Characteristics and Success of Wild Brown Trout Redds in 2 Western North Carolina Streams

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Abstract: Characteristics and success of 22 wild brown trout redds were studied in 2 western North Carolina streams. Choice of redd site by spawners was determined and intragravel characteristics of redds were followed throughout the incubation period. Spawning began during the last of October at a water temperature of 7° C. It appeared to have ceased by the middle of November. Redds were selected in pool-riffle transition areas or in riffles with a mean surface velocity of 34 cm/second and a mean water depth of 16 cm. Redd areas averaged 94 cm long and 47 cm wide. Egg pits averaged 31 cm in diameter and were 11 cm deep. During the incubation period, mean intragravel dissolved oxygen was 11.0 mg/l, permeability 1,367 cm/h and apparent velocity 19 cm/h.

About 3 weeks prior to emergence 5 alevins per redd were recovered from one creek and 68 per redd from another. Emergence occurred during the first 2 weeks of April. The number of fry emerging varied from 0 to 22 per redd. Anchor ice, scouring by high discharge, and deposition of fine sediment were environmental factors that affected the redds, and caused mortality even though dissolved oxygen, permeability, and apparent velocity were high.

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The life cycle of salmonids involves use of the stream substrate for incubation of developing embryos and alevins. Accordingly, maintenance of wild trout populations is dependent on a substrate that will supply oxygen to and remove metabolic wastes from eggs and alevins, and that will also allow fry to escape during emergence. Researchers have shown that siltation, freezing, scouring, predation, and other calamities may be detrimental to maintenance of wild trout populations (Wickett 1954, Peters 1962, Reiser and Wesche 1977). In laboratory experiments successful development of salmonid embryos is dependent on an adequate amount and delivery rate of intragravel dissolved oxygen (Silver et al. 1963). Lethal dissolved oxygen levels have been described by Wickett (1954), Shumway et al. (1964)

and Silver et al. (1963) whose estimates varied from 0.7 mg/liter to 2.5 mg/liter. Decreases in rates of delivery of dissolved oxygen have also been shown to be important to mortality, hatching time, and size of alevins (Shumway et al. 1964). Silver et al. (1963) found apparent velocities above 6.0 cm/h did not affect survival of eggs or emergence of fry. Wickett (1958) and McNeil and Ahnell (1964) felt permeability of the gravel was important in renewing water within salmonid redds. Coble (1961) found permeabilities as low as 400 cm/h did not affect mortality.

Streams impacted by sedimentation can limit the number of young-of-the-year fish (Saunders and Smith 1965). Cloern (1976) found low dissolved oxygen and high mortality of salmonid embryos in 2 heavily silted Lake Michigan tributaries. He also felt low mean water temperatures contributed to mortality. High dissolved oxygen and apparent velocities were favorable to the production of fry in Oregon (Coble 1961). Low water temperatures and the accompanying freezing of redds was a main factor of high egg mortality in artificial redds in the Laramie River in Wyoming (Reiser and Wesche 1977).

The brown trout (*Salmo trutta*) is an important sport fish in the Southern Appalachians and the characteristics and success of its spawning areas have not been studied. West (1979) sampled 7 relatively undisturbed streams in the Pisgah National Forest of Western North Carolina for permeability, dissolved oxygen, and apparent velocity. He found intragravel environments adequate for the production of trout fry when comparing his measurements with the laboratory studies of other researchers. In an egg-planting experiment conducted in 3 Pisgah National Forest streams, Dechant (1979) found intragravel conditions that were adequate for egg survival. Because of the lack of information on wild brown trout redds in the Southern Appalachians, the objectives of this study were to: (1) describe areas being used for spawning, (2) measure intragravel parameters within the redd area, and (3) estimate the success of redd areas.

Methods

Study Sites

Pisgah National Forest streams in western North Carolina (the South Mills River and a tributary, Poplar Creek, 35°22'N, 82°45'E) were chosen for study because of (1) an established wild brown trout population, (2) ease of observation and monitoring, and (3) no recent disturbance. Both streams are tributaries of the French Broad River and flow through the Pink Beds area of Pisgah National Forest. The Pink Beds is supposedly named for the swamp pink which grows there and is an uncharacteristically flat area in the Southern Appalachians; however, the substrate and redds are typical of Southern Appalachian streams. The streams are of low to moderate gradient and meander through a series of deep runs, pools, and riffles. Turbidity measurements were not taken, but subjective observations indicated very little turbidity even during high discharges.

The South Mills River

Flow in the South Mills River generally is in a southeasterly direction bisecting the Pink Beds area, a cove hardwood forest with dense thickets of *Rhododendron maximum* and mountain laurel (*Kalmia latifolia*) along the stream's banks. These thickets provide many areas with a partially closed canopy throughout the winter. Average flow in the study area was approximately 0.57 m^3/second. Sampling and observation included all sections of the stream beginning at a U.S. Geologic Survey gauging station at an elevation of 975 m upstream approximately 1.5 km to an elevation of 1,025 m. The lower 0.75 km ran over bedrock with large pools formed by log jams. The upper 0.75 km had a substrate of rubble grading to sand with several gravel shoals and many pool-riffle areas where we felt physical characteristics were suitable for spawning. Mean stream width was approximately 10 m.

Poplar Creek

Poplar Creek originates in a hardwood cove at an elevation of approximately 1,100 m. Most areas of the stream have a partial to completely closed canopy of *Rhododendron maximum* and mountain laurel (*Kalmia latifolia*). Poplar Creek flows in a southerly direction until converging with the South Mills at an elevation of approximately 1,010 m. The study area extended from the confluence with the South Mills to a point 1 km upstream at an elevation of approximately 1,030 m. Substrate in the study area varied from rubble to sand with many gravel shoals. Deep pools and gentle riffles typified the study section. Mean stream width was approximately 5.5 m, and the average discharge was 0.28 to 0.34 m^3/second.

Tagging of Trout

In September, prior to spawning time, a 1.0 km section of the South Mills River and a 0.5 km section of Poplar Creek were electrofished to obtain wild brown trout. All fish $\geq$ 175 mm were tagged, total length measured, and weighed. Colored spaghetti tags were inserted just below the dorsal fin. Each size class (25-mm increments) was given a different color tag so that size could be estimated if the fish were subsequently observed.

Locating Spawning Sites

Spawning activity was first observed on 28 October 1978 and appeared to have ceased by 12 November. Because of dry conditions during September and October, discharges were low and observation of spawning was enhanced. Spawning fish and redds were located by streamside observation. Each redd was marked by a small wire flag inserted in the substrate after spawning was completed. Measurements of redd dimensions, surface velocity, temperature, and water depth were made at this time. A total of 22 redds were marked, 15 in the South Mills River and 7 in Poplar Creek.

Monitoring the Redds

Fifteen redds (12 in the South Mills and 3 in Poplar Creek) were selected for monitoring of the intragravel environment during the incubation period by driving Mark VI standpipes into the substrate to the approximate depth of egg location 1 m downstream from the redd area. Intragravel measurements began on 30 November 1978 and were taken at each redd every 2 weeks unless prevented by bad weather. Apparent velocity and permeability were recorded according to Terhone (1958). Intragravel temperature and dissolved oxygen were monitored using a Yellow Springs Instrument Company Model 54 dissolved oxygen meter. Surface velocities were measured at the upstream and downstream points of the redds on each sampling date with a pygmy Gurley velocity meter, and these 2 measurements were averaged.

Two redds were selected for periodic excavation to monitor embryo development. On 12 March 1979, 7 redds (4 in the South Mills and 3 in Poplar Creek) were fitted with (1.2 × 1.8 m) nylon-mesh fry traps to capture emerging fry, and trapped fry were removed weekly. Mark VI standpipes were removed upon installation of the fry traps. The other redds were excavated on 20 and 27 March 1979 to determine the number of alevins surviving by thoroughly sifting the substrate with a shovel and collecting the alevins just downstream in a small-mesh net. This procedure was also used to collect any alevins remaining in the seven redds after the fry traps were removed.

Results

Physical Characteristics of Redds

Table 1 shows the physical characteristics of all redds and sizes of spawning fish. Water temperature during the spawning period varied from 5° to 9° C. There was a sharp drop from 12° C on 25 October 1978 to 7° C on 27 October, and spawning was first observed on 28 October. Fig. 1 is a summary of the physical characteristics measured for all redds. In all cases redds were found either in riffles or pool-riffle transitional areas. At the time of spawning, mean water depth was 16 cm, and surface velocity varied from 20 to 42 cm/second with an overall mean of 34 cm/second. Mean length of the excavated areas was 94 cm. Ottaway et al. (1981) divided the redd into a depression, the pot, at the head of a slightly raised area of gravel, the tail. The pot and tail each had mean lengths of 47 cm. The eggs were in an egg pit at a mean depth of 11 cm and a mean diameter of 31 cm. Observation of the substrate material indicated that it varied from 0.25 mm to 7.5 cm in diameter.

Of the 26 fish observed spawning, 6 had been tagged and their lengths known. The lengths of the others were estimated by comparing with fish and objects of known size. Several redds were found even though the spawning fish were not seen. Gravel associated with redds was cleaner and had a lighter color than the surrounding gravel, as if it were being illuminated with a flashlight.

Table 1. Characteristics of brown trout spawners and redds in the South Mills River and Poplar Creek.

Redd Number	Redd Location[a]	Fish Size (mm)		Water Temp. (° C)	Egg Pit Depth (cm) (Approximate)	Length of Excavated Area (cm)	Water Depth (cm)	Width of Redd (cm)	Surface Velocity (cm/s)	Egg Pit Diameter (Approximate)
		Male	Female							
South Mills River										
1.	R	235	250	7	11	90	16	47	30	31
2.	R	NS[b]	NS	7	11	90	16	47	30	31
3.	R	NS	NS	9	11	78	16	42	30	31
4.	R	225	225	9	11	78	16	47	38	31
5.	R	225	225	9	11	94	16	51	42	31
6.	PR	225	225	9	11	94	16	51	38	31
7.[e]	PR	225	225[d]	5	16	94	21	47	30	31
8.[e]	PR	325	275[d]	5	16	105	16	51	36	26
9.[e]	PR	250[d]	245[d]	9	8	105	21	51	28	36
10.	PR	NS	NS	9	8	105	26	62	42	36
11.[e]	R	200	225[d]	7	11	105	16	62	38	36
12.	PR	NS	NS	7	11	78	16	42	34	26
13.	PR[c]	NS	NS	5	11	94	11	47	38	31
14.	PR[c]	225	225	5	11	94	11	47	26	31
15.	PR[c]	225	225	5	11	94	16	36	38	31
Poplar Creek										
1.[e]	PR	275	275	5	8	94	16	42	20	31
2.	PR	NS	NS	5	8	94	16	42	30	36
3.[e]	R	275	225[d]	5	11	94	16	47	34	31
4.[e]	PR[c]	200	200	9	11	105	21	51	34	31
5.	PR[c]	NS	NS	7	11	105	16	42	32	36
6.	PR[c]	NS	NS	9	11	94	16	42	38	26
7.	PR[c]	NS	NS	9	11	64	11	26	34	26
Mean				7	11	94	16	47	34	31

[a] R = riffle, PR = pool-riffle transition
[b] Fish not seen
[c] Not monitored for intragravel characteristics
[d] Tagged fish
[e] Fry traps installed in March 1979

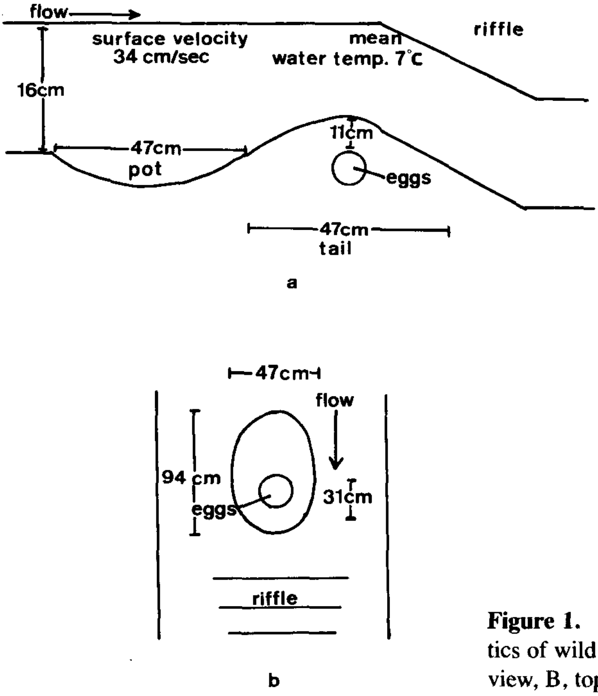

Figure 1. Mean of physical characteristics of wild brown trout redds. A is side view, B, top view.

Intragravel Measurements

High discharge caused displacement of some of the standpipes and during extremely cold periods, ice formed in the standpipes making a strict adherence to biweekly sampling impossible. All standpipes were sampled a minimum of 3 times for temperature, apparent velocity, dissolved oxygen, and permeability.

Surface and intragravel dissolved oxygen remained high and near saturation throughout the incubation period. Mean surface water dissolved oxygen never fell below 11.2 mg/liter, while mean intragravel dissolved oxygen was never below 8.8 mg/liter (Table 2). Thirteen of 15 redds had mean intragravel dissolved oxygen levels of over >10.0 mg/liter. Intragravel dissolved oxygen measurements varied from 7.4 mg/liter to 11.8 mg/liter with the lowest measurement recorded on the last sampling date (12 March 1979). This measurement is considerably higher than the minimum for trout embryo production.

Mean permeabilities varied from 635 cm/hour to 2,280 cm/hour (Table 2). Ten of 15 redds had mean permeabilities greater than or equal to 1,000 cm/hour. Individual measurements varied from 300 cm/hour to 4500 cm/hour. In some cases measurements varied greatly between sampling dates. Displacement and redriving of the standpipes caused by high discharges and ice may have contributed to this variation. Mean permeability for all stations and sampling dates was 1,367 cm/hour.

Table 2. Mean intragravel characteristics of wild brown trout redds in South Mills River and Poplar Creek. Values in parentheses are the number of measurements.

Redd number	Surface Dissolved Oxygen (mg/l)	Intragravel Dissolved Oxygen (mg/l)	Permeability (cm/h)	Apparent Velocity (cm/h)
South Mills River				
1	11.5 (6)	11.0 (6)	954 (6)	21 (5)
2	11.3 (5)	10.4 (5)	1,240 (5)	12 (4)
3	11.5 (6)	11.0 (6)	2,233 (6)	19 (5)
4	11.5 (6)	10.0 (6)	635 (5)	11 (4)
5	11.5 (4)	10.2 (4)	960 (5)	6 (4)
6	11.6 (5)	10.3 (5)	1,740 (5)	44 (4)
7	11.4 (4)	8.8 (4)	1,313 (4)	62 (3)
8	11.2 (3)	10.8 (3)	1,225 (4)	13 (3)
9	11.3 (3)	9.6 (3)	1,000 (3)	8 (3)
10	11.9 (4)	11.5 (4)	960 (4)	7 (4)
11	11.9 (4)	10.3 (4)	1,050 (5)	12 (3)
12	11.7 (5)	11.4 (5)	965 (5)	20 (4)
Poplar Creek				
1	11.2 (4)	10.8 (4)	2,280 (5)	17 (4)
2	11.2 (4)	10.3 (4)	2,160 (5)	21 (4)
3	11.2 (4)	10.6 (4)	1,800 (5)	17 (4)
Mean	11.5	11.0	1,367	19

Table 3. Number of alevins and fry recovered and observed environmental changes during the incubation period.

Redd Number	Number of Alevins	Number of Fry	Anchor Ice	Substrate Changes
		South Mills River		
1	0			Washed out
2	0		X	
3	0			Washed out
4	0			Washed out
5	36			
6	0			
7		22		
8		2		
9		0	X	
10	0		X	Washed out
11		7		
12	8			Fines
13	7			
14	0			Fines
15	0		X	Fines
		Poplar Creek		
1		0		
2	71			
3		12		
4		0	X	
5	150			
6	51			
7	0		X	

Mean apparent velocities varied from 6 cm/hour to 62 cm/hour (Table 2) and individual measurements varied from 4 cm/hour to 95 cm/hour. As with permeability, large flunctuations between sampling dates may have been due to redriving of the standpipes after dislocation. Mean apparent velocity for all stations and sampling dates was 19 cm/hour.

Intragravel water temperature and surface water temperature were found to be the same (±1° C) at all stations on each sampling date. Temperature varied from 9.5° C on 30 November 1978 to 0.0° C on 2 and 27 February 1979. Mean water temperature was 3.2° C.

Anchor ice was noted on 2, 12, and 27 February on both streams. Redds 2, 9, 10, and 15 on the South Mills River and 4 and 7 on Poplar Creek had visible accumulations of anchor ice on or in close proximity to the redd area on at least 1 of these dates (Table 3).

Alevin and Fry Recovery

When the redds were excavated (20 and 27 March 1979) the number of alevins recovered varied from 0 to 150 (Table 3). Alevins still had a prominent yolk sac and would not have emerged for an estimated 2 to 3 weeks. The greatest number of alevins recovered in the South Mills River was 36 and the mean for all 11 redds was only 5. Alevin recovery in Poplar Creek was higher with a mean of 68 for the 4 redds.

On 12 March 1979 intragravel measurements were stopped and fry traps were installed. Emergence was first noted the week of 2 April 1979 and appeared to be complete by 12 April. No fry were recovered from three redds (South Mills 9 and Poplar Creek 1 and 4, Table 3). The largest number collected (22) was from redd 7 on the South Mills River. Sand accumulation under fry traps was noted during emergence, presumably from the settling out of the streambed load under the nylon mesh. In comparison with adjacent areas, trapped redds had a very sandy appearance which may have affected the ability of the fish to emerge. Salamanders may also have been feeding on the trapped fry. In redd 9 on the South Mills River, 5 salamanders were captured during removal of the fry trap and subsequent search of the gravel for remaining fry. No fry were found at this site.

High discharges were noticed on two occasions during the incubation period. On 4 and 5 March, 1979, a major storm resulted in both streams overflowing their banks with large changes in the stream channel and substrate. Redds 1, 3, 4, and 10 on the South Mills River were apparently scoured out by the high discharge with no recognizable components of the redds remaining (Table 3). Redds 12, 14, and 15 were all impacted by the downstream transport and accumulation of fine materials. In all redds on the South Mills River where no alevins or fry were recovered (9 of 15) either anchor ice, scouring, or the deposition of fine sediment was observed. Such large scale changes were not noticed in Poplar Creek. Three of 7 redds produced no alevins or fry. Two of these were observed to have had anchor ice.

Discussion

Redd Site Selection

Spawning sites were similar with most fish (15) selecting pool-riffle transitional zones and 7 selecting riffle areas. Fish chose areas just upstream of a riffle. No fish were seen spawning in pools or deep runs. These observations correlate closely to brown trout redd sites in Wyoming monitored by Reiser and Wesche (1977). The mean water velocity of 34 cm/second is similar to that found by Ottaway et al. (1981) in England, Reiser and Wesche (1977) in Wyoming, Smith (1973) in Oregon, and Shirvell and Dungey (1983) in New Zealand. A mean depth of 16 cm was similar to the 14 cm reported by Reiser and Wesche (1977) and the 12.6 cm of Smith (1973), but was considerably less than the 31.7 cm reported by Shirvell and Dungey (1983) and more than the 5.1 to 18.6 cm of Ottaway et al. (1981). These differences could be due to differences in the sizes of spawning fish. The egg pit depth of 11 cm was similar to the 5–14 cm of Ottaway et al. (1981).

Intragravel Measurements

Intragravel measurements indicated that spawning fish chose sites with high intragravel dissolved oxygen, permeability and apparent velocity. Intragravel dissolved oxygen was consistently high with thirteen of fifteen redds having means of 10.0 mg/liter or higher. The lowest individual reading (7.4 mg/liter, South Mills 7) was considerably higher than the estimated lethal concentration of 2.5 mg/liter (Silver et al. 1963).

Permeabilities and apparent velocities were adequate for a continuous movement of water through the redd. Mean permeabilities varied from 635 cm/hour (South Mills River 4) to 2,280 cm/hour (Popular Creek 1, Table 2). Coble (1961) found that permeabilities as low as 400 cm/hour did not affect mortality. Only 2 of 73 measurements were below Coble's estimate. Apparent velocities of over 20 cm/hour were common, and the mean was 19 cm/hour. Only 1 of 58 measurements fell below 6 cm/hour, a level that did not affect survival of eggs or fry emergence (Silver et al. 1963).

Intragravel water temperatures during the incubation period remained cold, especially from 1 to 28 February, 1979, when they did not rise above 3° C. This cold may not only have delayed development and subsequent emergence, but also stressed developing fry to lethal limits. Anchor ice noted on 2 February 1979 and its presumed scouring effect could be responsible for the absence of fry on redd 9 in the South Mills River and redd 4 on Poplar Creek. Reiser and Wesche (1977) reported that freezing of the eggs in Vibert boxes buried at a depth of 15 cm was a probable cause of extensive mortality in an egg planting experiment in Wyoming. It seems that even though intragravel parameters such as dissolved oxygen, permeability and apparent velocity appeared to be adequate for fry production, severe weather may have been more important.

When comparing dissolved oxygen, permeability, and apparent velocity to comparable substrate data from the same drainage basin (Dechant 1979, West 1979), the natural spawning areas exhibited higher values for these parameters than random intragravel measurements (West 1979) and measurements in areas where eggs were planted (Dechant 1979). This indicates that the trout possess the ability to select the best spawning areas. In an experiment in which trout eggs were planted in the substrate (Dechant 1979), there also was a sharp decline of dissolved oxygen, permeability, and apparent velocity. This was not observed in the wild brown trout redds and was also probably due to better site selection by the wild brown trout.

Redd Success

The number of alevins recovered varied from 0 to 150. We expected to recover more. It was not possible to determine how many eggs were deposited, but in this drainage fecundity estimates of a few brown trout (West unpubl.) varied from 643 for a 205 mm female to 1,978 for a 371 mm female. Most of the females observed spawning were 225 mm (Table 1). Females of this size would be expected to have approximately 800 eggs. Ottaway et al. (1981) indicated that a female brown trout may deposit eggs up to 5 times before she is spent. If it is assumed that equal numbers of eggs are released at each of 5 depositions, a 225 mm female with 800 eggs would deposit approximately 160 eggs each time. With the exception of 1 redd (No. 5, Poplar Creek, Table 3) none produced even half this number, and many produced no alevins. One of the main reasons for this was high discharge during the incubation period which either caused the redd to be washed out completely or washed large amounts of fine sediment into it. Seven of 15 redds on the South Mills were altered by high discharge whereas none on Poplar Creek had similar damage. This is interesting since discharges in Poplar Creek are less than half those of the South Mills and suggests that at least in this drainage basin and for this year the smaller stream was less affected by high discharge and was more successful in producing young-of-the-year trout than the larger stream. A mean of 68 alevins per redd were recovered from Poplar Creek while the South Mills produced a mean of only 5.

The largest number of fry trapped was 22. This was also smaller than we expected. Apparently many of the alevins do not survive to emergence, also the number emerging was probably affected by deposition of fine sediment under the fry trap. This may have clogged escape routes of emerging fry.

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