INTRAGRAVEL CHARACTERISTICS IN SOME WESTERN NORTH CAROLINA TROUT STREAMS

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Abstract: Characteristics of the intragravel environment of Southern Appalachian trout streams have not been studied. It was the purpose of this study to measure intragravel permeability, apparent velocity, temperature, dissolved oxygen, and bottom composition in areas that visually appeared suitable for trout spawning in 8 relatively undisturbed streams in the Pisgah National Forest of western North Carolina. Comparisons were made between these measurements and the development requirements of salmonid embryos. Two types of standpipes were used, the Mark VI groundwater standpipe and polyvinyl chloride (PVC) standpipes. The lowest mean intragravel dissolved oxygen was 3.2 mg/ l. Dissolved oxygen measured by the Mark VI was consistently higher than when measured by the PVC standpipes which indicates that the Mark VI gives a better measure of the true intragravel dissolved oxygen than does the PVC standpipes. Between 1 November and 30 April, the period when trout embryos are in the gravel, none of the intragravel dissolved oxygen measurements taken with the Mark VI were below 6 mg/ l. The data indicate that during the development period the dissolved oxygen was adequate for normal embryo survival. Between 1 November and 30 April the intragravel temperature varied from 0.5 to 11 C, temperatures considered to be adequate for trout spawning and embryo development. On a given sampling day the temperature varied no more than 0.5 C from one site to another and the mean intragravel temperature was about the same as the mean surface temperature. This indicates that most of the intragravel water is from surface origin rather than from ground sources. Mean apparent velocity varied from 3.5 to 42.7 cm/hour and mean permeability from 838 to 1,967 cm/hour. The mean percentage of the bottom sample between 0.84 and 3.36 mm varied from 8.8 to 28.2%. When the measurements are compared with requirements of salmonid embryos and alevins, the areas sampled are adequate for embryo survival. There is a possibility that the embryos are smaller than if intragravel dissolved oxygen and apparent velocity were higher. With the exception of 1 creek, it is probable that the amount of sand does not affect fry emergence.

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A source of concern of fisheries biologists, foresters, ecologists, and land managers in the Southern Appalachians is the increasing occurrence of sediments in trout streams. Some investigators (Cordone and Kelley 1961, Wickett 1954, Hobbs 1937, Shapovalov and Berrian 1940, Gangmark and Bakkala 1960) believed that excessive sedimentation on trout spawning beds may be the most critical and detrimental influence of sediment on salmonid productivity. Characteristics of the intragravel environment have been studied in Alaska (McNeil 1962, McNeil and Ahnell 1964), Oregon (Coble 1961, Moring 1975), Wisconsin (Cloern 1976, Hausle and Coble 1976), British Columbia (Wickett 1954, 1958), and Montana (Peters 1965, Bianchi 1963). They have not been studied in Southern Appalachian trout streams. To understand the effects of increased sedimentation, it is necessary to know of the natural variability of the intragravel environment. Thus it was the purpose of this study to characterize the intragravel environment in relatively undisturbed Southern Appalachian streams. Characteristics measured were temperature, dissolved oxygen, apparent velocity, permeability and bottom composition. In addition, surface temperature, velocity, and dissolved oxygen were measured for comparisons.

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METHODS

Eight streams were studied (Fig. 1). Davidson River, Looking Glass Creek, Thompson Creek, Poplar Creek and the South Fork of the Mills River, all located in Transylvania County, North Carolina; Bradley Creek and Slate Rock located in Henderson County; and Mackey Creek located in McDowell County. All the streams are in the Pisgah National Forest.

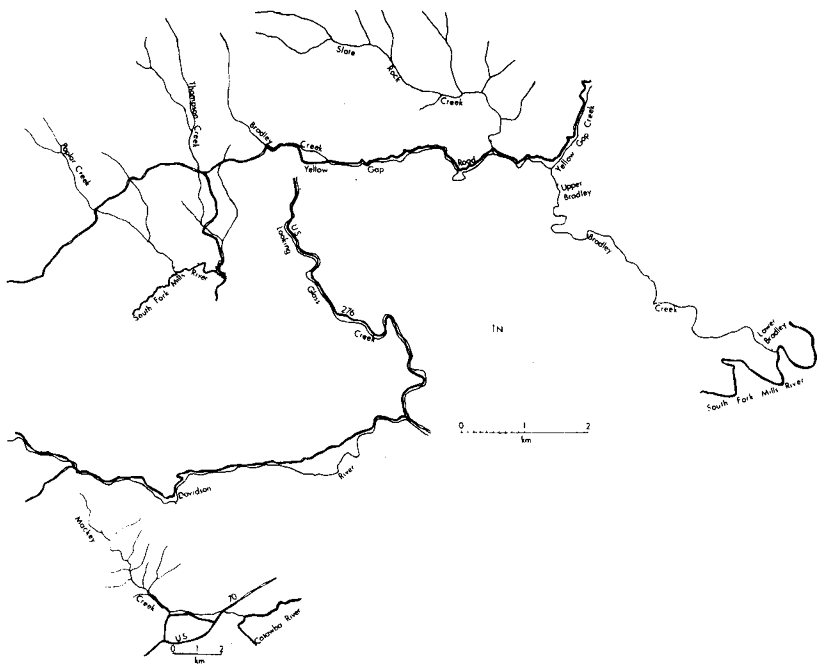

Fig. 1. Map showing the streams sampled. Arrows indicate sampling sites.

Poplar Creek originates at an elevation of approximately 1344 m and flows southeasterly for about 3 km and enters the South Fork of the Mills River at 954 m. It is heavily forested with the only input of sediment being from natural sources. It crosses Yellow Gap Road, an improved graveled road, maintained by the U.S. Forest Service, about half way from its origin, and has an overall gradient of 130 m/km; however, along its lower portion it traverses the Pink Beds, an area of very little gradient. In this section the stream has a gradient of only 6 m/km and is a relatively slow-moving meandering stream. The stream was studied in an area from its junction with the South Fork of the Mills River upstream for approximately 0.4 km. It was sampled from 21 October to 4 November 1976.

Thompson Creek also originates at an elevation of 1344 m and flows in a southerly direction to enter the South Fork of the Mills River. It is heavily forested throughout its watershed; however, a Forest Service road runs along its lower 0.7 km. In the area sampled, just above its junction with the South Fork of the Mills River, the gradient is 24 m/km. Sampling occurred from 18 March to 10 August 1976.

The area of the South Fork of the Mills River sampled was between the mouths of Poplar and Thompson Creeks, a 0.8 km stretch with a gradient of about 6 m/km and an elevation of 950 m. The area is heavily forested with the only input of sediment coming from natural sources. The river was sampled between 9 November and 9 December 1976.

Bradley Creek was sampled in 2 different areas. Since this creek has a large drainage, different gradients and discharge rates, since the sampling stations were some distance from each other, and since the upper section is probably impacted by Yellow Gap Road, the upper and lower sections were considered to be separate sampling areas and were designated Upper Bradley and Lower Bradley, respectively.

Upper Bradley is within the Hendersonville, NC water supply, an area where very little human activity is allowed. Yellow Gap Road follows Bradley Creek for approximately 4.8 km. Where Yellow Gap Creek enters, the road leaves Bradley Creek. The area studied was about 0.2 km below the entrance of Yellow Gap Creek. The impact of Yellow Gap Road on this section of Bradley Creek is not known, but it is assumed that there is some sediment coming from this source. In Upper Bradley the gradient is about 23 m/km and the elevation is 786 m. Upper Bradley was sampled from 29 March to 2 June 1977.

Lower Bradley is the area just upstream from its junction with the South Fork of the Mills River. This area is heavily forested and there is no input of sediment other than from natural sources. The elevation is 702 m and the gradient is 7 m/km. Sampling occurred on 1-8 March and 17 May 1977.

Slate Rock Creek originates at an elevation of 1344 m and flows southeasterly for approximately 5.0 km to enter Bradley Creek. It has a gradient of 101 m/km. The area sampled was, like Upper Bradley Creek, in the Hendersonville watershed and approximately 0.2 km upstream from where Yellow Gap Road crosses Slate Rock Creek. The creek is heavily forested with no input of sediment from human sources. It was sampled from 21 April to 15 June 1977.

Davidson River originates at an elevation of 1380 m and flows easterly. A Forest Service improved gravel road follows the river for much of its course until it joins Looking Glass Creek. It is assumed that this road is a source of some sediment. The area sampled was approximately 3 km upstream from the Pisgah National Fish Hatchery, and the elevation at the sampling site was about 768 m. The gradient is 35 m/km, and the river was sampled on 20-22 June 1977.

Looking Glass Creek follows U.S. 276 for much of its course. This paved, frequently-traveled highway probably contributes some sedment to the stream. The area sampled was about 4.8 km above Sliding Rock. The elevation of the area sampled was about 930 m and the gradient was 30 m/km. The stream was sampled on 23-24 June 1977.

Mackey Creek originates at an elevation of 840 m and falls at a rate of 43 m/km to enter the Catawba River. The upper portion of the stream drains part of the Pisgah National Forest with most of the sediment input from natural sources. The elevation at the sampling site was approximately 480 m. Sampling occurred from 18-31 December 1976.

Site Selection

In Thompson Creek sampling sites were selected at random with the main criterion being the suitability of the bottom for driving the standpipes. Sites were chosen that varied from almost pure sand to those with very little sand. In the other streams, attempts were made to sample areas that visually appeared suitable for salmonid reproduction.

Subjective criteria used in making the selection included bottom composition, water depth and surface flow characteristics.

Sampling Procedure

Two types of standpipes, the Mark VI ground-water standpipe (Terhune 1958) and 1 1/4 inch polyvinyl chloride (PVC) standpipes (McNeil 1962) with approximately 60 5-mm holes drilled into the lower end were used to measure streambed characteristics. The Mark VI and PVC standpipes were driven into the streambed to a depth of about 20 cm. They were driven at least 24 hours and usually a week prior to taking the measurements. This was to assure that the streambed had returned to a stable condition. After the measurements were taken, the Mark VI standpipes were moved to other locations. The PVC pipes were usually left at the same sites for periods varying from 1 day to 3 weeks.

Dissolved oxygen and temperature were measured in both the Mark VI and the PVC standpipes with a Yellow Springs Instrument Co. Model 54 oxygen meter calibrated in the field. For purposes of comparison, dissolved oxygen and temperature were also taken in the surface water about 30 cm upstream of the standpipes. Both permeability and apparent velocity were measured with the Mark VI standpipe as described by Terhune (1958) using his calibration curves. All permeabilities were corrected to a temperature of 10 C.

Streambed samples were obtained with a sampler described by McNeil (1962). The sampler took a 15.24 cm core of the bottom to a depth of up to 20 cm. The sample was taken for both the Mark VI and PVC standpipes following the permeability, apparent velocity, temperature, dissolved oxygen, and surface velocity determinations and at the same spot where the standpipes were located. Thus attempts were made to sample the bottom in the area immediately around the standpipe. We were successful in this because many times dye remaining in the gravel after the apparent velocity measurement had been obtained was seen in the bottom sampler. The bottom sample was passed through a series of standard sieves with the following numbers and mesh sizes: No. 1, 25.4 mm; No. 6, 3.36 mm and No. 20, 0.84 mm. The portion of the sample retained by each sieve was weighed on a spring balance. Bottom composition was expressed as the percentage of the sample retained by each of the sieves.

Surface water velocity was taken approximately 30 cm upstream from each Mark VI using a pygmy type current meter. Two measurements were taken, 1 at the surface and 1 with the base of the current meter resting on the bottom. These 2 measurements were then averaged. Surface velocity was also taken 30 cm upstream from the PVC pipes but only 1 measurement was taken with the exception of Thompson Creek where 2 measurements were averaged.

RESULTS AND DISCUSSION

Apparent Velocity and Dissolved Oxygen

Mean apparent velocity varied from 3.5 cm/hour in Poplar Creek (Table 1) to 42.7 cm/hour in Looking Glass Creek. Individual measurements varied from 0 to 160 cm/hour. Mean intragravel dissolved oxygen varied from 3.2 mg/l (Table 2) to 9.6 mg/l (Table 1), with individual measurements varying from 0.3 to 12.8 mg/l. A comparison of the means of intragravel dissolved oxygen obtained with the Mark VI (Table 1) and with the PVC pipes (Table 2) indicates that with the exception of Slate Rock Creek the mean obtained with Mark VI was higher than with the PVC pipes. In field observations, the water in the PVC pipes commonly had a surface film on it and appeared "stagnant." This was not observed in the Mark VI standpipes. It is possible that the arrangement and size of the holes and method of driving the PVC pipes prevent adequate water flow through the pipes. It appears that the PVC pipes gave an intragravel dissolved oxygen reading that was lower than the true level. The lowest measurement taken in the Mark VI (Table 1) was 4.0 mg/l.

Table 1. Range, mean, and number of measurements for intragravel apparent velocity, permeability, temperature, and dissolved oxygen, surface temperature and dissolved oxygen taken with or near the Mark VI standpipe.

Characteristic	*Poplar Creek*	*Thompson Creek*	*S. Fork Mills River*	*Upper Bradley*
Apparent Velocity (cm/hr)				
mean	3.5	5.7	12.6	28.9
range	1.2-4.0	0.0-51.0	1.3-45.0	1.0-72.0
number	6	21	8	19
Permeability (cm/hr)				
mean	838	922	1,235	1,146
range	140-2,520	130-2,450	132-3,510	275-2,000
number	6	18	8	19
Intragravel Dissolved Oxygen (mg/l, % saturation)				
mean	6.9,59.0	8.6,85.7	8.9,68.9	7.3,73.9
range	4.0-9.8,34-91	4.3-11.6,44-98	8.0-10.4,60-78	4.8-9.7,49-99
number	9	22	8	9
Surface Dissolved Oxygen (mg/l, % saturation)				
mean	11.0,93.9	9.8,98.2	11.9,96.2	9.7,97.5
range	10.2-11.4,84-99	9.0-11.8,93-100	10.6-12.9,92-100	9.5-9.8,94-100
number	9	22	8	9
Intragravel temp. (C)				
mean	4.9	11.8	1.4	13.0
range	4-6	3-16	-0.5-4	13
number	9	22	8	9
Surface temp. (C)				
mean	4.9	12.2	2.4	13.0
range	4-6	3-17	-2.0-6	13
number	9	22	8	9

Characteristic	*Lower Bradley*	*Slate Rock*	*Davidson River*	*Looking Glass*	*Mackey Creek*
Apparent Velocity (cm/hr)					
mean	15.5	37.5	32.7	42.7	30.4
range	4.5-40.0	1.8-140.0	7.5-61.0	2.0-160.0	0.0-105.0
number	8	15	6	4	8
Permeability (cm/hr)					
mean	763	1,377	1,238	1,116	1,967
range	166-1,365	450-3,200	616-2,376	157-2,262	635-3,159
number	6	15	6	4	9
Intragravel Dissolved Oxygen (mg/l, % saturation)					
mean	7.5,72.7	8.8,92.8	8.6,94.0	9.1,98.0	9.6,79.3
range	6.4-12.8,56-97	7.3-9.2,77-97	7.4-9.0,82-98	9.0-9.2, 97-99	8.3-12.0,73-94
number	3	6	6	4	9
Surface Dissolved Oxygen (mg/l, % saturation)					
mean	9.5,93.6	9.4,98.6	9.2,99.6	9.3,100	11.7,96.7
range	9.2-10.7,88-99	9.3-9.4,98-99	8.9-9.4,99-100	9.3,100	10.8-12.8,93-99
number	3	6	6	4	9
Intragravel temp. (C)					
mean	9.2	13.7	15.7	15.0	4.2
range	1.5-13	13.5-14	14.5-17	15	1.5-6
number	3	6	6	4	9
Surface temp. (C)					
mean	9.2	14.0	15.7	15.0	4.5
range	1.5-13	14	14.5-17	15	1.5-7
number	3	6	6	4	9

Table 2. Range, mean and number of measurements for intragravel temperature, and dissolved oxygen, surface temperature and dissolved oxygen, taken with or near the PVC standpipes.

Characteristic	*Poplar Creek*	*Thompson Creek*	*S. Fork Mills River*	*Upper Bradley*
Intragravel Dissolved Oxygen (mg l, % saturation)				
mean	3.2,35	8.2,75	6.6,51	6.4,66
range	0.3-7.9,3-67	1.1-12.2,11-100	1.3-9.9,11-73	0.6-9.5,6-99
number	29	243	28	30
Surface Dissolved Oxygen (mg l, % saturation)				
mean	10.9,94.7	10.2,94.4	12.1,98.4	9.4,98.7
range	10.3-11.5,89-100	8.2-12.5,81-100	10.6-13.0,96-100	8.9-9.8,95-100
number	29	253	28	30
Intragravel Temp. (C)				
mean	4.8	8.6	1.5	13.0
range	4-5.5	1.5-16	0.5-4	13-13.5
number	30	255	28	30
Surface Temp. (C)				
mean	4.7	8.8	1.5	13.3
range	4-6	1.5-16	0-6	13-14
number	30	256	28	30

Characteristic	*Slate Rock*	*Davidson River*	*Looking Glass*	*Mackey Creek*
Intragravel Dissolved Oxygen (mg l, % saturation)				
mean	8.9,94	6.9,74	8.1,88	8.9,74
range	8.2-9.3,88-98	1.6-9.3,17-99	5.9-9.1,63-98	3.6-10.9,31-92
number	20	20	10	30
Surface Dissolved Oxygen (mg l, % saturation)				
mean	9.3,100	9.3,99.7	9.3,100	9.4,98.9
range	9.1-9.5,100	9.0-9.4,98-100	9.2-9.3,100	9.1-9.5,94-100
number	20	20	10	20
Intragravel Temp. (C)				
mean	13.7	15.0	15.0	4.3
range	13.5-14	14.5-15.5	15	2-6
number	20	20	10	30
Surface Temp. (C)				
mean	14.0	15.0	15.0	4.3
range	14	14.5-15.0	15	2-6
number	20	20	10	30

Since, in the Southern Appalachians, salmonid embryos and alevins are in the gravel in general between 1 November and 30 April, the intragravel dissolved oxygen measurements taken during this period are the critical ones. No measurements taken during this period with the Mark VI were below 6 mg/l.

Several authors have indicated the importance of the relationship between apparent velocity and dissolved oxygen for embryo and alevin survival (Wickett 1954, Alderice et al. 1958, Coble 1961, Bianchi 1963). Coble (1961) indicated that oxygen is essential to the embryo with the function of water movement being mainly to deliver oxygen to the embryo and carry away metabolic wastes. Wickett (1954) indicated that to satisfy the potential oxygen demand of pre-eyed chum salmon eggs at 8 C, the oxygen content may vary between the equivalent of air saturation and 1.67 ppm depending on the velocity of the water. His curve of limiting values for dissolved oxygen for the mean apparent velocities measured in this study (3.5 to 42.7 cm/hour) are well below the dissolved oxygen means (3.2 to 9.6 mg/l). Also, Silver et al. (1963) and Shumway et al. (1964) had high survival of steelhead trout and coho salmon when dissolved oxygen was above 2.5 mg/l. It is concluded that, in the relatively undisturbed streams in this study, the intragravel dissolved oxygen and apparent velocity measurements taken during the period when the embryos and alevins are in the gravel are adequate for a high rate of survival. Shumway et al. (1964) have shown that reduction of either dissolved oxygen or water velocity results in a reduction in the dry weight of newly hatched coho salmon fry. They also estimated the combinations of dissolved oxygen and water velocity that would have reduced the weight of fry by certain percentages. The highest dissolved oxygen they tested was 11.2 mg/l and the highest velocity was 800 cm/hr. Reduction of either velocity or dissolved oxygen from these levels resulted in lighter fry. Using their relationships, and assuming that they apply to Southern Appalachian salmonids, we would expect that in Poplar Creek with a mean apparent velocity of 3.5 cm/hour and a mean dissolved oxygen of 6.9 mg/l, the mean dry weight of embryos hatching in this creek would be about 50% less than if the dissolved oxygen and apparent velocity were equivalent to the maxima tested by Shumway et al. (1964). For Looking Glass Creek, that had the highest mean apparent velocity (42.7 cm/hour) measured in this study and a mean dissolved oxygen of 9.1 mg/l, we would expect only a slight reduction in embryo size. Of course, whether or not smaller embryos are being produced in these creeks is unknown, and if they are the ecological significance is also unknown.

Permeability

Mean permeability varied from 838 cm/hour in Poplar Creek to 1,967 cm/hour in Mackey Creek (Table 1). Individual permeability measurements varied from a low of 130 cm/hr in Thompson Creek to 3,510 cm/hour in the South Fork of the Mills River. Moring (1975), over an 11-year period, found that the lowest mean permeability for 3 Oregon streams was 1,139 cm/hour and the highest was 5,640 cm/hour.

Wickett (1958), McNeil and Ahnell (1964) and Cloern (1976) believed that higher embryo survival occurs in gravel with higher permeabilities. Coble (1961), however, could not show any relationship between survival and permeabilities varying from 400 to 8,000 cm/hour. Comparisons of the permeabilities measured in the present study with those from Oregon, British Columbia, and Alaska lead to the conclusion that the permeabilities in the Southern Appalachians are in general lower than in the Northwest. Whether this has an effect on embryo mortality and size is unknown.

Temperature

The intragravel temperature varied from -0.5 to 17 C with the means varying from 1.4 to 15.7 C (Tables 1 and 2). From 1 November to 30 April, the period when embryos and alevins are in the gravel, temperature varied from 0.5 to 11 C. According to the U.S. Environmental Protection Agency (1976) the upper temperature for successful incubation and hatching of brook trout eggs is 13 C and 15 C for rainbow trout eggs. Thus it appears that the intragravel temperatures measured in this study are adequate for survival. Lennon (1967), however, observed that water temperatures in the Great Smoky Mountains National Park may remain at 0 C for several days resulting in the formation of anchor ice and a reduction in flows. At such times the redds of brook trout may become dewatered and frozen. Cloern (1976) indicated that mean water temperatures of 2.8 and 2.6 C in 2 Wisconsin streams may have been factors in embryo mortality. Thus it appears that prolonged exposure to low temperatures could affect embryo mortality in Southern Appalachian streams.

Groundwater in the gravel has been detected because of differences in intragravel water temperature measured on the same day (Hansen 1975). He observed temperature differences of up to 7 C. Such temperature differences were not observed in the present study. On a given day the temperature was usually constant and never varied more than 0.5 C. Also the mean intragravel temperatures were about the same as the mean surface temperatures (Tables 1 and 2). This indicates that groundwater makes up only a small proportion of the intragravel water with most of it being of surface origin.

Bottom Composition

The percentages of the bottom sample between 0.84 and 3.36 mm for both the Mark VI and the PVC pipes are shown in Table 3. The means ranged from 8.8% for Mackey Creek to 28.2% for Thompson Creek. The other means were between 11% and 18%. Individual measurements ranged from 2% to 57%.

It has generally been accepted that as the percentage of fine materials increases in the gravel the dissolved oxygen, permeability, and apparent velocity decreases. McNeil and Ahnell (1964) found an inverse relationship between permeability and the percentage of a bottom sample passing through a 0.833 mm sieve. Peters (1965) found that oxygen concentration and apparent velocity decreased with increasing sediment concentration. In the present study linear regression analysis failed to reveal any correlations between the percentage of the bottom sample between 0.84 and 3.36 mm and permeability, apparent velocity and intragravel dissolved oxygen. Hausle and Coble (1976) found no relation between dissolved oxygen and proportion of sand in artificial redds. Hansen (1975) also failed to demonstrate what he called "classical relations" and felt that 1 reason could have been the high variability from point to point within individual redds. This is a possibility in the present study. It is also possible that this failure could be due to different methods of designating fine materials.

Table 3. Range, mean and number of measurements for percent of bottom sample between 0.84 and 3.36 mm, for both the Mark VI and PVC standpipes.

Characteristic	*Poplar Creek*	*Thompson Creek*	*S. Fork Mills R.*	*Upper Bradley*	*Lower Bradley*	*Slate Rock*	*Davidson River*	*Looking Glass*	*Mackey Creek*
Bottom Composition (% between 0.84-3.36 mm)									
mean	15.5	28.2	11.6	14.7	12.5	13.6	15.4	17.6	8.8
range	3-57	6-56	4-25	2-27	3-19	5-28	6-23	4-26	2-19
number	19	71	12	29	6	25	16	14	9

Hausle and Coble (1976) in comparing their data on survival and emergence of brook trout (*Salvelinus fontinalis*) with that of other workers on steelhead trout (*Salmo gairdneri*), chinook (*Oncorhyncus tshawytscha*) and coho salmon (*O. kisutch*) concluded that the emergence of salmonid embryos is likely to be reduced from spawning gravel containing more than 20% sand (particles less than 2 mm). With the exception of Thompson Creek all the means were below this. It is probable that in the streams studied the amount of sand would not affect fry emergence.

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