

FINE SEDIMENT EFFECTS ON
BROOK TROUT EGG AND ALEVIN SURVIVAL IN VIRGINIA

by

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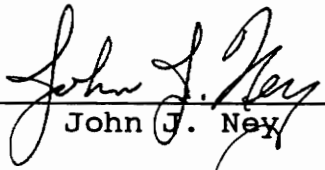
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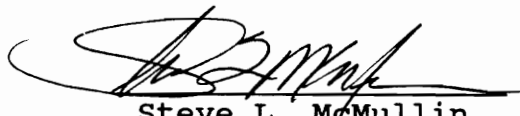
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FISHERIES AND WILDLIFE SCIENCES

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(ABSTRACT)

Detailed information about negative effects of fine sediments on early life stages of brook trout (Salvelinus fontinalis) in southern Appalachian streams is lacking. Information on survival to different stages of egg and alevin development could indicate critical timing of sediment impacts. This study was designed to determine the effects of fine sediments (0.43-0.85 mm in diameter) on survival of brook trout eggs through early development stages under controlled laboratory and field conditions. Recently fertilized eggs were loaded into Whitlock-Vibert (W-V) boxes lined with 0.4 mm Nitex netting that contained mixtures of gravel and fine sediments. Survival to eyed, hatched, and emerged stages of development was determined for six amounts of fine sediment (0-25% by weight) in the laboratory study and for three amounts of fine sediment (0-20% by weight) in the field study. Survival in laboratory systems to each stage of development was inversely related to the percentage of fine sediment; even at low levels of fine sediment survival was reduced. In the field study,

fine sediment may have played a role in the survival success of developing embryos, but determining a definitive relationship was confounded by effects of scouring flows and fungal infestations. The fungus Saprolegnia spp., may have increased the mortality rate of viable eggs and facilitated the disintegration of nonviable embryos, especially in the field study. Brook trout are sensitive to increasing levels of fine sediment through early development. However under field conditions such an effect may be difficult detect.

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Chapter 1 - Effects of Fine Sediment on Salmonid Survival: An Overview

Fisheries managers of the southern Appalachian Mountains have long been concerned with the detrimental effects of fine sediments imposed on trout streams by land use and forestry practices (King 1937; Seehorn 1987). Poor forest management, road construction, floods, and agricultural practices have in many cases increased sediment influxes and served as the primary sources of fine sediment introduction to streams (Greene 1950). Brook trout (Salvelinus fontinalis) is the only native salmonid species in the southern Appalachian Mountains and may exhibit reduced numbers during egg and alevin stages in areas prone to large amounts of fine sediment (Hausle 1973).

Sediment is defined as fragmental mineral material transported or deposited by water or air (Leopold 1974). When fishery biologists use this broad term they refer to fine sediment several millimeters or less in diameter, and thereby exclude up to 90% of sedimentary material in streams (Everest et al. 1987). Bedload and suspended load (<1.0 mm in diameter) are described as the two major sediment transport mechanisms for fine sediment (Leopold 1974; Everest et al. 1987).

Bedload transport usually refers to the movement of large, coarse particles (>1.0 mm in diameter) that are carried downstream, having intermittent contact with the unmoving bed. These particles often govern the channel morphology and the quality of spawning gravels (Everest et al. 1987). In large enough quantities, bedload transport can change the depth of pools, the available substrate in a given reach, and the rate at which water flows. Bedload transport can also include optimal brook trout spawning gravels (5 to 9 mm in diameter) and fine sediments (Witzel and MacCrimmon 1983b).

Suspended sediment loads, which are generally composed of silt and clay-sized particles, have a large enough surface area to weight ratio to allow them to remain suspended in the moving water column. They generally move at a velocity identical to that of the water without touching the stream bottom. In large, slow moving pools they often settle out and infiltrate the interstices of the gravel, clogging redds (Gammon 1970) and reducing intragravel water flow (Everest et al. 1987).

Researchers have studied the effects of various sediment sizes, at loadings ranging from 0 to 70%, on salmonid survival to emergence from the redd. Reduced emergence was associated with all of the following fine sediment diameters and species: ≤ 0.85 mm for chinook salmon

(Oncorhynchus tshawytscha) (Tappel and Bjornn 1983) and coho salmon (O. kisutch) (Tagart 1976; Cederholm et al. 1981b), ≤ 2.0 mm for brook trout (Hausle 1973), ≤ 3.3 mm for coho salmon (Koski 1966), ≤ 4 mm for rainbow trout (O. mykiss) (MacCrimmon and Gots 1986), and < 6 mm for chinook salmon (McCuddin 1977). While the species and size classes may differ, the outcome is the same--fine sediment reduces salmonid survival to emergence.

Forest Management and Fine Sediments

Timber-harvesting practices have been cited as a major contributor to stream sedimentation (Eschner and Larmoyeux 1963). Studies in the Pacific Northwest indicate that the removal of too much forest canopy, such as cutting all or a major portion of a watershed, can reduce the quality of spawning gravels by allowing excessive sedimentation to occur (Burns 1972; Megahan and Kidd 1972; Cederholm et al. 1981a). Extensive use of bulldozers on steep slopes and stream channels can cause increased erosion. As a result, gravels and sediments may shift and scour incubating embryos, thereby removing or burying them (Chapman 1962). In Clearwater River, Washington, excessive sedimentation from logging not only impeded the digging of redds but also reduced salmonid survival to emergence by 2 to 4% for each 1% increase in fine sediment (< 0.85 mm in diameter) (Cederholm et al. 1981a). In South Fork Salmon River, Idaho

extensive logging and road construction from 1950 to 1966 significantly increased fine sediment (<4.75 mm in diameter) amounts, reducing spawning and rearing habitat and reducing one of Idaho's most important chinook salmon fisheries to a mere 1200 individuals by 1985 (Platts et al. 1989).

Sediment is believed to be the principal nonpoint source of pollution from forestry activities (Swift 1988). Timber harvesting practices increase the sediment load in streams due to the direct effects of poorly located logging roads, soil disturbance, and subsequent runoff in the area (Eschner and Larmoyeux 1963).

Forest roads can substantially increase the frequency of soil movements in steep watersheds, causing added sediment to enter a stream (Everest et al. 1987; Swift 1988). Moreover, these effects generally increase with the increase in steepness of the terrain. As a means to reduce sedimentation, the Environmental Protection Agency encouraged each state to implement Best Management Practices (Swift 1988). In Virginia, streamside management zones range from approximately 20 to 38 m on both sides of permanent trout streams, depending on the slope of adjacent lands (Anon. 1989). These buffer strips are designed to provide a relatively undisturbed zone to trap and filter sediment before it reaches the stream (Anon. 1989).

In Virginia, clear cutting, group selection cutting, shelterwood cutting, and single-tree selection (the removal of a single harvestable tree), are commonly used logging practices. Clear cutting, or the removal of all timber over a certain minimum diameter, has a great impact on slope stability and sediment flow, by allowing patches of trees (1 to 16 ha on National Forests in the southern Appalachians, J. Overcash, USDA FS, Blacksburg, VA, personal communication) to be carved from the forest canopy, exposing underlying soils. Generally, forest managers try to limit road use in these areas to only a few access points, thereby minimizing forest entry and soil disturbance (G. Szarzynski, USDA FS, Natural Bridge, VA, personal communication).

Group selection is the removal of trees from a smaller area, up to 0.8 ha on National Forests in the southern Appalachians (J. Overcash, USDA FS, Blacksburg, VA, personal communication), dispersed throughout a selected site. This practice appears less detrimental to slope stability; but the frequency with which a harvest site is accessed is often greater than with a clear cut, increasing the disturbance of underlying soils (Brummel 1992).

Shelterwood cuts may be as large as clear cuts; however, select trees are left scattered throughout a site to provide seeds for regeneration and shelter for seedlings (Stokes et al. 1989). Disturbance in these areas is similar

to disturbance in clear cuts (G. Szarzynski, USDA FS, Natural Bridge, VA, personal communication). The effect of all these practices on sediment production depends on the intensity of the disturbance, the proximity of the disturbance to the stream channel, the location of roads, and the frequency with which sites are accessed.

Brook Trout Reproduction

Brook trout are indigenous to eastern North America and naturally occur in the headwater streams of the Appalachian Mountains (Power 1980). Of all the salmonids, they possess the shortest life span, normally living for only three to four years. Once mature (as early as 1+), males can spawn annually, while females generally fail to spawn one year in every two or three years (Power 1980). Spawning among brook trout begins in autumn, as the days get shorter and the temperatures begin to fall. Estimates of stream temperature at the time of spawning range from 6.7 to 11.1° C (Hale and Hilden 1970; Carlson and Hale 1973; Witzel and MacCrimmon 1983a).

A brook trout redd begins as a small pocket, located at the foot of a pool or just below springs and seepages where water breaks the surface. With the aid of the current and a series of turning motions, the female is able to lift streambed particles out and create a clean centrum or

grouping of rocks to line the bottom of the redd (Vronskiy 1972; Chapman 1988). Once this is complete, the female begins to release her eggs into the 30 to 60 cm diameter oval at a depth of 5 cm to 25 cm, while the male simultaneously fertilizes them (Hazzard 1932).

Once fertilization and egg deposition are complete, the female may dig obliquely upstream from the first pocket, creating another redd (Hobbs 1937). As a consequence of this action, particles are dislodged, carried downstream, and deposited in the previous pocket. This suspended sediment tends to lodge and to cake first among the surface material of the redds, and then penetrate to egg-pockets, virtually restoring the bed to its original state (Hobbs 1937).

Salmonid embryo development rate is directly related to the water temperature (Embody 1934; Kinne and Kinne 1962; Garside 1966). At a constant temperature of 10° C, brook trout incubation to hatch will last about 44 days (Embody 1934; Leitritz and Lewis 1980), and at 2.8° C this period can be extended to 165 days (Brasch et al. 1973). Egg development progresses from a green stage (newly fertilized) to an eyed stage, when distinct eyes become visible. After a few more weeks of development, the eggs hatch to produce alevins or sac-fry, which receive nourishment from attached

yolk sacs. When the yolk sacs are nearly depleted, alevins swim up and emerge from the gravel.

Fine Sediment Effects on Salmonid Development

Brook trout often select areas of upwelling to construct a redd (Brasch 1949; Power 1980); but due to the hydraulic nature of a redd, surface water and fine sediments are often drawn into the gravel (Stuart 1953; Cooper 1965) even if surface velocities are too great to allow for deposition (Witzel and MacCrimmon 1983b; Cooper 1965). A direct result of fine sediment deposition is the low permeability of bed material and the resultant limited exchange of intragravel water (Cooper 1965). Permeability is severely influenced by particles ≤ 0.83 mm in diameter (McNeil and Ahnell 1964). Low permeability occurs where bottom materials contain >15% by volume of silts (fine sediment) whereas high permeability occurs with silts of <5% by volume (McNeil and Ahnell 1964).

The exchange of intragravel water is crucial to incubating egg clutches as it allows dissolved oxygen to circulate. Low dissolved oxygen has been correlated with fine sediments as a cause for low survival of salmonid embryos because they suffocate (Wickett 1954, 1958; Alderdice et al. 1958; Coble 1961; Cordone and Kelley 1961; McNeil 1966; Tagart 1976). Dissolved oxygen is essential to embryo survival and a direct function of water movement

(Coble 1961). Exposure to low dissolved oxygen concentrations on chum salmon (O. keta) eggs causes premature hatching (Alderdice et al. 1958). Further, because the rate of oxygen uptake by eggs increases from fertilization to hatching (Hayes et al. 1951; Alderdice et al. 1958), suitable levels must be maintained throughout the incubation period. Various critical levels of dissolved oxygen, levels above which the respiratory rate is unmodified by oxygen availability (Alderdice et al. 1958), for salmonid survival have been determined: 2.6 mg/l for recently fertilized chinook salmon eggs to ensure 50% survival to hatch (Silver et al. 1963); 1-7 mg/l for chum salmon eggs, depending on developmental state, incubated for 7 days to ensure 50% survival (Alderdice et al. 1958); $\leq$ 50% saturation in the redd for embryo development (Harshbarger 1975); 8 mg/l for preemergent rainbow trout to ensure 50% survival to emergence (Sowden and Power 1985); and 7 mg/l for hatched steelhead trout to ensure survival greater than 50% (Phillips and Campbell 1962). Generally values less than 5 mg/l are considered detrimental to salmonid survival (Mills 1971).

Mason (1969) exposed coho salmon embryos and alevins to dissolved oxygen levels of 11, 5, and 3 mg/l. Mortalities to time of yolk absorption were 17, 23, and 41%, respectively. Further, embryos and alevins were smaller at

the lower oxygen levels than those subjected to the higher oxygen levels. This study demonstrated that dissolved oxygen is a key factor to salmonid survival and quality.

Fine sediments also reduce the survival of young embryos to emergence (Harrison 1923; Cordone and Kelley 1961; McNeil and Ahnell 1964; Koski 1966; Witzel and MacCrimmon 1981, 1983a, 1983b). Not only can fine sediments physically impede fry emergence (Hall and Lantz 1969), they can also cause poor fry quality at emergence (Mason 1969). Sediments smaller than 0.85 mm in diameter reduce the survival of coho salmon to emergence in both artificial and natural redds (Cederholm et al. 1981b). Survivals of only 18% in redds that had more than 20% fine sediment (<0.85 mm in diameter) were reported for coho salmon in Clearwater River, Washington (Tagart 1976). Similarly, emergence of brook trout in Lawrence Creek, Wisconsin is reduced when spawning gravels contain 20% sand (2 mm in diameter) (Hausle and Coble 1976). Potentially lethal physical pressure is placed on developing coho salmon and chum salmon with gravels finer than 3.36 mm in diameter (Cooper 1965). Studies such as these result in the same conclusion--sedimentation reduces the survival of emergent fry.

Fine Sediments and Brook Trout in Virginia

Most of the research concerning the effects of fine sediments on salmonids has been conducted on Oncorhynchus

spp. in western North America (Everest et al. 1987; Chapman 1988) and serves little specific value to managers in the southern Appalachians because of species, geologic, and watershed management differences. Little or no information exists on fine sediment effects on brook trout in the southern Appalachians. In fact, aside from two investigations (Hausle 1973; West et al. 1982), there have been no other studies documenting the effects of fine sediment on brook trout. The need to evaluate the effects of forest management activity that may introduce fine sediments to salmonid streams has become a concern to managers in this region. Therefore, this study will address the question of how detrimental fine sediments are to the survival of brook trout eggs and alevins under conditions found in the southern Appalachians.

I approached this question with both a laboratory study and a field study. A laboratory study was used to determine the influence of fine sediments on the development of brook trout eggs from planting to emergence because it provided the ability to control other factors that affect survival (e.g., temperature, fungus, predators). A field study was used to incubate a known quantity of eggs in Whitlock-Vibert (W-V) boxes containing known initial fine sediment loadings under conditions that could not be controlled (e.g.,

temperature, dissolved oxygen, flow, scour) to provide information on survival in a natural system.

While many size classes of fine sediment have been used in similar studies, fine sediments under 0.85 mm in diameter were selected for this study because they have been shown quantitatively to negatively influence intragravel permeability (McNeil and Ahnell 1964), and reduce salmonid survival in field (Cederholm et al. 1981b; Tagart 1976) and lab studies (Cederholm et al. 1981b; Tappel and Bjornn 1983). Fine sediment amounts were selected to cover a range of fine sediments found in Virginia streams as well as to cover a range thought lethal to brook trout, based on the literature review of salmonids above.

The specific objectives of this study were: 1) to determine survival to emergence and morphological condition of emergents in artificial streams at six different fine sediment levels (0%, 5%, 10%, 15%, 20%, 25%), 2) to determine survival to emergence and morphological condition of emergents in artificial redds in natural streams at three different fine sediment levels (0%, 10%, 20%), and 3) to determine the interaction that dissolved oxygen and water turnover rate have with sediment levels on the survival of brook trout eggs.

The results from these three objectives are presented in the following two chapters. Chapter Two describes the

laboratory study and Chapter Three describes the field study. Chapter Four compares the results of both studies.

Chapter 2 - Fine Sediment Effects on Survival of Brook Trout Eggs in Laboratory Streams

Inverse relationships between fine sediment and salmonid reproductive success were first reported by Harrison (1923). Since that time, other studies have shown that fine sediments reduce gravel permeability (Terhune 1958; McNeil and Ahnell 1964), reduce the flow of intragravel water (Vaux 1962; Cooper 1965), and reduce the rate of delivery of dissolved oxygen (Cordone and Kelley 1961; Sowden and Power 1985). Excessive sediment can effectively smother incubating eggs and entomb alevins and fry (Hall and Lantz 1969).

In the life history of salmonid fishes, survival is generally lowest during the intragravel period (MacKenzie and Moring 1988). However, the stage of development during the intragravel period at which the influence of fine sediment is greatest is largely unknown. Laboratory studies have demonstrated that higher percentages of fry emerge with increasing gravel size and decreasing proportions of fine sediments within a redd (Bjornn 1968; Hall and Lantz 1969; Hausle 1973; Phillips et al. 1975; Reiser and White 1988). Field studies have documented similar results (McNeil and Ahnell 1964; Koski 1966; Tagart 1976; Cederholm et al. 1981a), but the effects of fine sediment are more difficult

to isolate from other environmental variables (eg., predation and fungus).

Fisheries managers in the southern Appalachians have expressed a need for information concerning how much sediment can be tolerated by developing brook trout (Seehorn 1987). Brook trout are the only native salmonid species in the southern Appalachian Mountains and exhibit reduced numbers during egg and alevin stages in areas with high proportions of fine sediment (Hausle 1973). Therefore, this study was designed to determine how detrimental fine sediments are to the survival of brook trout during the intragravel period.

Artificial systems were used to incubate brook trout eggs because they provided an environment in which the effect of fine sediment could be examined under controlled, replicable conditions without the confounding effects of multiple variables associated with field studies. While artificial systems cannot directly assist managers in determining if sediment is limiting natural populations, they can be used to infer amounts likely to be limiting and specific life stages that salmonids are vulnerable to deposited sediment (Everest et al. 1987). The specific objectives were to: 1) determine survival to emergence at six different fine sediment (0.43-0.84 mm in diameter) treatments (0-25% by weight); 2) identify stages of

development at which intragravel mortality is greatest; 3) determine if declines in survival followed a linear or nonlinear relationship; 4) determine the interaction that dissolved oxygen and water turnover rate have with sediment levels and the survival of brook trout eggs; and 5) determine the condition of fry at emergence.

Materials and Methods

Incubation Chamber

Incubation chambers, made from 3.1 mm thick PVC sheeting welded to form a box (56 cm wide X 122 cm long X 30 cm deep, with end walls 25 cm deep), were placed in three "living streams" (Frigid Units, Inc., Toledo, OH) equipped with one-third horsepower chiller units (Fig. 2.1). Each chamber's floor, drilled with 3.1 mm holes spaced 15 mm apart, facilitated intragravel flow and the free exchange of newly oxygenated water. A 15 cm diameter PVC pipe (25 cm long) welded around a 13 cm diameter hole accommodated the impeller shaft of the chiller unit, allowed the chiller unit to be removed for maintenance, and prevented the intrusion of stream gravel to the impeller shaft (Fig. 2.1). A platform, made from 7.6 cm diameter PVC pipe drilled with 3.1 mm holes spaced 6 cm apart, raised the chamber above the floor of the living stream, allowing water to move freely under the chamber. This design was intended to maintain uniform flow, uniform dissolved oxygen levels, and uniform temperatures.

I obtained washed stream gravel (6.33-24.9 mm) from a local gravel supplier and added it to each incubation chamber to 15 cm depth (Fig. 2.1). I filled each chamber with well water and maintained the depth at 10 cm above the

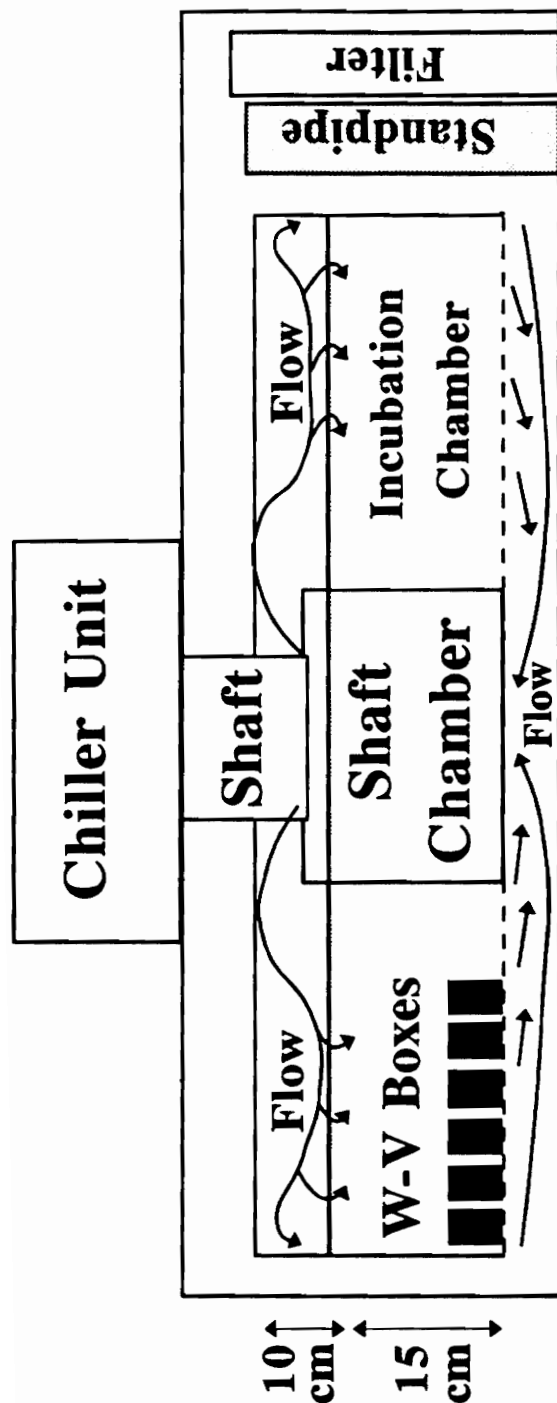


FIGURE 2.1.-Cross-section of incubation chamber. Whitlock-Vibert boxes (only a few are shown) covered the floor of the incubation chamber with approximately 10 cm between boxes. The shaft chamber protected the shaft propeller which drew water up through the shaft chamber and out over the water surface, thereby creating a downward flow through the gravel and W-V boxes. The standpipe maintained the water depth at 25 cm in the stream and served as an overflow when stream water was turned over.

gravel bed (Fig. 2.1). Artificial systems ran for one week prior to the study to stabilize temperatures at $7.0\pm 1^{\circ}\text{C}$ and saturate water with oxygen. I used well water, held at $7.0\pm 1^{\circ}\text{C}$ in a 636 liter reservoir, to flush waste materials and top up the streams daily.

Whitlock-Vibert Boxes

I loaded two-chambered Whitlock-Vibert (W-V) boxes (Federation of Fly Fishermen 1975), lined with 0.4 mm Nitex netting, with coarse gravel (6.33-12.49 mm in diameter) and one of six fine sediment (0.43-0.84 mm in diameter) treatments (0%, 5%, 10%, 15%, 20%, 25% by weight), 20 boxes per treatment. Gravel and fine sediment in each W-V box weighed approximately 550 g (Appendix A). The liner in the lower chamber retained fine sediments and eggs, while the liner in the upper chamber prevented emergent fry from escaping. Fine sediment was sieved from washed commercial sand and coarse gravel was obtained from a local gravel supplier.

On 4 October 1993, I obtained approximately 25,000 freshly fertilized (green) brook trout eggs, Nashua strain (National Survey of Trout Brood Stocks 1991), from the Paint Bank National Fish Hatchery, Craig County, Virginia, and transported them to Virginia Tech's Aquaculture center. At the Aquaculture center, eggs were held at approximately 8°C

until placed in W-V boxes (no more than 6 hours). The lower chamber of each lined W-V box was charged with 16 ml (200 ± 5 eggs) of eggs. Egg densities were selected based on literature describing brook trout fecundity (Vladykov and Legendre 1940; Morgan and Robinette 1978; Gray 1979; Power 1980). Forty W-V boxes, one box per treatment and retrieval, were randomly buried in each stream.

Whitlock-Vibert Retrievals

I retrieved W-V boxes at six times (retrievals) during the study to estimate survival to specific stages of embryonic development (Table 2.1). Early retrievals were at days 14, 28, and 37. By day 37 (Retrieval 3), temperatures and development rates diverged among streams, so a cumulative degree-day (midpoint temperature value for each 24 h period) schedule was used to determine retrieval times after retrieval three (Table 2.1). For the first five retrievals, six W-V boxes were taken from each stream, one at each sediment level (a total of 18 W-V boxes). At the sixth retrieval, all remaining W-V boxes (1 or 2 per treatment and stream) were removed (5 W-V boxes per treatment). When fry had swum up from the lower chamber to the upper chamber of the W-V box, they were considered emerged. Absolute counts of live to dead were used to derive percent survival estimates.

Table 2.1.1.- Retrieval schedule for laboratory streams. At each retrieval, one W-V box was taken at each of the six fine sediment treatments per incubation chamber. A day schedule was used until retrieval three to determine intragravel survival. A degree-day schedule was used after retrieval three because of divergent stream temperatures and different development rates.

Retrieval	Day of study	Degree-Days			Stage of development
		Stream 1	Stream 2	Stream 3	
1	14	95.5	111.0	122.5	Green
2	28	181.5	199.0	235.5	Green/Eyed
3	37	231.8	253.8	288.8	Eyed
4	64			479.9	Hatched
4	76		483.0		Hatched
4	83	482.4			Hatched
5	114			749.3	>90% emerged
5	120		751.6		>90% emerged
5	128	752.5			>90% emerged
6	123			809.3	Emerged
6	128		810.1		Emerged
6	136	810.5			Emerged

Emergent fry were recovered at approximately 750 degree-days and 810 degree-days, which corresponded to a range of 114-136 days to emergence (Table 2.1). A total of 2,049 fry were weighed (wet) to the nearest 0.1 mg and measured (wet) to the nearest 1.0 mm. Bams' (1970) developmental index (KD) was computed to compare the developmental stage of emergent fry:

$$KD = \frac{10 \times [\text{wet weight (mg)}]^{1/3}}{\text{wet fork length (mm)}}$$

Values of 1.90 or less indicate that emergent fry have resorbed body tissue at the expense of growth, values around 1.96 indicate total yolk absorption, and values greater than 2.0 indicate that high proportions of yolk remain at emergence (Bams 1970).

Stream Characteristics

I took maximum and minimum temperatures over 24 h periods daily to determine a 24-h midpoint value. I measured surface water dissolved oxygen (mg/l) once daily using a dissolved oxygen meter (Yellow Springs Instrument Co., Colorado Springs, CO) and recorded hydrogen ion concentration (pH) weekly with a hand held pH meter (Hach Co., Loveland, CO).

Gravel permeability (cm/hr) and intragravel dissolved oxygen (mg/l) were measured at the termination of the study

using standpipes (Pollard 1955; Terhune 1958; Wickett 1958) inserted in lined W-V boxes containing each of the six fine sediment treatments. An intragravel dissolved oxygen reading was taken after the dissolved oxygen probe, inserted into the standpipe, touched the bottom of each W-V box. Permeability was estimated by lowering the water level in the standpipe to create a hydraulic head of known volume and measuring the influx of water over time. I assumed that each chiller unit provided flow that remained constant during and after the study; therefore, intragravel measures should be reflective of the conditions embryos experienced.

Disease Control

The common egg fungus Saprolegnia spp. observed at the first retrieval was treated with 50 ml (2000 ppm) of Paracide-F (Argent Chemical Co., Redmond, WA) in each incubation chamber, for approximately 15 minutes and then flushed with fresh well water. Additional treatments given throughout the study (3 per week in each stream), reduced the spread of the fungus.

Sediment Samples

Fine sediments recovered at each retrieval were sieved using standard sieves (0.18 mm, 0.43 mm, 0.85 mm, and 6.33 mm) to determine the amount of fine sediment lost or gained over the course of the study. Fine sediment retained by the

matrix of eggs and Saprolegnia spp. was obtained by heavy washing with water. Gravel and fine sediment were dried at 60°C until all water was removed and weighed to the nearest 0.1 g.

Statistical Analyses

One-way ANOVAs were used to compare survival of developing brook trout among the six fine sediment levels at each retrieval. If significant ANOVAs were found, Fisher's least significant difference test (LSD), which controls for comparison-wise error (Ott 1988), was applied to determine specific differences in survival among fine sediment levels. One-way ANOVAs and Fisher's LSD were also used to test for significant differences in alevin size or developmental index among the six fine sediment levels. Significant differences in stream temperature, pH, and surface dissolved oxygen among streams were tested using one-way ANOVAs and Fisher's LSD where appropriate. Linear regression was used to determine if significant relationships existed between intragravel stream characteristics (permeability and dissolved oxygen) and fine sediment. Paired T-tests were used to detect differences in weight of starting and ending fine sediment treatments. Mean values in the text are reported as mean $\pm$ SD. All statistical analyses were

performed using the Statistical Analysis System (SAS) (SAS Institute 1985) at a significance level of 0.05.

Results

Stream Characteristics

Weekly pH measures (Appendix B) ranged from 8.2 to 8.7 for all three streams. Water temperature ranged from -1.0 to 18.0°C (Appendix C). The maximum temperature recorded resulted from a dysfunctional chiller unit on day two of the study in stream two. Otherwise, the maximum temperature was 15.0°C. Mean temperatures were $6.0 \pm 1.7^\circ\text{C}$ for stream one, $6.3 \pm 1.8^\circ\text{C}$ for stream two, and $6.6 \pm 2.0^\circ\text{C}$ for stream three and were significantly different (ANOVA, $P=0.02$). Stream three was significantly warmer than stream one (Fisher's LSD, $P<0.05$).

Surface dissolved oxygen ranged from 7.4 to 15.2 mg/l (Appendix D). The minimum value was recorded in stream one after an ice storm (February 11, day 129) cut off power to the lab facility; Emergency power was supplied within four hours. Otherwise, the minimum dissolved oxygen level was 7.8 mg/l. No significant difference existed in surface dissolved oxygen levels among streams (ANOVA, $P=0.48$). Intragravel dissolved oxygen was negatively associated with percent fine sediment (linear regression, $R^2=0.98$, $P<0.0001$) (Fig. 2.2) even though surface water dissolved oxygen was constant at 10.4 ± 0.2 mg/l in all three streams at the time measurements were taken. Permeability was negatively

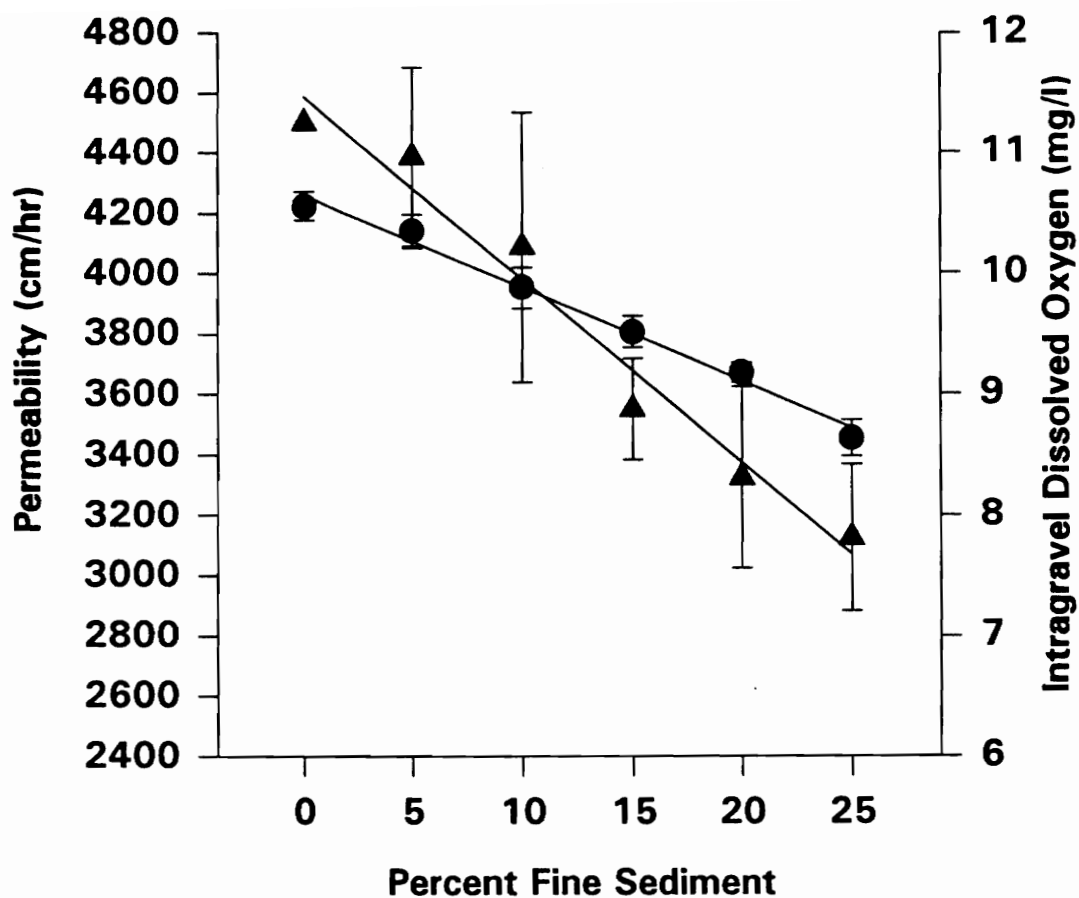


FIGURE 2.2.-Relation between intragravel dissolved oxygen (circles) and permeability (triangles) and percent fine sediment. Symbols represent means of 20 readings from W-V boxes loaded with gravel and fine sediment only. Error bars denote standard deviations around means. Surface dissolved oxygen at the time intragravel readings were taken was 10.4 ± 0.2 mg/l.

associated with the percentage of fine sediment (linear regression, $R^2=0.96$, $P<0.001$) (Fig. 2.2). Estimated permeabilites ranged from 4,500 cm/hr at the 0% fine sediment treatment to 3,125 cm/hr at the 25% fine sediment treatment. Permeability and intragravel dissolved oxygen were significantly correlated ($r=0.94$, $P<0.001$).

Fine Sediment Mixtures

The total amount of fine sediment retained at each retrieval was significantly lower than the initial level (Paired T-test, $p<0.001$), except for the 0% fine sediment treatment, which did not gain any sediment (Table 2.2, Appendix A). Of the fine sediment that remained, 19.6 to 49.3% was broken down to the next lower size class (0.18-0.43 mm in diameter) and below (<0.18 mm in diameter). To account for all the fine sediment, all size classes below 0.85 mm were summed for analysis. Whitlock-Vibert boxes lost similar amounts of fine sediment at all retrievals including an immediate retrieval (Retrieval 0, Table 2.2) indicating that time within the stream did not influence fine sediment loss (Table 2.2) and that fine sediment loss occurred due to handling when boxes were buried and retrieved.

TABLE 2.2.-Fine sediment loss (g) for W-V boxes that were planted and retrieved immediately (Retrieval 0, with no eggs) and for W-V boxes that were used to incubate eggs (retrievals 1, 3, and 6). Whitlock-Vibert boxes at the 5%, 10%, 15%, 20% and 25% contained 27.5 g, 55.0, g 82.5 g, 110.0 g, and 137.5 g of fine sediment initially. Negative table entries are mean fine sediment losses (SD).

Sediment (%)	Retrieval			
	0	1	3	6
0	0	0	0	0
5	-6.7 (1.5)	-6.9 (2.7)	-8.5 (0.8)	-7.4 (2.3)
10	-6.5 (1.5)	-6.6 (1.0)	-6.7 (2.8)	-4.9 (0.9)
15	-9.0 (2.6)	-9.2 (3.9)	-10.6 (2.3)	-8.7 (2.9)
20	-10.9 (1.9)	-8.5 (1.1)	-10.9 (3.4)	-9.9 (4.0)
25	-12.3 (2.6)	-12.6 (0.5)	-9.5 (4.4)	-8.6 (1.1)

Brook Trout Survival

Estimates of survival from planting to each stage of embryonic development generally declined with increasing fine sediment amounts, but differences were not significant at all retrievals (Table 2.3). At retrieval one (day 14) all viable eggs were still in the green stage. The influence of fine sediment on survival was significant (Table 2.3, ANOVA, $P < 0.001$). By retrieval two, (day 28) eggs were in one of two distinguishable developmental stages: green (streams one and two) or eyed (stream three). Nonviable eggs recovered in all three streams were found clumped together by Saprolegnia spp. hyphal strands. The influence of fine sediment was significant (Table 2.3, ANOVA, $P = 0.02$). At retrievals one and two, survival at the 0 and 5% fine sediment levels was significantly different from survival at the 20 and 25% fine sediment levels (Table 2.3).

At retrieval three (day 37) Saprolegnia spp. still existed in all boxes; however, clumped masses of eggs were not seen, suggesting that Paracide-F treatments had weakened the hyphae of the fungus and stopped its spread to other eggs. Fine sediment did not significantly influence survival at retrieval three (Table 2.3, ANOVA, $P = 0.07$). Greater than 98% of the eggs initially planted in each W-V box were retained through retrieval three (Appendix E).

TABLE 2.3.-Survival (%) of brook trout incubated in laboratory streams to each stage of development at each fine sediment treatment. Table entries are mean (SD). Differences among sediment treatments were significant for retrievals one, two, and four (ANOVA, $p < 0.05$) and not significant for retrievals three, five and six (ANOVA, $p < 0.05$). Lowercase letters denote significant differences within a column (i.e., each retrieval) (Fisher's LSD, $P < 0.05$).

Sediment (%)	Retrieval Number					
	1	2	3	4	5	6
0	84.83 z (1.53)	80.16 z (3.26)	76.80 (3.20)	55.32 z (7.96)	52.24 (17.15)	45.37 (11.17)
5	85.10 z (3.75)	79.73 z (4.97)	73.47 (2.72)	48.66 zy (3.96)	48.94 (4.27)	41.62 (13.30)
10	78.23 y (3.44)	74.73 zy (2.71)	71.67 (3.16)	45.01 yx (2.76)	41.55 (18.48)	35.54 (13.69)
15	78.60 y (2.01)	75.17 zy (3.92)	74.73 (2.55)	40.22 x (4.25)	42.43 (3.61)	36.41 (11.15)
20	72.50 y (4.19)	69.03 y (4.79)	68.97 (3.59)	40.95 yx (1.47)	43.39 (2.59)	33.48 (4.25)
25	72.56 y (4.83)	72.60 y (0.35)	66.53 (6.97)	40.61 x (2.39)	25.68 (18.29)	24.30 (4.88)

Eggs began to hatch prior to retrieval four (480 degree-days). Survival declined by nearly 25% from the previous retrieval, regardless of fine sediment treatment (Table 2.3). The effect of fine sediment on survival was significant at retrieval four (Table 2.3, ANOVA, $P=0.005$). Results from Fisher's LSD for retrieval four indicate that survival at 0% fine sediment was significantly different from survival at 25% fine sediment, that survival at 0 and 5% fine sediment are not significantly different, and that survival at all fine sediment levels greater than 10% are not significantly different (Table 2.3).

At retrieval five (750 degree-days) greater than 90% of fry had emerged from the lower chamber to the upper chamber of the W-V box. Dead eggs and alevins at this stage broke apart easily. Survival at the 0% fine sediment treatment was twice as great as survival at the 25% fine sediment treatment; however, fine sediment did not significantly influence survival (Table 2.3, ANOVA, $P=0.26$). The presence of outliers, attributed to dead spots in stream two, resulted in large variation among some sediment treatments (Table 2.3, Fig. 2.3). Survival at retrieval six, full emergence, was not significant among fine sediment treatments (Table 2.3, ANOVA, $P=0.06$). Of the total number of eggs planted, an average of 88% were recovered at emergence (Appendix E). While analysis of variance detected

no significant difference in survival among fine sediment levels at retrievals five and six, only half as many fry survived to emergence in 25% fine sediment as did in 0% fine sediment (Table 2.3). Differences in survival were probably not detected because of the large amount of variance associated with each fine sediment level.

Through time, survival at the 25% fine sediment treatment (linear regression, $R^2=0.83$, slope = -11.44) declined more rapidly than did survival at the 0% fine sediment treatment (linear regression, $R^2=0.76$, slope = -7.78) (Fig. 2.3). Generally, survival at intermediate fine sediment levels fell between these two extremes: 5% ($R^2=0.81$, slope = -9.38), 10% ($R^2=0.81$, slope = -10.38), 15% ($R^2=0.78$, slope = -9.59), 20% ($R^2=0.85$, slope = -8.59) and all were significant (linear regression, $P<0.001$).

Size and Condition of Emergent Fry

Condition indices of fry recovered at retrievals five and six are in Appendix F. The condition of emergent fry recovered at retrieval five (Table 2.4) is believed to be more representative of the actual condition of fry at emergence because fry had not used up their entire yolk sac and mortality unrelated to sediment treatments probably occurred in the week between retrieval five and retrieval six. Emergent fry at retrieval five, incubated at the 0 and

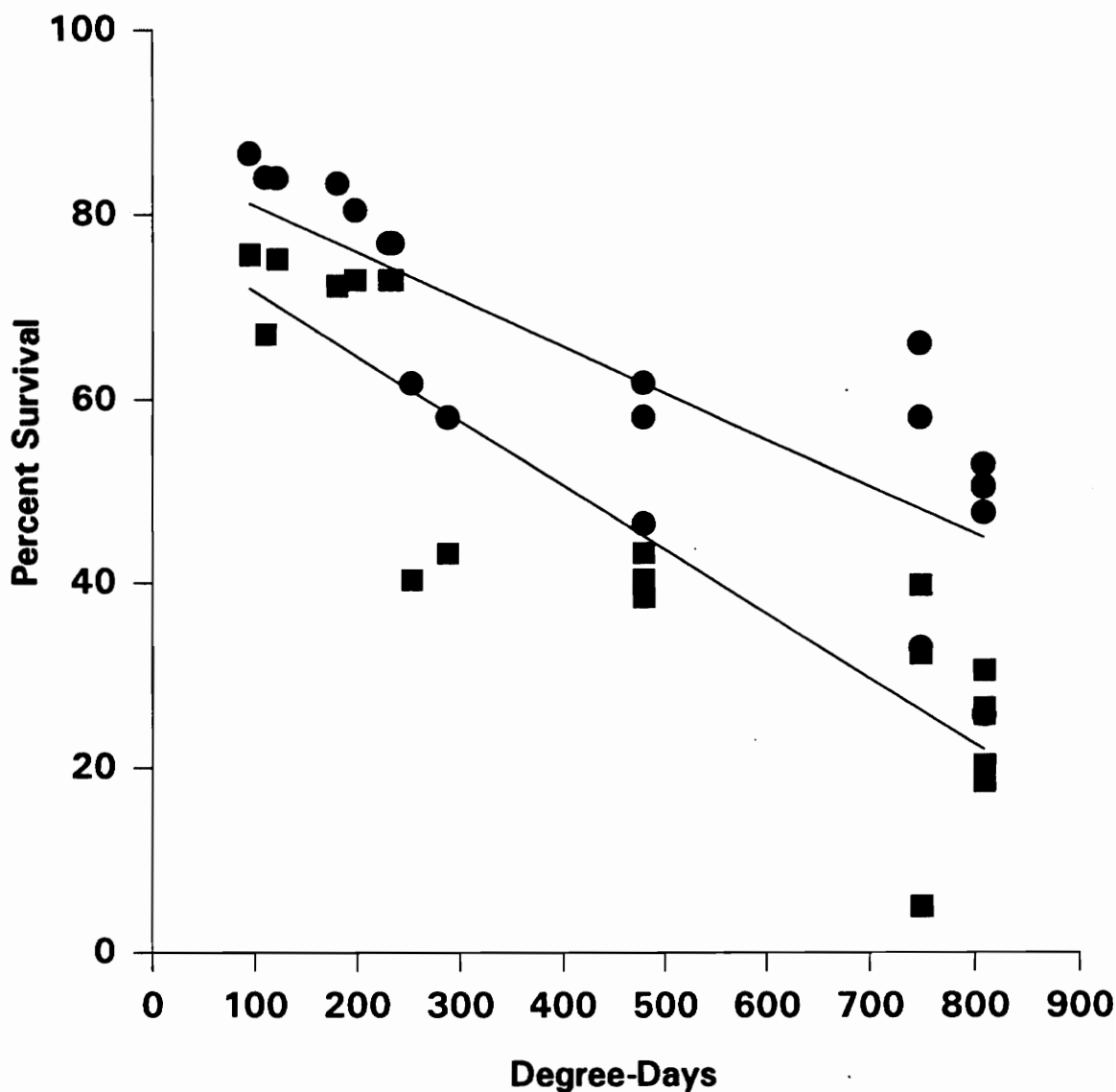


FIGURE 2.3.-Survival of brook trout at the 0% (circles, upper line, $R^2 = 0.76$, slope = -7.78, $P < 0.0001$) and 25% (squares, lower line, $R^2 = 0.83$, slope -11.44, $P < 0.0001$) sediment treatments in relation to degree-days.

TABLE 2.4. - Size and condition of emergent fry from retrieval 5. Significant differences were found among wet weight, wet length, and KD indices at all fine sediment treatments (ANOVA, $p < 0.05$). Lowercase letters indicate significant differences detected by Fisher's LSD ($P < 0.05$). Table entries are mean (SD).

Sediment (%)	Wet Weight (mg)	Wet Length (mm)	KD
0	62.7 z (26.6)	19.0 x (2.1)	2.02 z (0.23)
5	60.2 zy (20.7)	19.2 x (1.7)	2.00 zy (0.14)
10	62.3 z (14.3)	20.5 z (1.6)	1.93 x (0.13)
15	56.3 yx (18.9)	19.2 x (2.1)	1.97 y (0.17)
20	53.2 x (19.8)	19.3 x (1.9)	1.90 x (0.16)
25	55.1 x (11.9)	19.7 y (1.5)	1.92 x (0.13)

5% fine sediment level had significantly higher KD indices than emergent fry at the 10, 20, and 25% fine sediment levels (Fisher's LSD, $P < 0.05$, Table 2.4). Significantly heavier fry emerged from fine sediments less than 10% (Fisher's LSD, $P < 0.05$, Table 2.4). No apparent trend existed in wet length among the fine sediment levels.

Discussion

Brook Trout Survival

Survival of brook trout in this study during the intragravel period decreased as the proportion of fine sediment increased (Table 2.3). Fine sediment amounts less than 10% generally yielded higher survivals through eye-up (retrieval 3) and hatching (retrieval 4) than did all other fine sediment amounts. At emergence, survival of fry incubated in 25% fine sediment was about half that of fry incubated in fine sediment amounts less than 5% (Table 2.3). Differences in survival to emergence, while great, were not significant due to the large amount of variation in survival. Brook trout experience high survival (80%) to emergence when incubated in 0 and 5% sand (<2 mm in diameter) and low survival (27%) at sand proportions greater than 15% (Hausle 1973). McNeil and Ahnell (1964) suggest that productive salmonid spawning areas should contain less than 5% of material finer than 0.83 mm in diameter and that fine sediment amounts greater than 30% constitute nonreproductive spawning beds. The ideal stream bed for incubation should consist of gravel with voids just large enough to contain the individual eggs, yet allow adequate percolation of oxygenated water (Iwamoto et al. 1978). Other investigators working with brook trout, chinook salmon, and steelhead trout report similar declines in

survival to emergence as those reported here when spawning gravels contain 20% fine sediment or more (Hausle and Coble 1976; West et al. 1982; Bjornn 1969; Hall and Lantz 1969).

Egg survival, from the green stage (Retrieval 1; day 14) to the eyed stage (Retrieval 3; day 37), was greater than 85%. Once hatched, survival to emergence was greater than 80% in all but the 25% fine sediment treatment, where survival was approximately 60%. Estimated survival of 40 to 55% from planting to hatch (Retrieval 4) was lower than the 68 to 84% reported by Hausle (1973) for eyed brook trout eggs incubated in Lawrence Creek, Wisconsin at a range of fine sediment levels. In this study, survival from planting to emergence was less than 65%, which paralleled similar studies when incubation began from a green stage; of course, survival was lower when compared with studies that began at more advanced stages (Table 2.5).

Intragravel mortality appeared to be greatest between eye-up (retrieval 3) and hatch (retrieval 4) and survival as a function of fine sediment followed a non-linear decline over time (Table 2.3). However, since retrievals were not made at evenly spaced times and retrievals two and three overlapped on the degree-day schedule (Table 2.1), this result may be misleading. In fact the relatively constant and linear declines in survival over time for all fine sediment treatments (Fig. 2.3), indicated that no stage in

TABLE 2.5.-Salmonid survival to emergence from studies conducted in artificial systems.

Species	Sediment size (mm)	Fine sediment (%)	Starting stage of development	Survival range (%)	Reference
Brook trout	<2	0-25	Alevin	>82	Hausle and Coble (1976)
Brook trout	<0.85	0-25	Green	5-65	This study
Chinook salmon	9.5 0.85	<50 <20	Green	6-99	Tappel and Bjornn (1983)
Chinook salmon	0.84 and 0.84-4.6	0-50	Green	0-63	Reiser and White (1988)
Rainbow trout	<4	40-100	Eyed	51-74	MacCrimmon and Gots (1986)
Steelhead trout	0.84 and 0.84-4.6	0-50 0-50	Eyed Green	24-98 1.3-85	Reiser and White (1988)

development was more or less sensitive to fine sediment. Data from Paint Bank National Fish Hatchery (National Survey of Trout Brood Stocks 1991) over multiple year classes (1989-1991) indicate that in the absence of sediment (i.e., hatchery conditions) survival of the Nashua strain exceeds 90% to emergence. However, in this study survival at the 0% fine sediment treatment (control) was less than 90%, even at the first retrieval (day 14) indicating that egg and fry mortality occurred for other reasons other than fine sediments.

Surviving fry that were not included in final survival estimates escaped from misshapen mesh liners in W-V boxes and swam up before being retrieved. Approximately 230 surviving fry were able to wriggle out of lined W-V boxes prior to retrieval six. Had these fry been retained in their respective egg boxes, estimated survival to emergence relative to each sediment treatment may have increased by as much as 4% (8 escaped fry per box/200 eggs per box).

Even though the laboratory study provided a controlled environment to determine the effects of fine sediment, other factors influenced survival from egg planting to fry emergence including: natural mortality, handling, disintegration, fungal infestation, confounding effects of other W-V boxes, and incubation chamber egg density.

Whitlock-Vibert boxes at the 0% (control) fine sediment level taken at the first retrieval provided some estimate of mortality due to handling. Of the eggs planted, approximately 12% died by retrieval one. This, however, is an overestimation of true handling mortality because 14 days passed between planting and the first retrieval. If a few W-V boxes had been opened within 48 hours (a period in which green eggs may be safely handled) (Leitritz and Lewis 1976) and the contents examined, perhaps a better estimate of handling mortality would have been obtained. Reiser and White (1988) report a handling mortality of 9% for green chinook salmon eggs using similar planting techniques and W-V boxes.

To estimate the direct effect that fine sediment alone has on survival to emergence, survival at each fine sediment treatment can be subtracted from survival at the 0% sediment treatment (control) for retrieval five. However, since no significant differences were found in survival at retrieval five this subtraction technique cannot be expected to produce a significant trend. In fact, when the estimated mortality due to fine sediment (i.e., survival at 0% fine sediment - survival at X% fine sediment) was regressed on fine sediment, the following function was produced:

$$Y = SED*0.87+46.4$$

$$R^2 = 0.25$$

$$P = 0.058$$

where Y = estimated percent mortality due directly to fine sediment alone, SED = percent fine sediment*100. If survival of emergent fry in stream two had been similar to survivals reported in stream one and stream three (Appendix E), variability among treatments would have been reduced. Stream two also produced lower survivals at retrieval six (Appendix E), perhaps because emerging fry escaped W-V boxes and died in the gravel incubator.

Although low levels of dissolved oxygen may reduce survival (Wickett 1954; Alderdice et al. 1958; Coble 1961; Silver et al. 1963), no significant portion of mortality in this study can be attributed to low dissolved oxygen (Fig. 2.2) because it never fell below 50% saturation, a level below which survival of embryos can be negatively affected (Harshbarger 1975). From the inverse relationship between intragravel dissolved oxygen and fine sediment (Fig. 2.2), dissolved oxygen at 25% fine sediment was approximately 1.8 mg/l less than surface water dissolved oxygen at 0% fine sediment. Assuming that the intragravel environment remained relatively stable and that dissolved oxygen delivery was constant through time, eggs incubated at the

25% fine sediment level were constantly exposed to a 1.8 mg/l reduction in dissolved oxygen. Surface dissolved oxygen levels never fell below 7.2 mg/l (70% saturation, day 128) (Appendix C).

The rate at which dead eggs disintegrate is a function of the incubation time. In this study, $\leq 12.7\%$ of the total number of eggs planted disintegrated by emergence (114-136 days) (Appendix E). This relatively low disappearance rate may be due to the fact that egg clutches were contained in W-V boxes and not incubated directly in intragravel plants. Shocked brook trout eggs, in a similar laboratory study, disappeared at a rate of 2% by 53 days, 24% by 90 days, and 82% by 133 days (Hausle 1973). In Slovens Creek, New Zealand, brown trout (Salmo trutta) eggs disappeared at a rate of 0% in 35 days and 9% in 41 days (Hobbs 1937). In Mill Creek, California, only 50% of planted chinook salmon eggs were recovered after 45-58 days (Gangmark and Broad 1955).

Survival estimates (Table 2.3) at all retrievals were based on absolute counts of recovered live and dead eggs, alevins, and emergents. Survival values calculated this way overestimated actual survival to emergence (Retrieval 5) because alevins died and disintegrated and after retrieval four a small number escaped the W-V Box, reducing the total number of recovered individuals. One-way ANOVAs for

retrievals one, two, three, and six found no significant difference in the total number of eggs lost among fine sediment treatments ($P>0.05$). At retrieval four, the loss of eggs at the 25% sediment treatment was significantly greater than the loss of eggs at the 0% treatment (T-test, $P<0.05$). At retrieval five one-way ANOVA detected a significant difference in egg loss among sediment treatments ($P<0.01$). Less eggs were present in the higher sediment treatments (10, 20, and 25%) and were significantly different from the 0% sediment treatment (Fisher's LSD, $P<0.05$). By using an estimate of the total number of eggs deposited (average number retrieved at retrieval 1, $n=201$) and assuming that all eggs and emergents not recovered were dead and did not escape, new survival values were calculated for all fine sediment treatments at retrieval five. Average survival to emergence was 48.4 ± 17.2 , 48.1 ± 8.0 , 32.8 ± 17.6 , 43.6 ± 2.2 , 34.3 ± 1.5 , and 18.4 ± 13.8 at 0, 5, 10, 15, 20, and 25% fine sediment, respectively, and were not significantly different (ANOVA, $P>0.05$). True survivals of emergent fry probably fall between those reported in Table 2.3 (an overestimation) and these estimates (an underestimation).

The presence of fine sediments within a redd creates conditions conducive to the entry and persistence of disease-related organisms (Iwamoto et al. 1978). Nonviable eggs, alevins, and emergent fry collected during this study

were infested with the water borne fungus Saprolegnia spp., first observed at retrieval one (day 14), which spread among nonviable eggs and dead alevins. Treatments with Paracide-F did not eradicate this fungus, but treatments did slow the rate at which the fungus affected other eggs. Repeated doses were necessary to reduce the spread of this opportunistic facultative parasite because the sporangia often remain alive even when hyphae have been destroyed (Egusa 1992). Large amounts of this fungus were also observed in W-V boxes used to plant eyed brown trout eggs in South Mills River, North Carolina (Harshbarger and Porter 1979, 1982). Mycelia were observed four weeks after planting and by 15 weeks, eggs and dead fry were consolidated into a mass of fungi. Harshbarger and Porter (1979, 1982) believe that eggs confined in W-V boxes are more susceptible to fungal agents than eggs in intragravel plants, where egg distributions are more similar to that of natural redds. Fungal infestations like these may increase the susceptibility of viable eggs or alevins to die and disintegrate; however, this contention has not been directly tested. High brook trout egg densities of 8,000 per incubation chamber (200 per W-V box) may have increased the transmission of Saprolegnia spp. among eggs within a W-V box and among other W-V boxes in a given stream.

Quality of Emergents

The condition of fry at emergence is an indicator of the influence that the intragravel environment had on embryonic development. Emergents that possessed physical anomalies (n=18, 0.5% of live fry from retrievals five and six) (e.g., crooked backs, crooked tails, no tails, and two heads) were not used to calculate indices. Their occurrence was attributed to genetic defects common among hatchery strains, not to the effects of fine sediments imposed on developing embryos (C. Stevens, Paint Bank, VA personal communication). Deformed fry were found at all sediment treatments.

Bams (1970) reported that fry whose KD value is greater than 2.0 possess yolk material at emergence, while fry whose KD value is less than 1.96 have absorbed their yolk and begin to resorb body tissue. Emergent fry incubated in 0 and 5% fine sediment at retrieval five (Table 2.4) possessed KD indices greater than or equal to 2.0, while fry incubated in 20 and 25% fine sediment had KD indices less than or equal to 1.92. Moreover, fry weight generally declined as the proportion of fine sediment increased. The smaller size and lower KD indices of emergent fry incubated in higher proportions of fine sediment indicate that energy reserves were nearly depleted at emergence and that eggs were

stressed at higher sediment levels resulting in a sublethal effect.

Other studies that document the size and condition of salmonid fry at emergence report a wide range of findings. Hausle (1973) found no relationship between the percentage of sand and the size of emerging brook trout fry. On the other hand, the wet weight and standard length of emergent rainbow trout alevins increases with gravel size, while KD indices decrease (Witzel and MacCrimmon 1981). Coho salmon fry that emerge from high percentages of sand are smaller than those from gravels with low percentages, but steelhead fry are similar in size after emergence from gravels with different percentages of sand (Phillips et al. 1975).

Management Implications and Conclusions

Because the artificial systems used in this study protected against a complex array of factors (e.g., storm events, human disturbance, predation) that may influence embryonic survival, caution should be used when applying these results to natural systems. However, because natural redds are composed of mixes of fine sediment and gravel similar to those used in this study, it can be said that survival of developing brook trout is reduced when large proportions of a redd are composed of fine sediments. In the absence of fine sediment (i.e., 0% fine sediment) mortality can be as high as 60% from egg planting to fry

emergence. Mortality increases (although not significantly) even with modest (10%) fine sediment amounts. Survival to emergence under 25% fine sediment is about half of survival under 0% fine sediment. The lack of significance among treatments was due to high variability among replicates.

Even though no one developmental stage was found to be more sensitive than another, minimizing impacts that introduce fine sediments is strongly recommended for Virginia watersheds during the entire intragravel period (mid-October to mid-March). Therefore, it is incumbent upon managers to continue efforts to maintain the integrity of the stream bed and the integrity of the stream bank to ensure reproductive success.

Future research considerations should include fewer fine sediment treatments and more replicates. In doing so, a significant difference in survival to emergence may be discerned and variability within a treatment may be reduced. A sample size of seven or more per treatment would be necessary to detect a significant difference. Moreover, an investigation into the role that Saprolegnia spp. has on salmonid development and survival should undertaken.

Chapter 3 - Fine Sediment Effects on Survival of Brook Trout Eggs in a Field Study

In quantifying the effects of fine sediment on salmonid egg survival and fry emergence, researchers have frequently used controlled laboratory studies (Bjornn 1968; Hall and Lantz 1969; Hausle 1973; Phillips et al. 1975; Reiser and White 1988) and field studies (Koski 1966; Hall and Lantz 1969; Hausle 1973; Tagart 1976). Results from both approaches indicate that an inverse relationship exists between survival and increasing fine sediment amounts (Everest et al. 1987; Chapman 1988). Moreover, these studies demonstrate that sediments can reduce dissolved oxygen delivery, reduce gravel permeability, and physically impede fry at emergence.

Laboratory studies have allowed researchers to separate the effects of fine sediment from the confounding effects of multiple variables found in field studies and to test the difference between hatchery and wild strains (assuming hatchery strains are used in laboratory studies and wild strains in field studies). However, laboratory studies cannot accurately simulate natural environmental conditions (e.g., gravel mixtures, spawning behavior, weather, and flow) (Everest et al. 1987).

In field studies, survival of salmonids from egg deposition to fry emergence has been estimated by excavating

redds and calculating a ratio of live eggs and alevins to the total number recovered (Hobbs 1937; Koski 1966; Tagart 1976). However, survival is overestimated with this method if dead eggs and alevins are lost, decomposed, scoured, or eaten by predators (Shaw and Maga 1943; McDonald 1960; McNeil 1964). Traps used to collect emergent fry are not always 100% effective (Fraley et al. 1986), leading to an underestimation of survival to emergence. Moreover, fecundity estimates based on fish length may not accurately reflect actual egg deposition because there is often a large amount of variability among females, and because female salmonids often deposit eggs in several redds (MacKenzie and Moring 1988). As a result, survival estimates based on length-fecundity data may be higher than actual survival depending on the total number of eggs deposited.

In the life history of a salmonid, survival is generally lowest during the intragravel period (Mackenzie and Moring 1988). Mortality occurs for numerous reasons at varied stages of development, but the stage of development at which the influence of fine sediment is greatest during the intragravel period is largely unknown. The majority of research conducted on the effects of fine sediment on salmonid survival has been conducted on Pacific salmonids (Everest et al. 1987) and their survival to full emergence. Fisheries managers of the southern Appalachian Mountains

have long been concerned with the detrimental effects of fine sediments on salmonids (King 1937; Seehorn 1987). Brook trout are the only native salmonid in the southern Appalachian Mountains and may exhibit reduced numbers during egg and alevin stages in areas with large amounts of fine sediment (Hausle 1973; West et al. 1982).

This study was designed to incubate brook trout eggs in a natural system utilizing Whitlock-Vibert (W-V) boxes (Federation of Fly Fishermen 1975) that contained known levels of fine sediment and eggs. This design allowed W-V boxes to be retrieved periodically during incubation to estimate survival during specific stages of intragravel development. This approach also provided some of the control associated with laboratory studies (i.e., known quantity of eggs, known initial fine sediment levels, and protection from predators) while allowing for natural variability in temperature, stream flow, and dissolved oxygen in a natural stream channel.

The objectives of this study were to: 1) determine the survival of recently fertilized brook trout eggs incubated in mesh lined W-V boxes at three different fine sediment (0.43-0.84 mm in diameter) treatments (0, 10, and 20% by weight); 2) identify the stages of development at which intragravel mortality was the greatest; 3) determine the interaction that dissolved oxygen and water turnover rate

have with sediment levels on the survival of brook trout;
and 4) determine the condition of fry at emergence in a
field situation.

Materials and Methods

Study Area

Laurel Branch (LB) (N80°37'30", W37°23'30") and White Rock Branch (WRB) (N80°30', W37°26') are tributaries of Stony Creek, Giles Co., Virginia (Fig. 3.1). Both streams support reproducing populations of brook trout. Laurel Branch, a second order headwater stream, drains a watershed of approximately 614 ha. The study section (Fig. 3.1) varies in elevation from 609 to 664 m (stream varies from 567 to 1,006 m) and has a mean gradient of 7.1%. The majority of LB is located within the Jefferson National Forest. White Rock Branch, is found entirely within the Jefferson National Forest and drains a watershed of approximately 843 ha. The study section varies in elevation from 908 to 915 m (stream varies from 902 to 969 m) and has a mean gradient of 0.97%. Almost all precipitation in both drainages arrives as rain, with periodic snow melts in the winter months. Both drainages are characterized by sandstone and shale geology and a mixed upland overstory containing black locust (Robinia pseudoacacia), eastern hemlock (Tsuga canadensis), northern red oak (Quercus rubra), scarlet oak (Quercus coccinea), white pine (Pinus strobus), and tulip poplar (Liriodendron tulipifera). The riparian understory is predominantly rhododendron (Rhododendron spp.).

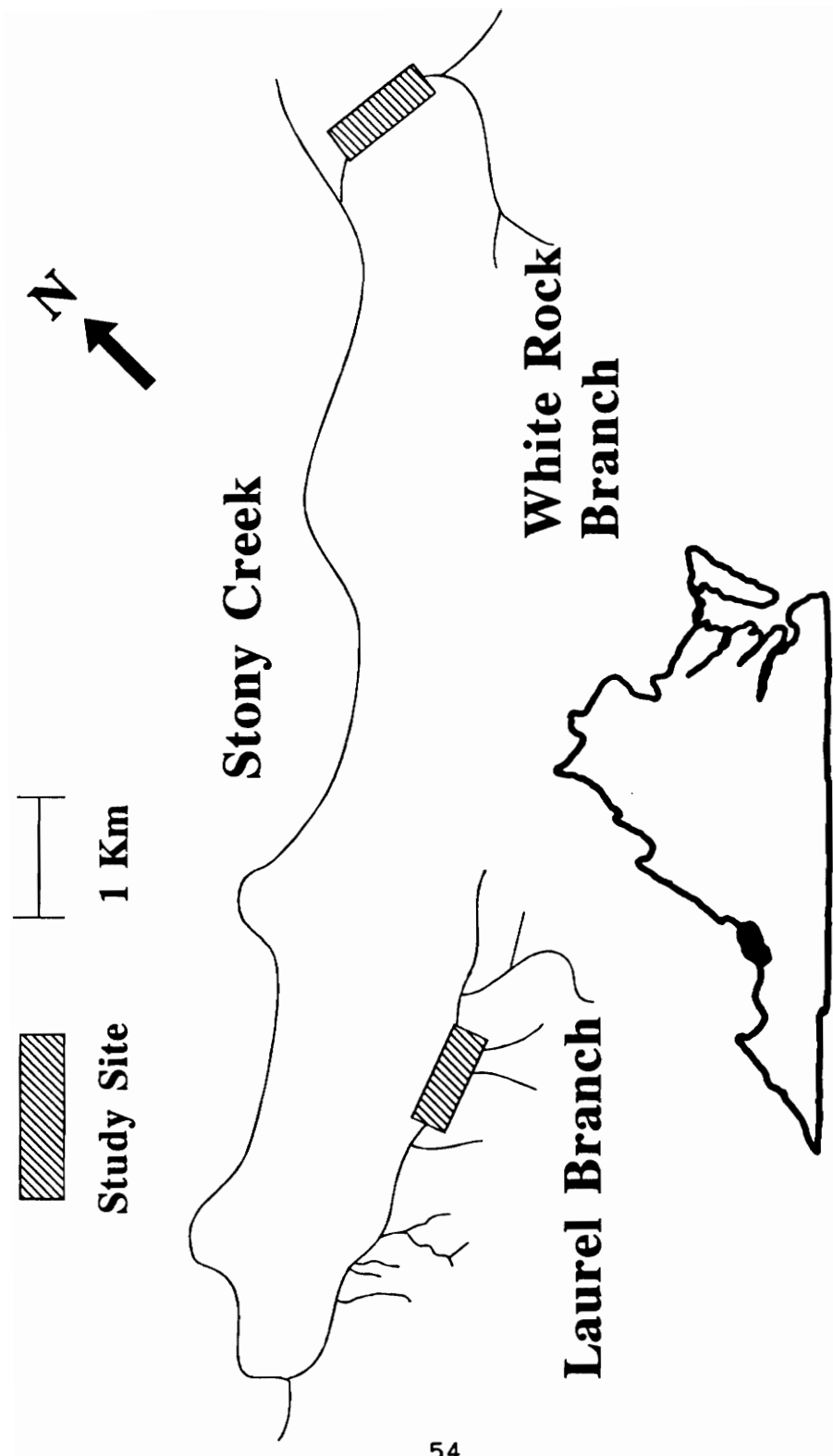


FIGURE 3.1.1.-Map of Laurel Branch and White Rock Branch. Shaded area denotes study reach.

I selected artificial redd sites (63 per stream) on 24 September 1993 and 2 October 1993 based on literature describing brook trout spawning habitat (White 1930; Hazzard 1932; Hobbs 1937; Hale and Hilden 1969, 1970; Brasch et al. 1973; Chapman 1988), my observations of brook trout spawning activity, apparent subsurface flow, and the depth of water (>10 cm). At the time boxes were planted velocities in both streams averaged 0.14 m/s, while average water depths were 12 cm in LB and 15 cm in WRB. Both streams are characterized by a cobble and gravel substrate with large boulders in and along the stream channel. I used a 780 m reach on LB (average width 2.4 m) and a 630 m reach on WRB (average width 2.9 m) (Fig. 3.1). Of the 63 sites selected in LB, 11 were later superimposed upon by spawning native brook trout. None of the 63 sites in WRB were superimposed upon.

Whitlock-Vibert Boxes

I loaded two-chambered Whitlock-Vibert (W-V) boxes (Federation of Fly Fishermen 1975) lined with 0.4 mm Nitex netting with coarse gravel (6.33-12.49 mm in diameter) and one of three fine sediment (0.43-0.84 mm in diameter) treatments (0, 10, and 20% by weight), 21 boxes per treatment per stream. Gravel and fine sediment in each W-V box weighed approximately 550 g (Appendix A). The liner in the lower chamber retained fine sediments and eggs, while

the liner in the upper chamber prevented the influx of additional sediment and kept emergent fry from escaping. Fine sediment was sieved from commercial sand.

On 11 October 1993 I obtained approximately 26,000 freshly fertilized (green) brook trout eggs, Nashua strain (National Survey of Trout Brood Stocks 1991) from the Paint Bank National Fish Hatchery, Craig County, Virginia. Eggs were held in a styrofoam cooler at approximately 7°C until placed in W-V boxes (no more than 8 hours). The lower chamber of each lined W-V box was charged with 16 ml (200±5 eggs) of eggs. Egg densities were selected based on literature describing brook trout fecundity (Vladykov and Legendre 1940; Morgan and Robinette 1978; Gray 1979; Power 1980). Charged W-V boxes were randomly placed among the 63 selected sites in each stream and affixed to a piece of rebar (40 cm long) using heavy fishing line. Washed stream gravel (6.33-24.9 mm in diameter) was arranged so that W-V boxes were completely covered with gravel and secure.

Whitlock-Vibert Box Retrievals

I retrieved W-V boxes at six times (retrievals) during the study to estimate survival to specific stages of embryonic development (Table 3.1). Three W-V boxes were removed from each stream at each sediment level for the first five retrievals (a total of 18 boxes). At the sixth

TABLE 3.1.-Retrieval schedule for artificial redd sites.
At each retrieval, one W-V box was taken at each of the
three fine sediment treatments per stream.

Retrieval	Day of study	Date	Stage of development
1	14	10-26-93	Green
2	28	11-9-93	Eyed
3	36	11-17-93	Eyed
4	70	12-21-93	Hatched
5	121	2-10-94	<90% emerged
6 ¹	139	2-28-94	Emergence
6 ²	143	3-4-94	Emergence

¹Laurel Branch, ²White Rock Branch

retrieval, all remaining W-V boxes were removed (6 at each sediment level in each stream) to determine survival to full emergence. When fry had swum up from the lower chamber to the upper chamber of the W-V box, they were considered emerged. Absolute counts of live to dead were used to derive percent survival estimates.

A total of 206 emergent fry were measured (total length) to the nearest 1.0 mm and weighed to the nearest 0.1 mg. Fry were dried at 100°C for 24 h, and weighed and measured. Individual and mean condition factors were calculated from wet weights and dry weights. The wet weight condition factor (K_{ww}) (Reiser and White 1988) is:

$$K_{ww} = \frac{\text{wet weight (mg)} \times 100}{[\text{wet fork length (mm)}]^3}$$

The dry weight condition factor (K_{dw}) is (Reiser and White 1988):

$$K_{dw} = \frac{\text{dry weight (mg)} \times 10^3}{[\text{dry fork length (mm)}]^3}$$

Bams' (1970) developmental index (k_D) was computed to allow comparison of the developmental stage among emergent fry:

$$k_D = \frac{10 \times [\text{wet weight (mg)}]^{1/3}}{\text{wet fork length (mm)}}$$

Values of 1.90 or less indicate that emergent fry have resorbed body tissue at the expense of growth, values around

1.96 indicate total yolk absorption, and values greater than 2.0 indicate that high proportions of yolk remain at emergence (Bams 1970).

Stream Characteristics

I measured several environmental stream characteristics (dissolved oxygen, current velocity, and depth) at each artificial redd site weekly, from mid-October to mid-February. Due to inclement weather in December, January, and February only three, two, and one trips were made, respectively. I recorded surface water temperatures ($^{\circ}\text{C}$) with a hand-held thermometer until 22 November when HOBO-Temps (Onset Computer Corp., Pocasset, MA) were buried 15 cm in the gravel (one per stream) to record stream temperatures every 1.6 hours. Temperatures were recorded until the last retrieval (28 February in LB and 4 March in WRB). Surface water dissolved oxygen (mg/l) was measured at each artificial redd site using a dissolved oxygen meter (Yellow Springs Instrument Co., Colorado Springs, CO). Surface water velocities were measured 10 cm upstream from each artificial redd at 0.6 of total water depth using a Marsh-McBirney (Marsh-McBirney Co., Gaitersburg, MD) current meter. I measured water depth over each artificial redd site with a PVC measuring rod. Hydrogen ion concentration (pH) was recorded at every tenth artificial redd site in

each stream with a hand held pH meter (Hach Co., Loveland, CO).

Permeability (cm/hr) and intragravel dissolved oxygen (mg/l) were measured weekly using standpipes (Pollard 1955; Terhune 1958; Wickett 1958) that were installed in lined W-V boxes with known levels of fine sediment (3 of each at 0, 10, and 20%) and no eggs. These boxes were planted downstream from randomly selected artificial redd sites matched for sediment treatment in each stream. These two measures were taken to estimate the intragravel environment of the developing eggs in W-V boxes containing corresponding fine sediment proportions. Intragravel dissolved oxygen (mg/l) was measured with a dissolved oxygen probe lowered to the bottom of the standpipe. Permeability was estimated by timing the influx of water over time by lowering the water level in the standpipe to create a hydraulic head of known volume.

Sediment Samples

Gravel and sediment from each W-V box were dried for 24 h at 60°C to a constant weight. Fine sediment retained by the matrix of eggs and Saprolegnia spp. was obtained by heavy washing with water and dried. Samples were sieved using standard sieves (0.18 mm, 0.43 mm, 0.85 mm, 1.70 mm, 3.35 mm, 6.33 mm, 9.50 mm, 12.5 mm, and 24.9 mm) and weighed

to the nearest 0.1 g to determine how much sediment was lost or gained over the course of the study. After each W-V box was removed, a McNeil stovepipe sampler (McNeil and Ahnell 1964) was inserted in artificial redds to obtain a measure of changes in gravel substrate composition. While biases are associated with all gravel samplers, the McNeil sampler is reported to produce samples that most accurately approximate the true substrate composition (Young et al. 1991). Core samples were placed in a drying oven, dried at 60°C until all water was removed, and sieved as above. The geometric mean (Lotspeich and Everest 1981) particle size (dg) was then calculated to derive a measure of pore size and permeability:

$$dg = [d_1w_1 \times d_2w_2 \dots \times d_nw_n]$$

where dg = geometric mean particle size, d = midpoint diameter of particles retained by the nth sieve, and w = decimal proportion of particles by weight retained by the nth sieve.

Statistical Analyses

One-way ANOVAs were used to compare survival of developing brook trout among the six fine sediment levels at each retrieval. One-way ANOVAs and Fisher's least significance difference (LSD) (Ott 1988) were used to test for significant differences in alevin size or developmental

index among the six fine sediment levels. Significant differences in stream temperatures, pHs, and surface dissolved oxygen levels between the two streams were tested using T-tests. One-way ANOVAs were used to determine if significant relationships existed between intragravel stream characteristics (permeability and dissolved oxygen) and fine sediment. Paired T-tests were used to detect differences in weight of starting and ending fine sediment treatments. Mean values in the text are reported as mean $\pm$ SD. All statistical analyses were performed using the Statistical Analysis System (SAS) (SAS Institute 1985) at a significance level of 0.05.

Results

Stream Characteristics

Mean pH ranged from 6.3 to 7.4 in LB and from 7.2 to 7.5 in WRB (Appendix Table G1). The minimum value in LB was recorded two days after a rain storm (day 68). Stream pH was significantly different between streams (T-test, $P < 0.01$). Temperatures taken for the first four weeks at artificial redd sites (until 22 November) (Appendix Table G2) indicated that LB ($\bar{X} \pm SD = 7.8 \pm 2.5^{\circ}\text{C}$) was slightly warmer than WRB ($\bar{X} \pm SD = 7.5 \pm 2.0^{\circ}\text{C}$). Temperatures recorded every 1.6 hours after 22 November using HOBO temps (Appendix Figure G1) indicated that LB's average temperature ($\bar{X} \pm SD = 2.9 \pm 2.1^{\circ}\text{C}$) was significantly lower (T-test, $P < 0.001$) than WRB's average temperature ($\bar{X} \pm SD = 3.7 \pm 1.9^{\circ}\text{C}$). Until 22 November, stream temperatures were recorded in the morning in WRB and in the afternoon in LB, yielding higher temperatures for LB; however, once HOBO temps were installed, temperatures were measured continuously (every 1.6 hours). Because LB has a much thicker riparian area than WRB, stream temperatures were lower. Anchor ice formed in both streams in mid-January (day 95) but lasted only two days. Average weekly surface water dissolved oxygen levels ranged from 9.2 to 13.0 mg/l in LB and from 9.2 to 12.7 mg/l in WRB (Appendix

Table G3) and were not significantly different (T-test, $P=0.47$).

Both permeability and intragravel dissolved oxygen fluctuated over time in W-V boxes with fine sediment and without fine sediment (Figs. 3.2 and 3.3, Appendix H). Permeability (Appendix H) was not significantly related to percent fine sediment (ANOVA, $P=0.56$). Intragravel dissolved oxygen (Appendix H) was not significantly related to percent fine sediment (ANOVA, $P=0.85$) or to permeability (correlation, $r=-0.04$, $P=0.58$).

Relatively stable flow conditions existed in both streams until week six (Figs. 3.4 and 3.5). After week five, depth and velocity measurements began to diverge (Figs. 3.4 and 3.5). High flow events recorded in both streams during weeks six and seven scoured out some redd sites and displaced W-V boxes (Fig. 3.4). Current velocity, as measured 10 cm in front of each artificial redd site, also increased during this time period (Fig. 3.5).

Fine Sediment and Gravel Mixtures

Minimal sediment gains and losses were found until retrieval four for all three sediment treatments (Fig. 3.6, Appendix I). After retrieval four, all W-V boxes gained or lost significant amounts of fine sediment (<0.85 mm in diameter) (Fig. 3.6). All egg boxes at the 0% sediment treatment taken after retrieval four gained fine sediment

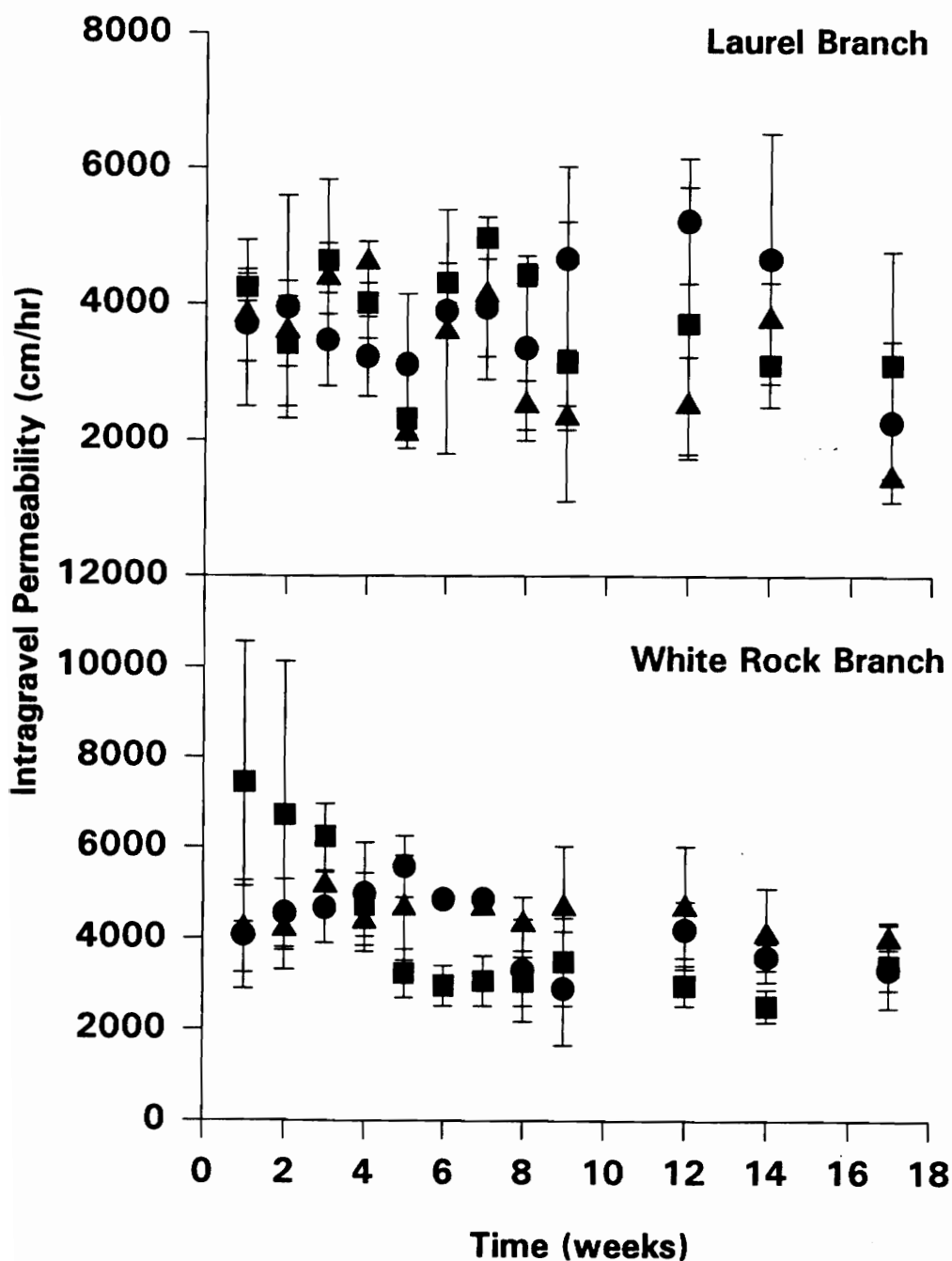


FIGURE 3.2.-Estimated intragravel permeability (cm/s) in Laurel Branch and in White Rock Branch. Circles denote modified W-V boxes that had 0% fine sediment, triangles denote W-V boxes that had 10% fine sediment and squares denote W-V boxes that had 20% fine sediment. Error bars represent standard deviation.

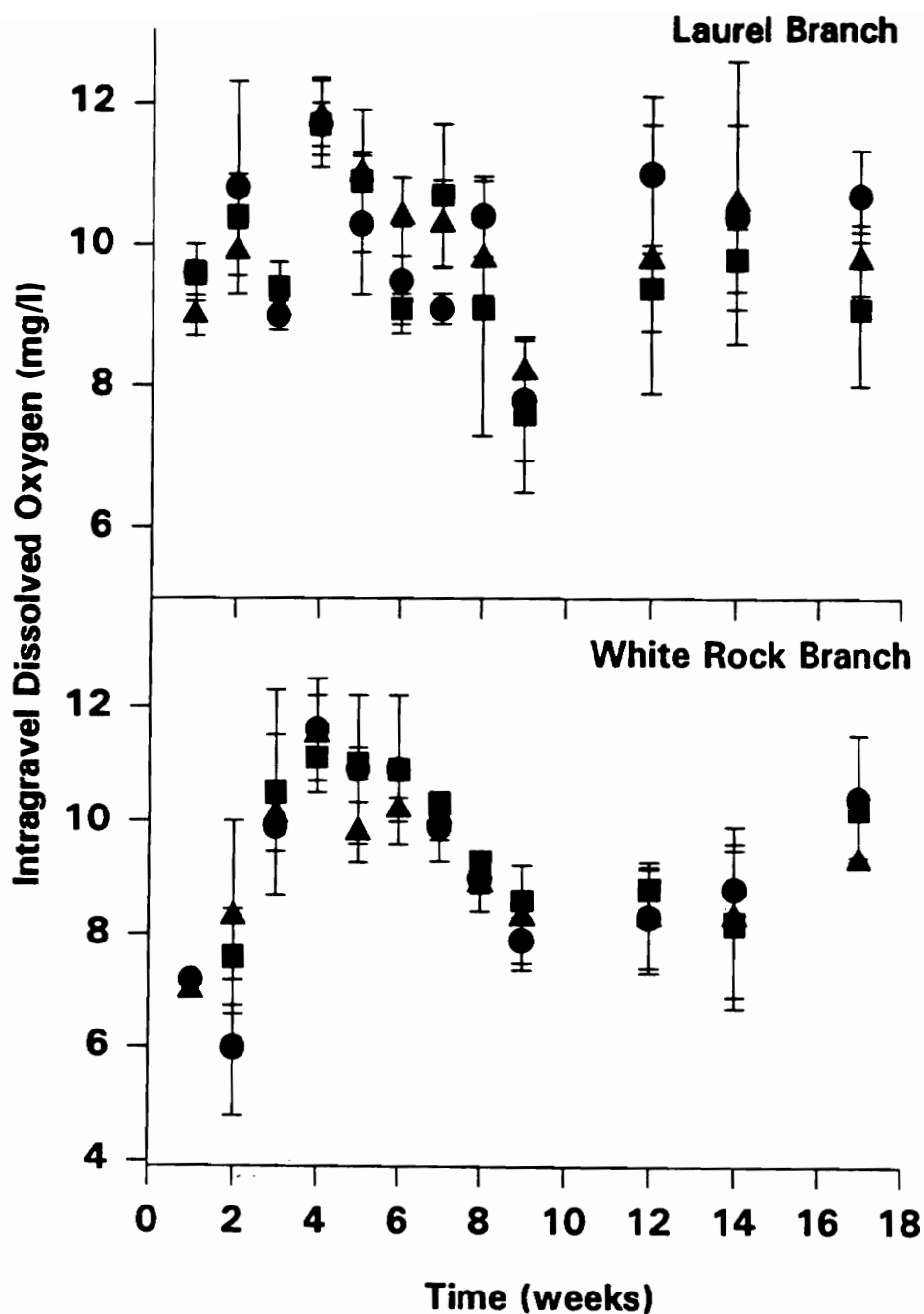


FIGURE 3.3.-Intragravel dissolved oxygen (mg/l) in Laurel Branch and in White Rock Branch. Circles denote modified W-V boxes that had 0% fine sediment, triangles denote W-V boxes that had 10% fine sediment and squares denote W-V boxes that had 20% fine sediment. Error bars represent standard deviation.

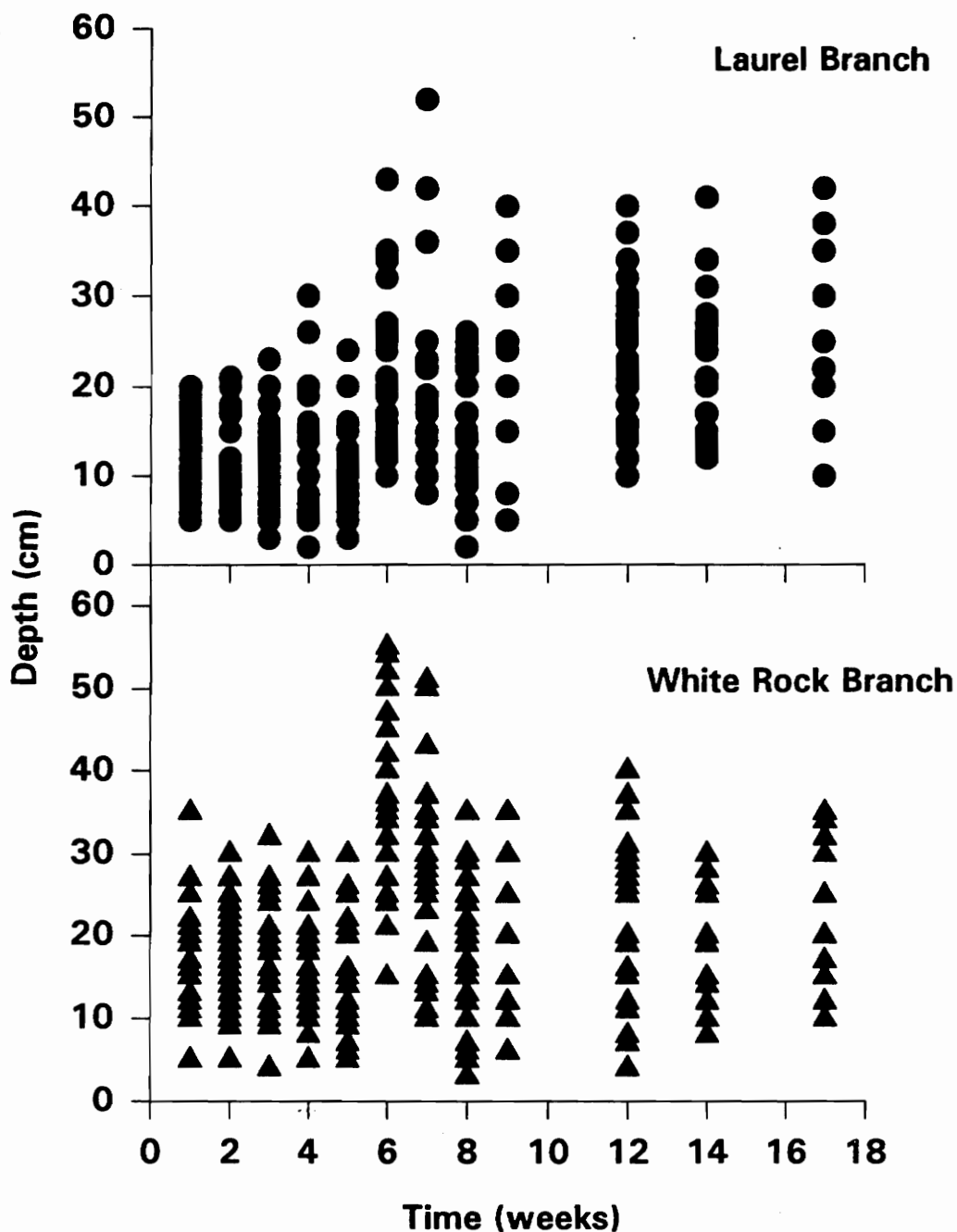


FIGURE 3.4.-Depth of water (cm) over artificial redd sites in Laurel Branch (circles) and White Rock Branch (triangles). Due to inclement weather, no measurements were made during weeks 10, 11, 13, 15, and 16. Symbols represent actual measurements.

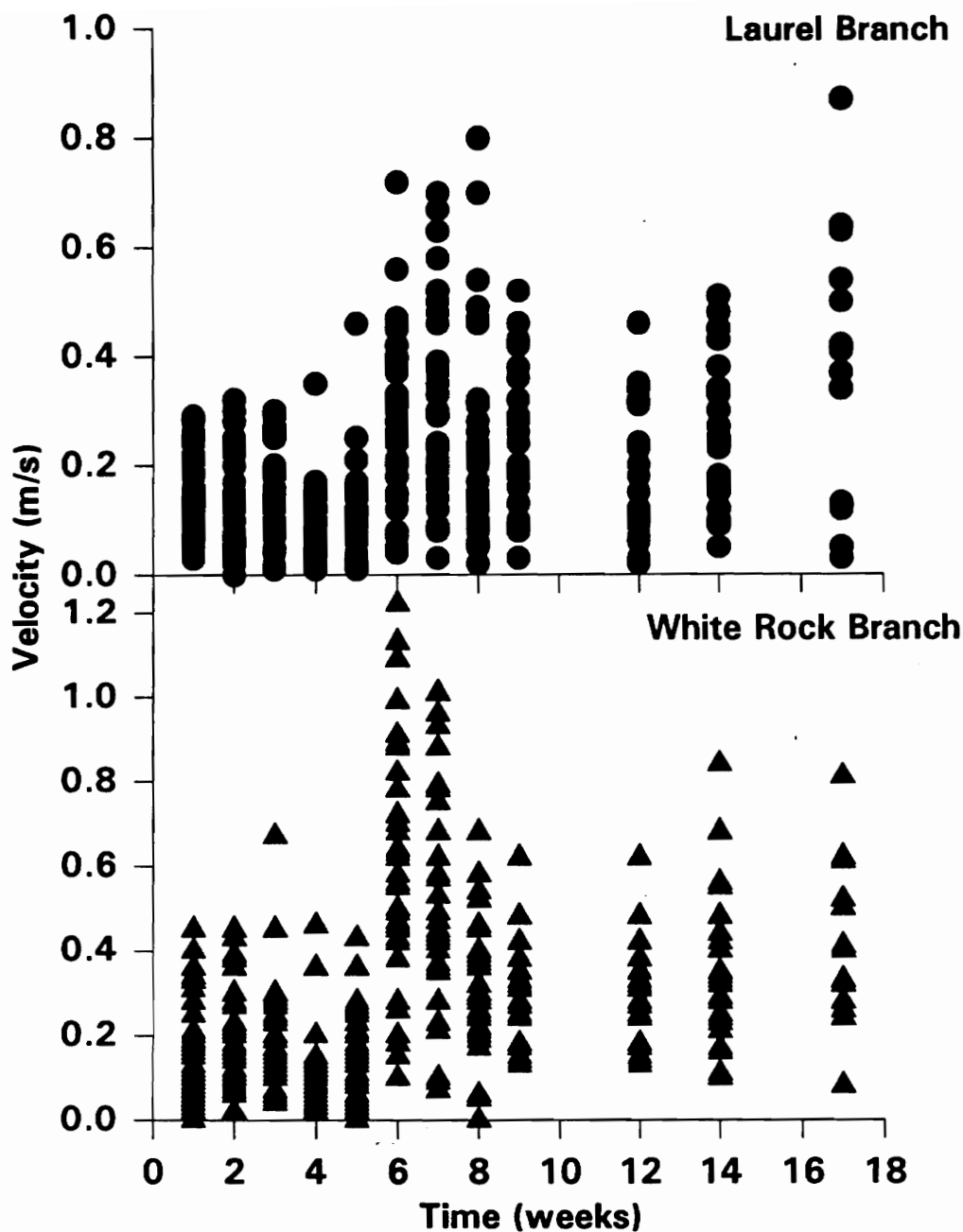


FIGURE 3.5.-Velocity of water (cm/s) over artificial redd sites in Laurel Branch (circles) and White Rock Branch (triangles). Due to inclement weather, no measurements were made during weeks 10, 11, 13, 15, and 16. Symbols represent actual measurements.

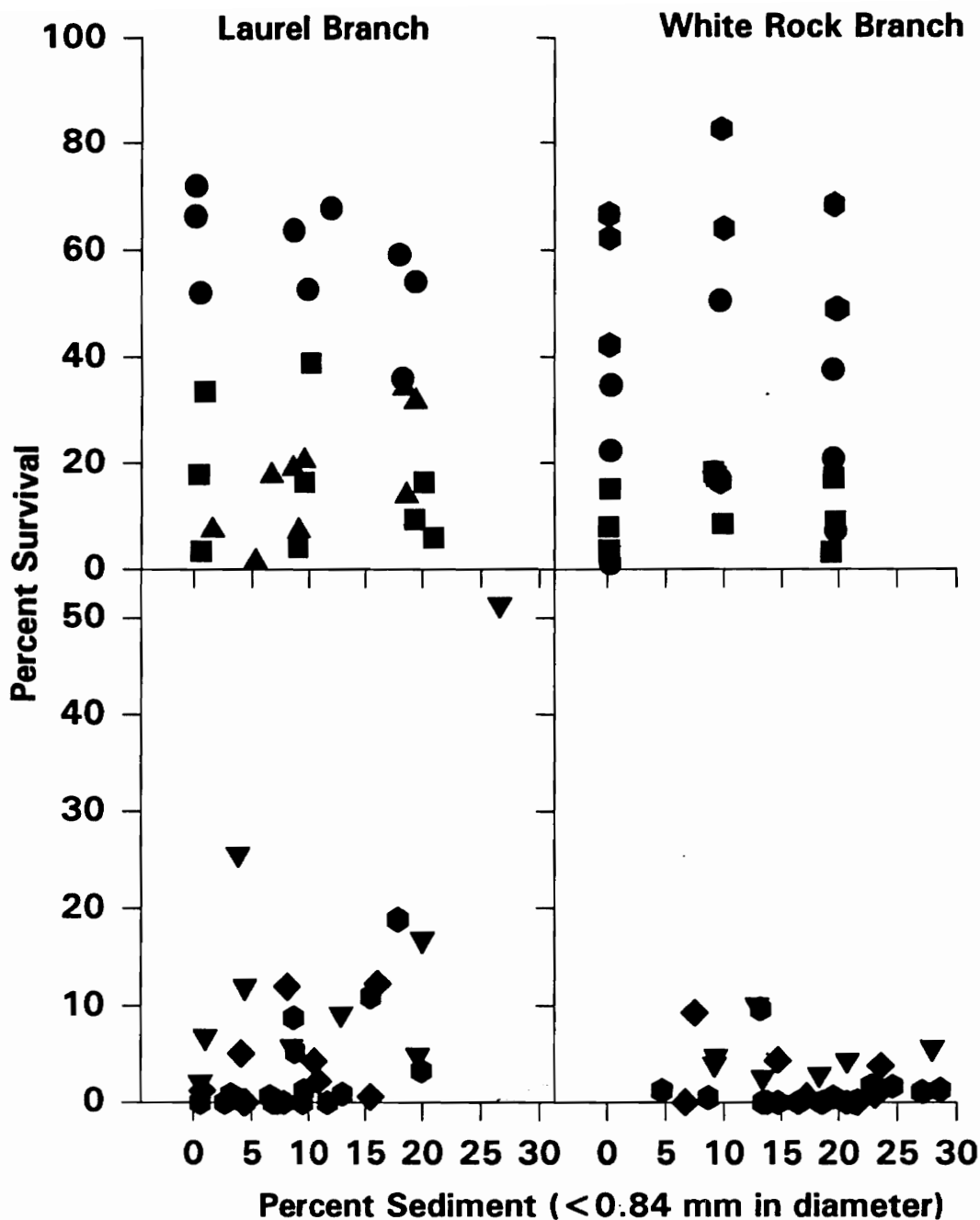


FIGURE 3.6.-Survival (%) in Laurel Branch and in White Rock Branch for retrievals 1 (circles), 2 (squares), 3 (triangles) in upper panels, 4 (upside down triangles), 5 (diamonds) and 6 (hexagon) in lower panels. Symbols represent percent of recovered eggs that survived at the final fine sediment amount for each retrieval.

(paired T-test, $P < 0.01$). Whitlock-Vibert boxes at the 10% sediment treatment generally lost sediment in LB but gained sediment in WRB, and these differences were significant (paired T-test, $P < 0.01$). Boxes at the 20% sediment treatment lost significant proportions of fine sediment at each retrieval after the third in both streams (paired T-test, $P < 0.01$). Distributions among size classes shifted as the study progressed, altering gravel compositions to include particles 0.85 to 12.4 mm in diameter and fine sediments less than 0.43 mm in diameter (Appendix I).

Artificial Redd Sites Core Samples

The scouring action of each stream displaced gravels used to bury W-V boxes; as a result the total number of cored sites was reduced. Because stream gravels washed away only 38 sites were cored in LB and 36 sites were cored in WRB (Appendix J). The geometric mean particle size (Appendix K), comprising artificial redds approximated 10 mm in diameter (8.4-11.5 mm in diameter), until retrieval four (initially planted gravels 6.3-24.9 mm in diameter). After retrieval four (day 70), the first retrieval after the scouring flows of weeks six and seven, artificial sites were composed of particles having a coarser or finer geometric mean diameter (4.2-29.6 mm) (Appendix K). By retrieval six, (day 139 in LB and day 143 in WRB), sites on both streams were composed of material averaging less than 5 mm in

diameter. These changes in gravel composition occurred because of the export of gravels used to bury W-V boxes and the import of new gravels from upstream.

Brook Trout Survival

Total counts of recovered eggs and fry (viable and nonviable) were 195.7 ± 10.6 in LB and 202.4 ± 12.3 in WRB through retrieval three (day 36) and declined to 159.3 ± 34.7 in LB and 168.8 ± 13.7 in WRB by retrieval four (day 70) (Appendix L). At emergence (retrievals 5 and 6), total counts of eggs and fry were 150.8 ± 42.4 in LB and 167.5 ± 26.3 in WRB (Appendix L). With the exception of one W-V box in LB, greater than 78% of eggs planted were recovered in LB and greater than 62% of eggs were recovered in WRB at retrieval five (day 121). With the exception of one box in each stream, greater than 69% of eggs planted in LB (day 139) and greater than 42% in WRB (day 143) were recovered at retrieval six. Survival calculations presented here are based on total numbers of recovered eggs and fry (viable and nonviable) rather than the 200 eggs initially planted.

Survival of embryos and alevins declined, in both streams, during the study (Table 3.2, Fig. 3.6). The largest declines in survival occurred between retrievals one (green) and two (eye-up), and between retrievals four (hatch) and five (emergence) in both streams (Table 3.2). General declines in survival were reported at each retrieval

TABLE 3.2.-Survival (%) of embryos incubated in Laurel Branch and White Rock Branch. The total number of W-V boxes collected is denoted by N; SD is the standard deviation. Differences among fine sediment treatments were not significant for any combination of stream and retrieval (ANOVA $P>0.05$). Survivals are based on total number of eggs and alevins recovered.

Retrieval	Day of study	Sediment (%)	Laurel Branch		White Rock Branch			
			N	Mean	SD	N	Mean	SD
1	14	0	3	63.4	10.3	3	57.1	13.1
		10	3	61.4	7.8	3	54.4	34.3
		20	3	49.7	2.3	3	55.4	11.2
2	28	0	3	18.2	15.1	3	19.3	16.9
		10	3	19.8	17.6	3	28.5	18.9
		20	3	23.1	26.9	3	21.8	15.2
3	36	0	3	8.7	8.2	3	8.8	5.8
		10	3	15.5	7.2	3	14.7	5.4
		20	3	26.5	11.1	3	9.7	6.9
4	70	0	3	10.8	12.9	2	7.4	3.7
		10	3	9.3	2.6	2	4.3	1.9
		20	3	24.7	23.8	3	3.6	0.9
5	121	0	3	2.1	2.7	3	1.5	2.5
		10	3	6.2	5.1	3	4.6	4.3
		20	3	4.3	6.9	1	0.6	
6	139 ¹ -143 ²	0	6	0.6	0.5	5	2.1	4.2
		10	5	7.8	8.0	6	0.9	0.7
		20	6	1.4	2.3	5	0.3	0.6

¹ Laurel Branch, ² White Rock Branch

(Table 3.2). Because of heavy scour events, one W-V box was lost in LB and seven W-V boxes were lost in WRB (Table 3.2). No significant differences (ANOVA, $P > 0.10$) were found in survival among fine sediment treatments at each retrieval in LB or WRB (Table 3.2). Survival remained relatively stable through retrieval three for all sediment treatments (Fig. 3.6). Between retrievals four and six, when fine sediment levels changed (Fig. 3.6, Appendix I), survival at all fine sediment levels generally remained at 10% or less (Fig. 3.6). No significant correlations were found between gravel permeability and survival to emergence in LB ($r = -0.14$, $P = 0.72$) or WRB ($r = -0.22$, $P = 0.56$) nor between intragravel dissolved oxygen and survival to emergence in LB ($r = -0.65$, $P > 0.05$) or WRB ($r = -0.09$, $P = 0.81$).

Size and Condition of Emergent Fry

A total of 143 emergent fry were weighed and measured from LB and 63 from WRB (Appendix N). Because of low sample sizes, measurements of emergent fry recovered from both retrievals five and six were lumped for analyses. In general, no significant differences in development indices existed among fine sediment treatments for emergent fry in both streams (ANOVA, $P > 0.05$, Table 3.3); however, there was a significant difference among sediment treatments in wet lengths of emergent fry in LB (ANOVA, $P < 0.02$, Table 3.3).

TABLE 3.3.-Condition indices and morphometric measurements of emergent fry from retrievals five and six combined from Laurel Branch and White Rock Branch. Table entries are mean and standard deviation (SD). No significant differences were found for any measure except for wet length in Laurel Branch (ANOVA, $P < 0.05$). Lowercase letters denote significant differences (Fisher's LSD, $P < 0.05$).

Index or Measure	Sed. (%)	Laurel Branch		White Rock Branch	
		Mean	SD	Mean	SD
Wet length (mm)	0	19.9 y	1.5	21.1	2.4
	10	19.2 y	1.6	20.4	1.9
	20	20.0 z	1.0	21.7	0.57
Wet weight (mg)	0	72.4	11.6	72.5	13.9
	10	64.9	16.6	67.3	12.6
	20	71.1	12.4	72.3	13.9
K_{ww}	0	0.93	0.15	0.81	0.36
	10	0.95	0.36	0.80	0.14
	20	0.88	0.15	0.71	0.09
K_{dw}	0	1.54	0.67	1.62	0.53
	10	1.52	0.82	1.98	0.58
	20	1.83	0.58	1.88	0.44
KD	0	2.09	0.11	1.98	0.21
	10	2.09	0.22	1.99	0.11
	20	2.06	0.11	1.91	0.08

Discussion

Brook Trout Survival

Survival in this study was generally lower than that reported for similar field studies (Table 3.4). Many factors contributed to the mortality of brook trout eggs, alevins, and fry in this study, making a definitive relationship between survival and fine sediment difficult to discern. Steps were taken to minimize handling stress: transporting eggs in a water filled cooler lined with cheese cloth, holding eggs at a constant temperature, promptly loading eggs into W-V boxes, and using sterile plastic spoons to handle eggs. Despite these steps, an estimated 12% mortality may have occurred because of egg handling (retrieval 1, Chapter 2). Some eggs may have been broken at the hatchery (during egg stripping) (Carl 1941). Because eggs were planted in WRB within four hours of being stripped, some nonviable eggs that had not yet turned opaque may have been inadvertently used, further contributing to low survival (Table 3.2). Eggs in LB were charged five to eight hours after being stripped, by which time nonviable, opaque eggs were easier to identify and discard before being loaded into W-V boxes.

Survival from planting (green) to emergence (retrieval 5) in this study averaged less than 6%, which is similar to other salmonid field studies (Tables 2.5 and 3.4). Survival

TABLE 3.4.-Salmonid survival from studies conducted in natural systems. Table entries for fine sediment percent (%) and survival (%) are means. In **this study** eyed, hatched, and emergent stages were at retrievals 2, 4, and 5, respectively.

Species	Sediment size (mm)	Approximate fine sediment percent	Starting stage of development	Ending stage of development	Survival (%)	Ref.
Brook trout	<2	20	Eyed	Hatch	87	West et al. (1982)
		40			40	
	<1	15		Emergence	11	
		23			0.4	
Brook trout	<2	31	Hatch	Emergence	70	Hausle (1973)
Brook trout	<0.85	0	Eyed	Hatch	60 ¹	This study
					38 ²	
					47 ¹	
					15 ²	
					100 ¹	
					17 ²	
					11 ¹	
					7 ²	
					31 ¹	
					16 ²	
		10			19 ¹	
					3 ²	
		20		Emergence		

continued.

TABLE 3.4.-Continued.

Species	Sediment size (mm)	Approximate fine sediment percent	Starting stage of development	Ending stage stage of development	Survival (%)	Ref.
Brook trout	<0.85	0	Green	Hatch	11 ¹	This study
					7 ²	
					9 ¹	
					4 ²	
		20			25 ¹	"
					4 ²	
		0	Green	Emergence	2 ¹	"
					2 ²	
					6 ¹	
					5 ²	
Coho salmon	<0.85	<20	Green	Emergence	4 ¹	"
					1 ²	
	<0.85	>20	Green	Emergence	0.9-75	Tagart (1976)
					11-30	

¹Laurel Branch, ²White Rock Branch

from eye-up (Retrieval 2) to hatching (Retrieval 4) and eye-up to emergence (Retrieval 5) also compared favorably in both LB and WRB to previous studies of brook trout (Table 3.4). Phillips (1971) notes that only 10 to 30% of the total number of eggs deposited by spawning trout and salmon survive to emerge.

Survival declined nearly 75% from the green stage, a very sensitive developmental stage, to the eyed stage of development (Retrieval 3, Table 3.2), a time during which intragravel dissolved oxygen levels were lower than during the green stage, even in W-V boxes with no fine sediments (Fig. 3.3). The stage of embryonic development that precedes the eyed stage, when the circulatory system develops, is the most critical for salmonid survival because embryos depend on diffusion through the surface of the egg for their oxygen needs (Wickett 1954). At this stage, oxygen diffuses within the embryo itself and is used at the same rate throughout the respiring egg (Silver et al. 1963). Oxygen availability is dependent on the oxygen tension around the egg (Hayes et al. 1951). Once eyed, the egg also gains a functioning circulatory system in which oxygen transport occurs more efficiently below the chorion (Silver et al. 1963). However, as development continues the overall oxygen requirement of the developing eyed egg increases, and if an adequate oxygen tension is not maintained, mortality

may result (Hayes et al. 1951; Alderdice et al. 1958). In this study, development progressed from the eyed stage (Retrieval 2) to hatch (Retrieval 4) concurrent with a decline in intragravel dissolved oxygen levels (Fig. 3.3, weeks 4-10). These low dissolved oxygen levels (Fig. 3.3), while not below 50% saturation, a level considered lethal to salmonid embryo survival (Harshbarger 1975), may have contributed to the mortality of pre-hatched embryos in need of increasing oxygen amounts.

Because survival was not significantly correlated with dissolved oxygen, permeability, or fine sediment it was difficult to determine the primary cause of mortality. While these three measurable stream characteristics have been correlated with salmonid survival in other studies (Koski 1966; Tagart 1976; Cederholm et al. 1981a; West et al. 1982; Chapter 2), their direct influence was not statistically detected in this study. In general, survival declined at each retrieval (Table 3.2, Fig. 3.6) because of the multitude of factors influencing the development of fry, including natural mortality, predation, and disease. Additionally, the total number (viable and nonviable) of eggs, alevins, and fry declined (Appendix L) because of disintegration, escapement, and mechanical dislodgement. However, the relative contribution of each source of mortality and loss could not be quantified in this study.

Misshapen W-V box liners facilitated the intrusion of predators that were found in the gravel and egg matrix at the time of retrieval (Retrievals 2-6). Predation by salamanders, carnivorous stoneflies, and odonates could have significantly reduced survival as well as reduced the total number of viable and nonviable eggs, alevins, and fry. While coarse bed materials hold more eggs and facilitate intragravel flow they also allow predators better access to eggs and alevins (McNeil 1966, 1969; Phillips 1971). Misshapen W-V box liners also permitted alevins to escape (Chapter 2); however, no estimate of the total number that did escape could be made.

Eggs, alevins, and fry unaccounted for at later retrievals may have decomposed. In this study, egg fragments were found in W-V boxes at retrieval three (day 36) and the remains of eggs and alevins were found at every retrieval thereafter. Reported decay rates of nonviable salmonid eggs vary widely. In one study, 98% of nonviable brook trout eggs incubated in W-V boxes were recognizable after 53 days; however, after 133 days, only egg fragments remained (Hausle 1973). Little or no decay occurred in Atlantic salmon eggs after 100 days of incubation (Mackenzie and Moring 1988). In Mill Creek, California, only 50% of planted chinook salmon eggs were recovered after 45-58 days (Gangmark and Broad 1955).

The presence of fine sediments within a redd creates conditions conducive to the entry and persistence of disease-related organisms (Iwamoto et al. 1978). Nonviable eggs, alevins, and emergent fry collected during this study were infested with Saprolegnia spp. even at the first retrieval (day 14) in W-V boxes at all initial fine sediment loadings. The distribution of eggs in each W-V box may have increased the transmission of this fungus. Large amounts of this fungus were observed in W-V boxes containing 500 eyed brown trout eggs in South Mills River, North Carolina (Harshbarger and Porter 1979, 1982). Mycelia were observed four weeks after planting, and by 15 weeks, eggs and dead fry were consolidated into a mass of fungi (Harshbarger and Porter 1982). Eggs confined in W-V boxes are more susceptible to fungal agents than eggs in intragravel plants, where egg distributions are more similar to that of natural redds (Harshbarger and Porter 1982). Contrary to Harshbarger and Porter (1979, 1982), Saprolegnia spp. was observed in excavated natural redds in LB and WRB (personal observation); but, because eggs are more dispersed in natural redds than they are in W-V boxes, consolidated masses of eggs were not observed (personal observation).

Fine particles trapped by the clustering fungus created a matrix of eggs, Saprolegnia spp., and sediment (personal observation). The flow of intragravel water may have been

altered by the presence of this fungal matrix, further reducing the actual rate of dissolved oxygen delivery. Because measurements of intragravel dissolved oxygen were taken in W-V boxes devoid of this clustered fungus, dissolved oxygen levels in egg boxes may have been lower than those reported. Furthermore, Saprolegnia spp. consumed oxygen that may otherwise have been available to the developing eggs. Fungal infestations like these may also increase the susceptibility of viable eggs or alevins to die and disintegrate; however, this contention has not been directly tested.

The grinding of stream gravels and the turbulent nature of winter flows between retrievals three and four and the following weeks (Fig. 3.4) could have jostled eggs and alevins against fine sediments and gravel, abrading the chorionic membrane of eggs and the yolk of newly hatched alevins. Fine sediments can adhere or abrade the chorion of salmon ova incubating in stream bed gravels (Phillips 1971). Mortality from this physical process may be common from one year to the next, but the magnitude of such losses is dependent of the strength and the frequency of high winter flows. Data collected at a gauging station on the New River (Glen Lyn), downstream (approximately 16 Km downstream) from these two sites, indicated that winter precipitation (October-February) from 1993 to 1994, was generally similar

to that reported over a 40 year period occurring at similar times from year to year (U.S. Weather Bureau 1954-1994). In spite of the turbulent intragravel environment and winter storms, some young-of-the-year fish were able to survive the first few months in these headwater streams; in a July 1994 sample, a 100 m reach (between my artificial redd sites 47 and 55) in LB yielded 24 young-of-the-year brook trout (J. Williams, personal communication, Virginia Department of Game and Inland Fisheries, Blacksburg, VA).

Quality of Emergents

Even though few fry survived to emergence and no significant differences were found in developmental indices among fine sediment levels in this study, the condition of fry at emergence can be used as an indicator of the influence that the intragravel environment had on development. Those fry that survived to emerge were generally in good condition, exhibiting no signs of physical damage or physical anomalies at the time of retrieval. Fry in LB had KD indices greater than 2.0, indicating that high proportions of yolk remained in relation to length and weight, while fry in WRB had KD indices less than 1.96, indicating that yolk material had been absorbed (Bams 1970). Differences in KD indices between the two streams suggest that eggs in LB may have developed more slowly than eggs in WRB because temperatures in LB were generally lower;

temperature has been cited as the primary factor affecting the rate of development (Kinne and Kinne 1962; Garside 1966).

Management Implications and Conclusions

From these results, we cannot predict what amounts of fine sediment are most detrimental to the intragravel survival of brook trout. Physical and biological factors like gravel stability, high water velocities, storms, insect predators, and disease may contribute to mortality even in the absence of intragravel fine sediment. In this study, these factors contributed to high mortality, perhaps in an additive way (Phillips 1971), even in the absence of fine sediments. If excessive levels of fine sediment exist in these systems, then survival surely will decline (Chapter 2), but in this study no minimum threshold was detected. Even though this study did not provide evidence that fine sediments increased brook trout mortality, a prudent manager would avoid activities that add fine sediments to brook trout streams, especially during the intragravel period. Moreover, because mortality was high even in W-V boxes without fine sediments, stream disturbance of any kind should be minimized during the intragravel period.

If this study were repeated, a measure of the timing and movement of fine sediments into and out of the intragravel environment, with specific attention to timing

of embryonic development, would be useful. Moreover, gravels used to cover W-V boxes should be more stable and artificial redds should be located to prevent surface scour, especially when water velocities increase. The rate of egg mortality and decay may be directly related to the presence of Saprolegnia spp.; the relative contribution of each source of mortality and loss should be quantified to help determine what limits brook trout survival during the intragravel period.

Chapter 4 - Evaluation of the Two Studies

Although the experimental designs of the laboratory (Chapter 2) and the field (Chapter 3) studies were nearly identical, very different results were obtained in assessing the survival of brook trout eggs, alevins, and fry during the intragravel period. In the laboratory study fine sediment influenced survival significantly at some developmental stages (Table 2.2), while in the field study fine sediment had no apparent effect (Table 3.2). This chapter summarizes the results of both the laboratory and the field study, compares the studies, and provides suggestions for future research.

The laboratory study facilitated the incubation of eggs under relatively stable, controlled conditions in which eggs were protected from flushing flows, predators, and inputs of additional fine sediment. Moreover, disease related organisms (e.g., fungus) were chemically treated and freezing temperatures prevented. This study demonstrated that brook trout survival can be negatively affected by the presence of relatively low levels of fine sediment (10%) when intragravel and surface stream characteristics (e.g., current velocity, disease control, no predators, dissolved oxygen) are well suited for incubation (Table 2.2). Moreover, in the absence of fine sediment (i.e., 0% fine

sediment) brook trout mortality can be as high as 60% from egg planting to fry emergence (Table 2.2). Through time, declines in survival of incubating brook trout occur more rapidly when fine sediments are present than when they are not (Fig. 2.3), perhaps because of the reduction in gravel permeability and intragravel dissolved oxygen with increasing fine sediment amounts (Fig. 2.2).

The field study failed to demonstrate that the survival of brook trout during the intragravel period was significantly related to fine sediment (Table 3.2) in these two Virginia Appalachian streams. These streams experienced fluctuations in temperature (Appendix Fig. G1), intragravel permeability (Fig. 3.2), intragravel dissolved oxygen (Fig. 3.3), depth (Fig. 3.4), and current velocity (Fig. 3.5) during the incubation period. Additionally, storm events recorded during weeks six and seven altered the composition of fine sediments in W-V boxes (Fig. 3.6) shifted gravels and scoured out artificial redd sites. These factors coupled with fungal infestations like Saprolegnia spp. and the intrusion of predators may have all contributed to low survival during all stages of embryonic development. The timing of these events may contribute to reductions in survival at specific developmental stages. In fact, survival declined the most between the green and the eyed

stages of development and between the hatched and the emerged stages of development (Table 3.2).

Although the field study did not demonstrate a direct link between fine sediments and survival, it did demonstrate that under field conditions survival at all sediment levels (including 0%) is reduced to 10% or less. Mortality due directly to fine sediment in the field study was probably masked by the other sources of mortality outlined in Chapter 3. When fine sediment was isolated as a source of mortality, in the laboratory study (Chapter 2), survival was significantly reduced even in the presence of low levels of fine sediment.

These two studies and those of past salmonid investigations (Tables 2.5 and 3.4) indicate that the intragravel period is a sensitive time for salmonid development and survival. As a result, conservative management strategies (e.g., fisheries and land use) should be used to ensure future reproductive salmonid success. Minimizing stream impacts that introduce fine sediments is recommended during the entire intragravel period (mid-October to mid-March for brook trout in Virginia) because such disturbances have the potential to negatively impact brook trout survival. Streamside management zones (riparian area) that filter sediments, provide bank stability, and insulate the stream from temperature extremes should

continue to be used on all permanent brook trout streams where the potential exists for sediment additions.

Even though fine sediments are not the sole cause for intragravel mortality in natural systems, fine sediments reduce intragravel water flow (Chapter 2), reduce dissolved oxygen delivery (Chapter 2), and create conditions conducive to the spread of disease related organisms (Iwamoto et al. 1987). Both laboratory and field studies should be used in future investigations concerning the effects of fine sediments on salmonid survival. In the laboratory, fewer fine sediment treatments and more replicates should be used to determine if a threshold level of fine sediment, at which survival is significantly reduced, can be established (e.g., 5-10% fine sediment, Chapter 2). Moreover, controlled studies of the effects of Saprolegnia spp. on salmonid eggs and alevins should be performed to determine if certain individuals have an immunity to this fungus, if the fungus spreads among eggs that are more densely distributed or more dense in number, and if certain developmental stages are more sensitive to the fungus than others. Future field investigations should focus on the stability and the quality of the gravel matrix, the role that sediment transport has on specific developmental stages, the void space necessary to flush away fungal agents and retard the intrusion of intragravel predators, and the ability of developing embryos

to resist disease. By examining the effects of fine sediment in this manner, we may be able to understand and to quantify the many factors that cause mortality in the presence of fine sediments within a salmonid redd.

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Appendices

APPENDIX A.-Whitlock-Vibert (W-V) boxes loaded with coarse gravel (6.33-12.49 mm in diameter) and one of six fine sediment (0.43-0.84 mm in diameter) treatments (0%, 5%, 10%, 15%, 20%, 25%) were randomly placed in incubation chambers. Fine sediment treatments were made to replicate the following target mixtures:

Sediment (%)	Coarse gravel (g)	Fine sediment (g)
0	550.0	0.0
5	522.5	27.5
10	495.0	55.0
15	467.5	82.5
20	440.0	110.0
25	412.5	137.5

Gravel and fine sediment obtained from each W-V box were dried at 60°C until all water was removed. Samples were sieved using standard sieves (0.18 mm, 0.43 mm, 0.85 mm, 6.33 mm) to determine how much sediment was lost or gained.

Differences between starting and ending gravel mixtures are presented in the following tables for W-V boxes retrieved immediately (5 boxes per treatment, without eggs) (Retrieval 0) and for W-V boxes used in the laboratory study (20 boxes per treatment) to incubate eggs (Retrievals 1-6).

Starting and ending fine sediment levels in each W-V box were compared for each retrieval (0-6). All W-V boxes lost significant amounts of fine sediment (except 0%) (Paired T-test, $p < 0.001$), and these losses were not significantly different through time (ANOVA, $P > 0.10$). Moreover, retrieval time did not influence the amount of fine sediment recovered. These data indicate that fine sediment losses were due to handling, not water flow during incubation.

TABLE A1.--Weights of actual gravel and fine sediment (<0.84 mm in diameter) in W-V boxes retrieved immediately (without eggs, retrieval 0) and in W-V used to incubate eggs at the 0% sediment treatment (retrievals 1-6). Table entries are mean (SD). Negative differences indicate a loss in weight from start to finish.

Retrieval	Coarse gravel (g)		Difference (g)	Fine sediment (g)		Difference (g)
	Start	Finish		Start	Finish	
0	550.5 (0.33)	550.4 (0.30)	-0.1 (0.07)	0	0	0
1	550.2 (0.05)	549.1 (1.3)	-1.1 (1.3)	0	0	0
2	549.9 (0.51)	550.9 (0.91)	1.0 (1.4)	0	0	0
3	549.8 (0.61)	549.5 (1.9)	-0.37 (1.5)	0	0	0
4	550.0 (0.72)	549.7 (1.2)	-0.37 (1.1)	0	0	0
5	549.8 (0.57)	549.3 (0.58)	-0.43 (0.15)	0	0	0
6	550.3 (0.41)	550.0 (0.41)	-0.24 (0.15)	0	0	0

TABLE A2.-Weights of actual gravel and fine sediment (<0.84 mm in diameter) in W-V boxes retrieved immediately (without eggs, retrieval 0) and in W-V used to incubate eggs at the 5% sediment treatment (retrievals 1-6). Table entries are mean (SD). Negative differences indicate a loss in weight from start to finish.

Retrieval	Coarse gravel (g)		Difference (g)	Fine sediment (g)		Difference (g)
	Start	Finish		Start	Finish	
0	522.3 (0.25)	522.2 (0.36)	-0.06 (0.15)	27.5	20.8 (1.5)	-6.7 (1.5)
1	522.6 (0.42)	522.7 (0.96)	0.13 (1.0)	27.5	20.6 (2.7)	-6.9 (2.7)
2	522.5 (0.29)	522.0 (1.8)	-0.50 (1.7)	27.5	21.0 (1.1)	-6.5 (1.1)
3	522.1 (0.61)	521.6 (0.65)	-0.50 (1.1)	27.5	19.0 (0.8)	-8.5 (0.8)
4	522.9 (0.75)	522.6 (0.55)	-0.27 (0.38)	27.5	19.3 (1.5)	-8.2 (1.5)
5	523.0 (0.21)	522.8 (0.38)	-0.20 (0.17)	27.5	19.0 (4.3)	-8.5 (4.3)
6	522.4 (0.49)	523.4 (3.5)	1.2 (3.1)	27.5	20.1 (2.3)	-7.4 (2.3)

TABLE A3.-Weights of actual gravel and fine sediment (<0.84 mm in diameter) in W-V boxes retrieved immediately (without eggs, retrieval 0) and in W-V used to incubate eggs at the 10% sediment treatment (retrievals 1-6). Table entries are mean (SD). Negative differences indicate a loss in weight from start to finish.

Retrieval	Coarse gravel (g)		Difference (g)	Fine sediment (g)		Difference (g)
	Start	Finish		Start	Finish	
0	495.4 (0.32)	495.4 (0.32)	0.02 (0.16)	55.0	48.5 (1.5)	-6.5 (1.5)
1	494.4 (0.57)	493.4 (1.5)	-1.0 (1.2)	55.0	48.4 (1.0)	-6.6 (1.0)
2	494.8 (0.38)	493.5 (1.2)	-1.3 (1.3)	55.0	47.5 (1.5)	-7.4 (1.5)
3	494.9 (0.35)	495.1 (0.98)	0.20 (0.66)	55.0	48.3 (2.8)	-6.7 (2.8)
4	495.1 (0.84)	494.9 (0.93)	-0.20 (0.17)	55.0	46.2 (7.6)	-8.8 (7.6)
5	494.9 (0.25)	494.8 (0.20)	-0.13 (0.21)	55.0	47.8 (2.8)	-7.2 (2.8)
6	495.4 (0.97)	495.2 (0.91)	-0.18 (0.16)	55.0	50.1 (0.97)	-4.9 (0.97)

TABLE A4.--Weights of actual gravel and fine sediment (<0.84 mm in diameter) in W-V boxes retrieved immediately (without eggs, retrieval 0) and in W-V used to incubate eggs at the 15% sediment treatment (retrievals 1-6). Table entries are mean (SD). Negative differences indicate a loss in weight from start to finish.

Retrieval	Coarse gravel (g)		Difference (g)	Fine sediment (g)		Difference (g)
	Start	Finish		Start	Finish	
0	467.4 (0.71)	467.4 (0.59)	0.02 (0.24)	82.5	73.5 (2.6)	-9.0 (2.6)
1	467.3 (0.91)	466.9 (0.29)	-0.57 (0.99)	82.5	73.3 (3.9)	-9.2 (3.9)
2	467.2 (0.75)	466.9 (0.79)	-0.30 (0.46)	82.5	73.8 (1.0)	-8.7 (1.0)
3	467.2 (0.25)	466.6 (1.4)	0.20 (0.66)	82.5	71.9 (2.3)	-10.6 (2.3)
4	467.7 (1.1)	467.8 (0.92)	0.07 (0.25)	82.5	73.8 (2.9)	-8.7 (2.9)
5	467.4 (0.65)	467.0 (0.92)	-0.37 (0.28)	82.5	74.6 (0.40)	-7.9 (0.40)
6	467.6 (0.31)	467.4 (0.23)	-0.22 (0.13)	82.5	73.8 (2.9)	-8.7 (2.9)

TABLE A5.-Weights of actual gravel and fine sediment (<0.84 mm in diameter) in W-V boxes retrieved immediately (without eggs, retrieval 0) and in W-V used to incubate eggs at the 20% sediment treatment (retrievals 1-6). Table entries are mean (SD). Negative differences indicate a loss in weight from start to finish.

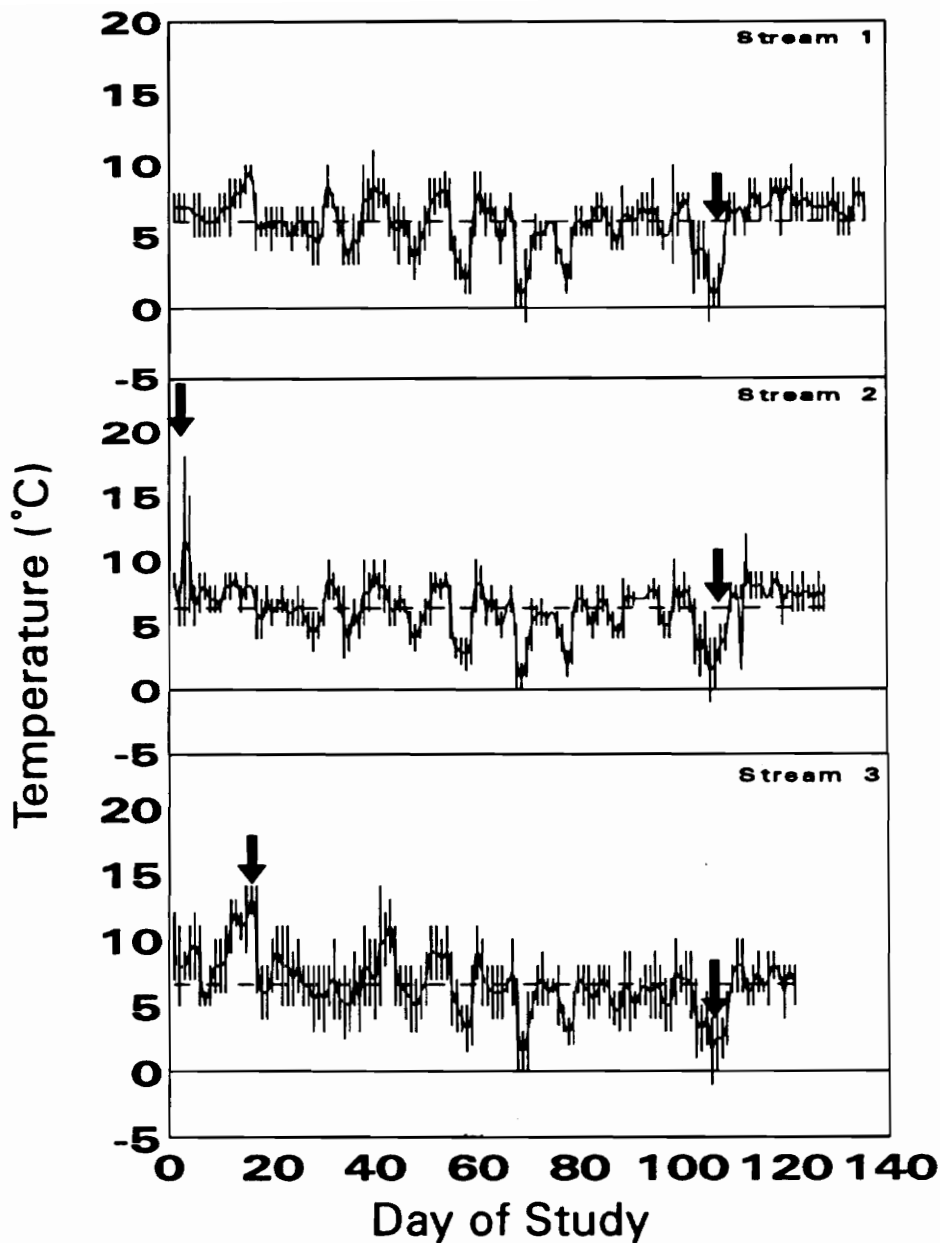
Retrieval	Coarse gravel (g)		Difference (g)	Fine sediment (g)		Difference (g)
	Start	Finish		Start	Finish	
0	440.2 (0.34)	440.1 (0.37)	-0.12 (0.44)	110.0	99.0 (1.9)	-10.9 (1.9)
1	439.8 (0.92)	439.6 (2.6)	-0.17 (1.7)	110.0	101.5 (1.1)	-8.5 (1.1)
2	439.9 (0.25)	437.9 (2.4)	-1.97 (2.2)	110.0	96.5 (2.5)	-13.5 (2.5)
3	440.5 (1.0)	440.9 (0.76)	0.47 0.50	110.0	99.1 (3.4)	-10.9 (3.4)
4	440.5 (0.36)	440.7 (0.61)	0.17 (0.25)	110.0	102.8 (5.9)	-7.2 (5.9)
5	440.3 (0.46)	440.2 (0.55)	-0.10 (0.36)	110.0	101.5 (1.7)	-8.5 (1.7)
6	440.5 (0.79)	440.2 (0.84)	-0.28 (0.16)	110.0	99.4 (4.0)	-9.9 (4.0)

TABLE A6. -Weights of actual gravel and fine sediment (<0.84 mm in diameter) in W-V boxes retrieved immediately (without eggs, retrieval 0) and in W-V used to incubate eggs at the 25% sediment treatment (retrievals 1-6). Table entries are mean (SD). Negative differences indicate a loss in weight from start to finish.

Retrieval	Coarse gravel (g)		Difference (g)		Fine sediment (g)		Difference (g)	
	Start	Finish			Start	Finish		
0	412.6 (0.24)	412.5 (0.19)	-0.10 (0.16)		137.5	125.2 (2.6)	-12.3 (2.6)	
1	412.6 (0.26)	412.5 (0.40)	-0.13 (0.15)		137.5	124.9 (0.55)	-12.6 (0.55)	
2	412.8 (0.31)	412.0 (1.2)	-0.83 (0.95)		137.5	126.6 (4.3)	-10.9 (4.3)	
3	412.8 (0.21)	413.0 (0.12)	0.20 (0.30)		137.5	128.0 (4.4)	-9.5 (4.4)	
4	412.2 (0.21)	412.1 (0.32)	-0.17 (0.15)		137.5	130.1 (2.6)	-7.4 (2.6)	
5	412.3 (0.26)	412.2 (0.15)	-0.07 (0.15)		137.5	127.5 (4.0)	-9.9 (4.0)	
6	412.3 (0.23)	412.2 (0.32)	-0.12 (0.19)		137.5	128.8 (1.1)	-8.6 (1.1)	

APPENDIX B.-Hydrogren ion concentration recorded once per week in each laboratory stream.

Week	Day	Stream 1	Stream 2	Stream 3
1	7	8.2	8.2	8.2
2	14	8.3	8.3	8.2
3	21	8.4	8.5	8.4
4	28	8.3	8.3	8.3
5	35	8.5	8.5	8.5
6	42	8.5	8.6	8.6
7	49	8.4	8.5	8.5
8	56	8.6	8.7	8.7
9	63	8.6	8.5	8.5
10	70	8.3	8.4	8.3
11	77	8.3	8.3	8.3
12	84	8.5	8.4	8.5
13	91	8.4	8.4	8.5
14	98	8.4	8.4	8.4
15	105	8.6	8.5	8.6
16	112	8.6	8.6	8.6
17	119	8.5	8.5	8.5
18	126	8.7	8.7	
19	133	8.3		



APPENDIX C.-Daily temperature in laboratory streams. Vertical bars denote daily temperature range. Solid line denotes daily midpoint temperature. Dashed line denotes mean stream temperature. Arrows indicate maximum temperatures in first 20 days caused by chiller unit failure (stream 2) and warm weather (stream 3) and an ice storm at day 105.

APPENDIX D.-Daily surface water dissolved oxygen levels recorded daily in each laboratory stream. Table entries are raw data. Minimum and maximum in bold face (Stream 1 in February).

Month	Stream number		
	1	2	3
Oct.	11.3	10.9	10.7
	12.2	13.3	12.1
	11.6	9.1	12.4
	12.3	12.5	12.4
	10.2	12.3	11.4
	11.5	11.4	12.9
	12.7	11.8	13.5
	11.1	11.4	11.4
	12.2	12.1	11.8
	11.1	11.1	12.2
	11.7	11.4	11.3
	11.4	11.2	10.9
	11.0	11.3	10.4
	11.4	11.1	10.8
	12.4	12.8	11.8
	10.4	11.4	10.4
	12.5	13.7	12.4
	13.1	13.2	13.4
	12.8	13.0	13.0
	13.8	14.3	14.7
	13.4	14.2	14.3
	12.1	11.2	10.2
	11.2	11.1	11.2
	14.1	13.1	12.5
	12.1	11.9	11.7
	12.1	12.1	12.2
Nov.	12.5	12.4	12.0
	12.6	12.9	13.1
	11.1	10.9	11.0
	10.0	10.0	11.9
	10.0	10.2	12.3
	11.4	11.5	13.0
	12.6	12.5	13.7
	13.6	13.5	13.5
	12.0	12.0	12.2
	12.5	12.8	12.9

continued.

Appendix D.-Continued.

Month	Stream number		
	1	2	3
Dec.	11.2	10.8	10.8
	9.0	10.0	10.6
	9.5	10.4	11.0
	9.8	9.8	11.5
	10.0	10.2	9.8
	9.8	10.6	10.6
	10.4	11.3	9.3
	14.5	14.1	14.3
	11.0	11.9	13.2
	12.1	12.2	12.8
	13.5	13.4	12.8
	13.5	13.4	13.1
	13.2	13.0	13.1
	12.6	12.3	10.9
	11.4	11.1	11.3
	11.0	11.3	11.0
	10.8	11.0	10.7
	10.9	11.1	11.3
	12.6	12.9	12.7
	13.8	13.8	14.1
	12.5	12.8	12.1
	12.8	13.4	13.4
	11.9	11.9	10.5
	9.9	9.9	10.3
	9.6	9.5	10.8
	12.2	12.2	12.4
	10.3	10.3	11.7
	11.2	11.3	12.0
	11.2	10.8	10.9
	11.4	11.9	11.8
	11.3	11.7	12.2
	14.3	14.0	14.6
	12.5	12.0	13.4
	9.1	9.2	8.8
	9.1	9.1	8.7
	12.2	12.0	12.2
	12.4	12.1	12.0
	12.0	11.8	12.0
	8.2	8.4	8.4

continued.

Appendix D.-Continued.

Month	Stream number		
	1	2	3
Jan.	9.3	9.3	9.3
	8.7	8.9	8.5
	9.1	9.5	9.5
	8.6	8.4	8.4
	8.0	7.6	8.3
	8.1	8.5	8.5
	8.7	8.5	8.7
	8.2	8.4	8.8
	8.0	8.2	8.2
	7.8	8.0	8.3
	12.1	12.2	12.9
	12.7	13.0	13.3
	12.8	12.8	13.1
	11.8	12.3	12.3
	11.1	10.3	12.9
	11.3	11.2	11.5
	11.1	11.0	12.1
	12.1	12.2	12.1
	11.8	12.1	12.8
	10.8	11.1	10.9
	11.9	12.4	12.2
	14.1	13.5	13.8
	13.2	12.8	13.1
	10.5	11.3	11.4
	10.8	11.7	11.4
	12.1	12.1	12.0
	10.6	12.1	12.0
	11.7	12.4	12.3
	13.6	14.0	13.9
	12.1	12.2	12.9
	14.3	14.0	14.1
	14.7	15.1	15.4
	13.7	14.2	15.0
	14.1	14.2	13.8
	12.4	11.8	12.5
	12.6	12.6	12.8
	13.2	11.8	13.2
	12.6	10.6	12.4
	13.8	13.2	13.1

continued.

Appendix D.-Continued.

Month	Stream number		
	1	2	3
Feb.	10.7	11.0	11.2
	10.9	11.3	11.6
	11.1	10.9	11.7
	11.2	10.9	10.6
	10.3	10.2	10.5
	12.2	12.3	12.0
	10.9	11.2	11.3
	12.5	13.4	12.6
	13.1	12.7	
	11.3	11.7	
	15.2	15.1	
	11.2	11.3	
	14.4	12.2	
	12.4	12.5	
	7.4		
	12.1		
	12.3		
	13.8		
	12.1		
	10.1		
	11.0		
	12.1		

APPENDIX E.-Total counts of live and dead eggs, alevins, and emergent fry from laboratory streams at each retrieval. Table entries are raw data and percent survival based on the ratio of live recovered:total live and dead recovered. Box-Sed denotes the random number assigned to each W-V box and the starting fine sediment (0.43 - 0.84 mm in diameter) amount.

Retrieval (number)	Stream (number)	Box-Sed (number-%)	Alive (number)	Dead (number)	N	Survival (%)
1	1	4-0	175	27	202	86.6
		5-5	174	37	211	82.5
		2-10	169	39	208	81.3
		1-15	153	36	189	81.0
		2-20	148	46	194	76.3
		6-25	149	48	197	75.6
	2	12-0	173	33	206	84.0
		14-5	186	22	208	89.4
		8-10	146	50	196	74.5
		10-15	150	43	193	77.7
		8-20	140	66	206	68.0
		8-25	134	66	200	67.0
	3	16-0	161	31	192	83.9
		15-5	176	35	211	83.4
		18-10	157	42	199	78.9
		16-15	159	47	206	77.2
		15-20	142	52	194	73.2
		15-25	154	51	205	75.1
2	1	7-0	174	35	209	83.3
		7-5	178	33	211	84.4
		4-10	151	59	210	71.9
		4-15	158	50	208	76.0
		4-20	143	49	192	74.5
		2-25	148	57	205	72.2
	2	10-0	160	39	199	80.4
		10-5	167	41	208	80.3
		10-10	156	52	208	75.0
		8-15	162	44	206	78.6
		11-20	144	71	215	67.0
		12-25	150	56	206	72.8
	3	18-0	152	46	198	76.8
		16-5	146	50	196	74.5
		19-10	163	48	211	77.3

continued.

APPENDIX E.-Continued.

Retrieval (number)	Stream (number)	Box-Sed (number-%)	Alive (number)	Dead (number)	N	Survival (%)
2	3	18-15	141	58	199	70.9
		17-20	126	66	192	65.6
		17-25	155	58	213	72.8
3	1	6-0	165	41	206	80.1
		6-5	147	57	204	72.1
		3-10	143	64	207	69.1
		2-15	148	58	206	71.8
		6-20	149	55	204	73.0
		4-25	150	55	205	73.2
		13-0	164	50	214	76.6
		12-5	143	58	201	71.1
	2	11-10	145	60	205	70.7
		11-15	162	50	212	76.4
		7-20	141	67	208	67.8
		11-25	139	68	207	67.1
		15-0	151	54	205	73.7
		18-5	151	46	197	76.6
		14-10	158	52	210	75.2
		17-15	158	50	208	76.0
	3	14-20	144	74	218	66.1
		19-25	127	87	214	59.3
4	1	5-0	127	79	206	61.7
		3-5	108	103	211	51.2
		1-10	100	108	208	48.1
		7-15	89	109	198	44.9
		1-20	92	125	217	42.4
		7-25	58	86	144	40.3
	2	8-0	109	79	188	58.0
		11-5	86	109	195	44.1
		9-10	85	114	199	42.7
		12-15	73	126	199	36.7
		13-20	80	115	195	41.0
		9-25	79	104	183	43.2
	3	20-0	89	103	192	46.4
		20-5	96	93	189	50.8
		17-10	85	107	192	44.3
		20-15	75	117	192	39.1
		19-20	71	109	180	39.4
		20-25	63	101	164	38.4
5	1	1-0	131	71	202	64.9

continued.

APPENDIX E.-Continued.

Retrieval (number)	Stream (number)	Box-Sed (number-%)	Alive (number)	Dead (number)	N	Survival (%)
5	1	4-5	106	95	201	52.7
		5-10	75	77	152	49.3
		3-15	92	108	200	46.0
		5-20	69	89	158	43.7
		1-25	42	88	130	32.3
	2	9-0	62	126	188	33.0
		8-5	78	98	176	44.3
		12-10	27	105	132	20.5
		9-15	83	131	214	38.8
		10-20	72	105	177	40.7
		14-25	7	133	140	5.0
		19-0	99	72	171	57.9
	3	19-5	104	107	211	49.2
		16-10	96	79	175	54.9
		14-15	88	119	207	42.5
		10-20	66	78	144	45.8
		14-25	62	94	156	39.7
6	1	2-0	94	84	178	52.8
		3-0	100	98	198	50.5
		1-5	123	80	203	60.6
		2-5	87	121	208	41.8
		6-10	114	96	210	54.3
		5-15	86	109	195	44.1
		6-15	81	127	208	38.9
		3-20	81	120	201	40.3
		3-25	47	131	178	26.4
		5-25	62	141	203	30.5
	2	11-0	88	96	184	47.8
		9-5	49	134	183	26.8
		13-5	61	131	192	31.8
		7-10	30	138	168	17.9
		13-10	63	130	193	32.6
		13-15	33	129	162	20.4
		9-20	35	73	108	32.4
		12-20	56	106	162	34.6
		10-25	29	114	143	20.3
		13-25	32	141	173	18.5
	3	14-0	94	93	187	50.3
		17-0	47	136	183	25.7
		17-5	90	101	191	47.1

continued.

APPENDIX E.-Continued.

Retrieval (number)	Stream (number)	Box-Sed (number-%)	Alive (number)	Dead (number)	N	Survival (%)
6	3	15-10	78	105	183	42.6
		20-10	60	138	198	30.3
		15-15	101	108	209	48.3
		19-15	54	122	176	30.7
		16-20	59	134	193	30.6
		20-20	58	138	196	29.6
		16-25	49	141	190	25.8

APPENDIX F.-Emergent fry were recovered at approximately 750 degree-days and 810 degree-days, which corresponded to a range of 114-136 days to emergence. A total of 2,049 fry were weighed (wet) to the nearest 0.1 mg and measured (wet) to the nearest 0.5 mm. Fry were then dried at 100°C for 24 h, weighed, and measured. Individual and mean condition factors were calculated from wet and dry weights, and wet and dry lengths to allow comparison among emergent fry. The wet weight condition factor (K_{ww}) (Reiser and White 1988) is:

$$K_{ww} = \frac{\text{wet weight (mg)} \times 100}{[\text{wet fork length (mm)}]^3}$$

The dry weight condition factor (K_{dw}) (Reiser and White 1988) is:

$$K_{dw} = \frac{\text{dry weight (mg)} \times 10^3}{[\text{dry fork length (mm)}]^3}$$

Bams' (1970) developmental index (KD) was computed to compare the developmental stage of emergent fry:

$$KD = \frac{10 \times [\text{wet weight (mg)}]^{1/3}}{\text{wet fork length (mm)}}$$

Results from morphometric measurements and calculated condition factors are presented in the following tables F1-F5.

TABLE F1.-Wet lengths (mm) of emergent fry retrieved from laboratory streams. Table entries are mean (SD). Results from ANOVAs indicated significant differences ($P<0.05$) among fine sediment treatments in all streams at all retrievals except retrieval 6 in stream 2. Lowercase letters indicate significant differences among column entries (Fisher's LSD, $P<0.05$).

Sediment (%)	Retrieval Number					
	Stream 1		Stream 2		Stream 3	
	5	6	5	6	5*	6
0	20.8 Y (1.5)	20.5 Y (0.64)	19.2 w (10.2)	20.4 (1.3)	16.9 yx (1.4)	20.1 w (7.8)
5	20.3 yx (1.2)	20.6 Y (0.94)	19.9 yxw (9.0)	20.7 (1.0)	17.2 Y (1.2)	20.2 w (10.2)
10	21.6 z (2.0)	20.4 Y (1.0)	19.4 xw (8.7)	20.7 (1.3)	19.7 z (1.4)	20.4 xw (12.5)
15	20.52 Y (1.1)	20.5 Y (0.89)	20.0 yx (10.4)	20.8 (2.3)	16.4 x (1.1)	21.6 z (7.6)
20	20.6 Y (0.67)	20.7 Y (1.0)	20.4 Y (9.1)	20.6 (1.2)	16.9 yx (1.3)	21.1 Y (12.8)
25	20.0 x (1.2)	21.2 z (1.2)	21.6 z (7.2)	20.9 (1.8)	19.3 z (1.6)	20.8 yx (11.3)

*Lengths are low because emergent fry were allowed to air-dry overnight.

TABLE F2.- Wet weights (mg) of emergent fry retrieved from laboratory streams. Table entries are mean (SD). Results from ANOVAs indicated significant differences (P<0.05) among fine sediment treatments in all streams at all retrievals. Lowercase letters indicate significant differences among column entries (Fisher's LSD, P<0.05).

Sediment (%)	Retrieval Number					
	5	6	5	6	5*	6
	Stream 1		Stream 2		Stream 3	
0	85.0 z (13.8)	77.2 x (11.4)	70.7 z (10.2)	67.7 wv (9.7)	26.7 v (8.3)	63.5 w (7.8)
5	81.9 z (13.0)	73.6 xw (12.0)	59.5 x (9.0)	66.5 v (12.1)	35.1 x (7.3)	67.3 xw (10.2)
10	72.8 y (12.2)	86.6 z (16.3)	60.4 x (8.7)	72.1 xw (10.0)	50.5 z (7.7)	92.3 z (12.5)
15	70.3 xy (11.8)	82.2 y (13.8)	62.0 x (10.4)	77.6 zy (11.1)	30.7 w (9.0)	68.7 x (7.6)
20	67.1 wx (10.1)	81.5 y (14.5)	64.8 yx (9.1)	75.3 yx (10.0)	28.1 wv (8.7)	76.1 y (12.8)
25	63.1 w (7.6)	69.5 w (10.7)	67.6 zy (7.2)	80.8 z (17.1)	46.6 y (8.6)	73.8 y (11.3)

*Weights are low because emergent fry were allowed to air-dry overnight.

TABLE F3.-Wet (K_{ww}) condition factors of emergent fry retrieved from laboratory streams. Table entries are mean (SD). Results from ANOVAs indicated significant differences ($P<0.05$) among fine sediment treatments in all streams at all retrievals except retrieval 6 in stream 2. Lowercase letters denote significant differences among column entries (Fisher's LSD, $P<0.05$).

Sediment (%)	Retrieval Number					
	Stream 1		Stream 2		Stream 3	
	5	6	5	6	5*	6
0	0.96 z (0.16)	0.89 xw (0.14)	1.0 z (0.28)	0.83 (0.24)	0.55 Y (0.16)	0.80 Y (0.15)
5	0.98 z (0.11)	0.85 w (0.16)	0.77 yx (0.12)	0.76 (0.15)	0.70 z (0.14)	0.83 Y (0.46)
10	0.73 w (0.13)	1.0 z (0.19)	0.86 Y (0.21)	0.81 (0.10)	0.66 z (0.11)	1.1 z (0.68)
15	0.83 Y (0.19)	0.96 Y (0.21)	0.78 Y (0.13)	1.0 (1.0)	0.71 z (0.24)	0.69 x (0.99)
20	0.76 xw (0.09)	0.93 yx (0.17)	0.77 yx (0.15)	0.87 (0.11)	0.57 Y (0.14)	0.82 Y (0.12)
25	0.80 yx (0.13)	0.74 v (0.16)	0.67 x (0.84)	0.90 (0.20)	0.65 z (0.13)	0.82 Y (0.12)

*Condition factors are low because emergent fry were allowed to air-dry overnight.

TABLE F4.-Dry (K_{pw}) condition factors of emergent fry retrieved from laboratory streams. Table entries are mean (SD). Results from ANOVAs indicated significant differences ($P<0.05$) among fine sediment treatments in all streams at all retrievals. Lowercase letters denote significant differences among column entries (Fisher's LSD, $P<0.05$).

Sediment (%)	Retrieval Number					
	Stream 1		Stream 2		Stream 3	
	5	6	5	6	5*	6
0	1.18 w (0.26)	1.33 y (0.31)	2.35 zy (0.67)	1.55 zy (0.41)	1.27 x (0.57)	2.03 z (0.54)
5	1.89 z (0.33)	1.29 yx (0.27)	2.12 y (0.58)	1.61 zy (0.35)	1.53 y (0.42)	1.78 y (0.48)
10	1.39 x (0.24)	1.28 yx (0.25)	2.04 y (0.71)	1.67 zy (0.41)	1.28 x (0.31)	1.53 xw (0.34)
15	1.67 y (0.38)	1.59 z (0.31)	2.07 y (0.70)	1.93 z (1.98)	2.04 z (0.78)	1.41 w (0.40)
20	1.65 y (0.26)	1.22 x (0.34)	2.48 z (0.62)	1.85 z (0.37)	1.14 x (0.32)	1.64 yx (0.29)
25	1.95 z (0.43)	1.51 z (0.45)	1.69 x (0.22)	1.39 y (0.45)	1.28 x (0.27)	1.41 w (0.26)

*Condition factors are low because emergent fry were allowed to air-dry overnight.

TABLE F5.- KD indices of emergent fry retrieved from laboratory streams. Table entries are mean (SD). Results from ANOVAs indicated significant differences (P<0.05) among fine sediment treatments in all streams at all retrievals. Lowercase letters denote significant differences among column entries (Fisher's LSD, P<0.05).

Sediment (%)	Retrieval Number					
	5	6	5	6	5*	6
	Stream 1		Stream 2		Stream 3	
0	2.12 z (0.12)	2.07 Y (0.11)	2.16 z (0.18)	2.00 zY (0.18)	1.75 Y (0.17)	1.99 Y (0.12)
5	2.13 z (0.08)	2.03 yX (0.12)	1.97 Y (0.09)	1.96 Y (0.12)	1.90 z (0.14)	2.01 Y (0.14)
10	1.93 x (0.11)	2.16 z (0.16)	2.03 Y (0.16)	2.00 zY (0.08)	1.87 z (0.10)	2.21 z (0.13)
15	2.00 Y (0.15)	2.11 Y (0.15)	1.98 Y (0.12)	2.08 z (0.39)	1.89 z (0.23)	1.89 x (0.09)
20	1.96 yX (0.09)	2.09 Y (0.13)	1.97 Y (0.13)	2.05 z (0.09)	1.78 Y (0.15)	2.00 Y (0.13)
25	1.99 Y (0.10)	1.93 w (0.14)	1.89 x (0.08)	2.07 z (0.16)	1.86 z (0.12)	2.01 Y (0.09)

*Condition indices are low because emergent fry were allowed to air-dry overnight.

APPENDIX G.-Characteristics of streams measured at artificial redd sites. Temperatures measured after 22 November were measured at one site in each stream (Fig. G1).

TABLE G1.-Hydrogen ion concentration (expressed as pH) for Laurel Branch and White Rock Branch. Table entries are mean hydrogen ion concentration (SD) expressed as pH.

Day of study	Laurel Branch	White Rock Branch
7	7.4 (1.0)	7.2 (1.0)
14	7.4 (1.0)	7.3 (1.0)
21	7.3 (1.0)	7.2 (1.0)
32	7.1 (0.0)	7.2 (1.0)
39	7.1 (1.0)	7.4 (1.0)
45	7.3 (1.0)	7.3 (1.0)
54	7.3 (1.0)	7.3 (1.0)
61	7.1 (1.0)	7.5 (1.0)
68	6.3 (1.0)	7.4 (1.0)
87	7.3 (1.0)	7.4 (1.0)
101	7.3 (1.0)	7.3 (1.0)
128	7.4 (1.0)	7.3 (1.0)

TABLE G.2-Weekly temperatures (°C) for Laurel Branch and White Rock Branch through 22 November.

Day of study	Laurel Branch	White Rock Branch
7	10.0	10.0
14	7.6	5.0
21	4.4	7.5
32	9.1	7.6

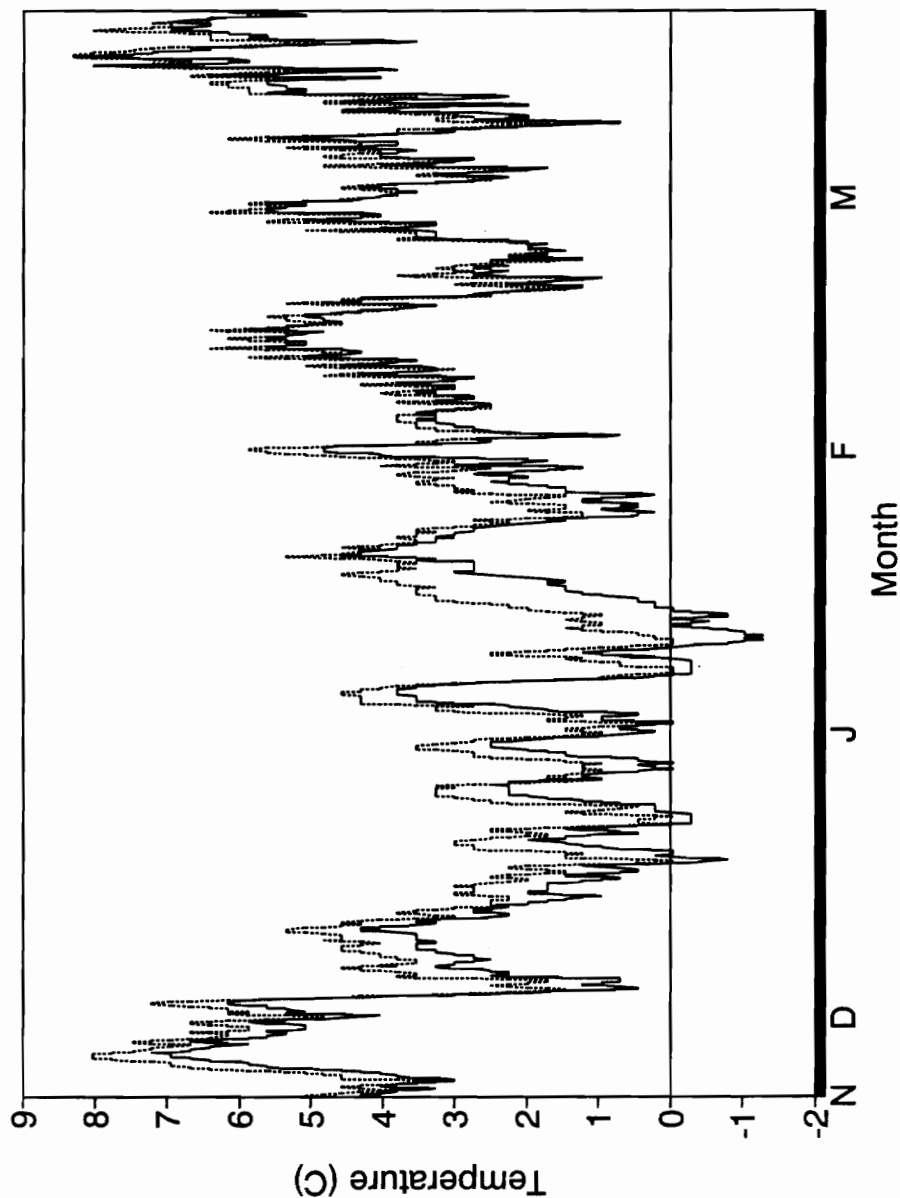


FIGURE G.1-Stream temperatures ($^{\circ}\text{C}$) recorded after 22 November using HOBO temps buried in the substrate that recorded temperature every 1.6 hours. Temperatures in Laurel Branch are denoted by the solid line. Temperatures in White Rock Branch are denoted by the dotted line.

TABLE G3.-Surface water dissolved oxygen (mg/l) for Laurel Branch and White Rock Branch. Table entries are means (SD).

Week of study	Laurel Branch	White Rock Branch
1	9.2 (1.4)	9.9 (0.37)
2	9.2 (1.5)	11.1 (0.54)
3	10.3 (0.74)	9.7 (0.47)
4	11.9 (0.50)	12.3 (0.30)
5	11.3 (1.0)	11.2 (0.34)
6	10.9 (0.59)	10.7 (0.50)
7	10.9 (0.22)	11.0 (0.14)
8	9.9 (0.38)	11.3 (0.19)
9	9.2 (0.21)	9.2 (0.07)
12	12.9 (0.25)	12.4 (0.30)
14	13.0 (0.47)	11.7 (0.27)
17	12.1 (0.78)	12.7 (1.2)

APPENDIX H.-Intragravel dissolved oxygen (mg/l) (D.O.) and gravel permeability (cm/hr) (Perm.) at various % fine sediment levels (Sed.) for Laurel Branch and White Rock Branch.

Week	Sed.	Laurel Branch		White Rock Branch	
		D.O.	Perm.	D.O.	Perm.
1	0	9.2	2520	7.2	5400
		9.6	5400		3240
		10.0	4320		2520
	10	9.5	7560	7.0	4320
		9.5	11880		3960
		9.8	3600		4450
	20	8.6	5040		2880
		9.1	4680		4320
		9.0	2880		4320
2	0	9.6	5400	7.4	6120
		10.3	3600	5.6	3600
		12.5	4680	5.1	2160
	10	10.0	6120	4.3	2160
		11.1	11160	7.0	4320
		10.2	2880	8.2	3780
	20	9.6	4320	7.0	3240
		10.3	4680	7.6	3240
		9.9	3600	10.2	4320
3	0	9.2	3600	10.0	3960
		8.8	5040	9.4	3960
		9.1	5400	10.2	2520
	10	9.8	6120	9.2	6120
		9.1	7200	11.8	3240
		9.3	5400	9.6	4580
	20	9.0	5400	11.6	4320
		9.0	4680	8.8	3780
		9.2	5400	10.0	5040
4	0	11.8	6480	12.2	3960
		12.2	3780	11.6	3240
		11.0	4680	11.0	2520
	10	11.4	3780	10.8	3420
		11.0	4320	11.4	3960
		12.0	5040	11.1	4680

continued.

APPENDIX H.-Continued.

Week	Sed.	Laurel Branch		White Rock Branch	
		D.O.	Perm.	D.O.	Perm.
	20	12.2	5220	11.6	4320
		12.0	3600	10.4	4500
		11.0	4320	12.4	5040
5	0	11.2	6480	9.6	4320
		10.4	3780	11.0	3240
		9.2	4860	12.2	1800
	10	11.0	3780	10.8	2160
		11.8	3420	11.2	2520
		9.8	2520	10.2	2280
	20	10.6	5400	10.0	2340
		11.2	5580	10.2	1800
		11.0	3060	9.2	2160
6	0	9.0		9.6	3960
		10.4		11.0	3420
		9.2	4860	12.2	4320
	10	11.0		10.8	3960
		11.8	3420	11.0	4680
		9.8	2520	10.0	4320
	20	10.6		10.0	5400
		9.8		10.4	1800
		11.0		10.1	0
7	0			9.2	5400
		8.9		10.3	3600
		9.2	4860	10.2	2880
	10	9.8	2520	2.7	5400
		10.6	0	10.4	4860
		11.8	3420	10.1	4680
	20	9.8	4680	10.4	3240
		1.4	0	9.8	5040
8	0	10.5	1800	9.2	1440
		10.9	3600	8.7	4320
		9.8	4500	7.5	4320
	10	7.0	0	9.2	4320
		10.2	3420	9.4	4320
		10.1	2520	8.7	4680

continued.

APPENDIX H.-Continued.

Week	Sed.	Laurel Branch		White Rock Branch	
		D.O.	Perm.	D.O.	Perm.
	20	10.2	3600	9.2	2880
		10.1	5040	8.5	2160
		9.5	4320		
9	0	8.1	1440	7.5	4320
		6.8	3960	8.3	6480
		8.4	3600	7.9	3240
	10	8.6	0	8.8	720
		6.4	3420	8.3	5760
		7.8	2520	7.8	2980
	20	7.8	3240	8.9	2160
		8.5	6480	7.6	2520
		5.3	4320		
12	0	12.3	5040	7.6	5610
		10.8	3960	9.3	6120
		10.1	3600	8.0	3960
	10	8.7	0	8.8	920
		9.7	3420	8.7	5400
		9.8	2520	8.1	4860
	20	10.8	3240	9.0	3240
		11.1	6480	7.6	1800
		7.6	4320		
14	0	11.8	3960	9.5	5400
		9.2	3600	8.9	6480
		10.2	3240	7.9	2160
	10	9.3	0	9.1	2520
		9.8	2880	7.3	2860
		8.7	2160	7.4	3960
	20	12.1	2880	9.4	3240
		11.5	5400	7.2	4320
		8.3	3960		
17	0	11.1	3240	11.1	3600
		10.2	3420	9.1	720
				11.0	2520
	10	8.3	4320	10.2	1440
		9.8	2520	10.1	5400

continued.

APPENDIX H.-Continued.

Week	Sed.	Laurel Branch		White Rock Branch	
		D.O.	Perm.	D.O.	Perm.
	20	9.2	6480	9.2	2520
		10.2	3960	9.3	1440
		10.1	3600		

APPENDIX I.-Fine sediment (g) and gravel (g) in W-V boxes recovered from Laurel Branch and White Rock Branch. Table entries are raw data of size classes (mm) sieved. Ret. denotes the retrieval number. Box# denotes the random number assigned to each W-V box. Start Sed. represents the starting fine sediment (%) (0.43 - 0.84 mm in diameter) amount.

Size Classes										
Ret.	Box#-Start Sed.	<0.18	0.18- 0.425	0.425- 0.84	0.85- 1.69	1.7- 3.34	3.35- 6.29	6.3- 9.49	9.49- 12.49	
Laurel Branch										
1	3-0	0.2	0.4	0.2	0.0	0.1	1.1	25.1	525.9	
1	8-0	0.1	0.6	0.3	0.1	0.0	0.0	17.2	531.6	
1	13-0	0.7	1.2	1.0	0.5	0.5	0.2	21.8	528.6	
1	6-10	0.5	20.7	33.2	0.2	0.2	0.0	16.4	477.4	
1	16-10	0.3	29.4	36.4	0.1	0.1	0.4	1.2	494.0	
1	17-10	0.2	12.3	35.7	0.4	0.0	0.2	6.4	488.8	
1	7-20	0.5	17.2	81.5	1.3	0.0	0.5	7.5	432.4	
1	16-20	0.4	13.6	86.5	0.7	0.4	0.3	6.6	432.2	
1	20-20	0.8	19.5	86.6	1.0	0.1	0.0	7.4	428.1	
2	15-0	0.2	2.0	1.2	0.6	0.2	0.0	12.0	538.2	
2	16-0	0.3	1.2	0.7	0.3	0.1	0.0	11.8	536.6	
2	17-0	0.4	2.8	2.0	2.9	2.0	0.9	11.2	540.3	
2	1-10	0.7	16.3	39.3	0.7	0.1	0.6	1.1	472.7	
2	7-10	0.7	15.9	32.9	0.2	0.1	0.1	11.6	485.8	
2	13-10	0.5	8.4	43.8	0.5	0.0	0.0	9.7	485.3	
2	11-20	0.9	17.8	96.0	1.6	0.9	0.7	8.4	430.8	
2	12-20	0.5	25.2	80.3	0.3	0.0	0.0	8.7	431.3	
2	13-20	0.9	22.4	87.3	1.5	0.1	0.1	7.2	432.7	
3	9-0	0.1	0.8	0.0	0.0	0.0	0.2	26.1	522.4	

continued.

APPENDIX I.-Continued.

Size Classes										
Ret.	Box#-Start	Sed.	<0.18	0.18- 0.425	0.425- 0.84	0.85- 1.69	1.7- 3.34	3.35- 6.29	6.3- 9.49	9.49- 12.49
3	11-0		0.3	1.8	1.6	2.0	0.8	0.2	21.6	527.5
3	21-0		0.5	1.9	0.5	0.2	0.0	0.7	14.2	531.9
3	12-10		1.5	14.3	37.1	2.8	1.2	1.9	19.4	472.5
3	15-10		1.2	17.5	31.5	0.1	0.0	0.5	16.8	474.8
3	21-10		0.5	15.6	31.3	1.7	2.5	3.0	13.9	478.3
3	3-20		0.6	25.7	76.5	0.2	0.1	0.1	10.9	428.7
3	6-20		0.7	26.4	74.1	1.9	0.3	0.3	10.6	428.7
3	15-20		1.4	18.3	87.2	3.0	0.5	0.7	4.4	435.5
4	2-0		3.3	8.7	9.2	9.4	15.6	5.6	19.2	529.7
4	14-0		1.1	1.2	0.9	0.9	1.4	1.0	2.3	540.6
4	18-0		13.8	49.3	45.0	34.7	13.4	2.4	14.9	533.5
4	14-10		7.3	27.3	36.1	3.4	1.3	0.5	5.8	489.3
4	19-10		1.5	2.3	2.1	2.7	3.7	1.3	21.9	470.7
4	20-10		2.2	8.4	14.0	6.5	4.7	2.0	13.3	424.5
4	1-20		4.3	12.5	30.2	13.7	13.3	5.2	10.1	428.4
4	8-20		9.5	37.2	99.8	10.7	10.9	7.4	13.2	430.0
4	9-20		3.8	18.1	88.2	3.9	0.6	0.5	9.3	430.9
5	10-0		1.0	2.6	0.6	0.2	0.1	0.0	29.3	520.2
5	19-0		1.8	8.8	11.9	8.2	4.3	1.2	17.3	532.7
5	20-0		2.7	7.9	13.1	10.5	10.5	2.0	25.7	519.9
5	2-10		4.0	20.0	36.1	1.9	0.8	0.1	7.8	486.9
5	5-10		2.4	15.7	39.6	1.5	0.4	0.1	10.3	482.9
5	18-10		1.5	14.1	29.0	2.7	2.6	0.1	9.0	484.4
5	5-20		11.3	31.4	45.6	49.6	54.6	17.5	5.9	433.0

continued.

APPENDIX I.-Continued.

Size Classes											
Ret.	Box#-Start Sed.	<0.18	0.18- 0.425	0.425- 0.84	0.85- 1.69	1.7- 3.34	3.35- 6.29	6.3- 9.49	9.49- 12.49		
5	17-20	2.0	7.9	15.2	10.8	7.8	1.8	0.5	438.3		
5	18-20	13.3	33.2	39.1	26.3	22.8	5.6	12.0	482.0		
6	1-0	3.4	5.9	8.4	8.4	7.4	2.4	36.0	512.7		
6	4-0	0.8	0.7	1.8	2.0	6.7	3.5	15.6	531.9		
6	5-0	2.3	37.6	31.7	41.8	50.2	14.0	38.2	509.2		
6	6-0	4.4	35.5	13.1	12.5	12.5	2.9	13.9	534.4		
6	7-0	3.6	23.7	9.0	10.7	17.3	4.9	32.1	517.8		
6	12-0	4.9	13.0	6.4	6.8	4.0	0.9	28.4	521.0		
6	3-0	6.8	3.2	58.8	15.3	9.0	6.4	2.9	492.3		
6	4-10	6.9	15.6	25.3	6.3	5.9	3.3	7.9	484.8		
6	8-10	lost									
6	9-10	4.5	11.9	26.3	23.8	29.0	10.8	16.1	481.5		
6	10-10	4.3	15.9	17.9	15.8	25.7	13.4	5.3	490.1		
6	11-10	11.8	45.4	27.8	9.1	6.0	3.4	5.3	489.0		
6	2-20	9.5	20.8	79.2	37.5	43.4	16.7	11.5	428.0		
6	4-20	3.5	6.7	38.2	23.7	45.2	22.2	8.4	431.1		
6	10-20	3.7	9.2	26.8	9.6	9.2	2.8	7.6	432.5		
6	14-20	8.9	23.1	20.3	11.1	10.1	2.7	2.3	437.7		
6	19-20	6.4	12.3	45.7	11.2	11.4	3.6	5.3	433.3		
6	21-20	2.4	5.2	7.0	3.0	3.0	1.5	12.8	426.7		

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continued.

APPENDIX I.-Continued.

Size Classes									
Ret.	Box#-Start Sed.	<0.18	0.18- 0.425	0.425- 0.84	0.85- 1.69	1.7- 3.34	3.35- 6.29	6.3- 9.49	9.49-
White Rock Branch									
1	3-0	0.1	0.3	0.6	0.3	0.3	0.7	61.1	479.0
1	7-0	0.2	0.3	0.3	0.1	0.1	0.9	22.3	528.1
1	12-0	0.2	0.6	0.3	0.3	0.2	1.3	25.4	522.8
1	2-10	0.2	1.4	0.2	0.2	0.1	0.6	38.0	510.5
1	3-10	0.4	1.1	0.1	0.0	0.1	0.5	35.6	514.0
1	6-10	0.2	1.0	0.3	0.2	0.2	0.5	25.8	525.2
1	4-20	0.0	0.3	0.1	0.0	0.0	0.2	30.6	518.9
1	5-20	0.1	0.5	0.2	0.1	0.1	0.0	53.5	496.0
1	8-20	0.2	0.8	0.2	0.1	0.1	0.3	14.2	534.4
2	1-0	0.7	17.0	36.1	0.3	0.0	0.2	33.2	459.7
2	5-0	0.6	17.7	36.7	0.6	2.8	4.5	28.8	409.7
2	18-0	0.3	12.9	39.3	0.2	0.0	0.2	37.7	453.3
2	4-10	0.9	16.8	35.6	1.0	0.3	0.1	35.2	436.7
2	13-10	0.4	21.6	31.4	0.2	0.3	0.8	55.1	437.2
2	19-10	0.3	18.2	32.0	0.2	0.1	0.0	85.0	409.2
2	9-20	0.5	16.4	33.4	0.0	0.2	0.0	39.1	455.3
2	11-20	0.7	16.5	33.8	0.1	0.1	0.0	30.7	462.1
2	19-20	0.6	18.3	35.1	0.3	0.0	0.4	44.5	450.1
3	6-0	0.8	21.2	85.9	1.0	0.6	0.4	18.8	475.6
3	13-0	0.6	17.9	89.1	0.4	0.7	0.6	47.4	393.1
3	14-0	0.3	18.6	91.2	1.0	0.5	0.8	45.2	393.9
3	5-10	0.8	21.6	84.7	0.2	0.1	0.0	26.2	413.9
3	10-10	0.1	13.9	94.3	0.7	0.1	0.5	21.5	417.1

continued.

APPENDIX I.-Continued.

		Size Classes										
Ret.	Box#-Start Sed.	<0.18	0.18- 0.425	0.425- 0.84	0.85- 1.69	1.7- 3.34	3.35- 6.29	6.3- 9.49	9.49- 12.49			
3	14-10	0.4	19.8	86.8	0.3	0.0	0.2	30.2	409.1			
3	3-20	0.7	23.2	83.4	0.9	0.3	1.3	39.2	401.0			
3	10-20	0.5	17.9	87.8	0.4	0.0	0.0	38.6	453.8			
3	21-20	0.3	12.7	93.7	1.3	1.0	0.5	20.8	418.4			
4	8-0	3.6	38.9	28.9	35.3	28.0	8.7	18.4	531.4			
4	9-0	4.3	24.5	21.3	19.3	12.0	0.8	10.1	539.8			
4	15-0	lost										
4	1-10	12.5	58.1	82.6	51.2	27.4	7.5	21.9	469.7			
4	12-10	2.7	24.1	69.0	75.5	55.8	4.9	47.1	446.9			
4	17-10	lost										
4	2-20	3.9	15.3	29.4	41.4	43.5	12.5	34.3	403.0			
4	12-20	12.3	25.5	73.6	21.4	8.8	4.6	52.0	379.7			
4	14-20	7.3	8.4	54.0	23.8	18.4	6.4	17.4	418.7			
5	2-0	11.9	34.5	34.2	71.2	86.0	22.1	16.3	533.1			
5	10-0	0.9	57.6	60.1	19.8	7.7	1.8	9.6	539.3			
5	19-0	3.5	12.0	21.7	24.3	21.6	10.2	9.6	534.3			
5	6-10	0.1	9.9	31.2	22.8	14.9	1.8	12.0	478.6			
5	8-10	7.4	41.9	80.4	62.6	48.8	22.6	45.1	447.2			
5	20-10	5.3	40.0	82.0	41.6	29.1	8.8	11.6	427.3			
5	16-20	lost										
5	17-20	lost										
5	6-20	2.7	28.9	63.2	91.8	71.1	7.9	15.0	425.4			
6	4-0	6.0	28.0	39.5	43.1	41.8	12.5	18.7	521.8			
6	11-0	12.0	75.4	19.7	4.8	2.3	1.8	18.6	530.6			

continued.

APPENDIX I.-Continued.

Ret.	Box#-Start Sed.	<0.18	0.18- 0.425	0.425- 0.84	0.85- 1.69	1.7- 3.34	3.35- 6.29	6.3- 9.49	9.49- 12.49
6	16-0	lost							
6	17-0	5.1	19.3	48.1	41.7	35.1	10.1	19.2	531.9
6	20-0	7.3	52.4	42.7	44.9	26.6	5.0	9.8	539.7
6	21-0	3.4	30.6	13.7	9.2	4.1	1.1	7.1	543.2
6	7-10	3.2	8.6	14.4	23.4	33.9	8.4	25.2	467.8
6	9-10	2.3	25.1	53.7	52.0	45.8	14.1	9.1	485.6
6	11-10	5.1	35.6	84.8	18.9	4.0	3.4	18.7	474.6
6	15-10	7.9	39.9	65.8	51.8	39.9	13.9	20.4	472.8
6	18-10	10.3	56.7	82.2	54.8	46.5	18.7	9.1	485.6
6	21-10	8.2	58.1	69.1	55.3	31.7	3.0	7.6	487.5
6	1-20	6.2	37.3	58.1	27.7	12.1	9.1	19.6	417.1
6	7-20	5.9	28.7	41.3	34.5	26.1	12.1	17.4	421.3
6	13-20	lost							
6	15-20	11.6	72.0	73.7	58.3	41.8	20.8	15.6	424.6
6	18-20	7.0	23.2	60.8	44.0	37.6	8.1	18.6	418.5
6	20-20	8.4	44.8	64.2	20.0	7.8	3.4	10.3	429.8

APPENDIX J.-Core samples from Laurel Branch and White Rock Branch taken at each retrieval with the McNeil stovepipe sampler. Table entries are weights (g) of size classes (mm in diameter) present in each sample.

Size Classes (mm)											
Ret.	<0.18	0.18- 0.43	0.43- 0.84	0.84- 1.7	1.7- 3.4	3.4- 6.3	6.3- 9.5	9.5- 12.5	12.5- 24.9	25- 50	
Laurel Branch											
1	0.4	0.2	0.3	1.3	6.1	135.1	431.9	197.9	160.0		
1	3.8	3.4	3.7	6.3	5.8	156.5	525.1	419.0	231.1		
1	1.2	0.7	0.4	0.3	1.2	98.2	547.3	427.2	232.3		
1	4.9	4.2	3.8	3.3	3.4	101.7	545.8	361.9	186.7		
1	2.7	3.2	3.2	2.4	1.8	38.8	239.5	313.3	145.3		
1	2.8	2.3	2.4	2.6	1.6	245.4	977.5	588.2	272.0		
1	5.9	5.8	3.3	3.1	11.7	232.7	831.0	493.3	262.9		
1	0.3	0.1	0.1	0.0	0.5	24.8	184.6	154.3	157.9		
1	1.8	1.1	0.6	0.3	0.2	78.1	399.7	377.1	279.1		
2	4.5	3.9	1.8	2.7	6.8	86.7	315.1	200.1	126.5		
2	10.7	9.1	4.4	7.1	11.5	104.3	429.9	322.8	221.9		
2	13.8	26.3	20.3	22.1	45.9	130.5	415.4	293.2	174.0		
2	5.1	4.5	3.0	2.2	1.8	56.4	376.7	488.0	236.7		
2	6.4	5.6	3.8	4.6	2.6	121.0	383.2	314.5	163.4		
2	9.6	14.0	8.5	11.4	12.6	49.8	267.2	456.3	304.4	27.9	
2	4.9	5.0	3.7	8.9	4.1	242.4	631.8	346.0	118.8		
2	4.4	3.6	3.3	5.7	4.3	78.2	472.7	345.2	284.2		
2	2.7	2.2	1.9	3.1	5.0	171.2	502.4	292.7	86.9		
3	11.2	7.6	5.0	11.0	7.6	132.5	601.2	266.1	190.9		
3	5.1	8.2	6.9	9.6	3.6	159.8	555.7	380.4	250.0		
3	6.6	6.8	3.6	6.1	9.0	129.8	516.2	292.1	183.7		

continued.

APPENDIX J.-Continued.

Size Classes (mm)										
Ret.	<0.18	0.18- 0.43	0.43- 0.84	0.84- 1.7	1.7- 3.4	3.4- 6.3	6.3- 9.5	9.5- 12.5	12.5- 24.9	25- 50
3	0.5	0.3	0.1	0.1	0.1	29.2	285.6	67.6	237.8	
3	3.6	3.6	5.7	10.2	6.3	90.3	427.2	383.1	346.4	
3	4.7	3.9	3.5	6.3	9.0	128.8	622.9	454.9	266.9	
3	5.0	4.4	4.6	10.3	7.8	50.3	410.7	417.3	241.4	
3	8.3	7.7	3.1	8.4	5.3	67.8	531.0	304.7	243.1	
3	13.8	36.3	27.8	36.5	44.7	113.1	233.7	207.7	212.8	
4	10.4	8.1	3.8	6.1	10.8	176.7	578.2	407.6	381.6	265.6
4	7.9	6.0	2.7	2.2	2.8	54.1	211.8	225.3	92.5	
5	20.7	74.4	63.2	67.6	156.2	419.6	438.6	311.2	182.4	
5	10.3	107.2	78.1	61.2	82.9	277.4	626.6	409.9	214.6	112.3
5	4.7	35.2	60.5	51.3	66.0	114.0	118.1	88.1	180.7	82.1
5	4.6	53.7	70.7	65.4	120.7	135.5	206.2	246.1	226.2	127.3
6	18.2	45.3	30.5	207.5	265.3	390.5	351.4	235.5	164.0	154.9
6	18.4	57.0	22.1	92.2	69.5	124.6	206.6	176.8	183.0	38.9
6	10.3	36.2	26.6	80.8	232.2	313.1	350.0	205.4	219.8	108.8
6	3.6	19.9	25.4	42.6	65.5	149.7	230.2	167.9	207.2	207.7
6	10.3	79.9	64.7	59.5	74.6	133.5	106.7	63.1	85.2	88.4

continued.

APPENDIX J.-Continued.

Size Classes (mm)										
Ret.	<0.18	0.18- 0.43	0.43- 0.84	0.84- 1.7	1.7- 3.4	3.4- 6.3	6.3- 9.5	9.5- 12.5	12.5- 24.9	25- 50
White Rock Branch										
1	1.8	2.7	2.4	5.6	18.4	95.3	297.9	246.5	157.0	
1	3.4	3.3	1.9	2.8	11.1	66.9	359.0	317.6	327.8	
1	2.3	3.2	1.3	0.6	2.3	65.7	224.7	263.3	208.5	
1	2.9	4.5	4.0	5.3	3.3	105.9	428.9	426.4	295.8	
1	2.0	1.9	1.8	2.4	1.2	34.2	442.0	350.7	214.0	
1	2.3	4.4	1.5	1.4	2.9	102.7	381.1	326.6	259.5	
1	5.4	16.9	7.7	5.6	22.3	108.7	458.3	343.2	209.6	
1	1.2	2.9	5.2	3.8	3.7	89.1	795.5	606.4	374.8	
1	2.2	3.6	3.7	4.0	6.6	97.4	454.1	454.0	283.2	
2	12.1	20.6	15.1	11.2	14.3	41.5	331.7	258.3	126.8	
2	4.6	7.2	3.2	3.6	5.1	150.2	501.9	361.4	184.3	
2	1.7	3.7	5.9	10.0	27.3	145.2	426.1	312.6	217.1	
2	1.8	2.0	1.6	0.8	0.6	61.5	371.5	436.6	398.0	
2	1.8	3.7	3.1	4.9	11.3	87.7	467.5	544.9	388.9	
2	1.0	1.6	1.5	1.0	0.3	69.9	452.4	433.3	261.8	
2	3.1	3.8	4.3	7.3	6.7	80.7	444.8	492.0	283.5	
2	2.3	2.4	1.4	0.6	0.4	78.2	427.5	324.3	162.0	
2	3.5	11.5	7.2	10.5	19.4	109.5	439.0	514.9	438.5	
3	4.0	5.2	1.4	1.8	14.6	97.4	314.6	227.2	214.2	
3	3.9	12.2	12.8	17.1	32.5	206.2	844.2	494.6	248.4	

continued.

APPENDIX J.-Continued.

Size Classes (mm)										
Ret.	<0.18	0.18- 0.43	0.43- 0.84	0.84- 1.7	1.7- 3.4	3.4- 6.3	6.3- 9.5	9.5- 12.5	12.5- 24.9	25- 50
3	5.7	11.1	11.9	17.6	29.1	133.3	514.6	441.7	210.6	
3	1.9	4.6	3.0	3.6	2.4	58.1	403.5	453.8	342.2	
3	3.4	7.9	6.0	6.1	9.4	138.2	584.8	412.1	259.6	
3	2.6	7.5	6.5	5.0	7.7	42.6	251.9	297.2	276.9	
3	7.3	15.9	5.8	4.0	4.5	55.3	275.0	257.6	170.7	
4	8.4	24.4	30.0	27.1	44.4	95.5	220.1	221.3	191.5	153.2
4	3.5	7.2	18.9	62.0	145.9	158.0	57.0	36.4	102.2	
4	5.6	20.2	29.3	52.6	100.7	176.8	153.1	65.1	102.0	30.1
5	5.3	42.3	104.3	103.7	82.4	127.6	181.7	219.8	319.8	216.8
5	5.7	15.1	23.2	23.8	24.6	55.8	97.2	113.4	231.5	43.4
5	5.8	21.4	36.4	114.7	109.8	150.5	113.1	81.9	276.1	108.7
6	45.4	179.7	358.0	254.7	183.0	215.1	264.9	236.6	158.8	
6	32.8	158.8	307.6	177.4	112.1	135.0	180.0	142.4	115.7	
6	6.2	115.6	233.8	434.3	536.3	780.9	481.9	224.0	125.2	
6	20.6	95.0	136.4	140.3	134.9	225.2	149.2	76.4	103.4	23.3
6	15.2	96.4	143.2	262.1	144.0	144.2	140.6	118.9	188.2	29.5

APPENDIX K.-Geometric mean particle size (mm) from cored artificial redd sites on Laurel Branch and White Rock Branch. Site is the random site number assigned to each W-V box. Dg is the geometric mean particle size (calculation given in methods of Chapter 3).

Laurel Branch			White Rock Branch		
Retrieval	Site	Dg	Retrieval	Site	Dg
1	8	9.2	1	6	9.6
1	19	9.9	1	8	10.4
1	21	10.6	1	9	10.7
1	24	9.8	1	13	10.4
1	35	11.1	1	17	10.8
1	46	9.8	1	18	10.2
1	48	9.4	1	23	9.2
1	50	10.9	1	34	10.6
1	61	10.9	1	50	10.6
2	7	9.3	2	4	8.4
2	20	9.3	2	11	9.6
2	34	7.6	2	12	9.3
2	37	11.3	2	26	11.3
2	39	9.6	2	33	11.0
2	40	11.5	2	39	11.0
2	43	8.8	2	53	10.8
2	45	10.1	2	55	10.4
2	51	9.2	2	57	10.4
3	5	8.6	3	7	9.5
3	14	9.4	3	14	9.0
3	28	9.1	3	15	9.3
3	32	11.3	3	27	11.1
3	38	10.2	3	31	9.7
3	44	9.9	3	41	10.5
3	47	10.6	3	62	9.4
3	60	9.5	4	1	15.9
3	63	6.5	4	25	4.2
4	25	17.4	4	38	7.9
4	41	9.8	5	20	14.0
5	10	5.3	5	21	29.6
5	16	6.0	5	29	14.7
5	58	4.7	6	19	3.3
5	49	5.5	6	32	2.8
6	6	4.6	6	45	3.9
6	11	5.1	6	51	3.8
6	1	4.9	6	60	4.8
6	3	6.6			
6	13	3.0			

APPENDIX L.-Total counts of live and dead eggs, alevins, and emergent fry retrieved from Laurel Branch and White Rock Branch. Table entries are raw data used to derive survival estimates. Box# denotes the random number assigned to each W-V box. Sed. denotes the starting fine sediment (0.43 - 0.84 mm in diameter) amount.

Retrieval	Laurel Branch				White Rock Branch			
	Box#-Sed.	Alive	Dead	Total	Box#-Sed.	Alive	Dead	Total
1	3-0	110.0	56.0	166.0	3-0	132.0	80.0	212.0
1	8-0	154.0	60.0	214.0	7-0	136.0	68.0	204.0
1	13-0	106.0	98.0	204.0	12-0	81.0	111.0	192.0
1	6-10	103.0	93.0	196.0	2-10	167.0	35.0	202.0
1	16-10	145.0	69.0	214.0	3-10	143.0	80.0	223.0
1	17-10	123.0	70.0	193.0	6-10	36.0	185.0	221.0
1	7-20	116.0	80.0	196.0	4-20	96.0	100.0	196.0
1	16-20	71.0	127.0	198.0	5-20	134.0	62.0	196.0
1	20-20	106.0	90.0	196.0	8-20	98.0	102.0	200.0
2	15-0	7.0	198.0	205.0	1-0	75.0	142.0	217.0
2	16-0	33.0	152.0	185.0	5-0	44.0	153.0	197.0
2	17-0	64.0	127.0	191.0	18-0	2.0	184.0	186.0
2	1-10	71.0	112.0	183.0	4-10	103.0	101.0	204.0
2	7-10	8.0	181.0	189.0	13-10	35.0	172.0	207.0
2	13-10	31.0	158.0	189.0	19-10	35.0	157.0	192.0
2	11-20	12.0	192.0	204.0	9-20	72.0	120.0	192.0
2	12-20	18.0	175.0	193.0	11-20	14.0	180.0	194.0
2	13-20	32.0	161.0	193.0	19-20	42.0	160.0	202.0
3	9-0	14.0	179.0	193.0	6-0	19.0	221.0	240.0
3	11-0	34.0	159.0	193.0	13-0	7.0	186.0	193.0
3	21-0	3.0	206.0	209.0	14-0	32.0	182.0	214.0
3	12-10	41.0	160.0	201.0	5-10	38.0	171.0	209.0

continued.

APPENDIX L.-Continued.

Retrieval	Laurel Branch				White Rock Branch			
	Box#-Sed.	Alive	Dead	Total	Box#-Sed.	Alive	Dead	Total
3	15-10	15.0	192.0	207.0	10-10	33.0	157.0	190.0
3	21-10	33.0	142.0	175.0	14-10	17.0	184.0	201.0
3	3-20	27.0	168.0	195.0	3-20	25.0	170.0	195.0
3	6-20	70.0	135.0	205.0	10-20	6.0	181.0	187.0
3	15-20	62.0	134.0	196.0	21-20	17.0	173.0	190.0
4	2-0	43.0	125.0	168.0	8-0	17.0	152.0	169.0
4	14-0	3.0	143.0	146.0	9-0	9.0	180.0	189.0
4	18-0	9.0	175.0	184.0	15-0	lost		
4	14-10	18.0	177.0	195.0	1-10	10.0	164.0	174.0
4	19-10	13.0	178.0	191.0	12-10	5.0	163.0	168.0
4	20-10	16.0	117.0	133.0	17-10	lost		
4	1-20	11.0	179.0	190.0	2-20	6.0	143.0	149.0
4	8-20	74.0	70.0	144.0	12-20	8.0	174.0	182.0
4	9-20	14.0	69.0	83.0	14-20	4.0	147.0	151.0
5	10-0	2.0	168.0	170.0	2-0	8.0	173.0	181.0
5	19-0	8.0	148.0	156.0	10-0	0.0	144.0	144.0
5	20-0	0.0	170.0	170.0	19-0	0.0	148.0	148.0
5	2-10	4.0	174.0	178.0	6-10	14.0	137.0	151.0
5	5-10	7.0	156.0	163.0	8-10	6.0	152.0	158.0
5	18-10	22.0	161.0	183.0	20-10	1.0	136.0	137.0
5	5-20	21.0	150.0	171.0	6-20	1.0	161.0	162.0
5	17-20	0.0	176.0	176.0	16-20	lost		
5	18-20	1.0	174.0	175.0	17-20	lost		
6	1-0	1.0	128.0	129.0	4-0	0.0	83.0	83.0
6	4-0	0.0	7.0	7.0	11-0	1.0	195.0	196.0

continued.

APPENDIX L.-Continued.

Retrieval	Laurel Branch				White Rock Branch			
	Box#-Sed.	Alive	Dead	Total	Box#-Sed.	Alive	Dead	Total
6	5-0	1.0	123.0	124.0	16-0	lost		
6	6-0	2.0	169.0	171.0	17-0	18.0	186.0	204.0
6	7-0	1.0	170.0	171.0	20-0	0.0	192.0	192.0
6	12-0	0.0	173.0	173.0	21-0	1.0	212.0	213.0
6	3-10	29.0	153.0	182.0	7-10	2.0	173.0	175.0
6	4-10	14.0	159.0	173.0	9-10	0.0	191.0	191.0
6	8-10	lost			11-10	3.0	177.0	180.0
6	9-10	0.0	187.0	187.0	15-10	0.0	145.0	145.0
6	10-10	0.0	28.0	28.0	18-10	2.0	189.0	191.0
6	11-10	19.0	172.0	191.0	21-10	3.0	182.0	185.0
6	2-20	5.0	153.0	158.0	1-20	0.0	184.0	184.0
6	4-20	8.0	151.0	159.0	7-20	2.0	155.0	157.0
6	10-20	0.0	123.0	123.0	13-20	lost		
6	14-20	0.0	159.0	159.0	15-20	0.0	152.0	152.0
6	19-20	0.0	187.0	187.0	18-20	0.0	171.0	171.0
6	21-20	0.0	137.0	137.0	20-20	0.0	183.0	183.0

APPENDIX M.-Final amount of fine sediment (%) and survival (%) of brook trout eggs, alevins, and emergent fry from Laurel Branch and White Rock Branch. Box# denotes the random number assigned to each W-V box. Start Sed. is the starting fine sediment (%) (0.43- 0.84 mm in diameter) amount. Final Sed. is the final fine sediment (%) (<0.84 mm in diameter) amount retained in each W-V box. Surv. is the % survival based on total counts of recovered eggs, alevins, and emergent fry.

Laurel Branch			White Rock Branch		
Retrieval (number)	Box#-Start Sed. (%)	Final Sed. Surv. (%)	Box#-Start Sed. (%)	Final Sed. Surv. (%)	Surv. (%)
1	3-0	0.14			62.3
1	8-0	0.18	3-0	0.18	66.7
1	13-0	0.53	7-0	0.15	42.2
1	6-10	9.9	12-0	0.2	82.7
1	16-10	12.0	2-10	9.8	64.1
1	17-10	8.7	3-10	10.0	16.3
1	7-20	18.0	6-10	9.7	49.0
1	16-20	18.3	4-20	19.7	68.4
1	20-20	19.4	5-20	19.6	49.0
2	15-0	0.6	8-20	20.0	34.6
2	16-0	0.4	1-0	0.32	22.3
2	17-0	0.9	5-0	0.29	1.1
2	1-10	10.2	18-0	0.27	50.5
2	7-10	9.0	4-10	9.7	16.9
2	13-10	9.6	13-10	9.7	18.2
2	11-20	20.9	19-10	9.2	37.5
2	12-20	19.3	9-20	19.5	7.2
2	13-20	20.1	11-20	19.7	20.8
3	9-0	1.6	19-20	19.5	7.9
			6-0	0.11	

continued.

APPENDIX M.-Continued.

Laurel Branch				White Rock Branch			
Retrieval (number)	Box#-Start Sed. (%)	Final Sed. (%)	Surv. (%)	Box#-Start Sed. (%)	Final Sed. (%)	Surv. (%)	
3	11-0	6.7	17.6	13-0	0.14	3.6	
3	21-0	5.3	1.4	14-0	0.22	15.0	
3	12-10	9.6	20.4	5-10	9.1	18.2	
3	15-10	9.1	7.2	10-10	9.3	17.4	
3	21-10	8.6	18.9	14-10	9.9	8.5	
3	3-20	18.6	13.8	3-20	19.5	17.1	
3	6-20	18.4	34.1	10-20	19.3	3.2	
3	15-20	19.4	31.6	21-20	19.7	8.9	
4	2-0	3.8	25.6	8-0	12.9	10.1	
4	14-0	0.58	2.1	9-0	9.3	4.8	
4	18-0	19.6	4.9	15-0	lost		
4	14-10	12.9	9.2	1-10	27.9	5.7	
4	19-10	1.0	6.8	12-10	lost		
4	20-10	4.4	12.0	17-10	18.3	2.9	
4	1-20	8.5	5.8	2-20	9.2	4.0	
4	8-20	26.6	51.4	12-20	20.7	4.4	
4	9-20	20.0	16.9	14-20	13.4	2.6	
5	10-0	0.76	1.2	2-0	14.7	4.4	
5	19-0	4.1	5.1	10-0	21.6	0.0	
5	20-0	4.3	0.0	19-0	6.7	0.0	
5	2-10	10.9	2.2	6-10	7.5	9.3	
5	5-10	10.5	4.3	8-10	23.6	3.8	
5	18-10	8.1	12.0	20-10	23.1	0.73	
5	5-20	16.1	12.3	6-20	17.2	0.62	
5	17-20	4.5	0.0	16-20	lost		

continued.

APPENDIX M.-Continued.

Laurel Branch				White Rock Branch			
Retrieval (number)	Box#-Start Sed. (%)	Final Sed. (%)	Surv. (%)	Box#-Start Sed. (%)	Final Sed. (%)	Surv. (%)	
5	18-20	15.5	0.57	17-20	lost	0.0	
6	1-0	3.2	0.78	4-0	13.4	0.0	
6	4-0	0.6	0.0	11-0	19.5	0.51	
6	5-0	13.0	0.81	17-0	13.2	9.7	
6	6-0	9.6	1.2	16-0	lost		
6	7-0	6.6	0.59	20-0	18.6	0.0	
6	12-0	4.4	0.0	21-0	8.7	0.47	
6	3-10	17.9	18.9	7-10	4.7	1.2	
6	4-10	8.7	8.8	9-10	14.7	0.0	
6	8-10	lost		11-10	22.8	1.7	
6	9-10	7.8	0.0	15-10	20.7	0.0	
6	10-10	6.9	0.0	18-10	27.1	1.1	
6	11-10	15.5	11.0	21-10	24.6	1.6	
6	2-20	19.9	3.3	1-20	18.5	0.0	
6	4-20	8.8	5.3	7-20	13.8	0.0	
6	10-20	7.2	0.0	13-20	lost		
6	14-20	9.5	0.0	15-20	28.6	1.3	
6	19-20	11.7	0.0	18-20	16.5	0.0	
6	21-20	2.7	0.0	20-20	21.3	0.0	

APPENDIX N.-Morphometric measures and condition indices for fry from retrievals five and six in Laurel Branch and White Rock Branch. Table entries are raw data. Abbreviated headings denote the following: Ret = retrieval number; Sed = fine sediment treatment; Len = length (mm); Wgt = weight (mg); K_{ww} = wet weight condition factor; K_{dw} = dry weight condition factor; KD = Bam's developmental index. Wet or Dry denotes whether measure is for wet fry or dry fry.

Ret	Sed	Wet		Dry		K _{ww}	K _{DW}	KD
		Len	Wgt	Len	Wgt			
Laurel Branch								
5	0	20	62.2	18	3.6	0.78	0.62	1.98
		19	63.1	16	14.3	0.92	3.49	2.10
		18	69.4	16	8.3	1.19	2.03	2.28
		23	96.4	21	12.7	0.79	1.37	1.99
		19	64.9	18	7.3	0.95	1.25	2.12
		19	67.6	18	7.1	0.99	1.22	2.14
		20	55.8	19	11.5	0.70	1.68	1.91
		20	70.8	18	12.5	0.89	2.14	2.07
		22	82.4	20	14.5	0.77	1.81	1.98
		21	80.6	19	8.2	0.87	1.2	2.06
	10	19	62.5	18	10.7	0.91	1.83	2.09
		19	59.5	17	12.6	0.87	2.56	2.05
		20	63.5	19	13.7	0.79	2.00	1.99
		21	66.8	20	13.8	0.72	1.73	1.93
		20	65.7	18	14.4	0.82	2.47	2.02
		20	69.4	17	12.6	0.87	2.56	2.05
		20	57.9	18	10.7	0.72	1.83	1.93
		20	67.0	16	13.1	0.84	3.20	2.03
		20	52.4	18	11.7	0.66	2.01	1.87
		22	76.6	19	14.6	0.72	2.13	1.93
		19	54.8	17	10.1	0.80	2.06	2.00
		19	77.9	18	12.3	1.14	2.11	2.25
		21	81.3	19	14.9	0.88	2.17	2.06
		20	76.3	18	11.7	0.95	2.01	2.12
		20	91.3	18	12.8	1.14	2.19	2.25
		20	89.0	19	12.2	1.11	1.78	2.23
		18	83.2	17	11.8	1.43	2.40	2.43
		19	79.1	17	8.7	1.15	1.77	2.26
		20	85.7	18	11.6	1.07	1.99	2.20
21	84.4	19	11.7	0.91	1.71	2.09		

continued.

APPENDIX N.-Continued.

Ret	Sed	Wet		Dry		K _{WW}	K _{DW}	KD
		Len	Wgt	Len	Wgt			
	10	22	93.6	19	12.1	0.88	1.76	2.06
		20	72.2	19	9.8	0.90	1.43	2.08
		22	84.7	20	10.9	0.80	1.36	2.00
		21	78.5	20	12.2	0.85	1.53	2.04
		21	80.8	18	12.7	0.87	2.18	2.06
		18	69.3	17	9.3	1.19	1.89	2.28
		19	77.8	18	10.1	1.13	1.73	2.25
		19	64.4	18	9.3	0.94	1.59	2.11
		19	75.3	17	11.2	1.10	2.28	2.22
		17	54.9	16	11.3	1.12	2.76	2.24
		19	50.6	18	13.2	0.74	2.26	1.95
		16	51.3	14	5.3	1.25	1.93	2.32
	20	20	74.0	19	20.7	0.93	3.02	2.10
		19	64.8	18	14.1	0.94	2.42	2.11
		20	55.2	18	12.2	0.69	2.09	1.90
		20	65.3	17	13.8	0.82	2.81	2.01
		21	67.4	20	12.6	0.73	1.58	1.94
		21	73.2	20	13.2	0.79	1.65	1.99
		21	75.0	20	14.2	0.81	1.78	2.01
		21	77.6	20	14.2	0.84	1.78	2.03
		19	63.5	18	7.8	0.93	1.34	2.10
		20	73.3	18	13.0	0.92	2.23	2.09
		20	71.8	18	11.5	0.90	1.97	2.08
		20	66.0	18	12.5	0.83	2.14	2.02
		20	78.5	19	13.9	0.98	2.03	2.14
		19	66.3	18	13.1	0.97	2.25	2.13
		21	74.8	19	12.8	0.81	1.87	2.01
		21	68.1	19	13.6	0.74	1.98	1.94
		20	64.1	19	6.2	0.80	0.90	2.00
		20	68.6	18	11.0	0.86	1.89	2.05
		20	57.5	17	12.5	0.72	2.54	1.93
		19	60.4	16	12.7	0.88	3.10	2.07
		18	63.8	17	12.1	1.09	2.46	2.22
6	0	21	94.3	21	10.4	1.02	1.12	2.17
		19	67.1	18	9.8	0.98	1.68	2.14
		17	64.1	16	5.4	1.30	1.32	2.35
		20	73.6	19	6.9	0.92	1.01	2.10
		20	73.9	19	8.0	0.92	1.17	2.10
		21	78.7	21	5.5	0.85	0.59	2.04

continued.

APPENDIX N.-Continued.

Ret	Sed	Wet		Dry		K _{ww}	K _{DW}	KD
		Len	Wgt	Len	Wgt			
	0	20	97.7	20	7.0	1.22	0.88	2.30
		20	82.5	20	7.6	1.03	0.95	2.18
		19	69.3	18	6.8	1.01	1.17	2.16
		19	63.4	18	7.4	0.92	1.27	2.10
		20	69.3	19	5.8	0.87	0.85	2.05
		18	50.5			0.87		2.05
		19	56.0	18	4.5	0.82	0.77	2.01
		20	70.8	19	5.4	0.89	0.79	2.07
		20	58.8	20	6.8	0.74	0.85	1.94
		19	44.2	18	3.8	0.64	0.65	1.86
		20	69.2	19	6.6	0.87	0.96	2.05
		19	53.3	18	7.1	0.78	1.22	1.98
		21	73.9	20	7.5	0.80	0.94	2.00
		11	45.1	10	5.6	3.39	5.60	3.24
		18	60.4			1.04		2.18
		21	65.0	20	5.3	0.70	0.66	1.91
		16	55.2	15	4.3	1.35	1.27	2.38
		20	46.0	19	6.2	0.58	0.9	1.79
		20	68.0	19	4.1	0.85	0.6	2.04
		20	67.2	19	8.1	0.84	1.18	2.03
		19	47.8	18	4.7	0.70	0.81	1.91
		19	44.7	18	4.8	0.65	0.82	1.87
		20	38.7	19	6.0	0.48	0.87	1.69
		20	58.3			0.73		1.94
		20	58.9	20	6.8	0.74	0.85	1.95
		20	62.7	20	4.9	0.78	0.61	1.99
		17	26.9	17	3.8	0.55	0.77	1.76
		20	46.0	19	7.5	0.58	1.09	1.79
	10	18	66.0	17	3.4	1.13	0.69	2.25
		19	74.7	18	4.0	1.09	0.69	2.22
		18	76.1	17	2.1	1.30	0.43	2.35
		17	77.4	17	2.8	1.58	0.57	2.51
		20	91.0	19	4.5	1.14	0.66	2.25
		17	63.4	17	3.7	1.29	0.75	2.35
		18	101.0	18	4.2	1.73	0.72	2.59
		18	81.2	17	2.7	1.39	0.55	2.41
		21	126.1	20	3.8	1.36	0.48	2.39
		17	79.2	17	4.1	1.61	0.83	2.53

continued.

APPENDIX N.-Continued.

Ret	Sed	Wet		Dry		K _{WW}	K _{DW}	KD
		Len	Wgt	Len	Wgt			
	10	20	58.9	19	5.1	0.74	0.74	1.95
		20	81.2	20	5.4	1.02	0.68	2.17
		20	70.3	20	4.7	0.88	0.59	2.06
		16	45.8	15	2.1	1.12	0.62	2.24
		21	46.7	20	6.9	0.50	0.86	1.71
		21	80.5	20	12.5	0.87	1.56	2.06
		20	64.6	19	13.4	0.81	1.95	2.01
		19	69.3	18	13.3	1.01	2.28	2.16
		17	46.1	17	7.7	0.94	1.57	2.11
		16	48.2	16	11.0	1.18	2.69	2.27
		19	60.3	18	11.9	0.88	2.04	2.06
		19	60.9	18	12.9	0.89	2.21	2.07
		19	49.3	18	7.9	0.72	1.35	1.93
		17	55.7	16	11.7	1.13	2.86	2.25
		18	32.8	17	7.4	0.56	1.51	1.78
		17	53.2	17	12.8	1.08	2.61	2.21
		17	47.2	16	11.8	0.96	2.88	2.13
		20	49.3	19	11.7	0.62	1.71	1.83
		20	47.2	20	11.4	0.59	1.43	1.81
		21	43.2	20	10.6	0.47	1.33	1.67
		20	47.2	19	12.9	0.59	1.88	1.81
		20	45.2	20	13.8	0.57	1.73	1.78
		19	44.2	19	12.4	0.64	1.81	1.86
	20	18	42.3	18	5.6	0.73	0.96	1.94
		20	67.8	19	9.6	0.85	1.40	2.04
		20	46.2	17	6.5	0.58	1.32	1.79
		20	63.3	18	10.2	0.79	1.75	1.99
		17	69.4	17	13.1	1.41	2.67	2.42
		21	96.6	20	11.1	1.04	1.39	2.18
		22	86.7	21	9.6	0.81	1.04	2.01
		21	93.0	21	12.1	1.00	1.31	2.16
		20	88.3	20	10.4	1.10	1.30	2.23
		21	88.2	21	11.7	0.95	1.26	2.12
		21	82.1	20	9.7	0.89	1.21	2.07
		21	92.0	20	11.8	0.99	1.48	2.15
		20	72.6	20	12.2	0.91	1.53	2.09

continued.

APPENDIX N.-Continued.

Ret	Sed	Wet		Dry		K _{ww}	K _{DW}	KD	
		Len	Wgt	Len	Wgt				
White Rock Branch									
5	0	20	59.9	17	11.6	0.75	2.36	1.96	
		20	64.7	18	11.9	0.81	2.04	2.01	
		21	67.4	18	13.0	0.73	2.23	1.94	
		20	68.9	17	14.0	0.86	2.85	2.05	
		21	69.6	18	10.8	0.75	1.85	1.96	
		20	65.0	18	15.1	0.81	2.59	2.01	
		20	64.8	17	11.9	0.81	2.42	2.01	
		11	34.5					2.96	
	10	20	67.3	19	6.4	0.84	0.93	2.03	
		20	70.3	18	12.7	0.88	2.18	2.06	
		21	70.8	19	13.7	0.76	2.00	1.97	
		20	54.6	18	12.2	0.68	2.09	1.90	
		20	64.4	18	15.2	0.81	2.61	2.00	
		20	64.2	18	14.9	0.80	2.55	2.00	
		18	43.3	17	7.0	0.74	1.42	1.95	
		18	52.8	17	13.7	0.91	2.79	2.08	
		19	57.8	18	15.4	0.84	2.64	2.03	
		18	51.4	18	14.3	0.88	2.45	2.07	
		19	68.3	18	15.5	1.00	2.66	2.15	
		18	46.7	17	7.8	0.80	1.59	2.00	
		19	60.5	18	13.9	0.88	2.38	2.07	
		19	67.1	18	16.9	0.98	2.90	2.14	
		20	60.2	19	15.5	0.75	2.26	1.96	
		21	76.0	18	13.2	0.82	2.26	2.02	
		20	74.1	18	13.7	0.93	2.35	2.10	
		21	69.6	19	9.1	0.75	1.33	1.96	
		20	61.9	18	10.7	0.77	1.83	1.98	
		15	46.0	14	1.0	1.36	0.36	2.39	
		20	67.9	18	14.2	0.85	2.43	2.04	
		21	65.3	18	13.1	0.71	2.25	1.92	
	6	20	21	57.9	18	13.9	0.63	2.38	1.84
0			22	69.6	19	9.2	0.65	1.34	1.87
			23	83.2	21	13.5	0.68	1.46	1.90
			21	55.4	19	8.3	0.60	1.21	1.82
			20	68.0	18	13.0	0.85	2.23	2.04

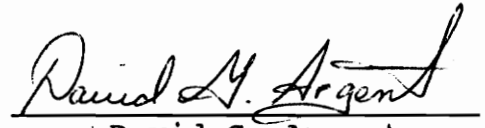
continued.

APPENDIX N.-Continued.

Ret	Sed	Wet		Dry		KWW	KDW	KD
		Len	Wgt	Len	Wgt			
6	0	23	79.8	20	12.0	0.66	1.50	1.87
		22	68.4	18	10.4	0.64	1.78	1.86
		22	79.5	20	11.8	0.75	1.48	1.95
		21	70.5	18	10.4	0.76	1.78	1.97
		21	77.4	20	9.4	0.84	1.18	2.03
		20	47.3	18	5.8	0.59	0.99	1.81
		23	94.9	21	10.8	0.78	1.17	1.98
		21	90.4	19	10.1	0.98	1.47	2.14
		22	69.9	19	10.6	0.66	1.55	1.87
		21	91.4	19	10.7	0.99	1.56	2.15
		24	102.8	22	13.2	0.74	1.24	1.95
		24	84.5	22	12.1	0.61	1.14	1.83
		22	82.2	21	11.1	0.77	1.20	1.98
		21	73.5	19	12.4	0.79	1.81	1.99
		22	72.7	21	11.2	0.68	1.21	1.90
		25	78.5	24	12.2	0.50	0.88	1.71
	10	23	82.2	21	10.5	0.60	1.13	1.82
		23	99.1	20	9.8	0.81	1.23	2.01
		22	74.9	18	9.9	0.70	1.70	1.92
		22	78.5	18	10.8	0.74	1.85	1.95
		22	80.9	18	10.3	0.76	1.77	1.97
		22	69.8	20	11.4	0.66	1.43	1.87
		23	75.0	20	11.8	0.62	1.48	1.83
		21	62.9	20	12.8	0.68		1.89
		23	79.5	19	12.0	0.65	1.75	1.87
		23	88.8	20	13.4	0.73	1.68	1.94
	20	22	85.8	19	11.8	0.81	1.72	2.00
		22	73.3	18	9.0	0.69	1.54	1.90

VITA

David G. Argent was born in Rochford, England, November 6, 1970. He moved with his family to Pittsburgh, Pennsylvania in 1978 where he resided for the next 10 years. After graduating high school in 1988, he went to Indiana University of Pennsylvania (IUP) to major in Biology. While at IUP he acquired minors in both Anthropology and Chemistry. In May 1992, he graduated with honors and went on to continue his studies at Virginia Tech. as a candidate for the Master of Science degree in Fisheries and Wildlife.



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