Studies of eelgrass areas in California during the past winter and spring indicate that the depleted condition first apparent in 1940, and last year reported as becoming serious to brant in some of the bays, had undergone general improvement by the spring of 1942. Most California localities reported greater abundance of the plant than in the previous year and more normal behavior of the brant, a probable result of this increase in their favorite food. In some localities, notably Bodega Bay, eelgrass conditions were still poor. Presence of the disease was observed in the eelgrass of Morro Bay and further substantiated by examination of samples from the area, yet almost record numbers of brant were recorded from the locality, where their behavior was observed to be quite normal. In spite of *Labyrinthula* being found in a sample of eelgrass collected in Mission Bay in March, 1942, the most luxuriant local growths of this plant in several years were observed, together with a record number of brant.

The above results make it difficult, with the information at hand, to reconcile brant abundance with eelgrass depletion, also to predict the course of the present infection of our eelgrass by *Labyrinthula*. It is certain that the disease is present in many of our bays and also in several bays in Oregon, but the effect of the organism upon Pacific Coast eelgrass appears to be mild indeed when compared to the disastrous results wrought upon stands of the plant on the Atlantic Coast ten years ago.

It is hoped that even during the present war period local observers, bearing in mind the possible critical effects of further eelgrass depletion upon the brant, may have opportunity to make occasional observations on both plants and birds.

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THE EFFECT OF MINING SILT ON YIELD OF FRY FROM SALMON SPAWNING BEDS[1]

By PAUL A. SHAW and JOHN A. MAGA, *Pollution Detail, California Division of Fish and Game*

Introduction

The silting of stream beds from mine tailings has long been regarded as deleterious to the development of salmon spawn, but little data have been available to show the extent of this damage. Ellis (1937), a recognized authority on stream pollution, states that "erosion silt and other suspensoids affect fisheries directly by covering the bottom of the stream with a blanket of material which kills out the bottom fauna, greatly reduces the available food, and covers nests and spawning grounds * * *." On the other hand, a study sponsored by the Oregon State Department of Geology and Mineral Industries (Ward, 1937-1938) asserts that mining activity was not found to be damaging to fish life on the Rogue River. This latter publication has been extensively quoted in California to combat control measures advocated by recreational groups and the Division of Fish and Game in the interest of clean streams and conservation of aquatic life.

In view of the extensive mining activity along trout streams and within watersheds that are essential to the maintenance of California salmon and steelhead, an experimental study was conducted to aid in settling the existing controversy and establish a factual basis for adequate but just enforcement action.

The experiments were conducted between January 7th and April 15, 1941, at the Brookdale Fish Hatchery, Santa Cruz County, California, and were planned in a manner to determine the yield of fry from salmon eggs in gravel nests subjected to mining silt as compared to the yield from similar nests without silt additions.

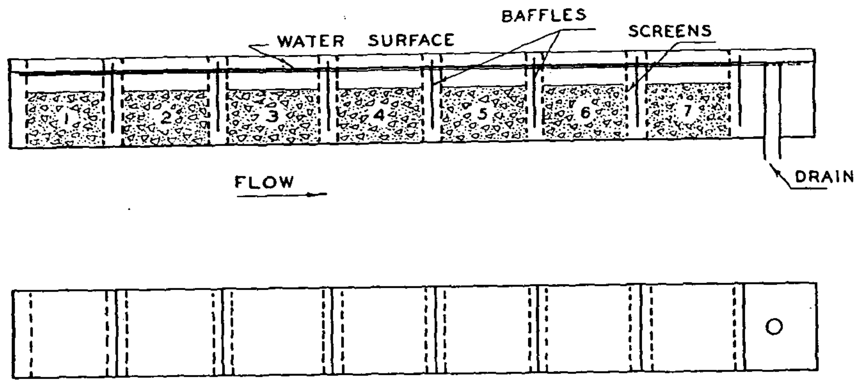
While the authors planned and supervised the investigations here recorded, they are greatly indebted to the late James L. Stinnett, hatchery foreman, and James Hinze, fish hatchery assistant, for aid in all phases of the work. These men handled the spawning operations, conducted a basket hatch control, and carried out the daily work of adding silt, adjusting water flows, recording temperatures, and collecting and counting fry as they emerged from each gravel nest. Leo Shapovalov, senior fisheries biologist, supervised the handling, counting and placing of the fertilized eggs in the gravel beds. Warden Donald Hall, of the Pollution Detail, located the site for collection of the mining silt, and personnel from the Central Valleys Hatchery transported the necessary amount from the Cosumnes River watershed to the Brookdale Hatchery.

[1] Submitted for publication October, 1942.

Experimental Procedure

Construction of Gravel Beds

Three standard hatchery troughs were each divided into seven nests 16″ wide and 20″ long by installing ¼″ wire screens on the upstream side and ⅛″ wire screens on the downstream side. A space of 4″ was left between nests. The finer mesh prevented loss of gravel or passage of fish to adjacent nests while the larger mesh permitted access of the emerging fry to the upstream space between nests where they could be caught and counted more readily. Baffles were placed between nests to force the water downward through the nests and prevent short circuiting above the gravel. Figure 11 shows a cross section of one trough to illustrate the arrangement more clearly. Gravel which had been secured from the San Lorenzo River bottom and freed of silt by washing on an ordinary window screen was placed in the 21 nests to a depth of one to two inches.



LONGITUDINAL SECTION & PLAN SHOWING GRAVEL BED ARRANGEMENT OF ONE TROUGH

FIG. 11

Spawning

A total of 37,700 silver salmon eggs (*Oncorhynchus kisutch*) measuring 198 per ounce were taken from 17 females at the San Lorenzo egg collecting station on January 7, 1941. The eggs were fertilized in the usual manner and covered with water in a 10-gallon fish planting can where they were allowed to harden for one hour before transportation to the hatchery.

Distribution of Eggs

The eggs were thoroughly mixed so that each experimental group would be uniform in character. Groups of 500 eggs were then counted and placed on the gravel in each of the 21 nests. The eggs were then covered by three to four inches of similar gravel and the trough drains arranged to maintain one to two inches of water above this level. In a

fourth trough 13,600 additional eggs were placed in each of two standard hatching baskets for determining the time of hatch and yield of fry under the usual hatchery procedure.

Addition of Mining Silt

The seven nests of Trough 1 received only the hatchery supply of water without addition of mining silt and served as a control for determining the yield of fry from salmon eggs in unsilted gravel beds, and also provided a comparison with the normal basket hatch.

For producing turbidity in the 14 nests of Troughs 2 and 3, wet mining silt was secured from the settling ponds of the Pacific Placers Engineering Company on Arkansas Creek, a tributary of the Cosumnes River. This material was typical of the fine silt and slimes discharged by gold dredging operations in many California mining areas. Figure 12 is a photograph showing the crew collecting this material.

FIG. 12. Crew collecting mining silt for experiment.

Two to three buckets of the wet slimes were agitated in a barrel of water by means of a recirculating pump and the addition of a small stream of water from the hatchery supply produced a muddy overflow which was led to the desired point of application by a small wooden flume installed between experimental Troughs 2 and 3. Fed in the manner described, the above quantity of silt lasted 2 to 4 hours after which the experimental nests received only hatchery water until the following day.

The silt laden water from the flume was introduced at the desired nest by boring ¾″ holes in the side of the flume. Outlets not in use were plugged with rubber stoppers. The muddy water was always added between nests and above the baffle board in order to cause mixing with the hatchery water before reaching the adjacent gravel nest.

In Trough 2 the turbid water was started above the first nest on January 7th, the initial day of the experiment. Entering at this point, the flow of water carried silt to all seven nests of the trough. During the course of the experiment the point of silt application was changed to gravel nests further downstream, thus producing turbidity in the lower nests for progressively longer periods, while the upper nests received silt only for the earlier stages of the incubation period.

The above procedure was reversed for Trough 3 in which silt was first applied to nest 7 and was progressively changed to upstream points as the period of incubation advanced. Silting was discontinued on March 20th. Thus the upper three nests did not receive silt during incubation but were subjected to silt for varying portions of the early emergence period. The four lower nests received silt during the first half of the emergence period and also were silted for progressively longer portions of the incubation period, nest 7 receiving silt from the initial day of the experiment. The period of silt addition for Troughs 2 and 3 may be visualized by referring to Figures 15 or 17.

Analyses and Records

Records were kept of water temperature, volume of flow, dissolved oxygen, pH, and suspended solids. Analyses will be found in Tables 4 and 5. In summary, the water temperature varied from 48° to 54° F.; dissolved oxygen from 10.0 to 11.8 p.p.m., and pH from 7.4 to 7.6. No appreciable difference in oxygen content was found above and below the gravel nests. The water flow in the trough containing the basket hatch was maintained at approximately 18 gallons per minute, while the flow in the three gravel bed troughs was approximately 8 gallons per minute.

Seven analyses of the suspended solids content of overflow water below the lowest nests of Troughs 2 and 3 showed an average of 1176 p.p.m. (Table 5). At the same time values for points 1-3 nests upstream showed an average of 1330 p.p.m. The average loss per nest was 83 p.p.m. While this may appear to be a high rate of deposition it should be remembered that silting was limited to 2-4 hours daily and that a gradual decrease occurred during this period from the above amount to clear hatchery water.

As fry began to appear above the gravel they were collected, counted and preserved with formaldehyde in bottles numbered to correspond to the different nests. After one hundred days, when no further fry appeared, the gravel was carefully removed from each nest in order to count and observe the condition of eggs and fry that remained in the beds.

Experimental Results

Yield of Fry—Basket Control

The salmon eggs that were handled by baskets in flowing water according to usual hatchery procedure hatched between February 12 and 14, corresponding to an incubation period of 36-38 days. The yield was 79.9%. The temperature averaged 51.3° F. for the 38 days to maximum hatch from which it may be calculated that 733 temperature units were required.

Yield of Fry—Gravel Control Nests

The first fry appeared above the gravel in six of the control nests of Trough 1 on February 27th. Assuming that the hatch time in the gravel corresponded to the basket hatch, then 13 days elapsed to first emergence of fry above the gravel. The temperature during this period averaged 51.9° F., representing an additional 259 temperature units. In the other nest (#3) the first fry appeared on March 4. Fry emerged for 44 days, until April 11, or a total of 94 days from the start of the experiment. The seven control nests yielded an average of 16.2% and a maximum of 25.4% fry from eggs (see Table 1). At the conclusion of the experiment the entire mass of gravel from each control bed was searched and the remaining eggs and fry counted. (See Table 1.)

TABLE I

Yield and Recoveries from Gravel Control Nests
(500 Salmon Eggs per Nest)

Nest	Yield of Fry		Fry and Eggs Recovered from Gravel	
	Number of Fry	Per Cent Yield	Number of Fry	Number of Eggs
1	30	6.0	36	4
2	8	1.6	3	4
3	64	12.8	5	9
4	127	25.4	24	1
5	106	21.2	12	11
6	111	22.2	7	14
7	120	24.0	35	3
Total	566		122	46
Average	81	16.2	17	7

During the incubation period several storms brought in natural sediment which tended to settle in the upper nests of the trough. Samples taken during one storm contained 50 p.p.m. of suspended solids above nest 1 and 33 p.p.m. below nest 7, indicating a deposition of 17 p.p.m. Visual observation indicated that most of this sediment, which was very dark in color, settled on the first three nests while the last four were relatively free from silt. The higher and fairly constant yield of live fry from the last four nests is therefore representative of development without appreciable silting, while the lower values from nests 1-3 represent yield of fry for gravel beds that were subject to natural silting. Previous experiments by Shapovalov (1937) on development of steelhead eggs in artificial gravel nests resulted in a yield of 29.8% during a period of storms and a yield of 79.9% in tests at a later date when storms were not prevalent. Further experiments by the same author (Shapovalov and Berrian, 1939) on development of salmon eggs in gravel resulted in the low yield of 10.2% which was attributed to silting from severe storms.

The rate of appearance above the gravel is of considerable interest and is shown in Figure 13 as the total number of fry for all seven control nests with respect to the time of emergence. The peak emergence, as shown by the slope of the curve, occurred 20-22 days after appearance of the first fry. The rate then decreased until the last fish appeared on the forty-fourth day. Table 6 includes the date and number of fish appearing from all control nests.

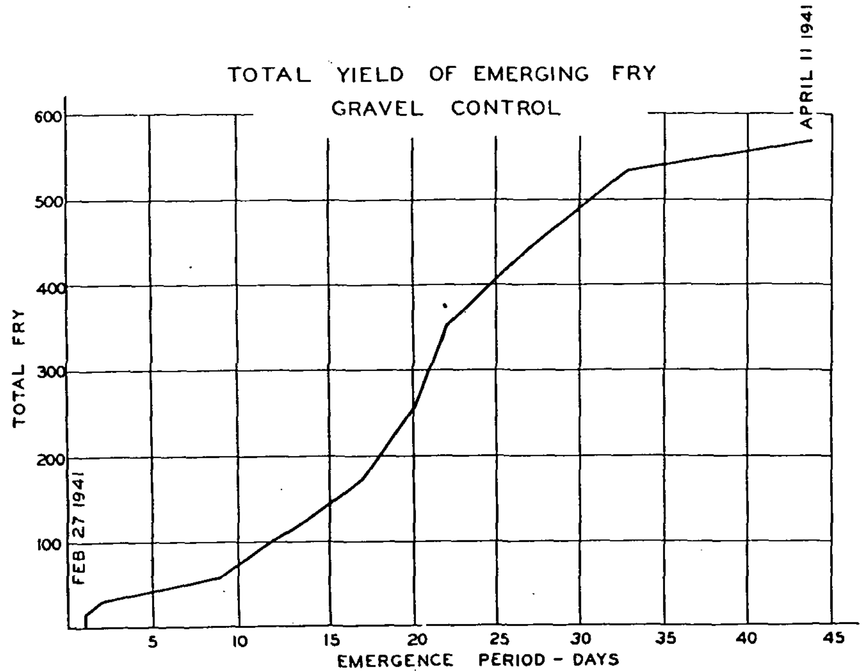


FIG. 13

In no case was the recovery of live fry plus fry and eggs in the gravel greater than 158 out of 500 originally placed in each nest. The recovery of relatively few eggs therefore indicates that undeveloped ones had decomposed and disappeared, as would be expected. The number of fry that hatched but died without working up through the gravel was relatively small.

Yield of Fry—Early Silt Addition

Table 2 shows the essential data for the seven nests of Trough 2 which received mining silt for varying time periods from the beginning of the experiment. The yield of fry from nest 7 is not included since this nest was dug into and the deposited silt flushed off on March 9th, when it was thought no fry were going to emerge from this series.

The average yield of 1.16% fry from this series is so low that comparisons between nests do not appear warranted. The outstanding fact is that silt added during the initial stages of incubation and continued for either a few days or a longer period, causes severe damage resulting in low yields of fry. The emergence of fry above the gravel

is also retarded, as a period of 19 days totalling 393 temperature units elapsed between the first appearance in the gravel controls and this series. The last fry emerged on April 15th. In general these fry were smaller and weaker than those of the control series and a number of deformities were noted.

TABLE 2

Effect of Mining Silt During Early Stages of Incubation—Trough 2

Nest	Date silt addition, 1941	Time silt addition (days)*	Date first fry appeared	Yield of fry		Recovered from gravel	
				Number	Per cent	Fry	Eggs
1	1/7-1/ 9	2	3/18	12	2.4	3	41
2	1/7-1/14	7	3/31	4	0.8	4	49
3	1/7-1/21	14	3/25	5	1.0	10	61
4	1/7-2/ 4	28	3/31	1	0.2	0	98
5	1/7-2/18	42	4/ 7	1	0.2	10	24
6	1/7-2/26	50	3/18	11	2.2	16	6
7	1/7-3/20	72				17	5
			Average	5.8	1.16		

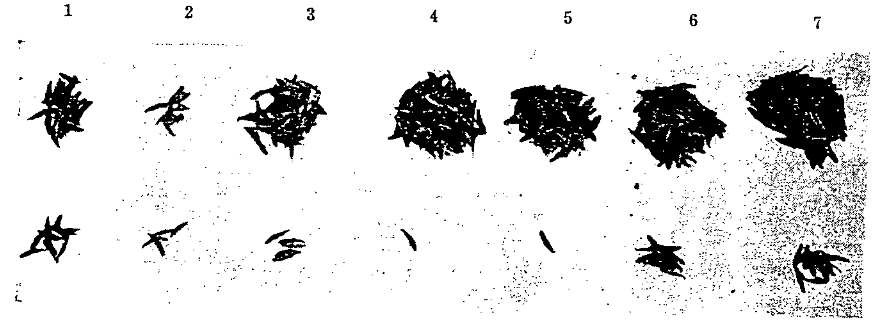
*2-4 hours daily.

The larger number of whole eggs remaining in the gravel at the conclusion of this experiment is significant as it shows a tendency for undeveloped eggs to resist decomposition apparently due to a protective coating of silt. The number of fry remaining in the gravel was small but totaled more than the fry that emerged and may therefore indicate difficulty in working through the deposited silt.

A comparison of the fry from the control nests and this series as shown in the photograph, Figure 14, reveals the striking reduction in yield from mining silt. As previously explained, the fry from nest 7, series 2 should be disregarded.

SERIES I. Control—No Silting

1 2 3 4 5 6 7



SERIES II. Mine Silt Added

FIG. 14. Showing the marked difference in yield between the Control, Series I, and Series II, with early silt addition.

Yield of Fry—Late Silt Addition

The yield of fry and the number of eggs recovered from the nests of Trough 3 follow a definite, consistent pattern and are of particular interest and significance. Table 3 shows the data for this series which received silt for varying periods of the latter portion of the incubation and emergence time.

TABLE 3

Effect of Mining Silt During Later Stages of Incubation and Emergence—Trough 3

Nest	Date silt addition, 1941	Time silt addition* (days)	Date first fry appeared	Yield of fry		Number recovered from gravel	
				Number	Per cent	Fry	Eggs
1	3/5-3/19	15	----------	----------	----------	4	10
2	2/26-3/19	22	2/28	67	13.4	2	10
3	2/18-3/19	30	3/4	42	8.4	1	12
4	2/11-3/19	37	2/28	38	7.6	0	15
5	2/4-3/19	44	3/16	8	1.6	1	39
6	1/21-3/19	58	3/4	4	0.8	0	90
7	1/7-3/19	72	----------	0	0.0	6	145

*2-4 hours daily.

In the first nest of this series only the first fry was removed, after which the others were allowed to remain in the water above the nest, as it was desired to determine the effect of turbid water on the fry. Unfortunately these fish were lost during a flood on the last day of the experiment and a count was not obtained.

The six nests of Trough 3 on which complete data were secured show a fair yield of fry when silt additions occurred only after the normal basket hatch period (nests 2 and 3). The yield steadily decreased for earlier initial dates of silt addition and nest 7, which received silt from the day the eggs were first placed in the gravel, yielded no fry. This series confirms series 2, that silt addition during the incubation period causes severe damage and indicates that silting during the last week of incubation (nest 5) may reduce the yield as much as silting during the first week, and almost as much as silting for the entire incubation period. Silting after the hatch date, but during the period the fry are working up through the gravel may reduce the yield, but the damage is not so extensive.

The eggs recovered from these nests at the conclusion of the experiment show steadily increasing numbers for earlier dates of silt addition corresponding to decreased yield of fry and further show that silt forms a coating which preserves the egg and prevents development of the fry. These eggs had faded in color but were not white and the coating with fine particles from the mine slimes was obvious. Figure 15 is a photograph showing this series of fry and eggs. As previously explained, the single fry shown for nest one should be disregarded as a total count was not obtained.

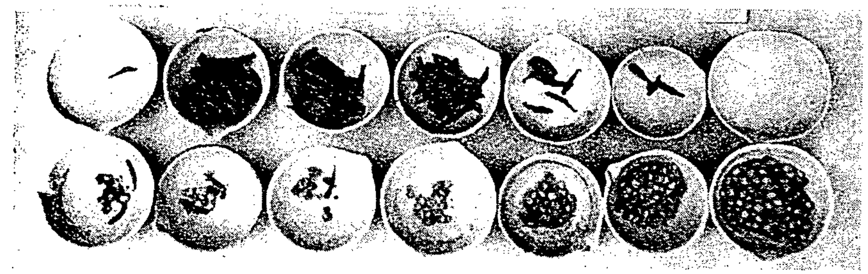
The number of fry recovered from the gravel of Trough 3 was small, apparently indicating egg damage rather than inability of the fry to work through the gravel and silt. In this connection it was observed that most fry appeared to emerge by coming through the ¼" screen into the space between nests rather than working directly upward through the deposited silt. For this reason the yields might have been still lower if finer screens had been installed on the upstream side of the gravel nests. For the total of 196 fry recovered at the conclusion of the experiment from the gravel of all 21 nests, only five

were found to be alive. In general these fry were small, poorly developed or deformed.

SERIES III

1 2 3 4 5 6 7

Fry that worked through gravel beds



Eggs and fry in beds at conclusion of experiment

FIG. 15. Showing the relation between emerging fry and silt-coated eggs remaining in the gravel of Series III. Fry in Bed 1 should be disregarded as explained in text.

The effect of silting on yield is strikingly revealed in Figure 16 which is a composite photograph showing fry that emerged from the gravel controls and all the silted nests combined with charts showing incubation, emergence and silt periods. In this connection it should be noted that the horizontal line for first emergence applies to the gravel control rather than the silted nests.

Figure 17 shows graphically the normal time of basket hatch in relation to period of emergence, time of silt additions, and yield of live fry for the 19 gravel nests on which full data were secured.

Summary, Conclusions and Recommendations

1. Salmon eggs hatched in the usual manner by placing a basket of eggs in the flowing water of a hatchery trough produced a yield of 79.9% fry with 733 temperature units.

2. Salmon eggs placed in prepared gravel beds constructed in a hatchery trough and receiving only normal hatchery water produced a maximum yield of 25.4% and an average yield of 16.2% fry. Occasional silting of the water supply due to storms may have lowered the yield. To first emergence from the gravel 992 temperature units were required.

3. Salmon eggs in prepared gravel beds that received mining silt for intervals of 2 to 72 days beginning with the initial stages of incubation produced a maximum yield of 2.4% and an average yield of only 1.16% fry. A total of 1385 temperature units were required to first emergence from the gravel. Many of the undeveloped eggs remaining in the gravel were preserved with a coating of silt. Fry that died or failed to emerge outnumbered those that worked through the gravel.

4. Salmon eggs in prepared gravel beds that only received mining silt during the emergence period produced a yield of 13.4% fry but

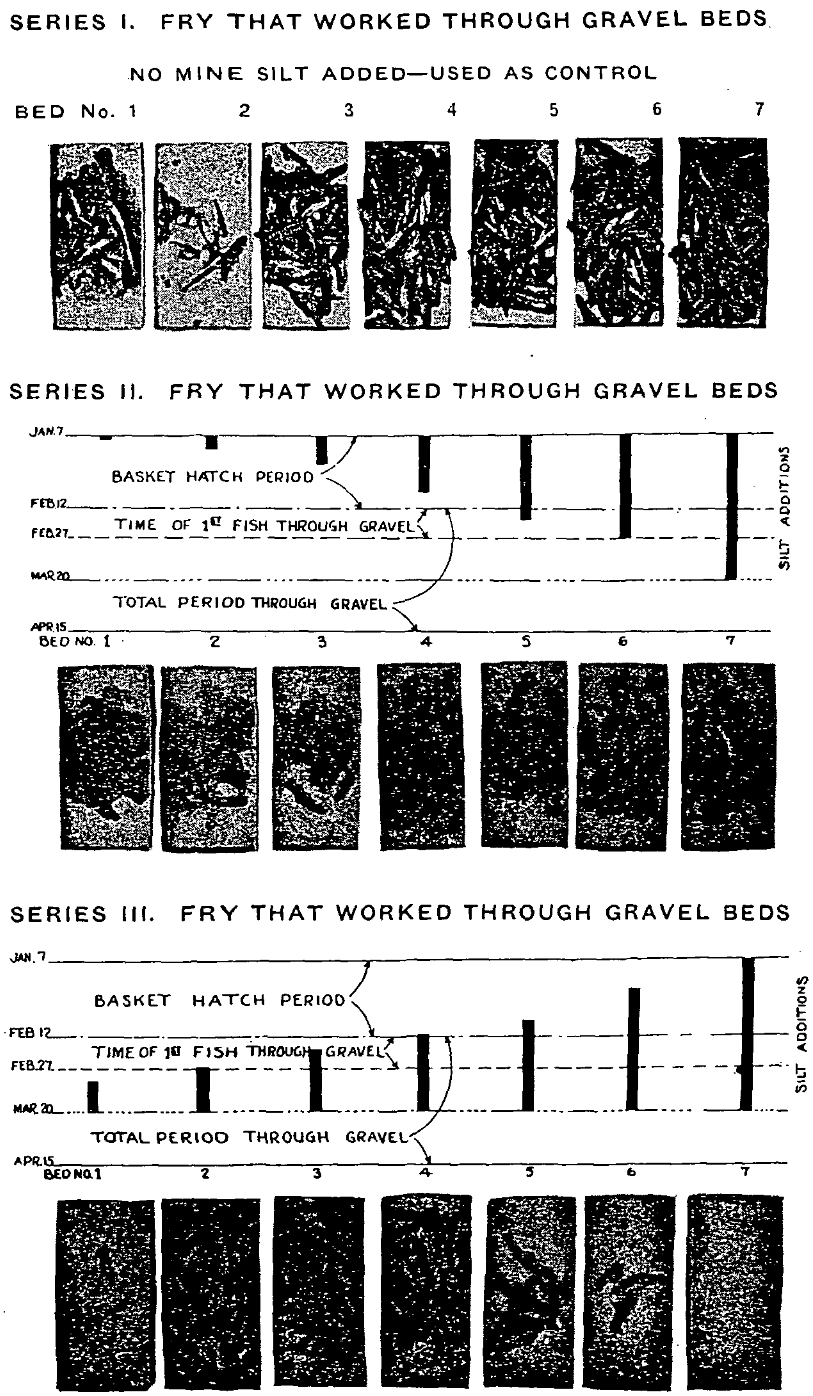


FIG. 16. A composite photograph showing the fry that emerged from the 7 control

earlier silt additions extending back into the incubation period produced progressively lower yields which reached zero with silting at the beginning of the incubation period. In this series the number of undeveloped eggs that were coated and preserved with silt increased steadily with earlier and longer periods of silt addition. Very few fish that hatched failed to emerge but many fry apparently worked forward through a screen rather than upward through the gravel and deposited silt.

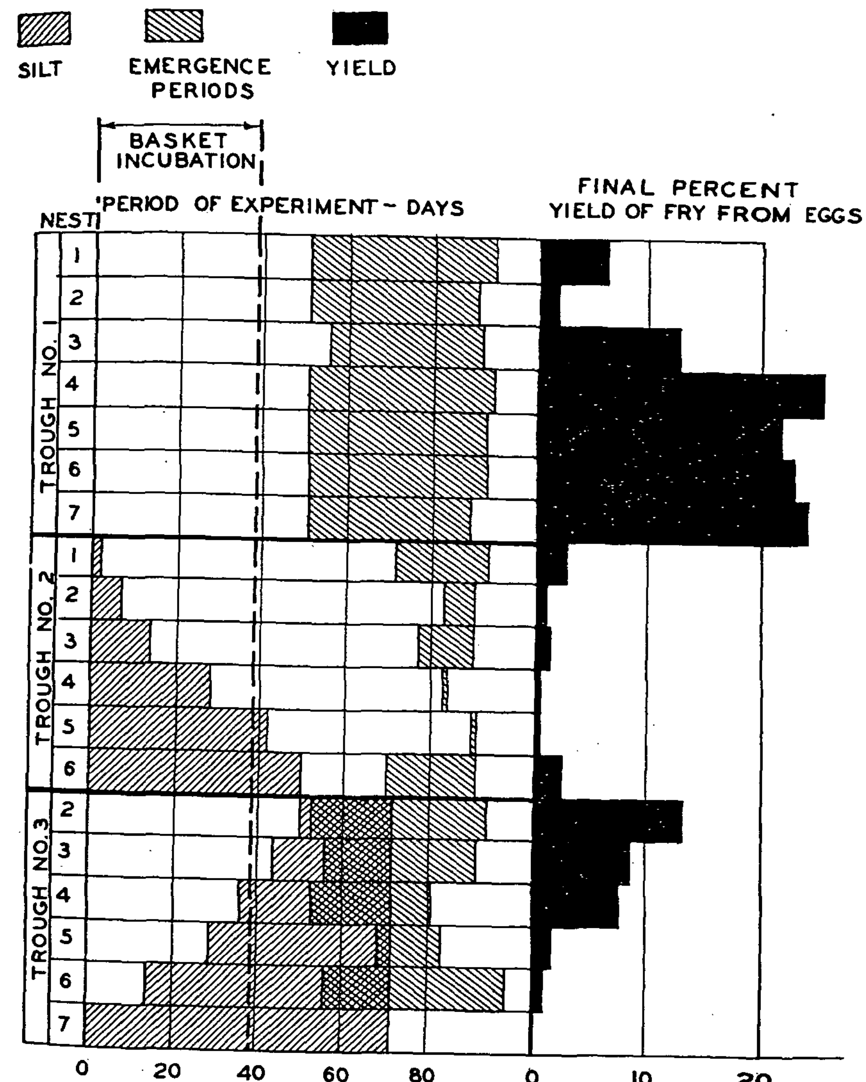


FIG. 17. Graphic summary showing 19 nests of the experiment, with days to emergence of first fry, total emergence periods, and yield from each nest of unsilted gravels (Trough 1) and silted gravels (Troughs 2 and 3) as compared with hatching time of 36-38 days in hatchery baskets ("Basket Incubation") which yielded 79.9% fry. Delayed emergence and decreased yields are particularly evident for Trough 2, with early silt additions.

From the data presented in this paper it is evident that the yield of fry from eggs hatched in gravel beds supplied with normal hatchery water is far below that attained by the usual procedure of basket hatching in flowing water. The experiments further show that mine silt deposited on gravel spawning beds during either the early or later stages of incubation results in negligible yields of fry and is therefore a serious menace to natural propagation.

From a practical standpoint this damage to spawning beds would occur when mining silt enters a stream at times other than storm periods when the water velocity is insufficient to carry the sediment in suspension. It is a well known fact that the velocities necessary to dislodge deposited particles are far greater than the velocities required to carry the same particles in suspension. For this reason natural stream turbidity is largely limited to those periods when storm water causes erosion. During these periods stream flows in areas suitable for steelhead, trout, or salmon spawning are sufficient to prevent bottom deposits of natural erosion silt and damage to eggs in the gravel is minimized. Thus, while mining silt may be natural material, its presence in waterways during nonerosion periods results in bottom deposition which is unnatural and damaging.

From the data presented it is apparent that adequate control to prevent the discharge of mining silt where spawning grounds may be affected is essential to the preservation of normal fish populations, and legislation to secure the necessary protection is therefore recommended. This recommendation applies only to protection of spawning grounds, as the studies did not include the effect of suspended silt on fry after emergence above the gravel. However, irrespective of whether fry and adult fish are injured by silt in suspension, the damage to domestic, agricultural, industrial and recreational water uses from high turbidity is sufficient to justify a reasonable but adequate control. To secure such control, not only on mining but on pollution from varied sources, the authors suggest that a state agency with authority to act with respect to all water values and uses above mentioned would be desirable. In this way the public could be assured of proper action on complaints and violations rather than being referred from agency to agency having different jurisdictions, as now happens.

TABLE 4

Water Analyses

Date, 1941	Temp., F.	pH	Dissolved oxygen P.P.M.							
			Basket		Control		Trough 2		Trough 3	
			Above	Below	Above Nest 1	Below Nest 7	Above Nest 1	Below Nest 2	Above Nest 1	Below Nest 7
1/9	53½°	7.6	11.6	11.6	11.3	11.3	11.4	11.5	11.8	11.8
1/13	51	7.5	11.6	11.6	11.8	11.7	11.8	11.8	11.6	11.6
1/21	51	7.6	11.4	11.4	11.1	11.0	11.3	11.4	11.3	11.4
2/4	51	7.6	11.2	11.2	11.3	11.3	11.3	--------	11.4	--------
2/11	52½	7.5	11.0	10.9	10.9	11.0	11.0	11.1	10.9	11.0
2/18	53½	7.5	11.2	11.2	11.2	11.2	11.2	11.1	11.1	11.2
3/31	53	7.4	--------	--------	10.0	--------	10.2	10.3	10.1	--------

TABLE 5

Suspended Solids

Date, 1941	Sample point	P.P.M.	Sample point	P.P.M.	Number of intervening beds
1/15	Trough 2, Bed 4	1500	Trough 2, Bed 7	1200	3
1/21	Trough 2, Bed 5	860	Trough 2, Bed 7	896	2
2/4	Trough 2, Bed 5	2020	Trough 2, Bed 7	1760	2
2/18	Trough 2, Bed 6	1100	Trough 2, Bed 7	1100	1
1/21	Trough 3, Bed 6	1170	Trough 3, Bed 7	1040	1
2/4	Trough 3, Bed 5	1460	Trough 3, Bed 7	1060	2
2/18	Trough 3, Bed 5	1200	Trough 3, Bed 7	1180	2
	Average	1330		1176	1.86

Deposit per bed $= \frac{1330-1176}{1.86} = 83$ p.p.m.

TABLE 6

Gravel Control Nests

Date, 1941	Number fry emerging								
	Nest							Total	
	1	2	3	4	5	6	7	Daily	To date
2/27	1	1	--------	2	5	3	1	13	13
2/28	--------	1	--------	3	3	4	7	18	31
3/1	--------	1	--------	--------	--------	--------	2	3	34
3/2	--------	--------	--------	1	1	--------	--------	2	36
3/4	--------	1	4	2	--------	2	--------	9	45
3/5	--------	--------	--------	--------	--------	1	1	2	47
3/6	--------	--------	1	--------	--------	5	3	9	56
3/7	--------	--------	--------	1	1	1	--------	3	59
3/9	--------	--------	6	2	3	11	4	26	85
3/10	--------	1	4	4	4	7	--------	20	105
3/12	--------	--------	1	2	1	3	4	11	116
3/13	--------	--------	--------	9	2	5	4	20	136
3/15	--------	--------	2	15	7	5	6	35	171
3/16	3	--------	4	6	5	7	5	30	201
3/18	5	--------	2	31	11	1	3	53	254
3/20	7	--------	9	19	24	12	27	98	352
3/25	8	1	15	10	13	16	25	88	440
3/28	3	--------	8	10	7	10	15	53	493
3/30	1	--------	3	5	7	7	3	26	519
3/31	1	--------	1	--------	3	5	7	17	536
4/4	--------	--------	1	2	2	1	3	9	545
4/7	--------	2	--------	1	3	2	--------	8	553
4/8	--------	--------	3	1	2	1	--------	7	560
4/9	--------	--------	--------	--------	2	2	--------	4	564
4/11	1	--------	--------	1	--------	--------	--------	2	566
Total	30	8	64	127	106	111	120	566	

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