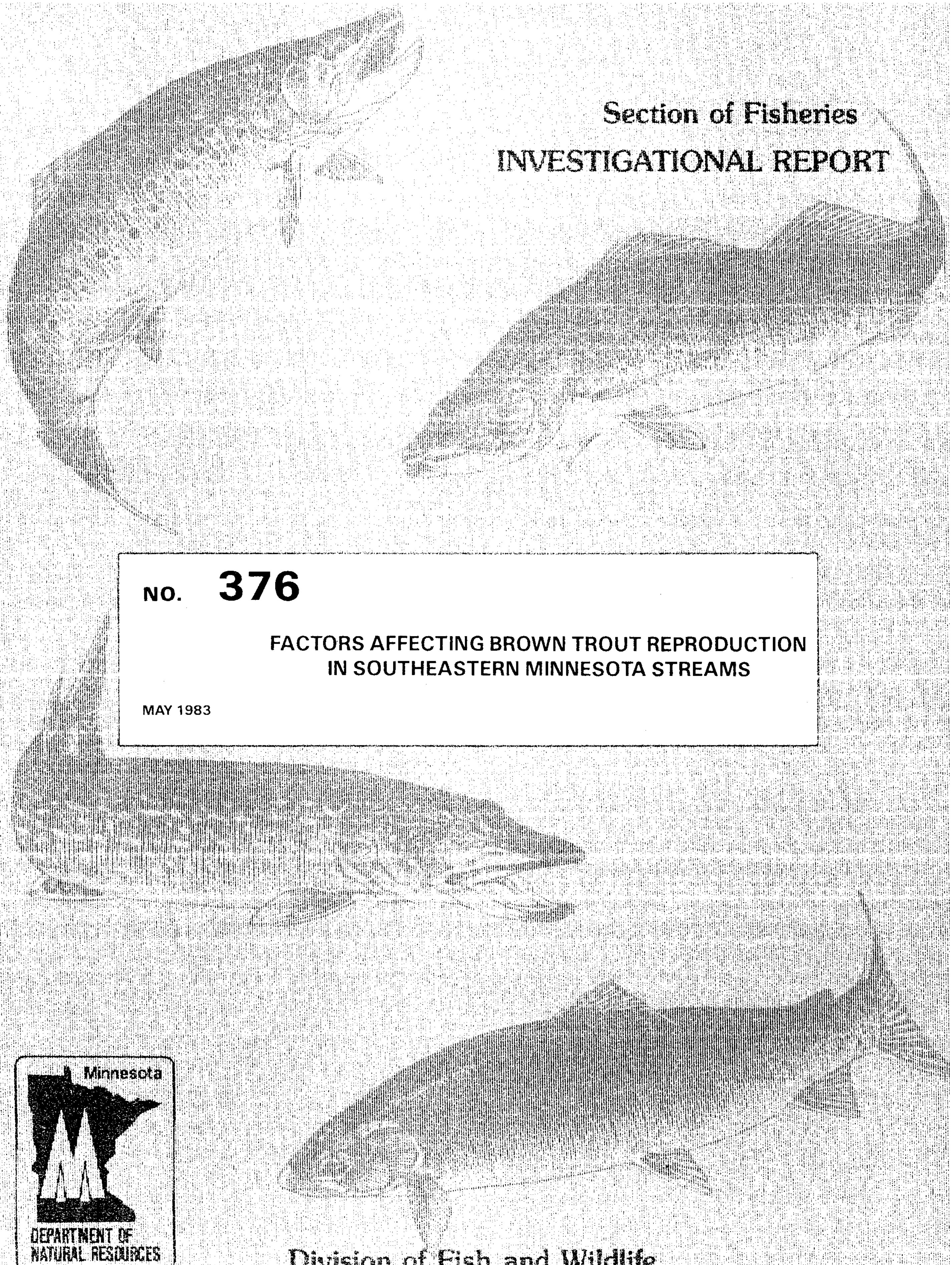

Section of Fisheries

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FACTORS AFFECTING BROWN TROUT REPRODUCTION IN SOUTHEASTERN MINNESOTA STREAMS

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Minnesota
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FACTORS AFFECTING BROWN TROUT REPRODUCTION IN SOUTHEASTERN MINNESOTA STREAMS[1]

by

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ABSTRACT

Late winter and spring flooding was the major factor affecting reproductive success of brown trout (Salmo trutta) in six southeastern Minnesota streams. Incubation success and fingerling abundance were high in stream sections where fry emergence occurred before spring runoff. Dates of hatch and emergence were determined by spawning dates and water temperature regimes. Fry survival was higher when spring runoff was gradual. Other factors such as redd superimposition, substrate composition, water velocity, hydraulic gradient, intra-redd dissolved oxygen and stream morphometry were not limiting to brown trout recruitment. Siltation, long believed to cause egg and fry suffocation, could not be related to low dissolved oxygen levels or to egg and fry survival. Dissolved oxygen was generally lower after high water periods but the silt content in the redds was not changed.

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[1] Completion report, Study 216 D-J Project F-26-R Minnesota

INTRODUCTION

Southeastern Minnesota river and stream valleys are in the driftless or unglaciated region of Minnesota where hills may be as high as 500 feet. The landscape is rugged as a result of erosion of the streams from high, flat plateau lands to the lower elevation of the Mississippi River (Schwartz and Thiel 1954). The valleys are cut through lime and sandstone layers and have steep hardwood covered slopes. Stream gradients are often 35 ft/mi or greater. Numerous large springs occur at the valley bottoms where limestone faults, caverns and sandstone aquifers are exposed. Water supply and quality are excellent for brown trout (Salmo trutta). Pasturing of many of the hillsides and row cropping on the gentler slopes have led to severe flooding and erosion problems. Silt and sediment resulting from these poor land use practices was believed to blanket and suffocate incubating trout eggs. Flooding and sedimentation problems, however, are most severe during spring and summer, not during fall and winter when brown trout eggs and sac fry are incubating.

Some of the streams in southeastern Minnesota have excellent trout reproduction and some of the best streams have heavy silt loads. The need for expensive hatchery stocks of trout could be greatly reduced if the factors limiting natural trout populations were known. At the very least, the ability to predict year-class strength would improve fisheries management capabilities. Factors expected to be important to successful egg and fry incubation include: silt and sediment (Hobbs 1937; Cordone and Kelley 1961); flooding (Hobbs 1937; Gangmark and Broad 1956); flow conditions (Warner 1963); hydraulic gradient (Coble

1961); gravel characteristics (McNeil and Ahnel 1964; Pollard 1955; Wickett 1954; Terhume 1958; Coble 1961); water velocity (Cordone and Kelley 1961; Hynes 1970); dissolved oxygen (Shumway et al. 1964); water percolation through gravel (Pollard 1955; Wickett 1954; Terhume 1958; Shumway et al. 1964); and water temperature. This study was designed to determine if brown trout reproduction in southeast Minnesota streams was failing, and if so, what factors caused the failure.

DESCRIPTION OF STUDY AREAS

Study sections (Figs. 1, 2, 3) were chosen on six streams with a range of good to poor reproduction and heavy to light sediment and silt conditions. The basic features of the stream sections are illustrated in Table 1.

METHODS

Redds and Stream Morphometry

Stream sections were walked at least weekly from 1 October through 30 November each year 1976 through 1978. Dates of observed spawning, spawning locations and stream morphometry were documented and flagged metal pins were placed in the redds. Morphometric characteristics included sinuosity, width and depth and basic features such as flat, run, pool and riffle were recorded. Sinuosity was calculated as channel length divided by valley length (Leopold et al. 1964). The influence of stream morphometry on redd stability was observed periodically throughout the incubation period and judgments on redd disturbances were made after expected emergence dates. Large scale maps were constructed showing riffle, pool and basic stream features.

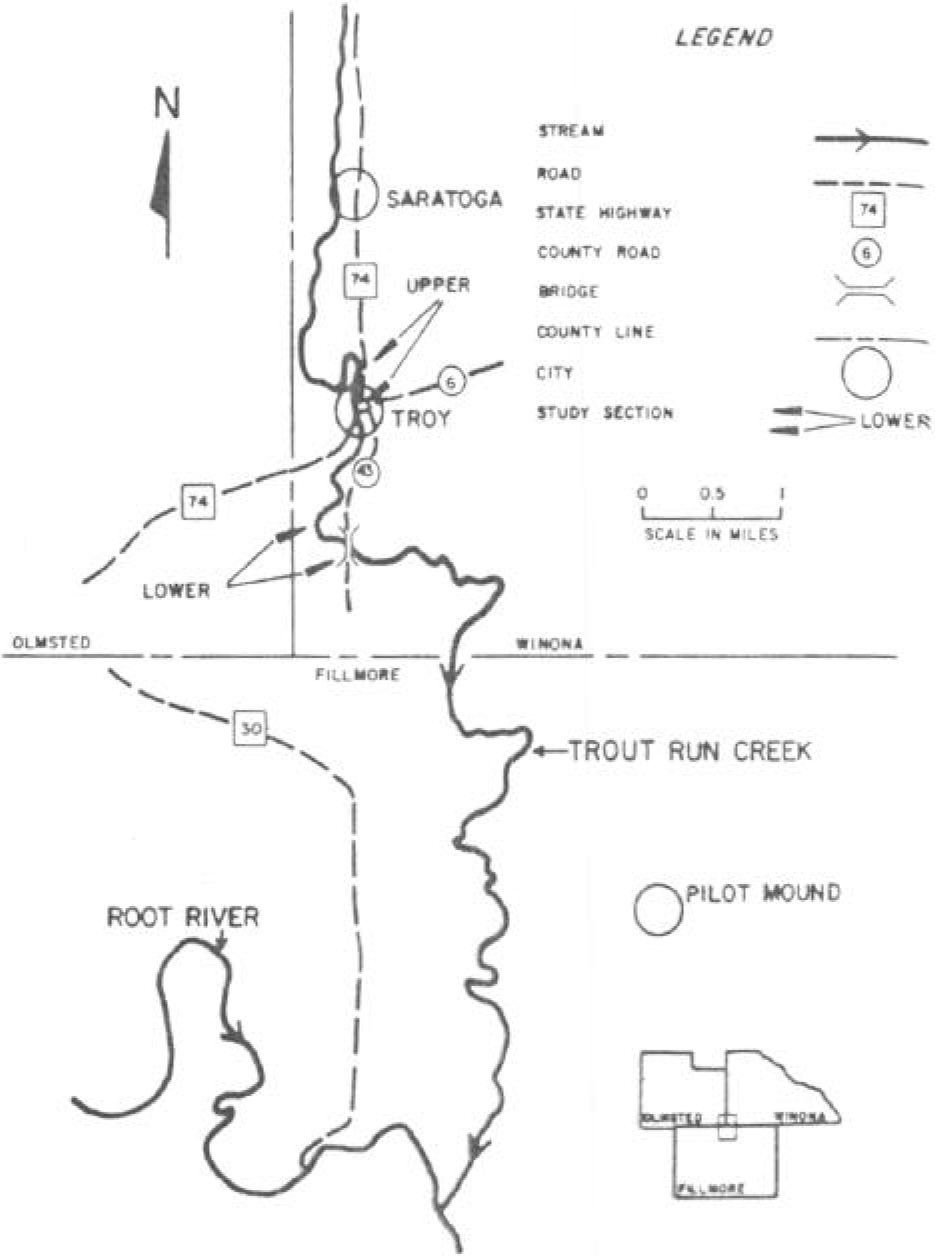

Figure 1. Trout Run Creek study sections.

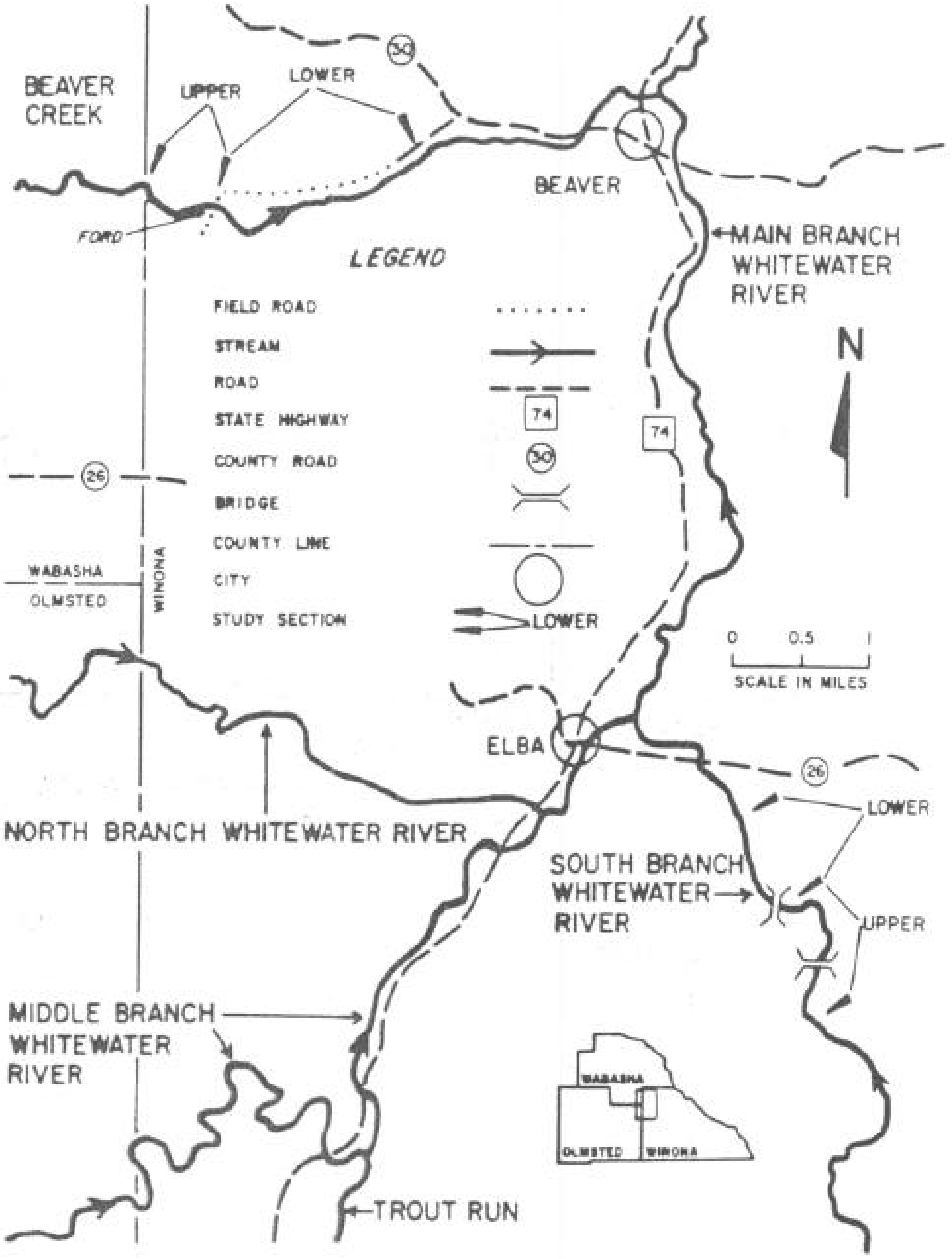

Figure 2. Beaver Creek and South Branch Whitewater River study sections.

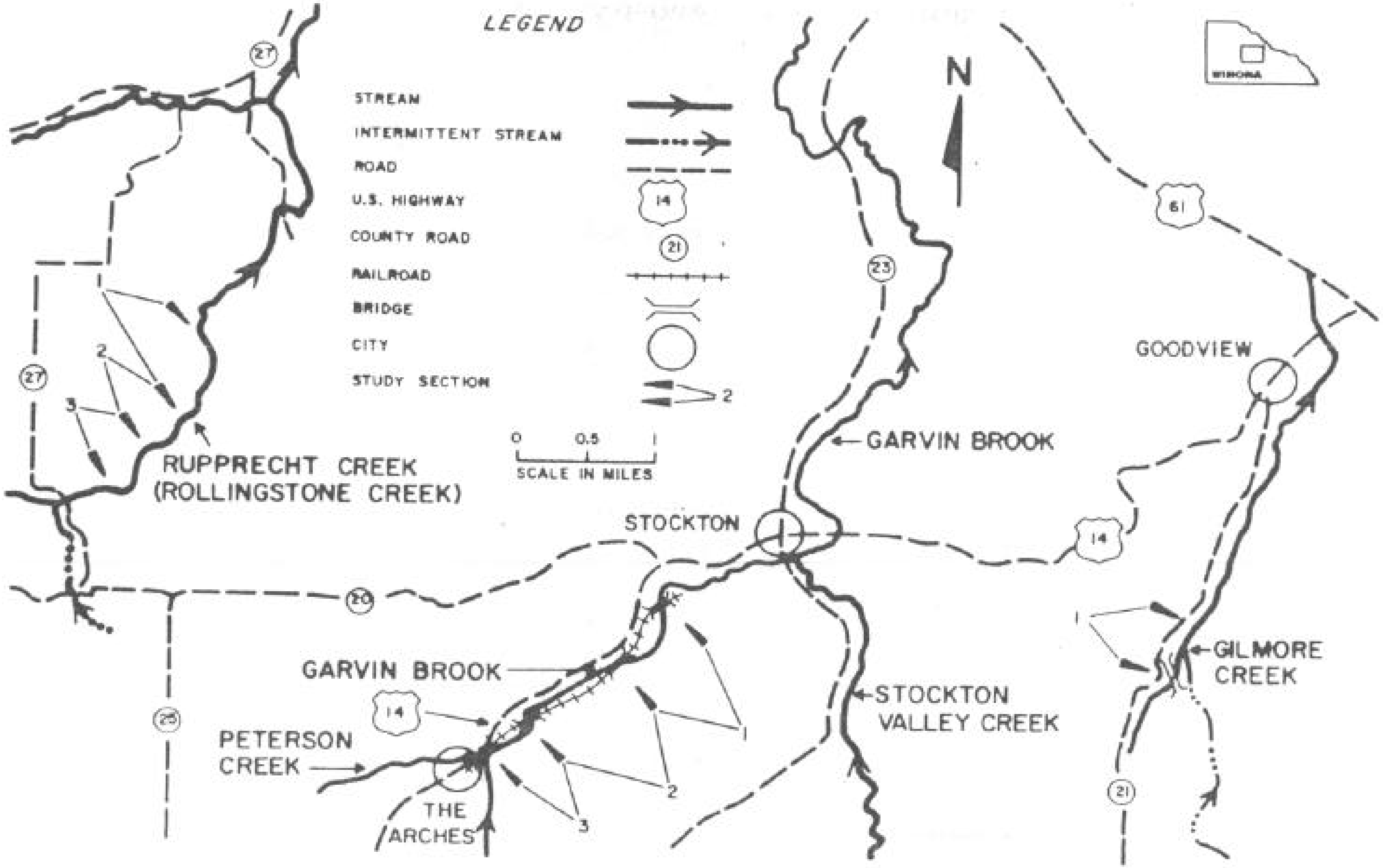

Figure 3. Rupprecht Creek, Garvin Brook, and Gilmore Creek study sections.

Table 1. Basic characteristics of 13 southeast Minnesota brown trout stream study sections.

Stream section	Floodplain land use	Spring flooding	Reproduction	Watershed size	Silt and sediment deposits
Lower South Branch[a] Whitewater	Wild	Severe	Fair-God	Very large	Heavy
Upper South Branch[a] Whitewater	Wild	Severe	Good	Very large	Heavy
Lower Beaver[a]	Wild	Light-Moderate	Poor-Fair	Medium	Heavy
Upper Beaver[a]	Wild	Light	Good-Excellent	Medium	Heavy
Lower Trout Run[a]	Pasture	Moderate	Poor-Fair	Large	Heavy
Upper Trout Run[a]	Pasture	Moderate	Poor-Fair	Large	Heavy
Gilmore	Wild-Urban	Moderate	Excellent	Small	Heavy
Garvin no. 1	Pasture	Light-Moderate	Poor-Fair	Small	Moderate-Heavy
Garvin no. 2[a]	Pasture	Light-Moderate	Fair-Good	Small	Moderate-Heavy
Garvin no. 3	Wild	Light-Moderate	Good-Excellent	Small	Light-Moderate
Rupprecht no. 1	Pasture	Moderate	Good-Excellent	Small	Moderate
Rupprecht no. 2[a]	Pasture-Wild	Light-Moderate	Good-Excellent	Small	Light
Rupprecht no. 3	Wild	Light-Moderate	Good-Excellent	Small-Medium	Light

[a] Sections chosen for 1978-1979 redd gradient measurement, redd substrate sampling and redd excavation.

Monitoring of Incubation Conditions

Water temperatures and general incubation conditions were recorded for all stream sections. Temperatures were measured weekly with maximum-minimum and hand-held thermometers. Conditions such as flooding, ice formation and newly fallen trees that had direct or potential effect on incubation were noted.

Trout Run and Beaver Creeks were the most intensively studied. These streams were divided into sections which had notable differences in spawning habitat, spawning activity and water temperature. After the peak of spawning in each section, all mapped redds were numbered and a random sample of at least 10 redds was selected for intensive work. Hydraulic and bottom gradients were measurted at 1 ft intervals for a distance 5 ft upstream and 5 ft downstream of the center of each redd. A substrate sample was taken from each selected redd at the beginning of incubationn and again shortly before the date of expected fry emergence. The substrate sampler (modified from McNeil and Ahnell 1974) was fabricated from either a 4 in or 6 in diameter, 18 in long section of aluminum irrigation pipe passed through and sealed to the bottom of a metal pan. The sampler was worked into the redd and the substrate materials enclosed were lifted by hand up the pipe into the pan. Materials of each sample were separated with a series of sieves ranging from 0.0049 in through 0.74 in. Particles were separated into categories of large particles 0.079 in through 0.74 in and larger, intermediate particles 0.0049 in through 0.078 in and fine particles smaller than 0.0049 in. Relative composition of the larger sizes of substrate materials was determined by volumetric water displacement.

Fine particles were settled in an Imhoff settling cone for 10 min before settleable sediment readings. With the substrate sampler in place, a perforated pipe (Gangmark and Bakkola 1958) modified to accept constant intra-gravel water flow was placed in each void created when the substrate sample was removed. Stream gravel larger than 0.187 in was placed around the perforated pipe to within 1 in of the top. The original profile of the redd determined during gradient measurement was then restored.

Dissolved oxygen concentration and water temperature in redds were measured bi-weekly from all implanted perforated pipes. To take an oxygen reading from a perforated pipe, the pipe cap was removed from the exposed end of the submerged pipe and a wooden dowel with a diameter slightly less than the inside diameter of the pipe was inserted forcing water out. An extension reaching above the water surface was then attached to the pipe. The dowel was extracted and water flowed into the pipe from the surrounding gravel. A dissolved oxygen meter and probe was then used to measure the oxygen concentration and temperature within each pipe. The perforated pipes were removed from the redds at the end of the incubation period and the accumulated sediments in each pipe were extracted for substrate analysis using the above processing methods. The redds were then excavated and any egg and fry remains were retained for further examination. Water velocity was measured at redd sites during the winter of 1976-77.

After the 1977-78 sampling season, it was determined that more could be learned from redd excavations than from the other measurements. Consequently, pre-incubation substrate sampling, perforated pipe sediment measurements, redd dissolved oxygen and redd temperature monitoring were discontinued. Post-incubation substrate sampling, gradient measurement and mainstream temperature monitoring were conducted on eight stream study sections. Mainstream temperature, spawning and fingerling abundance data only were collected from the remaining five study stream sections during 1978-79 (Table 1).

Hatch Success

Substrate samples taken the winter of 1978-79 were from redds selected for excavation. This differed from previous years when perforated pipe placement and pre-incubation substrate sample activities caused unknown egg mortalities. Another set of five samples with similar hydraulic gradients was taken from study sections of Trout Run Creek and Beaver Creek to examine redds not subjected to the above disturbances.

Sixty redds were randomly selected for excavation (pipe redds plus additional redds) for Beaver and Trout Run Creeks the winters of 1976-77 and 1977-78. The actual sample size was 49 redds in 1976-77 and 50 redds in 1977-78 as some redds were eliminated by spring high waters. Ten redds were excavated from each of the eight stream sections in 1978-79 except in the upper South Branch Whitewater River where only six samples were taken (Table 1).

Redds were excavated after the expected date of hatch but before the fry were expected to emerge (Embody 1934). Fry were collected with a Surber type sampler. Incubation success was expressed as the number of live fry/redd and as the percentage of redds that contained live fry. The percentage of live fry within redds was not calculated because of the unknown disappearance of dead eggs and fry (McDonald

1960). Fry traps (Phillips and Koski 1969) were tried but discarded because they trapped sand and sediment, a problem also noted in Wisconsin (Hausle and Coble 1976).

Fingerling Abundance

Electrofishing stations were established on all study stream sections in an effort to develop relationships between expected reproductive success and fingerling populations. Results were tabulated as the number of fingerlings caught/100 ft of stream length electrofished. When possible, stations were electrofished in June and again in August. Fingerlings captured in June were given an adipose fin clip to differentiate recaptures in the August sample.

RESULTS

Incubation Conditions and Success

Brown trout reproduction was poor in southeastern Minnesota trout streams when flooding occurred prior to egg hatch and fry emergence. Incubation was incomplete in many stream locations when 1977 spring high water levels occurred in early March and incubation success was poor (Table 2). Spring runoff was unusually gradual the springs of 1978 and 1979 and incubation success was greatly improved (Tables 3 and 4).

Dates of hatch and emergence of fry were dependent upon spawning dates and incubation water temperature (Figs. 4 and 5). Correlations of 1978-79 stream section mean hatch dates with the 1978-79 mean percentage of redds containing live fry and with the mean number of live

Table 2. Calculated pre-runoff fry emergence, incubation success and fingerling abundance of brown trout in 13 southeast Minnesota stream sections, 1976-1977.

Stream section	Redds/100 ft with emergence before runoff	Redds with live fry (%)[a]	Fgl/100 ft electrofished
Lower South Branch Whitewater	0,0	-	5.3
Upper South Branch Whitewater	0.0	-	0.0
Lower Beaver	0.0	35.7	0.0-1.4
Upper Beaver	0.0	69.2	2.0-4.5
Lower Trout Run	0.3	16.7	0.6
Upper Trout Run	0.0	20.0	1.2
Gilmore	0.3	-	8.8
Garvin no. 1	0.0	-	2.3
Garvin no. 2	0.0	-	2.8
Garvin no. 3	0.1	-	5.6
Rupprecht no. 1	0.0	-	7.2
Rupprecht no. 2	0.1	-	8.5
Rupprecht no. 3	0.07	-	2.2

[a] These values were calculated assuming that redds that could not be located after the flood were total losses. The determination was made only for the four intensively studied stream sections.

Table 3. Calculated pre-runoff fry emergence, incubation success and fingerling abundance of brown trout in 13 southeastern Minnesota stream sections, 1977-1978.

Stream section	Redds/100 ft with emergence before runoff	Mean no. live fry /redd[a]	Redds with live fry (%)[a]	Fgl/100 ft electrofished
Lower South Branch Whitewater	0.4	-	-	10.9
Upper South Branch Whitewater	0.1	-	-	Trace-2.8
Lower Beaver	0.2	13.3	80.0	2.0-4.8
Upper Beaver	1.2	45.8	60.0	4.6-10.3
Lower Trout Run	0.0	13.6	70.0	5.1
Upper Trout Run	1.1	2.7	20.0	6.7
Gilmore	4.0	-	-	24.3
Garvin no. 1	0.3	-	-	3.9
Garvin no. 2	0.4	-	-	2.1
Garvin no. 3[b]	-	-	-	4.0
Rupprecht no. 1	0.4	-	-	45.2
Rupprecht no. 2	0.8	-	-	12.0
Rupprecht no. 3	1.5	-	-	12.0

[a] Determined only for the four intensively studied stream sections.

[b] No predictions were made because spawning could not be properly observed. Water was turbid during spawning in this section.

Table 4. Calculated pre-runoff fry emergence, incubation success and fingerling abundance of brown trout in 13 southeast Minnesota stream sections, 1978-1979.

Stream section	Redds/100 ft with emergence before runoff	Mean no. live fry /redd[a]	Redds with live fry (%)	Fgl/100 ft electrofished
Lower South Branch Whitewater	0.2	44.7	36.4	1.2
Upper South Branch Whitewater	0.0	9.8	17.7	1.0-2.2
Lower Beaver	0.5	25.3	90.0	8.4-33.0
Upper Beaver	2.3	45.3	100.0	15.6-50.4
Lower Trout Run	0.1	6.9	50.0	5.0
Upper Trout Run	0.3	14.8	60.0	0.4
Gilmore	2.0	-	-	31.4
Garvin no. 1	Trace	-	-	1.4
Garvin no. 2	0.2	53.5	50.0	1.2-8.9
Garvin no. 3	0.7	-	-	11.4
Rupprecht no. 1	0.0	-	-	45.4-80.8
Rupprecht no. 2	0.2	54.3	80.0	10.0-25.0
Rupprecht no. 3	1.4	-	-	6.4-15.2

[a] Samples were taken from an increased number of stream sections the spring of 1979.

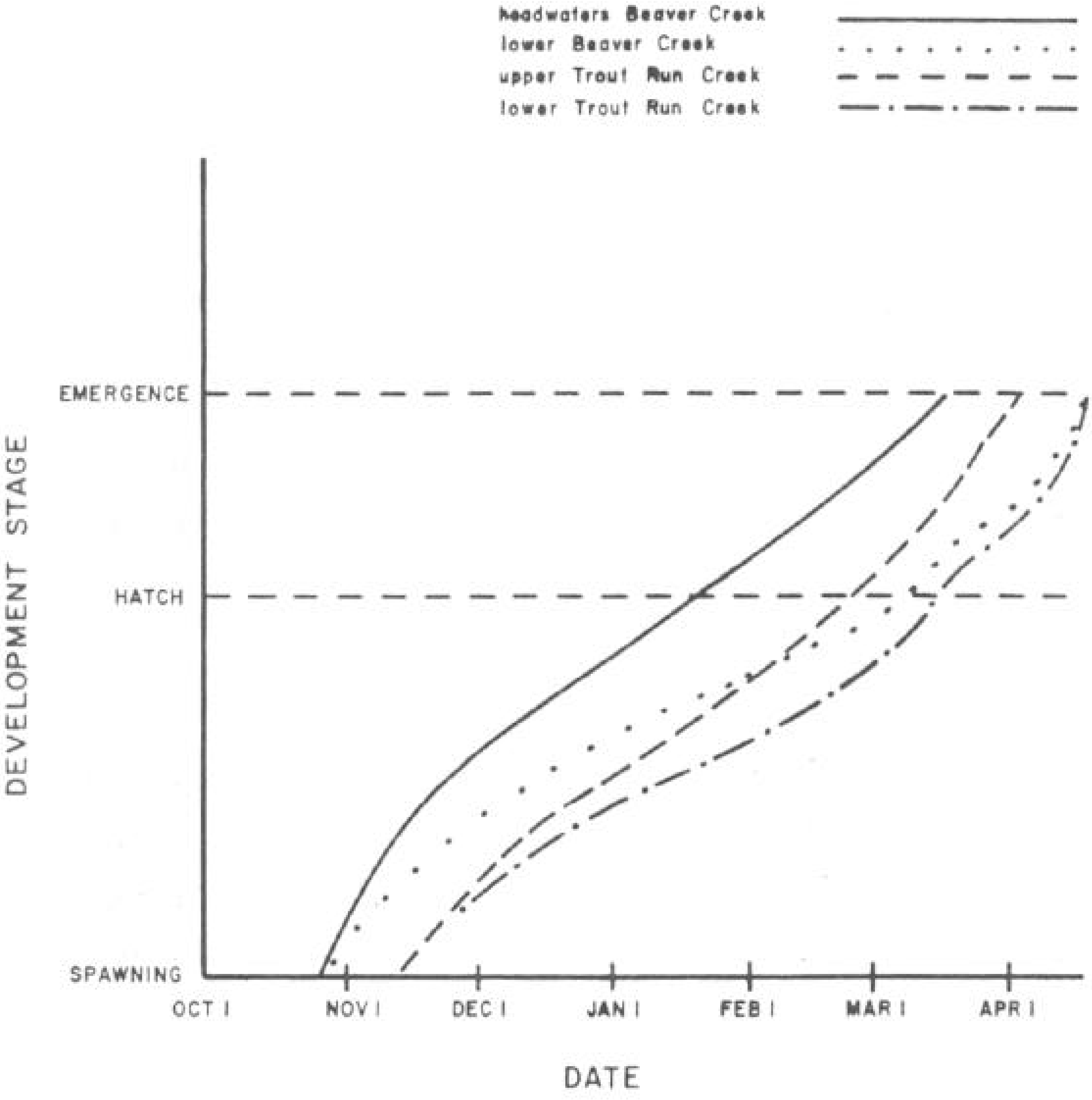

Figure 4. Development rates of mean hatch of brown trout eggs and emergence of fry in Beaver Creek headwaters, lower Beaver Creek, upper Trout Run Creek and lower Trout Run Creek October-April 1978-79. Spawning dates are the mean spawning dates for the respective stream sections. Different development rates are responses to different temperature regimes.

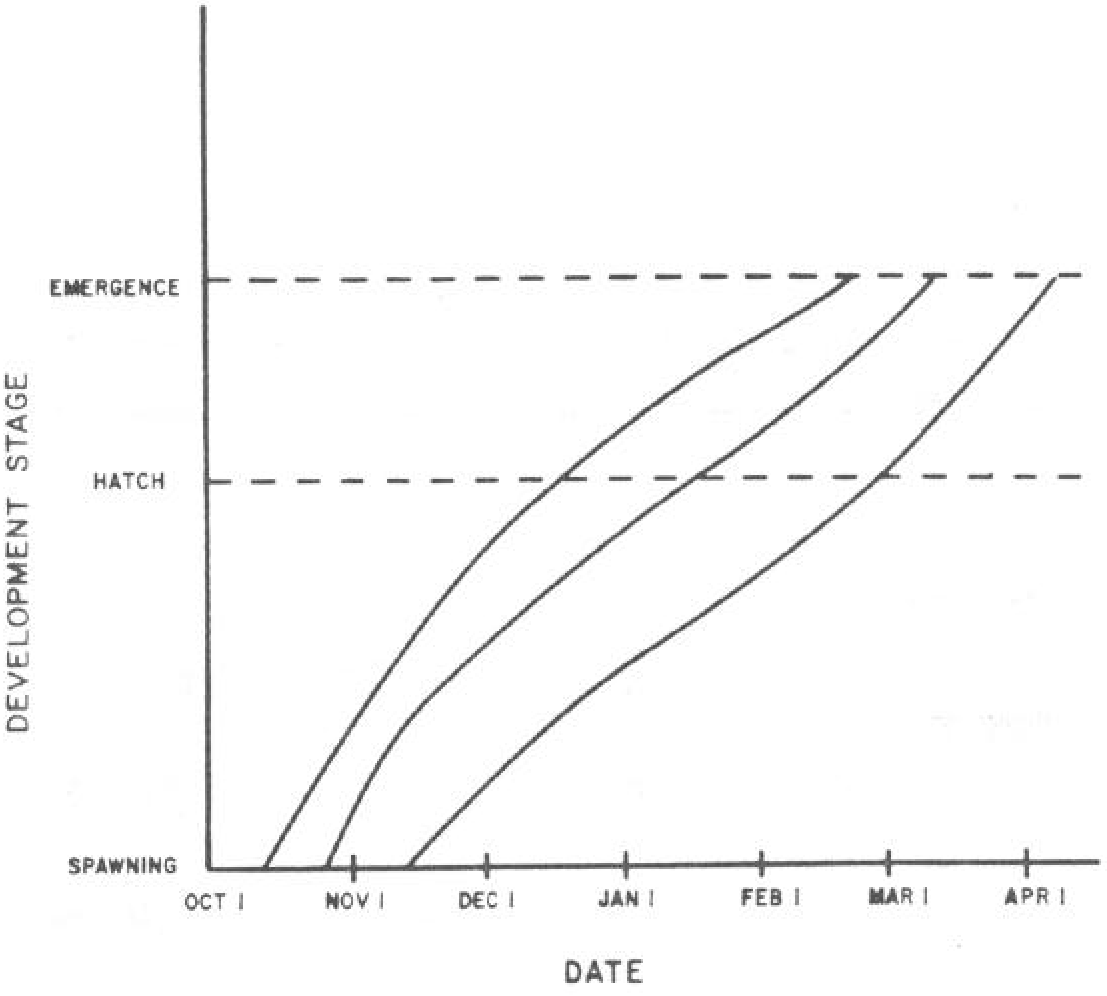

Figure 5. Hatch and emergence dates of brown trout eggs and fry of different spawning dates, Beaver Creek headwaters, 1978-1979.

fry/redd were negative (r = -0.582, p = 0.14 and r = -0.688, p = 0.06, respectively).

Mean monthly water temperatures of stream sections varied considerably (Table 5). The largest differences among years occurred during the month of October. Stream sections with the warmest winter temperatures had more consistent mean monthly temperatures from year to year. A mean monthly temperature of 33 F represents a situation where ice cover persists for weeks at a time. Mean monthly temperatures of 35 F and greater represent situations where ice cover was rare.

Incubation of eggs and sac fry occurred at warmer temperatures when redds were located in ground water seepage areas. Temperatures within different redds in the same proximity of lower Trout Run Creek varied from each other by up to 7 F. Warm ground water temperatures of redds were not detected in any other stream sections.

Spawning

Brown trout spawned from the first week in October through the last week in November. Mean spawning dates varied among stream sections and among years (Table 6). Spawning was notably late in some stream sections, especially in Trout Run Creek. Differences in stream flows from year to year did not influence spawning timetables.

The number of redds/stream length varied considerably among stream sections and among years (Table 7). There was a general increase in redd abundance from the fall of 1975 through the fall of 1978. Abundance in lower Beaver Creek increased almost fourfold from fall 1976 through fall 1978. Some years the number of redds was extremely low in the upper South Branch of the Whitewater River, Garvin Brook sections

Table 5. Mean monthly water temperatures (F) for 10 southeast Minnesota stream locations, 1976-1979.

Stream section	October			November			December			January			February		
	1976	1977	1978	1976	1977	1978	1976	1977	1978	1977	1978	1979	1977	1978	1979
Lower South Branch Whitewater	42	46	49	39	45	43	41	37	38	36	34	35	37	35	36
Upper South Branch Whitewater	44	48	49	40	44	42	34	35	35	33	32	33	35	33	34
Lower Beaver	44	47	49	39	40	42	33	35	35	33	33	33	32	33	34
Upper Beaver	43	48	48	42	45	44	39	40	40	39	38	39	40	38	38
Lower Trout Run	45	48	48	41	45	43	36	40	38	35	38	35	37	38	36
Upper Trout Run	45	47	43	42	43	45	38	37	40	37	34	38	39	36	38
Gilmore	48	50	49	43	45	46	38	40	40	37	37	37	39	37	38
Garvin no. 1	45	50	49	42	45	44	37	38	38	37	36	35	39	37	37
Garvin no. 2	47	50	50	42	44	44	38	38	38	36	36	36	38	37	37
Rupprecht no. 2	43	48	49	42	45	45	38	39	40	37	36	36	40	38	37

Table 6. Mean spawning, hatch and emergence dates of brown trout in 134 southeast Minnesota stream sections, 1976-1979.

	Mean spawning			Mean hatch			Mean emergence		
Stream section	1976	1977	1978	1976-77	1977-78	1978-79	1977	1978	1979
Lower South Branch Whitewater	10-29	10-24	10-31	03-10	01-30	02-17	04-11	03-26	04-05
Upper South Branch Whitewater	10-20	10-30	10-30	03-04	02-28	03-06	04-08	04-11	04-13
Lower Beaver	10-27	11-14	10-17	03-02	02-14	02-04	04-08	04-06	03-30
Upper Beaver	10-25	10-23	10-29	02-15	01-12	02-04	03-30	03-16	02-21
Lower Trout Run	11-11	11-03	11-11	03-12	02-28	03-09	04-11	04-08	04-15
Upper Trout Run	11-11	11-06	11-10	02-28	02-11	02-20	04-05	03-28	03-29
Gilmore	10-29	10-27	11-05	01-27	01-20	02-11	03-22	03-08	03-23
Garvin no. 1	11-08	10-22	10-31	03-10	01-12	02-08	04-09	03-12	04-01
Garvin no. 2	10-30	11-04	11-06	02-13	02-07	02-20	03-28	03-25	04-05
Garvin No. 3	10-25	----	10-25	02-14	12-31	01-24	03-19	02-26	03-14
Rupprecht No. 1	11-01	10-30	11-03	03-07	02-12	02-26	04-09	04-03	04-09
Rupprecht No. 2	10-13	11-04	11-06	02-13	02-07	02-20	03-28	03-25	04-05
Rupprecht No. 3	11-01	11-03	11-04	01-30	01-23	01-28	03-13	03-07	03-12

Table 7. Brown trout redds/100 ft and percentage of spawning superimposition for 13 southeast Minnesota stream sections, 1975-1978.[a]

	Number/100 ft				Percent superimposed	
Stream section	1975	1976	1977[b]	1978	1977	1978
Lower South Branch Whitewater	.07	0.6	0.8	1.0-1.1	4.5	3.4
Upper South Branch Whitewater	Trace	0.2	0.4	0.2	7.1	Trace
Lower Beaver	P[c]	0.3	0.7-0.8	1.3-1.4	5.6	7.0
Upper Beaver	P	1.2	1.6-2.1	4.1-4.4	11.8	7.9
Lower Trout Run	P	2.5	1.4- .1	1.7-2.7	34.8	14.3
Upper Trout Run	P	1.9	1.8-2.1	1.2-1.5	12.5	14.7
Gilmore	P	1.8	4.0	4.2-4.9	50+	13.9
Garvin no. 1	0.0	0.3	0.4	0.3	0.0	0.0
Garvin no. 2	0.0	0.2	0.7	0.5	4.9	0.0
Garvin no. 3	P	0.2	1.0	1.0	6.9	0.0
Rupprecht no. 1	P	0.5	1.8-2.2	2.0-2.2	15.5	9.2
Rupprecht no. 2	P	0.8	1.8-2.0	1.4	11.6	2.0
Rupprecht no. 3	0.0	0.2	1.5-1.6	1.7	4.2	0.0

[a] Ranges of redd abundance shown under 1977 and 1978 reflect notable differences over the stream section length and losses to superimposition.

[b] 1977 rates of superimposing make some of the tabled values underestimates of the actual spawning effort.

[c] P indicates some redds present.

no. 1 and 2 and Rupprecht Creek no. 3.

Spawning activity in 1977 and 1978 was often excessive for the available spawning habitat and redd superimposition (overspawning) was common (Table 7). Overspawning sometimes so obscured previous redds that total redd number was likely underestimated. In streams where the greatest spawning activity took place, most of the early redds were disrupted by later spawning fish. A previous redd was not necessarily lost when superimposition occurred as redd excavation samples often contained live eggs or fry of two completely different development stages and/or two distinctly different sizes of eggs or fry. Such surviving eggs and fry were obviously spawned by different fish and/or at different times.

Fingerling Abundance

Fingerling abundance was correlated with several spawning and incubation factors. The correlations of 1978 and 1979 fingerling catch/effort (minus the Rupprecht Creek section no. 1 data) with the abundance of redds, with the number of redds with fry emergence before spring runoff, with mean hydraulic gradient and with the incidence of redds containing live fry were all significant ($P=0.05$) (Table 8). Correlations of dates of mean spawning, mean hatch and mean emergence with fingerling abundance for the same period were insignificant and negative. Correlations of fingerling abundance with all factors were weak for the 1976-77 incubation year. The correlation of the percentage of large substrate ($\geq$0.079 in particles) with fingerling abundance was weak and insignificant.

Table 8. Regressions of brown trout fingerling CPUE (no./100 ft electrofished) with redd abundance, spawning date, hatch, emergence, incubation success, substrate and hydraulic gradient data[a]

	Intercept	Slope	r	P	df
No. redds/100 ft					
1976	3.266	0.202	0.055	>0.50	10
1977	0.118	5.439	0.861	<0.001	10
1978	0.126	6.949	0.840	<0.001	10
Mean spawning date					
1976	4.649	-0.060	-0.139	0.50	10
1977	9.337	-0.0916	-0.101	>0.50	9[b]
1978	16.672	-0.342	-0.207	>0.50	10
Mean hatch date					
1976-77	8.451	-0.0973	-0.517	0.088	10
1977-78	12.914	-0.145	-0.371	0.274	9[b]
1978-79	23.70	-0.282	-0.342	0.290	10
Mean emergence date					
1976-77	5.829	-0.060	-0.216	0.500	10
1977-78	17.328	-0.311	-0.581	0.064	9[b]
1978-79	26.303	-0.423	-0.392	0.210	10
Pre-runoff fry emergence (redds/100 ft)					
1976-77	2.823	9.489	0.330	>0.308	10
1977-78	3.430	5.141	0.893	<0.001	9
1978-79	3.743	11.990	0.832	<0.001	10
No. fry/redd (1979)	2.944	0.239	0.400	0.339	6
Percentage of redds with live fry (1979)	-12.24	0.377	0.885	0.004	6
Percentage of substrate ≥ 0.079	-72.35	1.040	0.486	0.229	6
Hydraulic gradient	-12.45	17.45	0.865	0.002	10

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[a] The data from Rupprecht Creek section no. 1 was excluded from these calculations.

[b] Garvin Brook section no. 1 water turbidity caused by road construction prevented observations, reducing df to 9.

Physical Factors

Correlations of physical factors with each other and with incubation success were often high among stream section means. The gradual runoff and expanded substrate and redd sampling efforts in 1979 facilitated comparison of stream section substrate, gradient and incubation success (Table 9). Simple correlation of the percentage of large substrate with the number of live fry/redd was positive and significant ($P=0.05$) but a sigmoid curve may more accurately represent the relationship (Fig. 6). Correlation of hydraulic gradient with the percentage of redds containing live fry (Fig. 7) was significant ($P=0.05$). Correlation of the perecentage of large substrate with the percentage of redds containing live fry and correlation of hydraulic gradient with the stream section mean number of live fry/redd were low and insignificant ($r = 0.530$, $p = 0.182$ and $r = 0.585$, $p = 0.135$, respectively). Hydraulic gradient of stream sections was positively correlated with percentage of large substrate (Fig. 8).

Substrate composition usually did not change significantly during incubation periods. Mean percentages of large substrate of stream sections usually declined but the only significant difference between pre and post-incubation means was detected from upper Beaver Creek samples 1976-77 (Table 10). The mean percentages of sediment from the combined 1976 and 1977 stream section substrate samples correlated positively with the volume of sediment accumulated in perforated pipes from the same redds ($r=0.877$, $p=0.001$).

All rank correlations among dissolved oxygen, physical conditions, reproductive success and fingerling abundance factors within stream sections were weak and insignificant (r_s values <0.500). Rank correla-

Table 9. Brown trout redd data from eight southeast Minnesota trout stream sections, 1978-1979.

Stream section	Substrate (%)			Bottom gradient (%)	Hydraulic gradient (%)	Mean no. live fry /redd	Redds with live fry (%)
	0.74-0.079 in	0.039-0.005 in	Settleable				
Lower South Branch Whitewater	78.75	16.99	4.42	0.73	1.41	44.73	36.4
Upper South Branch Whitewater	76.34	20.17	3.51	1.53	0.65	9.71	17.7
Lower Beaver	80.08	11.95	8.08	2.24	1.84	25.3	90.0
Upper Beaver	83.22	7.96	8.81	0.67	2.14	45.3	100.0
Lower Trout Run	69.22	18.16	12.62	0.41	0.75	6.9	50.0
Upper Trout Run	80.16	11.09	8.76	1.68	0.96	14.8	60.0
Garvin no. 2	81.88	10.68	7.41	0.30	0.87	53.5	50.0
Rupprecht no. 2	88.41	8.22	3.39	1.64	1.93	54.3	80.0

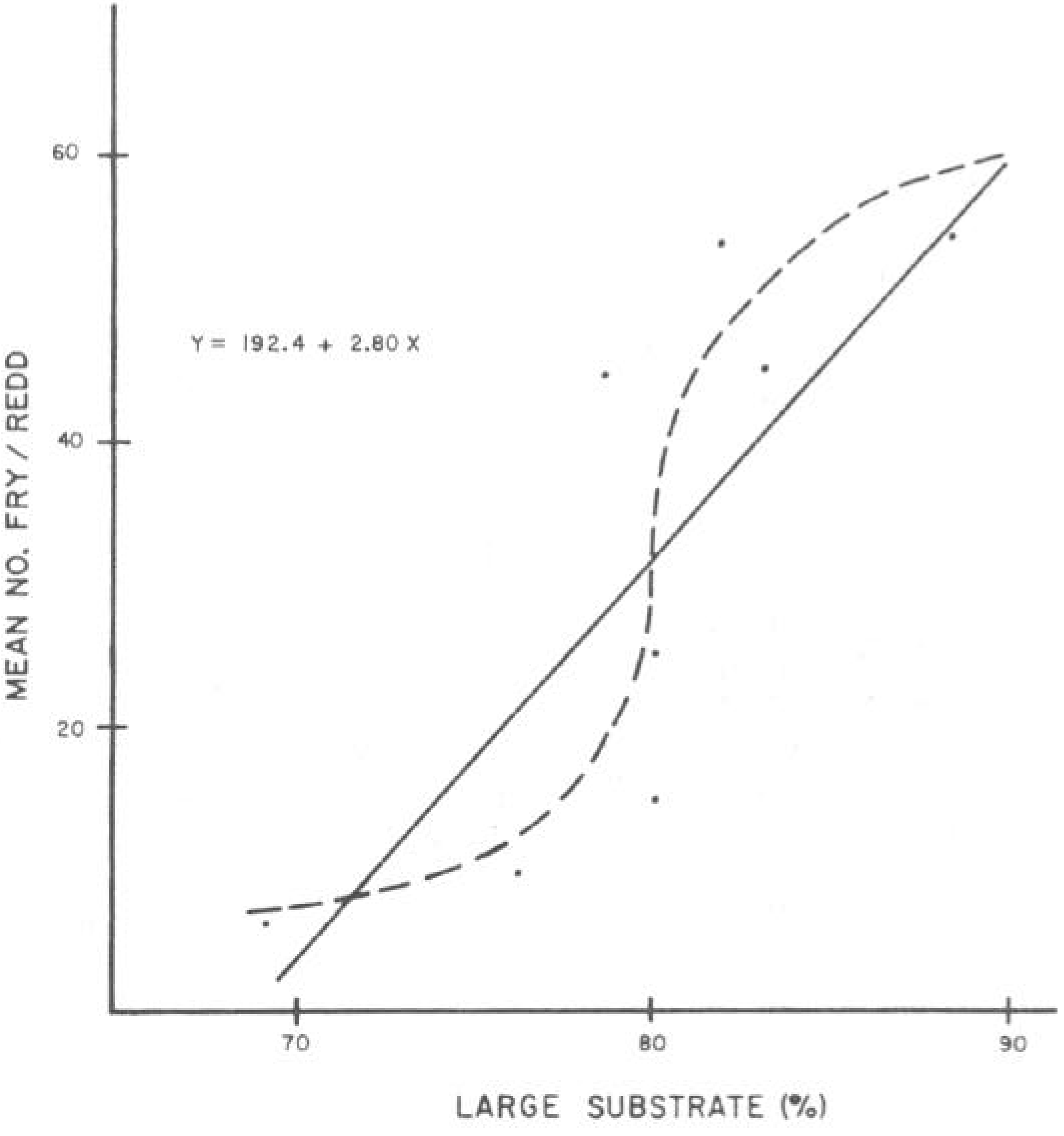

Figure 6. Linear regression of the percent composition of large substrate (particle size ≥ 0.079 in) and the mean number of live fry/redd ($r = 0.780$, $p = 0.023$). The dashed line was fitted by eye.

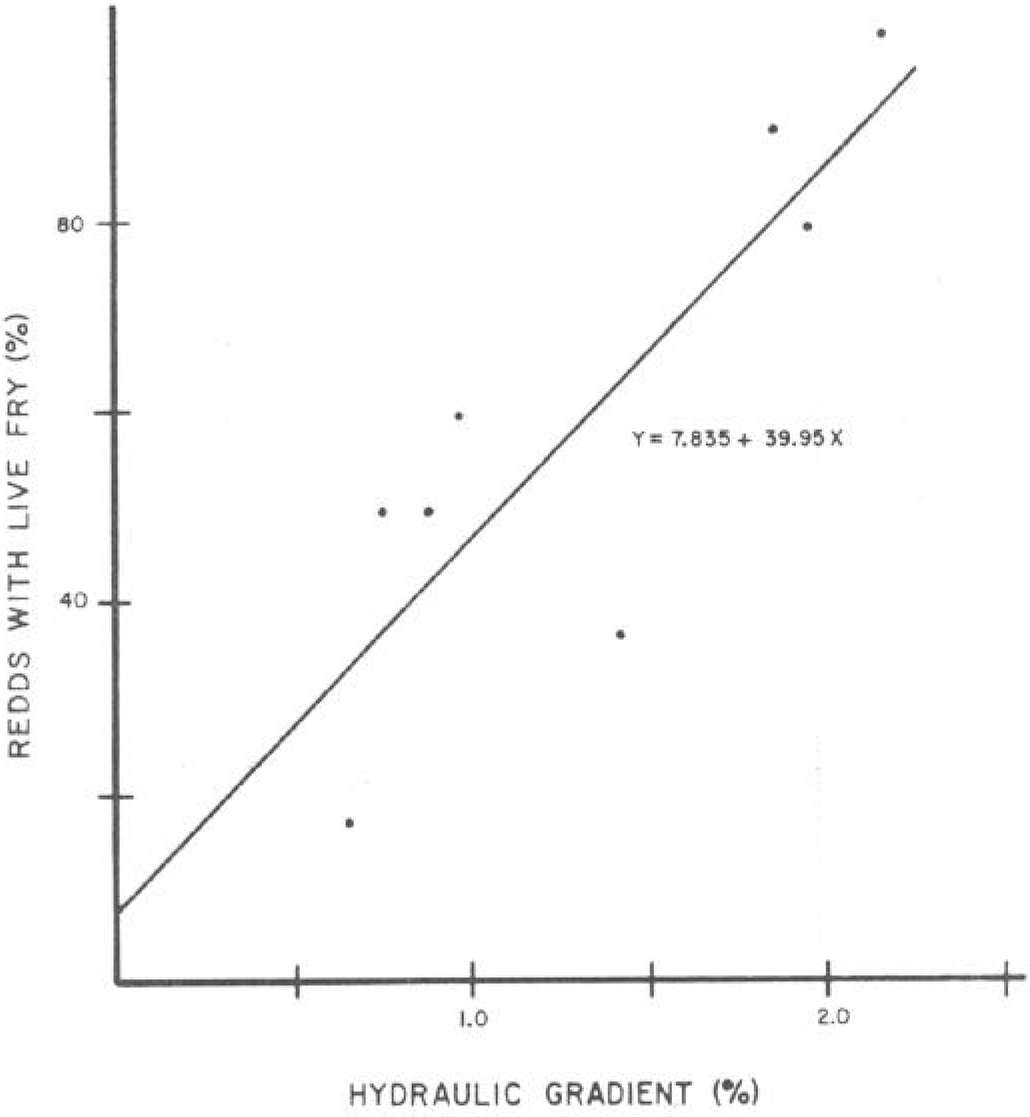

Figure 7. Linear regression of mean percentages of redds having live fry and redd hydraulic gradient (r=0.844, p=0.021).

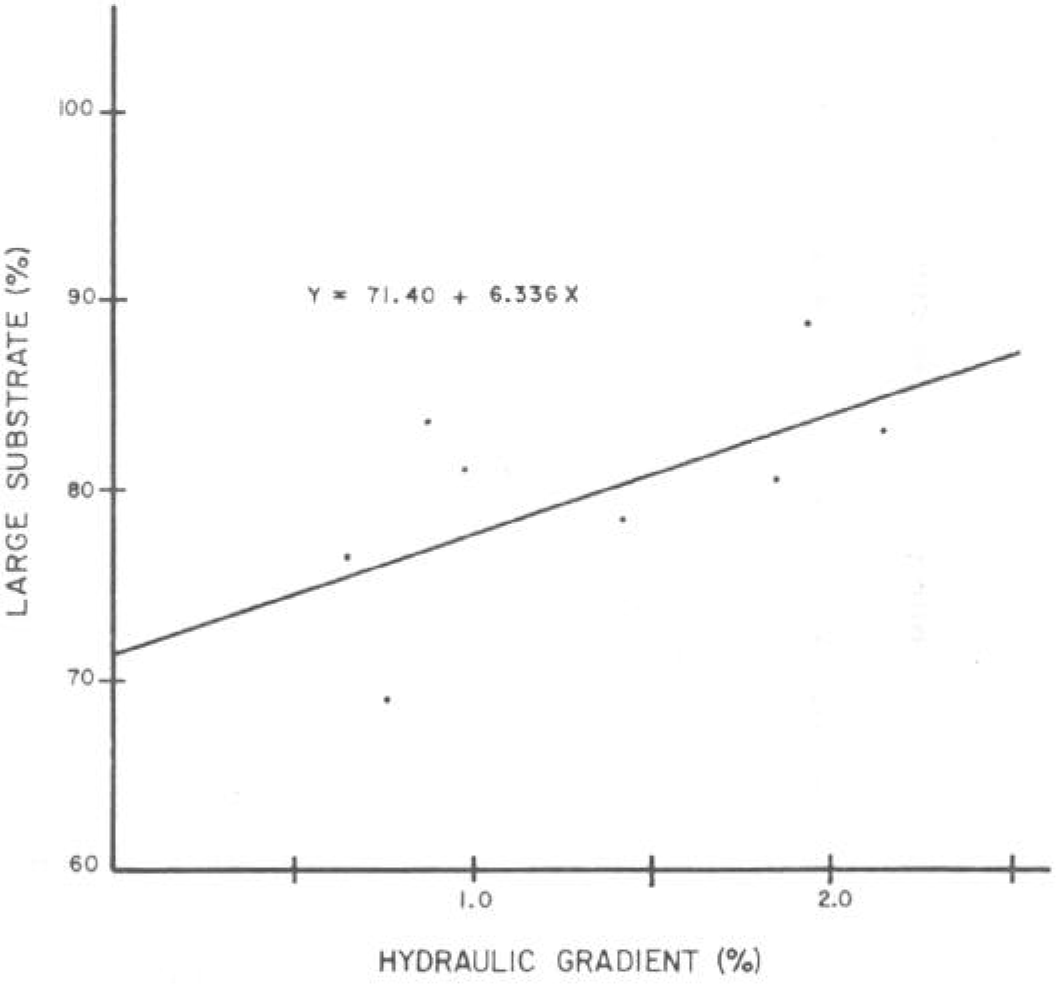

Figure 8. Linear regression of mean percentages of large substrate (particle size $\geq$ 0.079 in) and hydraulic gradient ($r = 0.673$, $p = 0.0720$).

tions for these factors varied widely each year even within the same stream section.

Table 10. Change in mean percentage of large substrate composition ($\geq$0.079 in) of brown trout redds during incubation, 1976-77 and 1977-78 in four southeast Minnesota stream sections.

	Incubation beginning (%)	Post incubation (%)	t	df	n	P
Lower Beaver						
1976-77	78.83	70.69	0.155	14	16	0.50
1977-78	79.59	67.42	1.730	18	20	0.10
Upper Beaver						
1976-77	75.44	73.29	2.07	18	20	0.05
1977-78	77.05	78.13	0.156	17	19	0.50
Lower Trout Run						
1976-77	71.79	64.68	0.902	16	18	0.384
1977-78	72.87	67.34	0.895	18	20	0.386
Upper Trout Run						
1976-77	76.87	61.77	1.701	10	12	0.12
1977-78	75.20	77.57	0.616	18	20	0.50

Dissolved Oxygen

Dissolved oxygen concentrations remained near 80% saturation in most monitored redds. Concentrations below 5.0 ppm in redds were measured primarily after spring runoff. Some redds with low dissolved oxygen had dead, rotting, blackened egg and fry remains. Dissolved oxygen concentration ranged from 8-9 ppm in redds receiving stream bed ground water.

DISCUSSION

There is little doubt that high water during egg incubation and pre-emergence fry development is the cause of brown trout reproduction failures in southeastern Minnesota. The historical belief that silt and sediment caused egg and fry suffocation was not verified. Stream waters remained clear and silt and sediment transport was not serious until runoff occurred.

Pre and post-runoff substrate samples tended to contain similar percentages of substrate particle sizes. Often runoff seemed to have as much of a cleaning action as it did a sedimenting one. Sediment transport was occurring throughout the incubation season but much of the sediment apparently passed around or through redds without being retained.

Sediment content in substrate samples would be expected to relate to the sediment accumulation in perforated pipes buried in the same redds. The high correlation between these two factors is evidence that they are similarily sensitive to detecting sedimentation and improves confidence in the methods.

The relationship of sedimentation to incubation success was difficult to assess. In some stream sections, runoff occurred part way through substrate sampling and redd excavation. Replication of sampling effort was impossible from year to year and from stream to stream. When runoff occurred, some redds were completely scoured from the stream bottom. Relationships of factors studied and incubation success represented only the redds that were less affected by runoff. It was always a question whether the scoured redds were the "best" redds or simply "average".

Low dissolved oxygen concentrations within redds was not a consistent problem until after high water periods. Changes in substrate composition were not significant following high waters but redd materials may have become compacted and less permeable. Decomposing dead eggs and fry may have caused low dissolved oxygen concentrations rather than low oxygen concentrations causing the mortality.

All efforts at relating redd conditions including sedimentation, dissolved oxygen and hydraulic gradient to incubation success within stream sections were inconclusive. This contrasts with the relationships among stream section means. Apparently differences among stream sections are more important than differences from site to site within stream sections.

Successful reproduction is more likely when egg hatch and fry emergence occur before spring high water. A small mean monthly temperature difference between stream sections can have a major effect on incubation time. Brown trout egg incubation time is 20.8 days longer at 35.6 F than at 37.4 F (Embody 1934). At higher temperatures, the difference in development rate/degree temperature increase becomes progressively less important.

Ground water percolation through redds probably optimizes incubation conditions and may account for some unexpectedly high reproductive successes (such as Rupprecht Creek no. 1). Warmer incubation temperature increases the probability of hatch and emergence before spring runoff. Ground water upwelling through redd gravels should provide water exchange equal to that of optimum substrate and hydraulic gradient conditions regardless of existing substrates and gradients.

Hydraulic gradient and substrate composition were not limiting to brown trout fingerling populations. In years when water levels remained stable, relationships with incubation success and fingerling abundance could be detected. However, reproduction success was usually so much better in those years that there was a surplus of fingerlings.

The correlations of mean fingerling abundance of stream sections with mean dates of spawning, hatch and emergence were all weakly negative, while the correlation of fingerling abundance with the number of redds having emergence before runoff was highly positive. The negative correlations reflect the expected negative effect of late spawning, hatch and emergence dates but are weak correlations because these calculations contain no quantification of redds, eggs or fry. The correlation of the number of redds having fry emergence before runoff with fingerling abundance was strong and was a more useful quantitative comparison.

There were poor fingerling populations in study stream sections in 1977 although pre-flood emergence should have been adequate in some of these sections. Calculations of incubation rates were generally accurate as reflected by development stages of eggs and fry within excavated redds. If a significant number of fry had emerged before runoff, then the problem was the survival of the early free swimming life stages rather than reproduction failure.

The consistently high abundance of fingerlings at the Rupprecht Creek no. 1 location apparently was caused by some unmeasured factor. Upstream areas have incubating conditions judged to be superior to this section. Although it is an area of small spring inlets and redds may have been located on ground water seeps, the upstream sections often had slightly lower than expected fingerling abundance. Migration of fingerlings from other stream sections is thus a possibility. Exclusion of the Rupprecht Creek no. 1 data from fingerling abundance correlation calculations was based on these considerations.

There was no direct evidence of fingerling migration in any of the stream sections. Fin-clipped fingerlings from the June sample did not appear to have a tendency for upstream or downstream movement. However, large fingerlings were sometimes abundant in August where none were found in June.

Spawning was not dependent on stream water levels or water temperatures. Water levels were always adequate for trout movement and spawning. Water temperatures were suitable for spawning by 1 October in all study streams but mean spawning dates were generally after 20 October. Mean spawning dates tended to approximate the same date each year in spite of differing temperature regimes from year to year.

The spawning effort documented in any stream section for any year was believed to be a reflection of breeding stock abundance. There was no evidence that stream conditions prevented trout spawning. The general annual increase in spawning effort during this study was believed to reflect increasing abundance of adult stocks. The 1975 year-class was extremely strong in most stream sections and accounted for much of the increased spawning of 1977. The apparently very low adult population in some stream sections the fall of 1975 cannot be completely explained but some of the low 1976 fingerling populations were probably a result of very low breeding populations.

Redd superimposition did not seem to influence fingerling abundance. Overspawning incidence was usually greatest where adult stocks were abundant and did not appear to be a function of a shortage of spawning habitat. The total effect of superimposition was not estimated but it was determined that the contents of pre-existing redds were not necessarily destroyed.

Hydraulic gradient may be the best predictor of reproductive success when flooding does not occur and where water temperatures are satisfactory. Hydraulic gradient was directly related to the percentage of redds with live fry and to the fingerling catch/effort. The relationship with the mean no.

fry/redd was weak.

Relationships among substrate composition, incubation success and fingerling abudance were inconclusive. There was a strong positive, apparently sigmoid relationship between large substrate and the mean number of fry/redd. Substrate with 75% to 85% large particles was necessary for a high mean number of live fry/redd. The relationship of large substrate to the percentage of redds with live fry was weak, possibly because of the unaccounted for sigmoid nature of substrate influence on the number of fry surviving. However, the percentage of redds with live fry was strongly related to fingerling catch/effort, while substrate composition and fingerling catch/effort were weakly related.

Correlation of morphometric characteristics with each other and with measures of reproduction are unlikely to be meaningful in southeastern Minnesota streams. Morphometry is out of synchrony with mean stream discharge, as riffles and sinuosity are products of flood stage water levels. Hydraulic gradient and bottom materials are largely products of extreme, often localized, watershed contributions. Dry runs periodically contribute extreme flow and substrate materials to the mainstream. Water level fluctuations of 10 vertical ft and discharge increases of up to 1,000% during a 24 h period following summer storms are not unusual. Spring runoff is not as localized but peak intensity can equal summer flash floods.

Late spawning in some stream sections, notably Trout Run Creek, may enhance reproductive success. Trout Run Creek study sections were located within heavily pastured areas. Many early egg depositions were destroyed by cattle crossing the riffle sections and obliterating redds. Since cattle were generally removed from riparian pastures during the spawning period, late redds were not destroyed. The gene pool of wild trout may be shifted toward late spawners. This was more probable in Trout Run Creek than in many other stream sections because winter water temperatures were relatively warm and some pre-runoff emergence occurs most years. A stream with cooler winter water temperatures and the same cattle problem would have less chance to sustain reproduction.

The most likely approach to further explain reproduction variation would be multiple regression analysis; however, the high simple correlations cited above were not notably improved upon. Furthermore, the value of substrate and hydraulic gradient as independent variables in a multiple regression were reduced because these two factors were positively correlated. Further investigation of these factors is not recommended since reproduction does not seem to be limiting to brown trout populations unless flooding occurs.

RECOMMENDATIONS

The following are suggested as means of predicting year-class strengths and for improving brown trout management in southeastern Minnesota trout streams:

1. Document winter and spring flood severity.
2. Develop stream section records of spawning dates.
3. Develop winter water temperature records.
4. Locate streambed ground water seeps.
5. Enumerate and record the date of formation of redds to monitor the status of breeding trout populations and to establish possible reasons for subsequent low fingerling abundance.
6. Protect spawning areas from cattle.

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