY DATA

As part of the Alaska Department of Fish and Game pink salmon program in Prince William Sound, relative indices of abundance of the salmon life history stages are pinpointed to determine the time and place of mortalities which may seriously effect the magnitude of the returning runs. In this program each cyle of salmon is monitored by obtaining an index to abundance at three stages in the life history:

(1) Spawning adults
(2) Pre-emergent alevins
(3) Estuarine fry

(Noerenberg, 1961, 1963). The pre-emergent alevin index is of primary importance in this study. Samples used to establish this index are taken in stream spawning gravels throughout the Sound just prior to the downstream migration each spring. This index serves as a measure of the abundance of salmon surviving at the end of the freshwater stage of life. Figure 1 shows a sketch of a typical stream spawning area and the random location of sample points in this area. Figure 2 shows the field operation of the sampling frame and hydraulic probe used to pump eggs and alevins from the gravel.

A representative group of streams and intertidal spawning areas have been sampled for pre-emergent pink salmon alevins since 1958 with data on the number of dead alevins since 1961. Table 1 lists the history of this past data. Figure 3 shows the location of 13 streams which have been sampled each of the years 1961, 1962, 1963, and 1964.

In 1964, immediately following the March 27 earthquake during the period April 1 to 18 the Department of Fish and Game conducted an intensive sampling program to determine the number of alevins and dead eggs in the spawning gravels of Prince

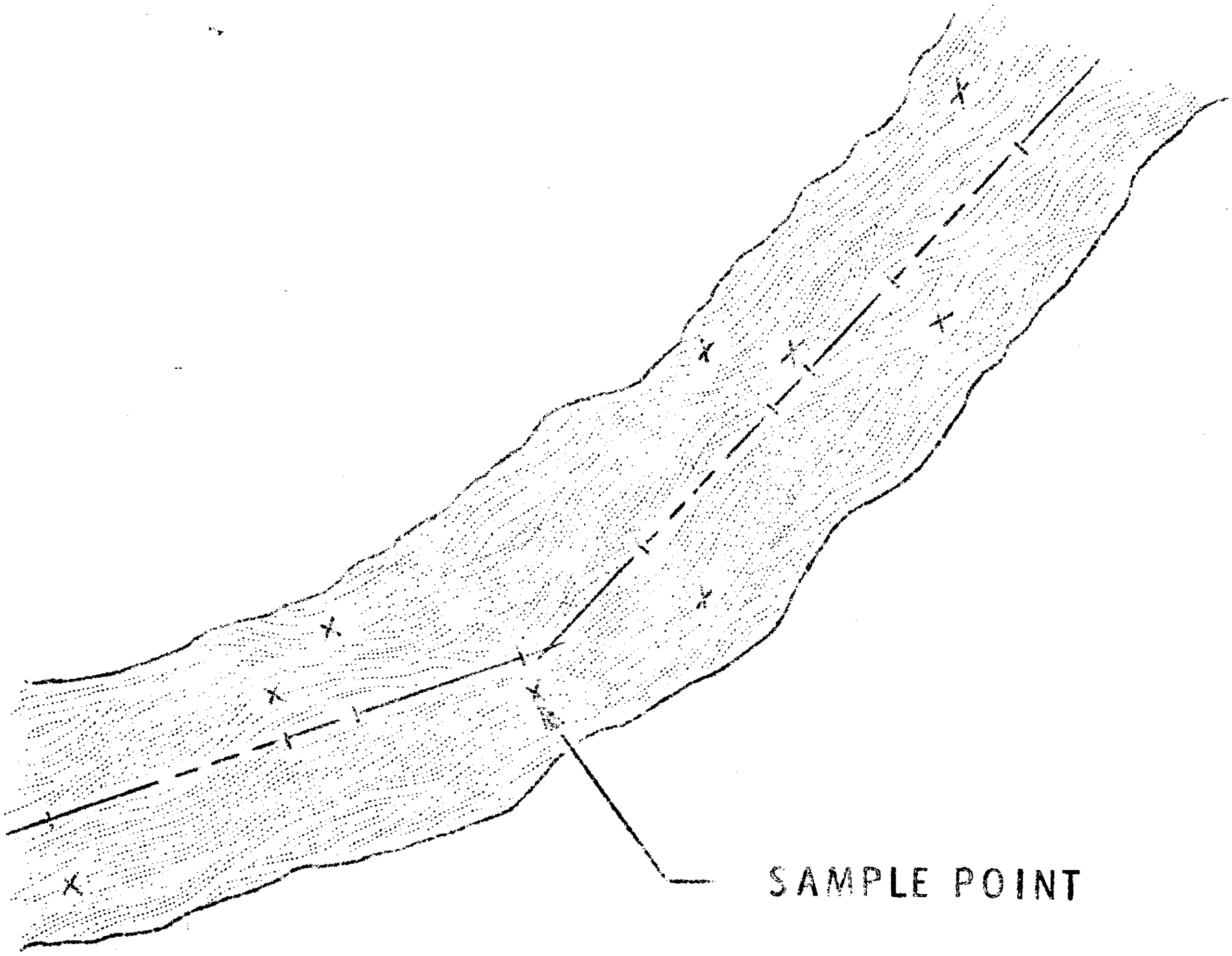

Figure 1. Section of spawning stream showing random location of sample points.

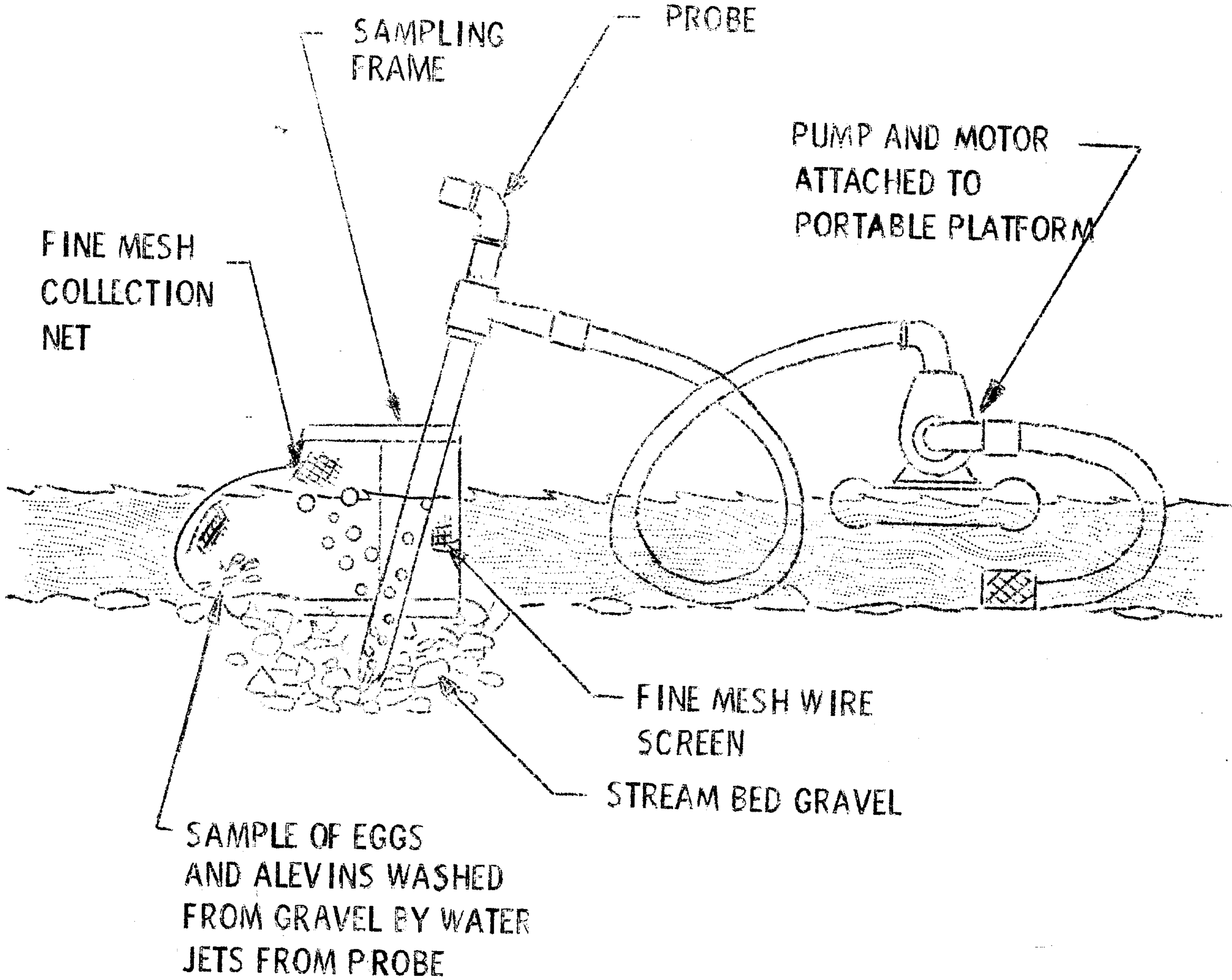

Figure 2. Sampling equipment as used in the field. The sampling frame is located over a sampling point and the probe is being used to remove eggs and alevins from the gravel.

Table 1. History of pre-emergent pink salmon alevin sampling.

Year	Sampling Period	Number of Streams Sampled	Number of Samples Taken
1961	March 15 - April 20	29	552[1]
1962	March 10 - April 15	29	1,114[2]
1963	March 10 - April 15	38	1,125[2]
1964	April 1 - April 18	29	1,145[2]

[1] Sampling unit one square yard.

[2] Sampling unit three square feet.

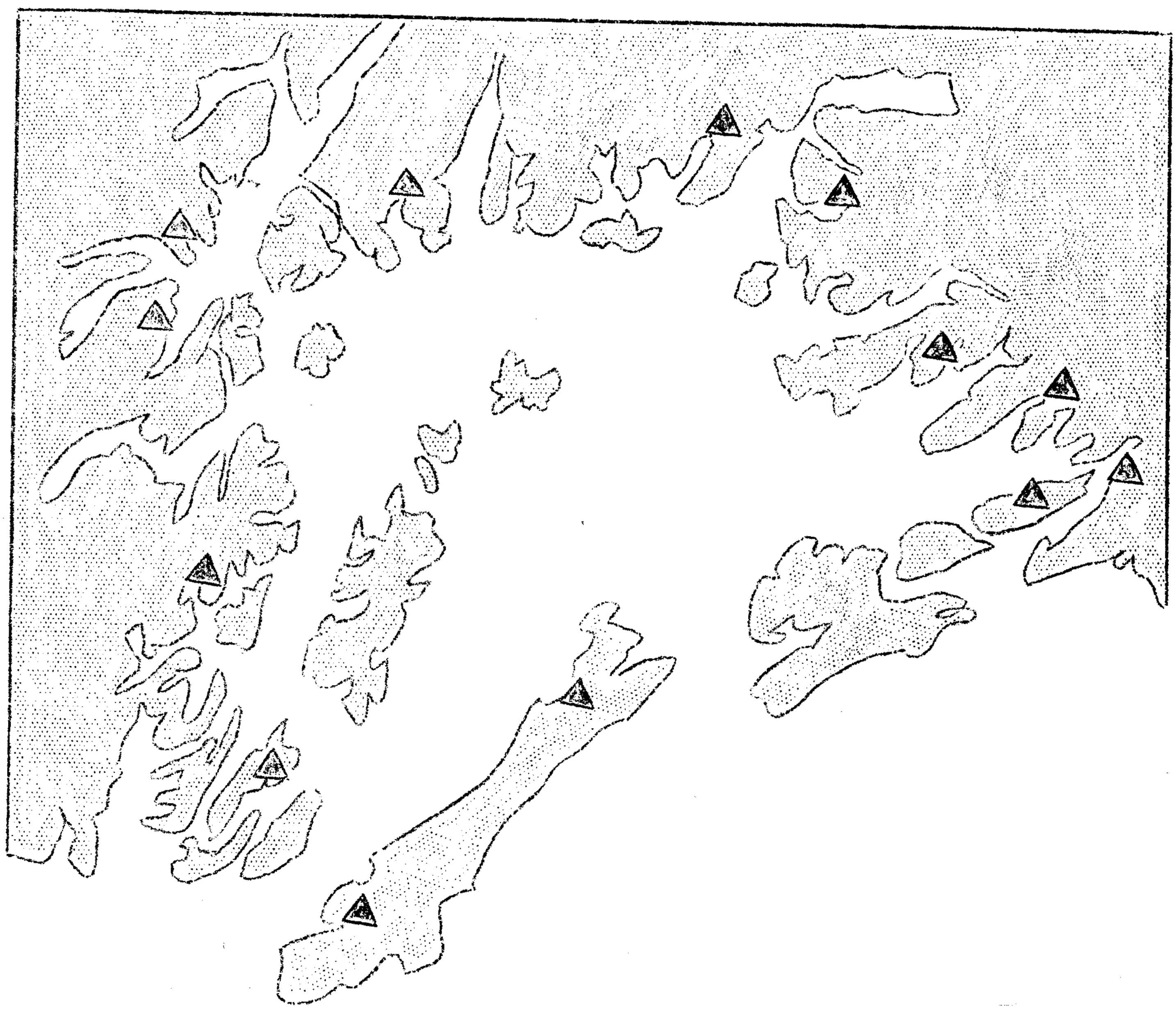

Figure 3. Location of 13 streams sampled each of the years 1961, 1962, 1963, and 1964.

William Sound. The streams sampled in 1964 are shown in Figure 4, the location of these streams is almost identical to the streams sampled in 1961, 1962, and 1963 as shown in Figures 5, 6, and 7 respectively; thus, providing excellent comparison among years. While the primary objective of the program has been to enumerate live alevins for use in forecasting subsequent adult runs, the number of dead eggs from mortalities occurring during fall and mid-winter and the number of dead alevins from relatively recent late-spring mortalities were recorded each year.

II. ANALYSIS OF THE DATA

This report is concerned with an analysis of the data on the number of dead alevins, since this category alone would include mortalities associated with seismic activity, and consequently, indicate whether the 1964 alevins suffered a significantly higher mortality. In this analysis the multiple range test developed by David B. Duncan and extended to group means with unequal numbers of replications by Clyde Y. Kramer is used to test for significant differences among alevin mortalities for the years 1961, 1962, 1963, and 1964 (Duncan, 1955; Kramer, 1956).

The procedure for the application of this test consists of the following four stages:

(1) Determine the standard error of the yearly means, s.

(2) Determine the "shortest significant range," R_p, by multiplying the standard error of the yearly means, s, by a given value, $Z_{p,n}$, obtained from Duncan's table of "significant studentized ranges." In Duncan's terminology, n is the degrees of freedom of the error mean square and p = 1,2,...,t is the number of means concerned.

(3) Rank the means from low to high.

(4) Test the differences in the following order: largest minus smallest, largest minus second smallest, ..., largest minus second largest, then second largest minus second smallest, and so on down to second smallest minus smallest. Each difference is declared significant if it exceeds the corresponding shortest significant range, R_p, otherwise it is declared nonsignificant.

Before statistical tests were applied the number of dead alevins found in each sampling dig were adjusted for the number of live alevins and then, in order to satisfy the requirements of homogeneity of variance, the adjusted number of dead alevins were transformed logorithmically. All computations and tests were performed using the transformed data.

The original data, adjusted data, and transformed data is listed in Tables 2, 3, 4, and 5. The results of computations are listed in Table 6.

Figure 4. Location of streams sampled in 1964.

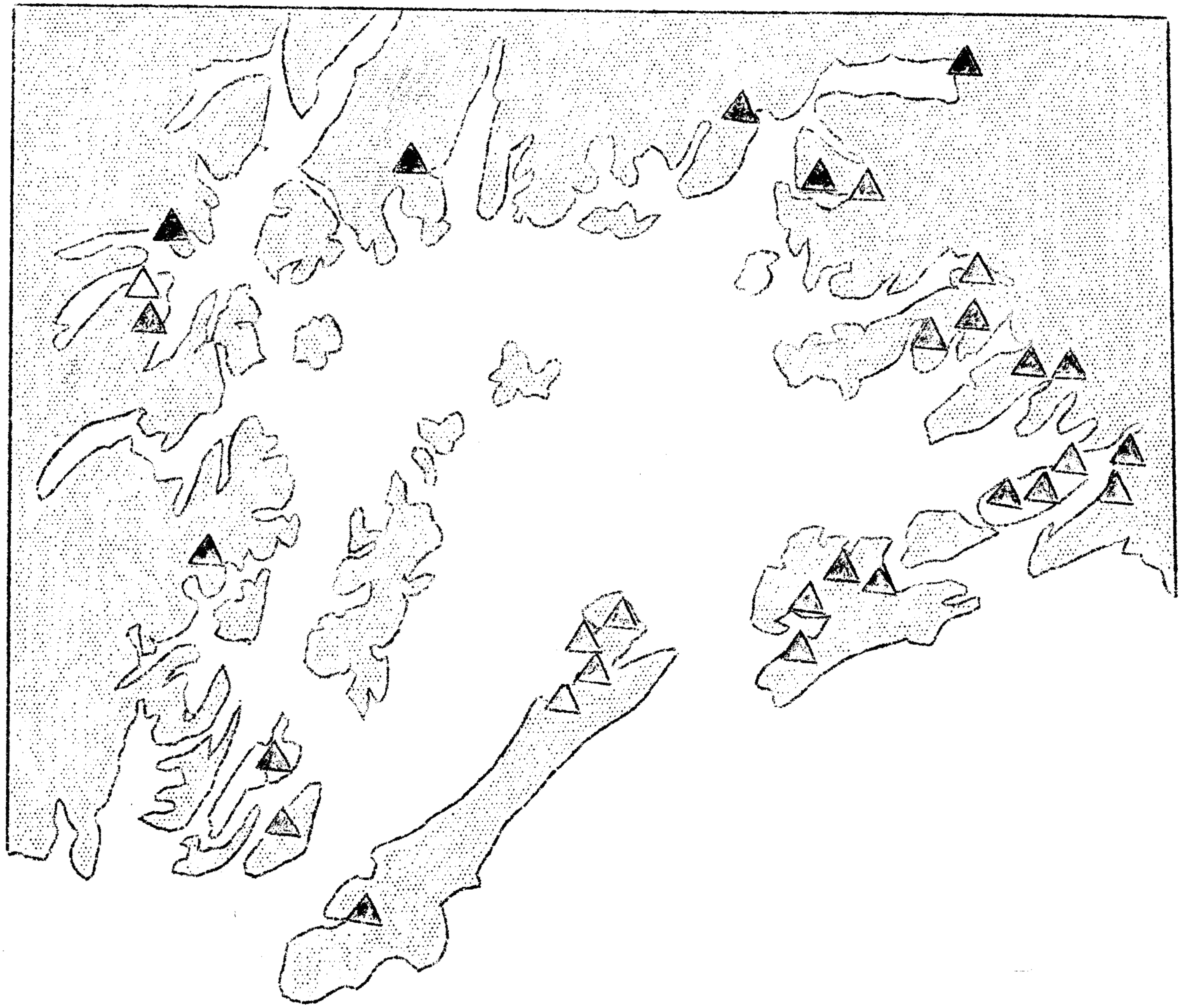

Figure 5. Location of streams sampled in 1961.

Figure 6. Location of streams sampled in 1962.

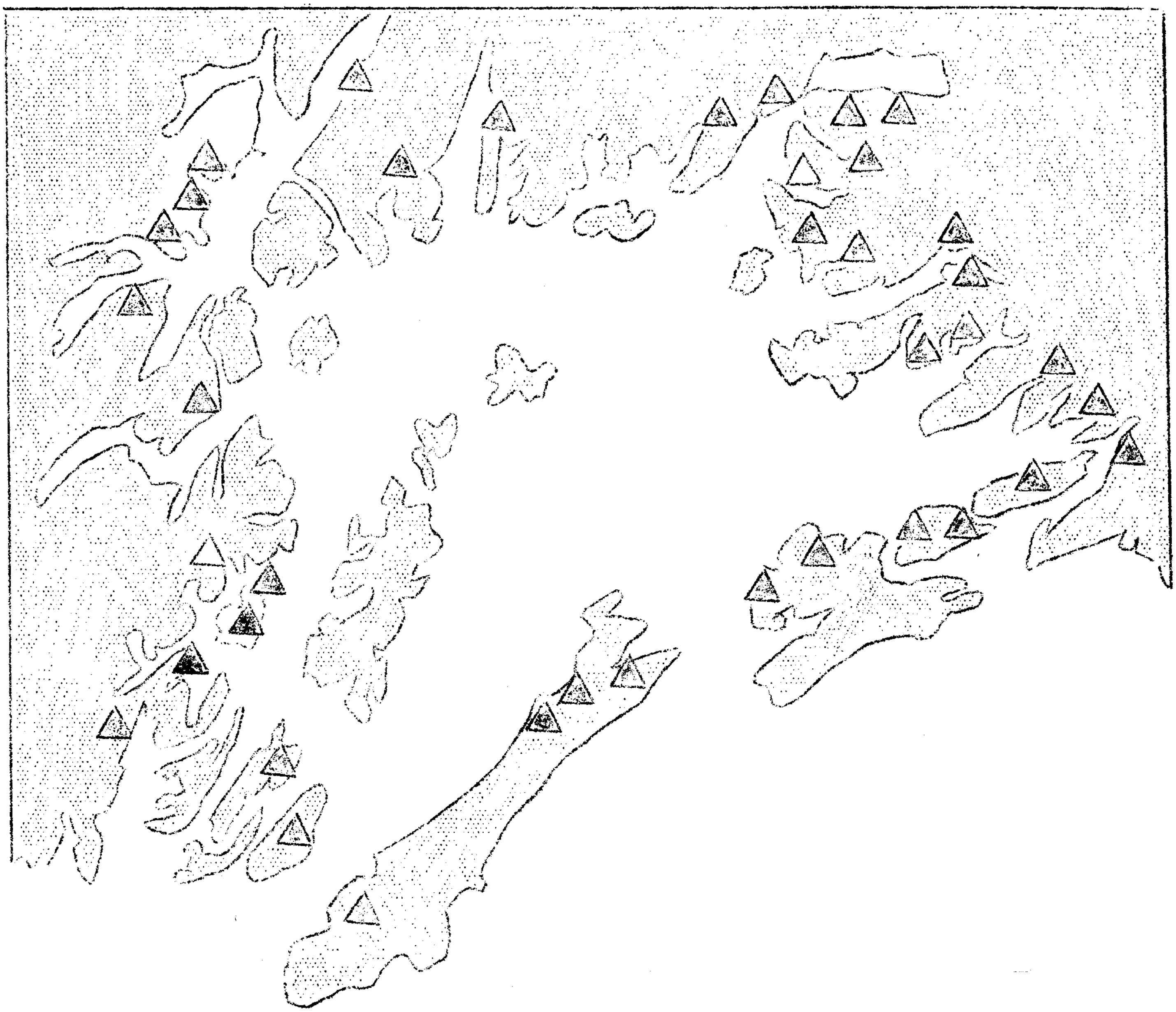

Figure 7. Location of streams sampled in 1963.

Table 2. 1961 pink salmon alevin sampling results.

Stream	Number of Samples	Number of Dead Alevins	Number of Live Alevins	D	Log D
8	17	4	4,681	9.5379	0.978997
11	19	8	5,766	14.855	1.171873
35	18	4	9,016	5.4346	0.735168
36	22	13	7,233	18.941	1.277403
52	22	0	3,791	1	0
80	27	0	1,830	1	0
116	18	1	7,298	2.3701	0.374766
117	29	1	5,524	2.8010	0.447313
143	20	1	3,171	4.1526	0.618320
153	25	0	2,554	1	0
264-2	27	107	6,879	154.16	2.187972
432	29	3	3,948	8.5930	0.934145
451	13	4	2,975	14.427	1.159176
455	17	0	6,195	1	0
604	16	0	2,039	1	0
666	24	0	5,164	1	0
673	17	1	6,403	2.5615	0.408495
707	18	0	3,122	1	0
745	14	0	2,163	1	0
747	12	1	809	13.346	1.125351
749	15	37	4,363	85.091	1.929884
759	11	12	6,091	20.662	1.315172
806	20	0	5,906	1	0
815	22	0	1,201	1	0
829	20	2	4,536	5.4072	0.732972
834	20	0	2,775	1	0
856	7	0	3,685	1	0
861	17	21	10,289	21.369	1.329784
863	12	0	4,796	1	0

$$D = \left(\frac{\text{No. of Dead Alevins}}{\text{No. of Dead + No. Live Alevins}}\right) X 10^4 + 1$$

Table 3. 1962 pink salmon alevin sampling results.

Stream	Number of Samples	Number of Dead Alevins	Number of Live Alevins	D	Log D
11	59	0	2,752	1	0
35	45	0	314	1	0
36	28	10	2,362	43.159	1.635072
52	60	25	4,325	57.471	1.759449
83	35	0	225	1	0
88	25	0	2,105	1	0
102	17	0	31	1	0
116	31	10	1,698	59.548	1.774867
117	53	0	4,011	1	0
123	28	0	2,099	1	0
153	45	17	2,326	73.557	1.866624
264-2	40	1	164	61.606	1.789624
430	36	34	5,014	68.353	1.834758
432	65	3	2,591	12.565	1.099163
451	35	0	502	1	0
455	36	0	55	1	0
604	22	0	1,520	1	0
630	40	91	5,670	158.96	2.191288
666	44	0	959	1	0
673	27	0	231	1	0
707	51	590	2,657	1818.1	3.259618
744	20	0	1,057	1	0
745	23	0	4	1	0
749	27	0	2,260	1	0
759	33	2	2,325	9.5948	0.982036
815	38	0	2,374	1	0
834	2	0	500	1	0
861	41	1	1,396	8.1582	0.911595
863	24	1	799	13.500	1.130334

$$D = \left(\frac{\text{No. of Dead Alevins}}{\text{No. of Dead + No. Live Alevins}} \right) \times 10^4 + 1$$

Table 4. 1963 pink salmon alevin sampling results.

Stream	Number of Samples	Number of Dead Alevins	Number of Live Alevins	D	Log D
11	45	22	3,238	68.485	1.835596
35	49	4	1,286	32.008	1.505259
52	32	0	3,627	1	0
80	40	0	24	1	0
87	27	0	236	1	0
99	27	2	1,686	12.848	1.108835
112	11	1	144	69.966	1.844887
117	24	0	1,860	1	0
123	27	0	6,902	1	0
131	13	0	1,220	1	0
133	17	0	949	1	0
152	12	0	596	1	0
153	50	0	4,937	1	0
241	45	1	4,276	3.3381	0.523499
264-2	35	38	2,388	157.64	2.197666
322	55	0	936	1	0
414	30	0	642	1	0
428	11	0	2.038	1	0
430	43	0	3,787	1	0
455	25	8	4,919	17.237	1.236461
480	32	0	1,799	1	0
604	30	0	3,083	1	0
621	25	0	949	1	0
628	30	4	4,432	10.017	1.000736
630	38	30	3,978	75.850	1.879956
632	20	0	625	1	0
666	34	1	2,606	4.8358	0.684468
677	15	1	4,010	3.4931	0.543211
707	29	5	2,806	18.787	1.273858
744	20	0	977	1	0
745	30	0	907	1	0
770	34	15	1,294	115.59	2.062920
817	29	31	420	688.36	2.837816
828	26	1	351	29.409	1.468480
847	37	1	2,032	5.9188	0.772233
850	24	2	1,168	18.094	1.257535
861	26	0	725	1	0
863	28	0	1,704	1	0

$$D = \left(\frac{\text{No. of Dead Alevins}}{\text{No. of Dead + No. Live Alevins}}\right) X\, 10^4 + 1$$

Table 5. 1964 pink salmon alevin sampling results.

Stream	Number of Samples	Number of Dead Alevins	Number of Live Alevins	D	Log D
21	22	0	1	1	0
35	66	2	2,103	10.501	1.021230
36	46	9	3,372	27.619	1.441207
52	38	1	2,338	5.2753	0.722247
80	37	8	125	602.50	2.779957
83	36	1	56	176.44	2.246597
87	26	1	675	15.793	1.198465
116	67	32	3,431	93.405	1.970370
117	38	2	1,745	12.448	1.095099
123	30	0	419	1	0
133	18	0	50	1	0
153	65	80	4,946	160.17	2.204581
241	33	40	1,346	289.60	2.461799
264-3	32	20	780	251.00	2.399674
322	100	548	4,537	1,078.7	3.022902
428	12	116	208	3,581.2	3.554028
430	61	2,474	688	7,825.2	3.893495
455	29	17	1,816	93.744	1.971943
480	27	175	1,142	1,329.8	3.123787
604	29	6	2,146	28.881	1.450612
630	28	30	2,430	122.95	2.089730
666	23	0	972	1	0
707	50	138	2,935	450.07	2.653280
744	20	0	66	1	0
745	35	33	186	1,507.8	3.178056
749	31	0	929	1	0
770	31	177	739	1,933.3	3.286300
815	45	0	1,433	1	0
861	46	0	867	1	0

$$D = \left(\frac{\text{No. of Dead Alevins}}{\text{No. of Dead + No. Live Alevins}}\right) X 10^4 + 1$$

Table 6. Computations using adjusted and transformed alevin mortalities.

Year	1961	1962	1963	1964	Grand Sum
# of streams	29	29	30	29	125
Yearly sum	16.672835	20.244655	24.033724	47.786106	108.737320
Yearly sum of observations squared	21.361730	38.725240	40.466518	124.693358	225.246846
Yearly mean	0.595458	0.723023	0.649560	1.706647	0.870

The error mean square, s^2, is:

$$s^2 = \frac{1}{\Sigma n_j(\Sigma n_j - 1)} \quad [\Sigma n_j \; \Sigma\Sigma \; X_{ij}^2 - (\Sigma\Sigma \; X_{ij}{}^2)]$$

where X_{ij} is observation i in years j and n_j is the number of streams surveyed in year j. Hence,

$$s^2 = \frac{1}{(125)\ (124)} \quad [(125)\ (225.246846) - (108.737320)^2]$$

$$= 1.053681.$$

The standard error of the yearly means is:

$$s = \sqrt{1.053681} = 1.02648 \text{ round to } 1.026$$

Values of $Z_{p,n}$ obtained from Duncan's Tables for a 5% Multiple Range test are:

order of comparison, p :	(2)	(3)	(4)
value from tables, $Z_{p.n.}$:	2.89	3.04	3.12

The values, $Z_{p,n}$, are multiplied by the standard error of the yearly means, s = 1.026, to obtain the appropriate shortest significant range factor, R_p;

p:	(2)	(3)	(4)
R_p:	2.97	3.12	3.20

Let the years 1961, 1962, 1963, and 1964 be designated by the numerals 1, 2, 3, and 4 respectively, then ranking the yearly means from highest to lowest,

year:	1964	1962	1963	1961
designation:	4	2	3	1
mean:	1.707	0.723	0.650	0.595

the tests for significant differences are:

In order for the mean difference between 1964 and 1961 to be significant

$$(\text{mean}_4 - \text{mean}_1) \qquad \sqrt{2\frac{(n_4)\ (n_1)}{n_4 + n_1}}$$

must exceed $R_4 = 3.20$

$$(1.707 - 0.595)\sqrt{2\,\frac{(29)\ (29)}{29 + 29}} = 5.988$$

which is greater than 3.20, therefore 1964 had a higher alevin mortality than 1961.

In order for the mean difference between 1964 and 1963 to be significant

$$(\text{mean}_4 - \text{mean}_3)\sqrt{2\,\frac{(n_4)\ (n_3)}{n_4 + n_3}}$$

must exceed $R_3 = 3.12$.

$$(1.707 - 0.650)\sqrt{2\,\frac{(29)\ (38)}{29 + 38}} = 6.062$$

which is greater than 3.12, therefore 1964 had a higher alevin mortality than 1961.

In order for the mean difference between 1964 and 1962 to be significant

$$(\text{mean}_4 - \text{mean}_2)\sqrt{2\,\frac{(n_4)\ (n_2)}{n_4 + n_2}}$$

must exceed $\$_2 = 2.97$

$$(1.707 - 0.723)\sqrt{2\,\frac{(29)\ (29)}{29 + 29}} = 5.299$$

which is greater than 2.97, therefore 1964 had a higher alevin mortality than 1962.

In order for the mean difference between 1962 and 1961 to be significant.

$$(\text{mean}_2 - \text{mean}_1)\sqrt{2\,\frac{(n_2)\ (n_1)}{n_2 + n_1}}$$

must exceed $R_3 = 3.12$.

$$(0.723 - 0.595)\sqrt{2\,\frac{(29)\ (29)}{29 + 29}} = 0.689$$

which is less than 3.12, therefore 1962 and 1961 did not have a significant difference in alevin mortality.

In order for the mean difference between 1962 and 1963 to be significant

$$(\text{mean}_2 - \text{mean}_3)\sqrt{2\,\frac{(n_2)\ (n_3)}{n_2 + n_3}}$$

must exceed $R_2 = 2.97$.

$$(0.723 - 0.650) \sqrt{2 \frac{(29)\ (38)}{29 + 38}} = 0.419$$

which is less than 2.97, therefore 1962 and 1963 did not have a significant difference in alevin mortality.

In order for the mean difference between 1963 and 1961 to be significant

$$(\text{mean}_3 - \text{mean}_1) \sqrt{2 \frac{(n_3)\ (n_1)}{n_3 + n_1}}$$

must exceed $R_2 = 2.97$.

$$(0.650 - 0.595) \sqrt{2 \frac{(38)\ (29)}{38 + 29}} = 0.315$$

which is less than 2.97, therefore 1963 and 1962 did not have significant difference in alevin mortality.

These results may be concisely arranged as follows:

year:	1961	1962	1963	1964
mean alevin mortality:	0.595	0.723	0.650	1.707

(A single line underscores 0.595, 0.723 and 0.650.)

where any two means not underscored by the same line are significantly different. Therefore, it is seen that the 1964 alevin mortality is significantly higher than that for the years 1961, 1962, and 1963 but the years 1961, 1962, and 1963 are not significantly different.

III. ENVIRONMENTAL CAUSES OF MORTALITY TO ALEVINS

It has been established that alevins suffer mortality from movement and mechanical disturbances of spawning gravel beds (Coble, 1960, Gangmark and Bakkala, 1960) from rapid stream runoff and erosion of the stream beds with the resultant deposition of silt and sand (Gangmark and Bakkala, 1960) (Gangmark and Broad, 1956). Additional factors which have been shown to cause mortality of deposited eggs and alevins are water level changes and fluctuating water flows (Wickett, 1958). From this work it may be definitely concluded that factors relating to the condition of the stream gravel and events taking place in the gravel have a critical influence on the survival of eggs and alevins in the gravel.

IV. THE RELATION OF THE EARTHQUAKE TO CAUSES OF ALEVIN MORTALITY

During the occurrence of the most severe seismic activity this cycle of pink salmon was in the alevin life phase occupying stream gravels and susceptible to the mortality causes mentioned above. Detrimental seismic effects extended for several weeks. Following the initial earthquake a great number of relatively severe after shocks were recorded. The epicenter of the initial earthquake was in Prince William Sound and those of the after shocks principally along a line between Prince William Sound and Kodiak Island as shown in Figure 8. (Preliminary Report Prince William Sound Alaskan Earthquakes March-April 1964).

The most obvious changes appear on land features, especially areas of uplift and subsidence in the vicinity of streams. The extent of these changes is shown in Figure 9. The intertidal zones used for spawning are now changed in nearly all streams (personal observation W. Noerenberg). It has been found (Noerenberg, 1964) that these intertidal and lower upstream areas make up most of Prince William Sound spawning gravel and these spawning gravels are especially subject to damage from abnormal tide and wave action.

The 1964 field observations indicated alevin mortalities from at least three sources:

(1) Mechanical kills from gravel shifting and shaking during earth movement.

(2) Siltation from deposition of mud and sand from stream deltas by seismic waves, and

(3) Massive destruction of stream beds from tsunamic action.

This report, however, analyzes additional mortalities resulting only from sources (1) and (2).

V. FUTURE CONSEQUENCES OF THE INCREASED ALEVIN MORTALITY

The relation of natural large-scale catastrophes to subsequent salmon returns has been reported in many studies (notably Neave, 1953; Wickett, 1958). These catastrophic physical causes may be considered to have physical effects, and the relationship is such that when causes are adequately known effects can be reliably predicted. Therefore, using the data presented in this study, an estimate can be formed of the consequences the March-April seismic occurrences will produce on this cycle of pink salmon returns to Prince William Sound.

The pre-emergent alevin index has been the most efficient index for use in forecasting future pink salmon returns to Prince William Sound (Noerenberg, 1964). Table 7 gives the indices and returns for the years 1958 to 1964 except for 1960. The regression of return on alevin index computed from this table is

$$R = 565.555 + 266.762\ A$$

where,

R is the return in thousands of pink salmon, and

A is the alevin index.

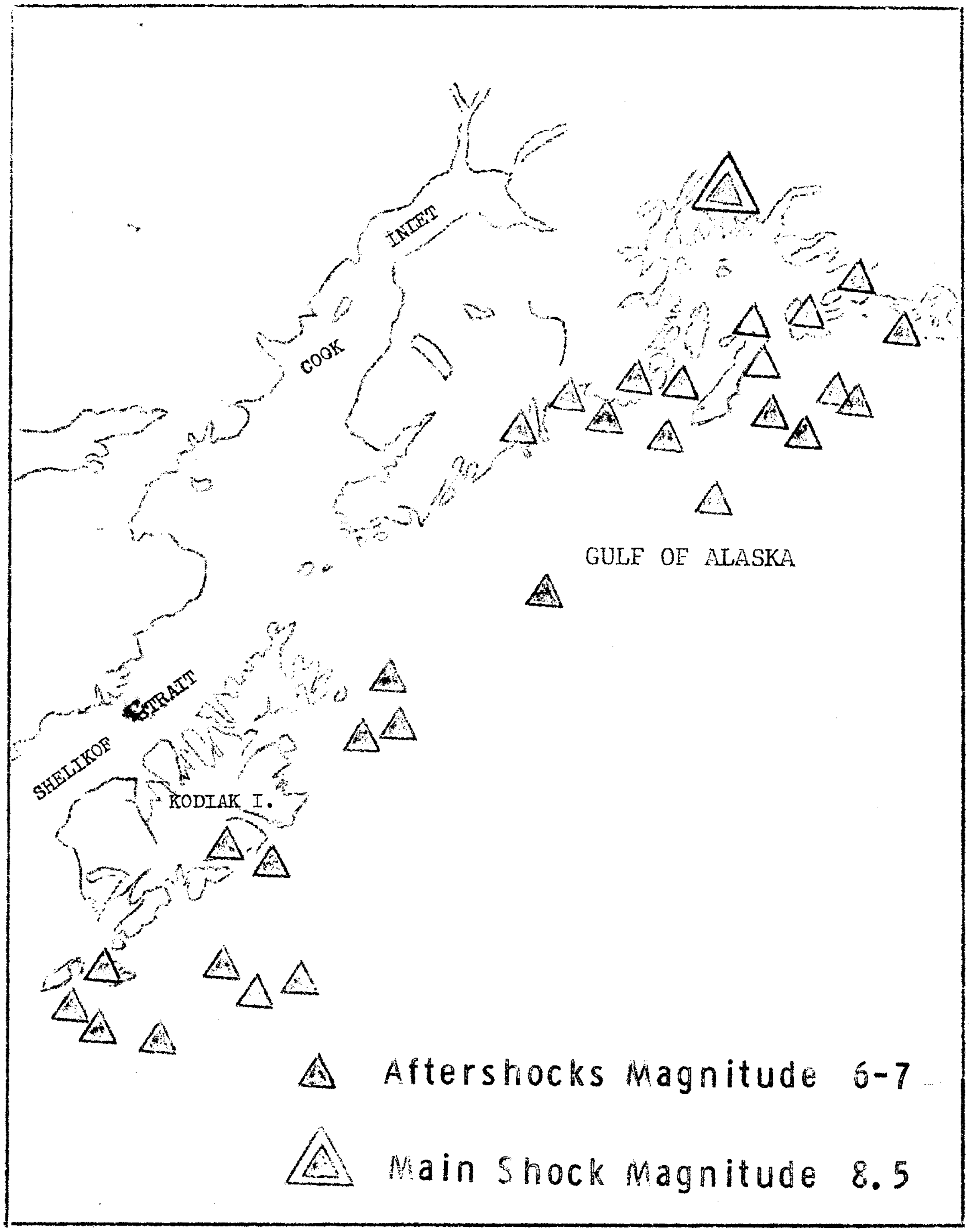

Figure 8. Epicenter map Prince William Sound earthquake of March 28, 1964 and aftershocks.

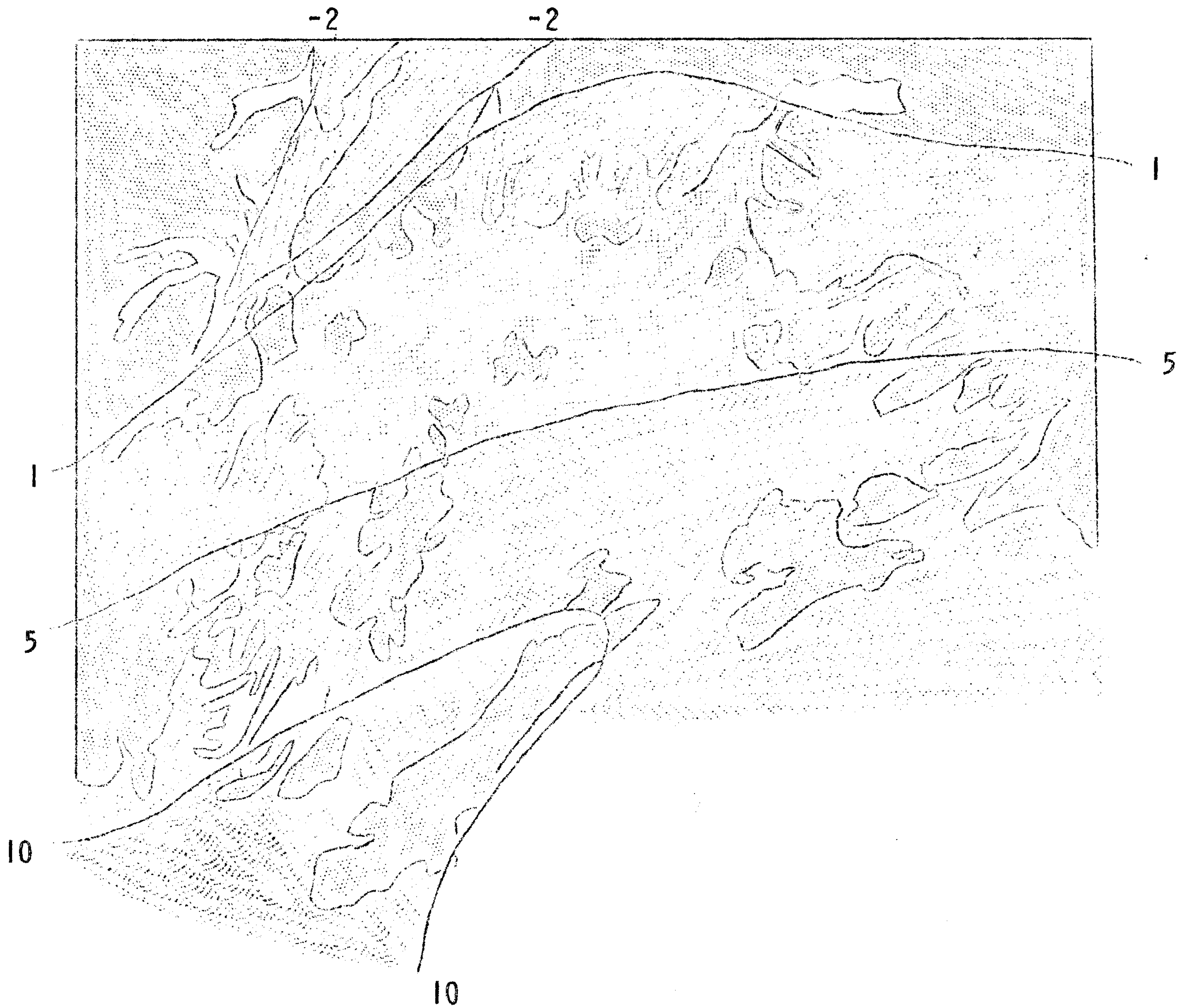

Figure 9. Uplift and subsidence in Prince William Sound.

Table 7. Pre-emergent alevin indices and returns for Prince William Sound pink salmon.

Spring of Sampling	Alevins per Square Foot[1]	Returns One Year After Sampling (in thousands)
1958	2.13	601
1959	9.94	3,190
1961	30.67	8,822
1962	16.48	6,700
1963	23.57	5,600[2]
1964	12.37	3,865[3]

1 Intertidal and upstream zones for all streams sampled.

2 Estimated return for 1964 as of August 21, 1964.

3 Predicted return for 1965 obtained from equation R=565.555 + 206.762 A. This is a preliminary prediction and its use in this report is to show the estimated magnitude of pink salmon loss due to the earthquake.

Source: Noerenberg, 1964; Noerenberg, Roys field sampling 1964.

Using this equation and the 12.37 alevin index the forecasted return in 1965 would be 3,865,000 pink salmon. However, the 12.37 index figure is lower than normal because of the earthquake effects. If the average percent live alevins for the years 1961, 1962, and 1963 is taken as the expected percent life alevins for any year, the percent live alevins in 1964 can be adjusted to this figure and an adjusted index can be computed which would be the expected index if there were no earthquake effects.

The average percent live alevins for the years 1961, 1962, and 1963 is 99.57. The percent live alevins for 1964 is 93.24. The adjusted index for 1964 is,

$$\text{adjusted index} = \frac{(99.57)\ (12.37)}{(93.24)} = 13.21.$$

The expected return for 1964 if there were no earthquake effects is,

$$R = 565.555 + 266.762\ (13.21)$$

$$= 4{,}100{,}000 \text{ pink salmon.}$$

These results are shown in Figure 10. The estimated loss occasioned by the earthquake effects can be estimated as

$$4{,}100{,}000 - 3{,}865{,}000 = 235{,}000$$

pink salmon in the 1965 returns.

ACKNOWLEDGMENTS

The writers are particularly indebted to Robert S. Roys for consultation, field work, and helpful review of the report. Acknowledgment is also extended to our statistical clerk, Mrs. Wanda J. Brown, who diligently worked on the computations, typing of tables, and drawing of the figures.

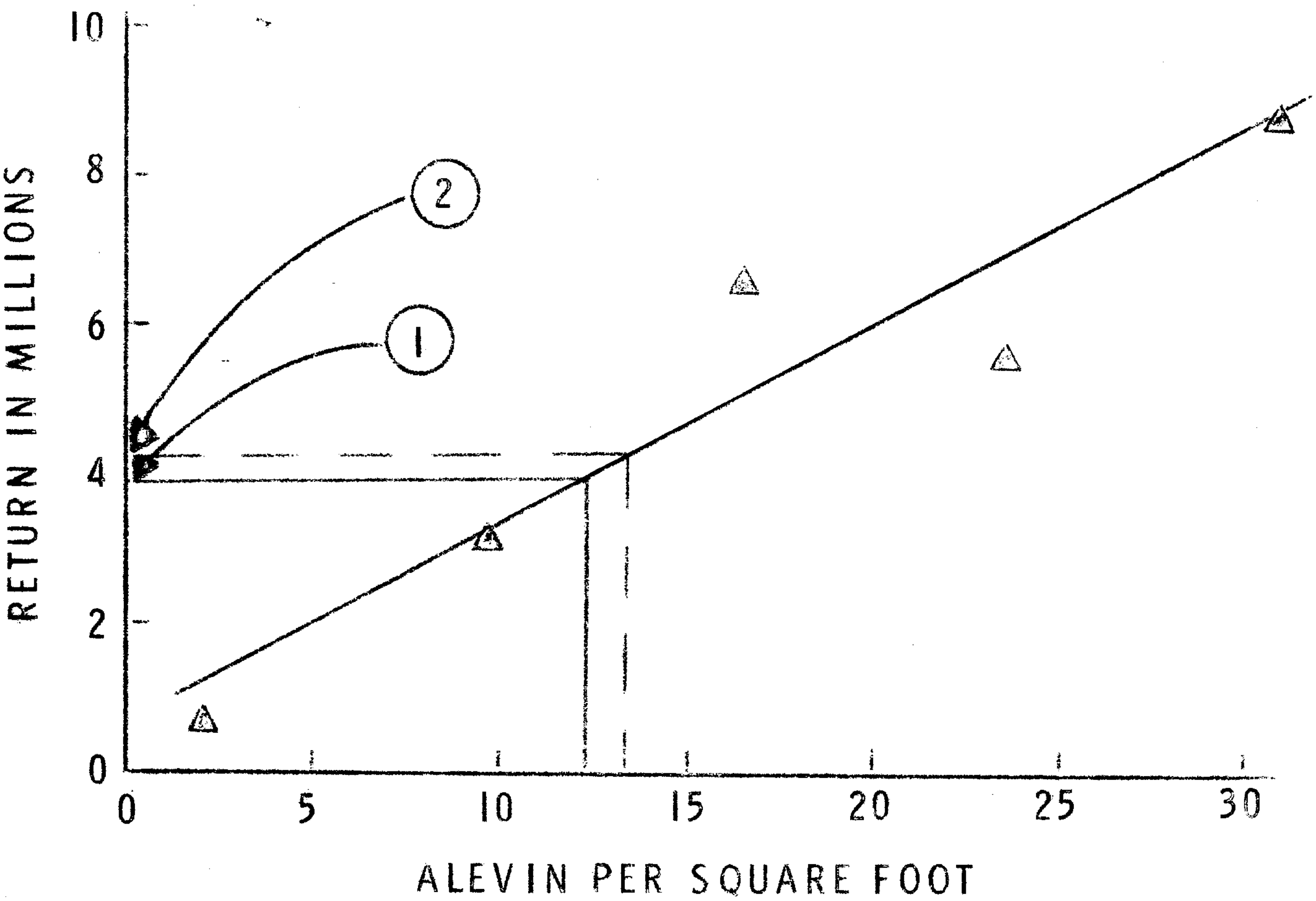

Figure 10. Relation of alevin abundance to return one year later.

(1) Expected return of 3,865,000 fish in 1965.

(2) Expected return of 4,100,000 fish in 1965 if earthquake effects were removed.

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