Influences of Fluctuating Releases on Stream Habitats for Brown Trout in the Smith River below Philpott Dam

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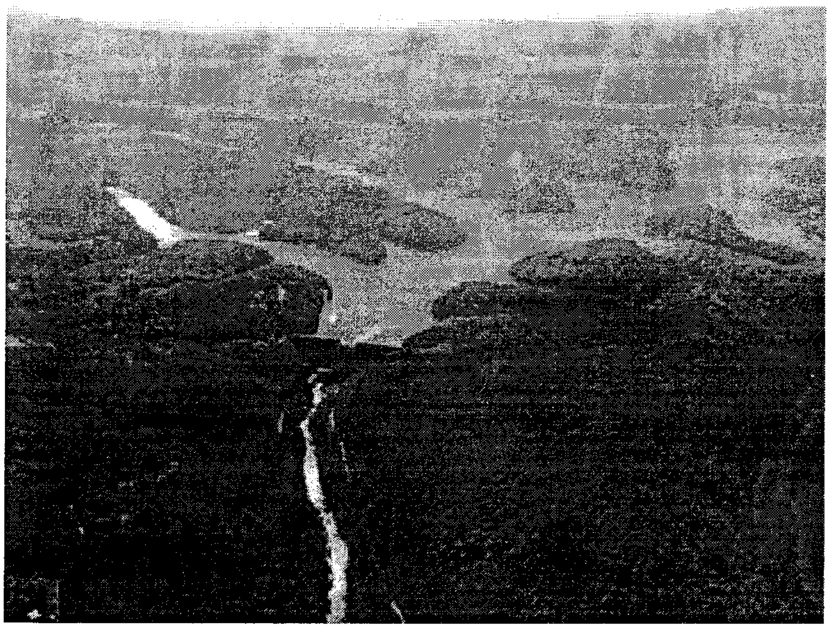

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EXECUTIVE SUMMARY

State: Virginia Project Number: F-121-R

Project Title: **Influences of Fluctuating Releases on Stream Fishes and Habitat in the Smith River, below Philpott Dam**

We report on the third-year activities of a five-year study designed to develop the scientific basis for supporting alternative flow scenarios below the Philpott Dam (US Army Corps of Engineers) tailwater. This important 25 km reach of the Smith River supports urban angling for wild brown trout (*Salmo trutta*) and catchable rainbow trout (*Oncorhynchus mykiss*), as well as a unique but depauperate fauna of invertebrates and fishes, including the federally endangered Roanoke log perch (*Percina rex*). A section of the Smith River from 5 to 10 km below Philpott dam is under special fishing regulations and is especially important in supporting good habitat and successful reproduction of wild brown trout. The first three study years have been devoted largely to exploratory field studies, detailed population and habitat studies, and temperature and flow modeling.

The study is organized in three distinct jobs.

Job 1: Characteristics of Spawning and Rearing Habitats for Brown Trout

Objective: To characterize instream habitat conditions in areas where successful spawning and juvenile rearing of brown trout occurs.

Job 2: Determinants of Brown Trout Growth and Abundance, and Patterns of Nongame Abundance and Distribution

Objective: To collect biological data to quantify relative abundance of trout and nongame fishes in Smith River from Philpott Dam to Martinsville, quantify temperature limits on fish occurrence, and monitor annual variation in brown trout recruitment success. To evaluate the bioenergetic constraints on growth under existing temperature regimes.

Job 3: Hydraulic Model Development and Application to Smith River Tailwater

Objective: To design a field survey and modeling protocol to measure effects of varying flows on the shear stress, mobilization of streambed gravels, and relate discharge to the amount of redd scouring or brown trout fry displacement that would occur at sites in the tailwater. This information coupled with flow records should permit prediction of catastrophic year-class failures and flow ranges that provide for acceptable reproduction.

Temperature dynamics are an important driver influencing fish production processes (e.g. growth and mortality), reproductive behavior and timing, and overall suitability of the tailwater for various fishes. Therefore, a separately funded study (funding from Virginia Water Resources Research Center) by Colin Krause (Evaluation and use of stream temperature prediction models for instream flow and fish habitat management. M.S. thesis, 2002) provides an assessment of alternative flow scenarios on temperature regimes throughout the 25 km tailwater. Within the constraints imposed by temperature additional studies have been focused on several hypotheses.

1. High flows during the incubation period for salmonids scour spawning gravels causing catastrophic mortality of eggs and embryos depending on timing and magnitude of high flows. Over the long-term, peaking flows have had the effect of concentrating and removing spawning gravels and thus limited potential spawning habitat. By contrast, tributaries have delivered fine sediment leading to highly impacted substrates downstream of their confluence with the mainstem.
2. Short-term, pulsing flows create localized areas of high shear stress that disturb benthic habitat, thereby limiting growth and production of young trout and their prey. Daily peaking operations may therefore lead to rapid deterioration and/or failure of redds and displacement of newly-emerged age-0.
3. Growth rates and abundance of brown trout are being constrained by the thermal regime and food availability in the tailwater.
4. The community structure of nongame fish persists over time with a stable pattern of abundance and diversity along a longitudinal gradient both annually and seasonally.
5. A spatial pattern of recovery, in terms of increased numbers and diversity of fish, occurs at tributary junctions, or areas in the mainstem that are adjacent to tributaries.
6. The highest abundance and diversity of nongame fish is present in areas with high levels of primary productivity.
7. The highest levels of primary productivity will occur in areas directly below tributary confluences.
8. The effects of non-steady flow fluctuations can be accurately predicted with the application of two-dimensional steady-flow hydraulic modeling coupled with hydraulic metrics describing essential habitats for the key life stages.

Reproduction of wild brown trout occurred during November and December in 2000 and 2001. The magnitude of peak flows was lessened during the incubation and emergence periods in 2001/2002 because only one turbine was in operation for part of the time and because reservoir levels are low due to drought conditions. The abundance and size of post-emergent brown trout were higher in 2002 than in previous study years, especially in the special regulations reach. Additional quantification of fine sediments in gravels also supports the hypothesis that high quality spawning and incubation habitat may be very limited spatially. Low abundances of young brown trout in the downstream reaches may be directly attributed to fine sediment intrusion. The flow regime in 2002 resulted in less daily change in water surface elevation and provided warmer temperatures. The effect of reduced peak flow appears to be very critical during a short time window after emergence, suggesting that minimal disruptions in power generation may result in substantial improvement in brown trout recruitment.

Although we believe that alternative flow fluctuations could enhance brown trout recruitment, the ongoing research in Job 2 will assist us in evaluating the concurrent influence on nongame fishes and brown trout growth. The combined use of PIT tagged brown trout and otolith examination were adequate to discern cohorts, which enabled us to reconstruct the growth history of the 1998, 1999, 2000, and 2001 cohort. Additional sampling will permit us to complete the size at age estimation necessary for relating growth to flow and temperature regimes. Nongame fish abundance was predictable based upon tributary location, mean temperature, and brown trout abundance. Therefore, we believe we can develop flow management scenarios to optimize both wild brown trout and nongame fishes.

Finally, the hydraulic model has been calibrated with minimal error for two sites at baseflow conditions. A variety of spatially-explicit hydraulic metrics have been evaluated for use in describing habitat suitability (e.g. kinetic energy gradients, vorticity, and circulation). Further field and computer analyses are needed to verify model predictions and evaluate the additional parameters needed to analyze and simulate the unsteady nature of Smith River flows. Preliminary biological investigations have focused on the hydraulic characteristics of habitat used for redds by brown trout. Early findings clearly indicate that fish prefer a specific hydraulic environment when spawning (namely, strongly subcritical flow). Additional research is planned for developing habitat suitability metrics that can be applied to the unsteady flow model. Newly acquired acoustic Doppler profiling equipment will be employed for field measurement of water velocity at base and peakflows and a sediment transport model will be incorporated in the final analyses.

PROJECT NARRATIVE

State: Virginia   Project Number: F-121-R

Project Title: **Influences of Fluctuating Releases on Stream Fishes and Habitat in the Smith River, below Philpott Dam**

Introduction

Need: This study was designed in response to discussions with fisheries biologists from the Virginia Department of Game and Inland Fisheries and the U.S. Army Corps of Engineers. These agencies are interested in determining the feasibility of enhancing habitat for wild brown trout (*Salmo trutta*) in the Smith River below Philpott Dam, Henry County, Virginia. A three-mile special trout regulation area is regulated by a 16-inch minimum, 2-fish-per-day limit. The full potential of the brown trout fishery is limited by a flow regime that fluctuates from 45 cfs to 1280 cfs on a daily basis; the minimum flows are now significantly lower than before dam construction. The Smith River supported over 36,000 anglers hours of trout fishing in 1995 and trout anglers indicated they were willing to pay more for opportunities to catch wild trout and not cancel fishing plans due to generation flows (Hartwig 1998). Presently trout catches are dominated by catchable rainbow trout, with the exception of the special regulations section where catches of wild brown trout exceed that of rainbow trout by thirteen to one. Only 3.6% of brown trout caught by anglers exceed 16 inches. Doubling an angler's chance of catching a large brown trout would more than double the net economic value of the riverine fishery (Hartwig 1998). High mortality coupled with modest growth rates of 1+ and older brown trout appear to limit recruitment of trophy fish. While it appears clear that the flow regime could be improved to benefit the trout fishery, it is not clear what changes in flows or channel enhancements should be proposed. The working hypothesis is that the brown trout recruitment is limited by spawning and rearing habitat and adult growth rates are constrained by reliance on small drifting invertebrate prey base and reproductive costs. This study will (1) determine timing and flow levels needed to enhance spawning and rearing habitats to benefit the wild brown trout population, (2) develop a protocol for estimating brown trout population characteristics (growth, mortality, population density), (3) survey the nongame fishes along a continuum of temperature and fluctuating flow levels, and (4) develop a hydraulic model to evaluate the effect of different releases on physical habitat conditions during spawning, incubation, and fry rearing periods. We assume long-term investment in monitoring the effects of any actions to enhance this fishery; therefore, the study elements (Jobs 1 and 2) will provide the framework for adaptive management of this important tailwater fishery.

Significant advances have been made in developing assessment tools for analyzing flow effects on stream fauna (Stalnaker 1994, Van Winkle et al. 1998) and dam operators are more routinely reconsidering their operations in response to the demands of anglers and recreationists who use tailwaters. The altered conditions in tailwaters have a variety of effects (Cushman 1985, Hunter 1992) and create novel habitat conditions that permit the establishment of valuable salmonid fisheries in regions where these resources are limited. The predictive reliability of instream flow assessment tools are most limited in situations where streamflow may vary by several orders of magnitude over short (hourly or more) time periods (Gore et al. 1989), such as the Smith River tailwater. Furthermore, reliance on single factors to predict population responses is unreliable (Jager et al. 1999). It is clear from initial correspondence with staff of the U.S. Army Corps of Engineers that more specific proposals for reservoir releases will be needed before they are able to respond and evaluate the feasibility of changes in the flow releases.

Objectives: To conduct research to validate and discover new fish-population and habitat relationships and provide defensible fish-habitat relationships to be used for developing specific management actions to improve the fisheries resources of the Smith River tailwater. Specific working hypotheses to be tested under this study include:

1. High flows during the incubation period for salmonids can scour spawning gravels causing catastrophic mortality of a year class depending on timing and magnitude of floods. This short-term event represents a typical habitat bottleneck on population abundance.
2. Short-term pulsing flows create localized areas of high shear stress that disturb benthic habitat, thereby limiting growth and production of young trout and their prey.
3. These impacts are spatially variable and characterizing the extent of sensitive and nonsensitive locations at different flows will suggest suitable flow regimes or mitigation strategies. For example, middle sections of the Smith R. (special regulations section) support reproduction ("source") while upstream and downstream reaches are "sink" populations.
4. These impacts can be more adequately modeled with 2-dimensional finite element or finite difference methods than traditional 1-dimensional models and mitigation measures (e.g., boulder placements) can be evaluated with this modeling technology.

Expected Results and Benefits: The Smith River supports over 36,000 angler hours of trout fishing annually; total economic value of the trout fishery was $440,000/yr (1995 dollars, Hartwig 1998) under current suboptimal conditions. Anglers report a highest willingness to pay for catching larger trout, wild trout, and more fishable flows. It is likely that management actions could enhance the value of this fishery with minor influence on the value of power production ($670,000/yr). Essential data will be collected to permit managers to coordinate and cooperate with other agencies and utilities interested in optimal management of the flowing water resources of the Smith River. Information generated will provide the Fish Division with a reliable modeling tool for evaluating effects of flow on trout habitat.

Approach: Flow release schedules in tailwaters may influence salmonid populations through at least two major pathways: (1) disturbance during early life history or (2) impoverishment of the prey base. Adult trout seem to be quite adaptable at dealing with the flow fluctuations (Niemala 1989, Pert and Erman 1994). Disturbance causing high mortality early in life would create a habitat bottleneck constraining population abundance. The bottleneck could occur if high flood flows during incubation scour eggs from redd pockets. The descriptions of brown trout redds (Dechant and West 1985, Crisp and Carling 1989, Grost and Hubert 1991) do not currently permit the prediction of susceptibility to scour at high flows. Even if redds are protected, however, high flows may cause downstream displacement and mortality in the fry stage (Heggenes 1988, Heggenes and Traaen 1988, Crisp and Hurley 1991), unless the bottom topography provides hydraulic refugia during flow pulses (Lobón-Cerviá 1996). In severe cases the trout fishery would have to be sustained via stocking. Furthermore, siltation of redds is greater when flows are fluctuating (Carling and McCahon 1987). The indirect pathway limits the quality, quantity, or stability of habitat for prey organisms, thereby depressing the growth and ultimate size of resident trout. Both of these effects may play a role in a tailwater. In the Smith River tailwater, brown trout may be influenced via both of these pathways. In addition, nongame fishes may be affected by similar habitat bottlenecks due to fluctuating flow. Operation of Philpott Dam also restricts non-game fishes from much of the tailwater reach (~10 km below the dam) due in part to cold temperatures. However, some of the nongame species in the Smith River often occur with trout in other drainages and may be similarly affected by the pulsing flow regime. Because of their spawning and rearing habits, these fishes (e.g., rosyside dace, bluehead chub, Roanoke hog sucker, Roanoke darter, and fantail darter) may be more vulnerable than brown trout to disruption of spawning habitat (Smith 1999). Minor changes in operation of the tailwater or other mitigation strategies (e.g., boulder placements, Shuler and Nehring 1993, or changes in releases) may reduce the effects of these limitations. Another unanswered question is the extent to which the apparent high mortality is due to movement of brown trout outside the special regulation area; previous studies elsewhere indicate that large brown trout move longer distances (Clapp et al. 1990; Bunnell et al. 1998). To address these distinct problems this study consists of three distinct jobs.

Site Description: The proposed study site is the Smith River below Philpott Dam in the Roanoke River drainage. Philpott Dam is operated by the U. S. Army Corps of Engineers and is operated in a peaking mode, depending on energy demands and water availability. Hypolimnetic releases range from 4 to 14°C annually below the dam, but approach 25°C in reaches more than 20 km downstream. Temperatures between 12-19°C result in optimal growth of juvenile brown trout (Ojanguren et al. 2001) and temperatures > 19°C results in visible thermal stress (e.g. cessation of feeding; Elliott 1981). Lethal temperatures for brown trout range from 25 to 30°C. Considering the information available on brown trout response to temperature, we hypothesize that higher temperatures during extended low flows would induce stress and perhaps increased movements of brown trout (McMichael and Kaya 1991). Generation flows of 1400 cfs (USGS gage 02072000) are typically released at peak demand times during week days, and minimum flows of 45 cfs are released at other times. Flows increase from baseflow to maximum levels in approximately 15 minutes. This may be accompanied by rapid declines in temperature (10°C in 1 hr) in downstream reaches during summer months.

Despite daily fluctuation in flows and temperature, a reproducing population of brown trout exists from the dam downstream to Martinsville (32 km), and densities decrease with distance from the dam in response to increasing warm-season temperatures. There is also a gradient in sediment characteristics. The channel immediately below the dam has highly armored streambed sediments while numerous tributaries between Bassett and Koehler increase sediment loading to the stream. Generation flows likely cause displacement of young brown trout (Heggenes 1988) and invertebrates immediately below the dam. Brown trout recruitment is variable from year to year, presumably due to variation in flow during incubation and/or emergence and early rearing stages. Qualitative sampling of trout indicate that brown trout are most abundant in the middle sections from 4 to 10 km below the dam. Age-0 brown trout are rare near the dam (possible flow disruption effect) and downstream of Bassett (possible sedimentation or temperature effect; Smith 1994, 1995, 1998; Orth 2000, 2001). Previous studies in other streams indicate that redd densities are patchily distributed and correlated with densities of age-0 and older brown trout (Beard and Carline 1991). Highest redd densities are expected in glides and riffles and a high proportion of riffles facilitates production of fry (Baran et al. 1997). However, in hydropeaking situations the flow fluctuations may limit successful reproduction in otherwise suitable spawning habitat (Liebig et al. 1996). This research focuses on understanding the local topographical influence that would lead to displacement of young brown trout; experiments have shown that young grayling (*Thymallus thymallus*) may not be substantially displaced by flow increases depending on the availability of refugia and shelter seeking behavior (Valentin et al. 1994).

Most work that is routinely done to assess the suitability of spawning gravels for trout may have limited predictive power under conditions of pulsing and nonuniform flow (i.e. varied depth of flow). Reiser et al. (1989) describe some the approaches for developing a window of acceptability for flows that will protect spawning gravels and indicate wide variability in recommendations based on different methods. Suitability of spawning areas depends on at least four factors: (1) streamflows that continuously infiltrate the gravels during incubation and larval development, (2) location where local depth and velocity conditions are within ranges where spawners can construct redds and complete mating, (3) flushing of fine sediments that intrude the interstices of gravel at least once per year prior to spawning season, (4) flows must be less than those sufficient to mobilize and transport gravel.

Job 1. Characteristics of Spawning and Rearing Habitats for Brown Trout

Job Objective: To characterize instream habitat conditions in areas where successful spawning and juvenile rearing of brown trout occurs.

The Smith River tailwater supports a naturally reproducing population of brown trout, thus spawning patterns, age-0 emergence and growth, as well as spawning habitat quality is of interest to fisheries managers. Monitoring of spawning activity (redd surveys) and age-0 emergence and growth (electro-fishing) continued during 2002 to build on the findings from 2000 and 2001. Continued monitoring and studies conducted during 2002 provide insight into the working hypotheses of Job 1, which address factors that could potentially impair spawning success. Those factors are:

1. High flows during the incubation period for salmonids scour spawning gravels causing catastrophic mortality of eggs and embryos depending on timing and magnitude of high flows. Over the long-term, peaking flows have had the effect of concentrating and removing spawning gravels and thus limited potential spawning habitat. By contrast, tributaries have delivered fine sediment leading to highly impacted substrates downstream of their confluence with the mainstem.
2. Short-term, pulsing flows create localized areas of high shear stress that disturb benthic habitat, thereby limiting growth and production of young trout and their prey. Daily peaking operations may therefore lead to rapid deterioration and/or failure of redds and displacement of newly-emerged age-0.

These hypotheses were addressed in 2002 by focusing effort on the following activities: 1) describing spatial and temporal patterns of brown trout spawning and measuring attributes of individual redds within a subset of spawning areas, 2) describing temporal patterns of emergence of age-0 brown trout and relative production from a subset of spawning areas, and 3) assessing sediment intrusion within Vibert boxes placed in artificial redds in the Smith River.

Procedures

Spatial and Temporal Patterns of Spawning - Two observers noted the presence of redds in 5 reaches 200-400 m long at 4.2, 6.2, 12.6, 14.3, and 22.0 km below Philpott dam where redds were observed the previous year (Figure 1). Searches were conducted by wading during daylight hours and at base flow conditions with observers traversing upstream on both sides of the river. Redd surveys were conducted on November 28 and 30 and December 4, 7, 11, and 21, 2001. When redds were discovered, we drew a detailed map of the river reach noting the location of redds. Each redd was carefully approached to ascertain spawning activity. For each redd we measured 1) redd dimensions including the length and width of the pit, length of the tailspill, and width of the upstream edge of the tailspill, 2) depth at the upstream edge of the pit, middle of the pit, top of the tailspill, and downstream edge of the tailspill, 3) water velocity at 2 cm above the bottom at locations measured for depth and mean column velocity at 60% depth over the middle of the pit. Hourly temperature recorders provided data used relate spawning activity with water temperature.

Age-0 Emergence and Growth - On February 26, 2002, we visually searched (on foot) for age-0 in the same spawning areas where redds surveys were conducted. Age-0 were present at 3 of 5 assessed sites, thus we allowed two weeks for more age-0 to emerge before commencing surveys using a backpack electrofisher (March 15, 22, and 24, 2002). We conducted 3-pass depletion samples in 25 m reaches located at the downstream boundary of the spawning area (0 - 25 m), 75 m downstream (75 - 100 m), and 150 m downstream (150 - 175 m). Only the non-channel side of the river was sampled within 3 m of the bank as this area appeared to offer potential refugia for age-0. Counts of age-0 per pass, total length (mm), and weight to the tenth of a gram was recorded. These locations and sampling methods were identical to those used in 2001.

Our own visual assessment of the limited avoidance capabilities of age-0 < 50 mm in length supports the validity of depletion samples without a blocking mechanism. An additional electrofishing sample, using the same procedures, was performed on May 9, 15, and 16, 2002. These river reaches were also sampled in conjunction with Job 2 in April and June using protocols and gear described in a later section of this report. Age-0 data from April is not presented in this Job 1 report section because the sampling method (2 barge electofishers and use of nets designed for larger fish) had limited effectiveness at capturing these small fish.

Sediment Intrusion - Substrate compositions representative of spawning redds at 5 spawning areas located 4.2, 6.2, 12.6, 14.3, and 22.0 km downstream from Philpott Dam were placed in vibert boxes. The compositions did not include fines < 2 mm or pebbles > 64 mm, thus intruded fines < 2mm could be assessed. Fines < 2 mm can detrimentally effect incubating eggs in redds by blocking intragravel flow and dissolved oxygen (DO). Substrate was collected from 5 redds in each of the 5 spawning areas in January 2001, using a McNeil bulk core sampler (Orth 2001). At each of the 5 spawning areas 9 vibert boxes were installed where redds had been observed during fall 2000. Vibert boxes were buried under 8-10 cm of sediment that had been tossed repeatedly with a shovel in the water column to remove fines (Garrett and Bennett 1996). The 8-10 cm of sediment overlying vibert box was flush with surrounding channel bottom. The burial depth represents the egg pocket depth (8-22 cm) of brown trout (Devries 1997). Vibert boxes were placed in a grid pattern of 3 boxes per row (rows spaced 1.0 m and boxes within rows spaced 0.5 m) where the most upstream row was installed first followed by the second then third downstream rows to prevent deposition of fines on vibert boxes when tossing sediment. Burial location was marked with flagging tape tied to rebar and large rocks placed at the end of each row. At each spawning site three vibert boxes were retrieved after 2, 4, and 6 weeks starting with the most downstream row. Vibert boxes were carefully excavated until the tops of the boxes were exposed. A zip-lock bag was held open along the river bottom immediately downstream of the vibert box. The vibert box was pulled out of the sediment and placed directly into the zip-lock bag. In the laboratory, samples were dried to constant mass in a 60°C oven, fines < 2 mm were separated by manual shaking (for 45 sec) through a #10 (2 mm) mesh sieve, and dry weight (to the hundredth of a gram) was recorded.

Results and Discussion

Spatial and Temporal Patterns of Spawning - Surveys for redds were performed during 2000 (November 7 – January 9) and 2001 (November 28 – December 21). Within the areas surveyed during 2000 and 2001, 72 redds were found in 2000 and 3 redds were found in 2001 (Figure 1).

Based on angler observation and emergence model predictions we believe peak redd development occurred prior to the 2001 surveys when temperature was around 9°C. An angler (Stephen Hiner, Entomology Lab Specialist Senior, VA Tech) observed redds with trout on them on November 18th located in the special regulations area. An emergence model developed by Crisp (1981, 1988) was used to back-calculate the date of egg fertilization (i.e. redd development) if 50% fry emergence occurred on 2/26/02 when age-0 were visually observed at 3 of the 5 sampling sites. The model predicted fertilization occurred between November 14-22, 2001 depending on distance below the dam. Elliott (1994) found that brown trout hatch after 444 degree days and disperse after an additional 408 degree days, which would put fertilization at November 6-13, 2001 assuming dispersal on February 26, 2002. The Crisp model predictions and data from Elliott (1994) place the event of spawning before redd surveys were started and when water temperature was near and/or slightly below 9°C.

The reason 9°C is of importance is because this temperature and the onset of spawning activity in the Smith River appears closely related and 9°C is within the range observed during spawning elsewhere (Armour 1994; Orth 2001). In 2000, redd development began the second week of November when daily mean water temperature dropped below 9°C (Figure 2). In 2001, water temperatures were near and/or slightly below 9°C before redd surveys (November 5-23), warmed to 10-11°C during surveys, and fell below 9°C again around December 22 (Figure 2). If spawning in the Smith River coincides with 9°C (which was observed in 2000), the temperature data portrays that redd development and spawning would have occurred before the 2001 redd surveys began.

No remnants of redds were found during the surveys, suggesting redds or evidence of redds were washed out by high flows (Figure 3). Peak flow increased from a 7 hr 19 m^3/s release to a 4 hr 36 m^3/s November 19th. Temperature data from 1999 through 2001 shows the date that temperatures fall below 9°C is highly variable from year to year (Figure 2). Despite a lack of observed redds during 2001, spawning was successful because a greater abundance of age-0 were sampled spring 2002 than 2001. This may indicate that the substrate surface can be disturbed without destroying eggs buried deeper.

Age-0 Emergence and Growth - On February 26, 2002 a visual search found age-0 present at 4.2, 12.6, and 14.3 km below Philpott Dam (3 of 5 assessed sites) (Figure 1). On March 12, 2001 a visual search found age-0 at 4.2 and 12.6 km (2 of 5 assessed sites). Thus emergence occurred earlier in 2002 than 2001. Because spawning occurred during approximately the same time period both years, we believe the earlier emergence was due to warmer water temperatures during the incubation period (≈ November 15, 2001 to March 15, 2002). During this period, degree days (sum of daily mean temperature) were 159 - 344 °C (depending on distance below dam) greater this year (2001/02) compared to last year (2000/01) (Figure 4).

Number of age-0 sampled per 25 m section at the 5 assessed spawning sites was variable due to habitat type. For example, at 12.6 rkm (March 24th) 90 age-0 were found in the most upstream 25 m sampling section where habitat was comprised of slow moving water with refuge structure (personal observation) and only 15 were found in the downstream most 25 m section where habitat was a riffle. During March and May sampling was conducted within 3 m of the bank, yet the majority of age-0 sampled were found within 1 m of the bank (personal observation). This provides evidence that age-0 strongly use lateral channel habitat and not mid-channel habitats. Later in June, sampling covered the whole channel and though age-0 were found in mid-channel habitats, the majority of age-0 sampled were still found in or close to lateral habitats (personal observation).

In 2001 there was evidence that age-0 emergence in upstream reaches continued into June (Orth 2001). The evidence for delayed emergence was the small size of age-0 in June 2001 upstream samples (as small as 25 mm), which were similar in size to age-0 sampled in March 2001 (23-31 mm). However, in June 2002 the smallest age-0 sampled was 34 mm and there was only one this small, the next smallest was 40 mm, both of which are larger than age-0 sampled during March 2002 (21-31 mm). This difference between years could mean many things, one of which is that there was no delayed emergence during 2001, rather the small sizes were due to a lack of growth potentially from 2001 higher peak discharges (Figure 3). It is also possible that delayed emergence did occur in 2002, but small age-0 were not collected during the sampling process due mesh size of collection nets and difficulty seeing small age-0 fish.

As downstream distance from the dam increased the abundance of age-0 declined and age-0 length and weight increased (Figures 5-7). Abundance was consistently low during June 2000 - 2002 at 11.3 km below Philpott dam and was consistently high just upstream at 8.9 km (Figure 5). Up and downstream of these sites, age-0 abundance appears to be responding to different sets of limitations. The reason for this pattern in abundance is currently not apparent and requires further investigation. Age-0 were larger in length and weight, and present in greater abundance during 2002 than 2001. Despite an increase in the age-0 population, which would require more food resources, they were still able to grow (Figures 5-7). Similarities in total lengths of age-0 among sites during March confirmed consistent initial emergence dates regardless of distance from the dam, which was also observed in 2001 (Orth 2001) (Figure 8). The range of age-0 lengths by May is broad, depicting either continued emergence at upstream sites and/or some age-0 are able to grow and others do not (Figure 8). Among sites, mean lengths of age-0 in March 2002 ranged from 25 to 28 mm, which is the same as in March 2001 (Figure 6). Mean lengths of age-0 in May ranged from 37 to 47 mm in 2002 versus 28 to 42 mm in 2001, and in June ranged from 52 to 73 mm in 2002 versus 31 to 72 mm in 2001 (Figure 6). Thus, growth (i.e., length and weight) at some sites was significantly greater (based on non-overlapping error bars) in 2002 than 2001 (Figures 6 and 7).

Age-0 population estimates were larger in 2002 (Figure 5). Population estimates during March 2002 were significantly greater than those for 2001 at all sampled sites (Figure 5). This is likely due to the earlier emergence from warmer water temperatures during the incubation period as previously discussed. Population estimates between May 2002 and 2001 are not significantly different at most sites likely due to the later emergence that occurred during 2001 (Orth 2001) (Figure 5). Population estimates for June 2002 are significantly greater than those for 2001 at most sites (Figure 5). This is likely due to improved survival from lessened flow fluctuation and magnitude (Figure 3). In 2002, peak flow during the emergence /growth period was 19 m^3/s, whereas in 2001 peak flow was 37 m^3/s (Figure 3). This reveals the main question of why was growth and abundance greater in 2002 versus 2001; was it from lessened flow, warmer water temperatures, or both?

An attempt to separate the flow versus temperature effect was performed with a one-dimensional hydrodynamic model (ADYN) coupled with a water temperature model (RQUAL). The model enabled evaluation of changes in water surface elevation and temperature under the 2002 versus 2001 flow regime. The 2002 flow caused less daily change in water surface elevation and provided warmer water temperatures. During the emergence/growth period the daily maximum hourly water surface elevation change was 0.1 to 0.4 m (varies with distance from dam) less under the 2002 19 m^3/s peak flow than the 2001 37 m^3/s peak flow (Figure 9). The reduction in water surface elevation change was greater upstream (avg. 0.3 m reduction 0-14 km below dam) than downstream (avg. 0.2 m reduction 15-24 km below dam) (Figure 9). Water temperature was predicted using the 2002 and 2001 flow regime experiencing the 2001 meteorological conditions. Thus, the difference between each year's temperature predictions reveals which flow would provide warmer water temperatures regardless of that year's meteorological conditions. From this exercise it was determined that the 2002 flow regime causes warmer water temperatures during the incubation and emergence periods (Figure 10). This is because less water is released and less water is more easily thermally altered, thus more easily warmed by ambient conditions (Krause 2002). If the 2002 flow regime had occurred in 2001 the daily mean water temperature would have been warmer; up to 0.3°C during the incubation period and 0.77°C during the emergence/growth period (at downstream locations) (Figure 10). The reduced flow fluctuation likely improved age-0 survival and feeding ability from reduced water velocities and shear stress, and warmer temperatures likely improved food assimilation which in turn increased growth.

We believe however, that the effect of reduced peak flow, rather than increased temperature, had a greater effect. This preliminary conclusion is based on upstream reaches (0-14 km below dam) having a larger reduction in water surface elevation fluctuation (Figure 9) and age-0 in these upstream locations having significantly greater growth (i.e., length and weight) by June 2002 (Figures 6 and 7). Despite a greater increase in temperature at downstream locations (Figure 10), we did not find significantly improved growth in June 2002 (Figures 6 and 7), we only found significantly greater abundance (Figure 5).

Sediment Intrusion - Fine sediment (< 2 mm) intrusion into vibert boxes increased with downstream distance from the dam, which is consistent with previous substrate studies (Orth 2001) (Figure 11). However, fine sediment intrusion did not significantly increase with time. A possible explanation for this is that the duration of the experiment was not long enough to reveal temporal changes. Another explanation may be that sampled fine sediment was mostly from the outer edges of the vibert box and not from within the interstitial gravel spaces in the box. This blocking of the outer perimeter of the box could prevent additional sediment from intruding within the box. If this is the case then much of the sampled sediment could be from when the vibert boxes were buried at the beginning of the experiment, however, this effect should have been minimized by the thorough tossing of sediment to let fines washout and be carried downstream. Another unexpected result was the decline in fine sediment over time at some sites. Because of the variability in weight of fine sediment among the 3 boxes per site it seems possible that there was inconsistency in the amount of sediment lost from the box during removal from the streambed. During removal it was observed that sediment had packed into the plastic openings along the outside of the box and that this sediment easily fell out when pulled from the streambed into the water column. Effort was made to place the vibert box into the plastic bag as immediately as possible to minimize sediment loss. Even if the majority of fine sediment is from the outer perimeter of the vibert box this may still be somewhat representative of a redd. We would expect sediment deposition on a redd to be most dense on the outer edges. This layer of fine sediment would then block intra-gravel flow preventing adequate DO from reaching the eggs. Initial findings indicate that fine sediment intrusion increases with distance from the dam and that fine sediment intrusion does not increase over the short duration of 6 weeks.

Preliminary Conclusions

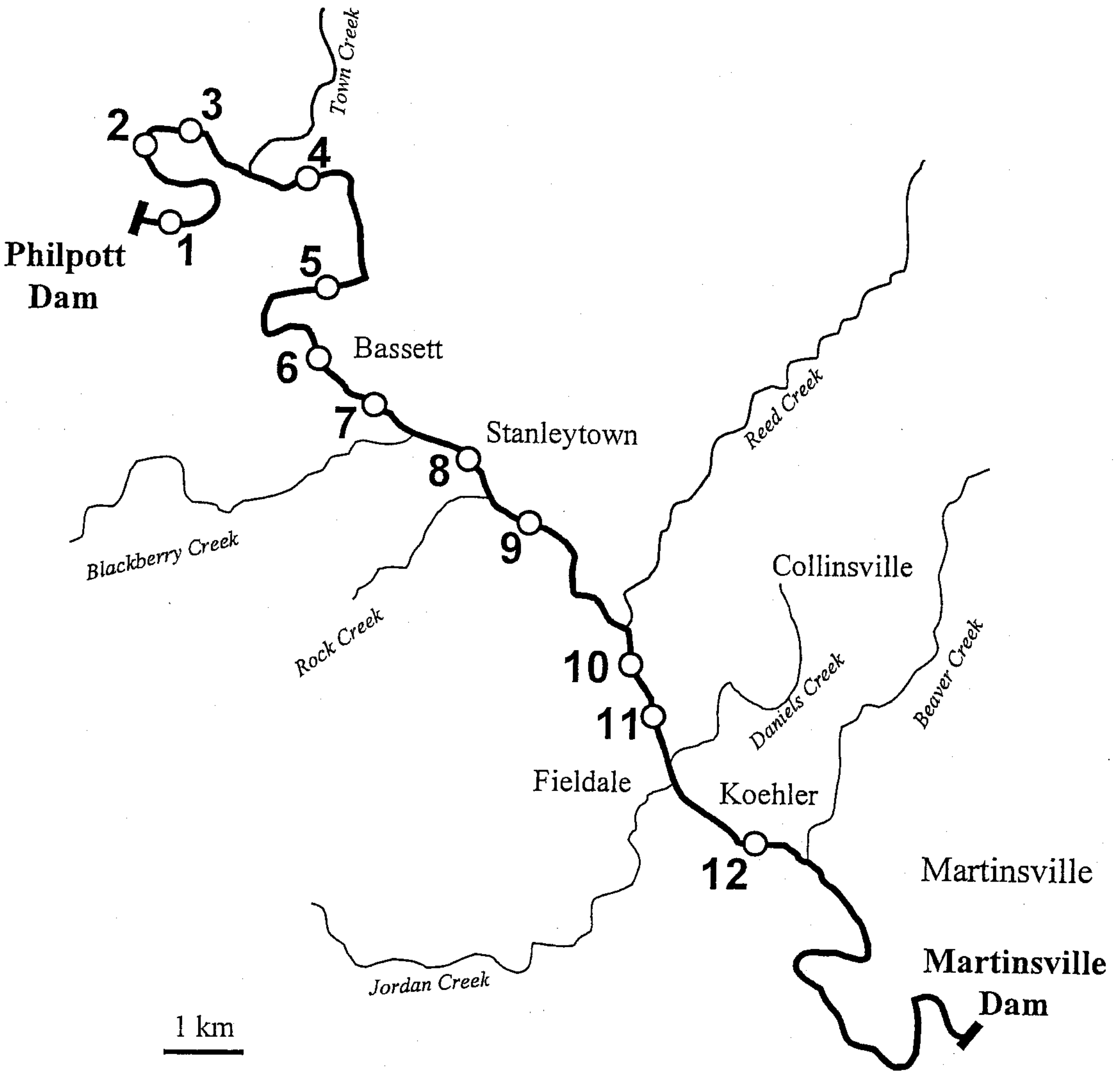
Spawning activity in the Smith River appears to be cued by 9°C water temperatures. Though few redds were observed in November 2001, angler observation, water temperature data, and emergence model predictions provided evidence that spawning occurred during temperatures at or below 9°C. The lack of observed redds suggests that their evidence was washed out by high flows. Despite the possibility that redds were washed out, eggs did survive to hatch. Age-0 emergence occurred earlier in 2002 than 2001 due to warmer water temperatures. Following emergence, age-0 abundance was greatest in stream margin habitat comprised of slow moving water with refuge structure (personal observation). Unlike in 2001, there was no evidence of delayed emergence at upstream sites during 2002 suggesting emergence was not delayed but growth was poor during 2001. Age-0 abundance declined with distance from the dam and was also low close to the dam. Low abundance in downstream reaches may be from poor egg incubation success from higher levels of fine sediment prohibiting sufficient flow and DO within redd intragravel spaces. Age-0 length and weight increased with distance from the dam. Larger population estimates and larger size age-0 in 2002 is likely due to the lessened fluctuation, magnitude, and duration of peaking flow releases which also resulted in warmer water temperatures.

Future Research and Job Schedule

Future research efforts will continue to document spatial and temporal characteristics of spawning and emergence via redd surveys and age-0 sampling (fall and spring 2002-2004). Continued assessment is required to determine if trends in abundance and growth hold over time and to determine whether differences in trends among years is due to flow and/or temperature effects. Literature documenting the effect of fine sediment on incubating eggs will be reviewed and coupled with findings from our field studies. Assessment of fine sediment intrusion over time with vibert boxes will be conducted during the 2002-2003 spawning/incubation period. Substrate permeability sampling to assess intragravel flow and dissolved oxygen content of interstitial gravels of redds and surrounding substrate is planned during the 2002-2003 spawning/incubation period. Comparison of permeability values with those in the literature will determine whether spawning substrate conditions are within a suitable or unsuitable range for success. An emersion staining method to mark fish will be used to assess downstream displacement of age-0 brown trout from peak flows and will be conducted during the 2003 emergence period. This study will determine whether downstream displacement occurs as well as where it occurs in the tailwater. Coupling of temperature modeling (Krause 2002), development and emergence models (Crisp 1981, 1988), and these additional studies, we will be able to identify time periods where peaking flow reductions would benefit brown trout recruitment.

Job 1 Schedule. All aspects of Job 1 are on schedule with no significant changes anticipated at this time. Reporting period extends to bold line.

Calendar Year	1999			2000				2001			2002				2003				2004	
Project Year		Year 1				Year 2			Year 3				Year 4				Year 5			
Quarter	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
Purchase supplies		X																			
Recruit students	X																				
Assemble supplies		X																			
Redd surveys					X				X				X				X				
Fine sediment intrusion													X	X							
Substrate permeability													X	X							
Downstream displacement													X	X							
Redd and fry monitoring			X			X	X			X	X			X	X			X	X		
Rearing habitat surveys				X				X				X				X					
Data analyses								X	X			X	X			X	X	X			
Manuscript preparation										X	X			X	X			X	X		
Final report																					X



Site #	1	2	3	4	5	6	7	8	9	10	11	12
km below dam	0.5	3.4	4.2	6.2	8.9	11.3	12.6	14.3	15.9	18.9	20.1	23.0

Figure 1. Map of the Smith River tailwater between Philpott Dam and Martinsville Dam with sampling sites numbered upstream to downstream. Redd surveys and age-0 sampling (March and May) were conducted at sites 3, 4, 7, 8, and between sites 11 and 12 at 22 km.

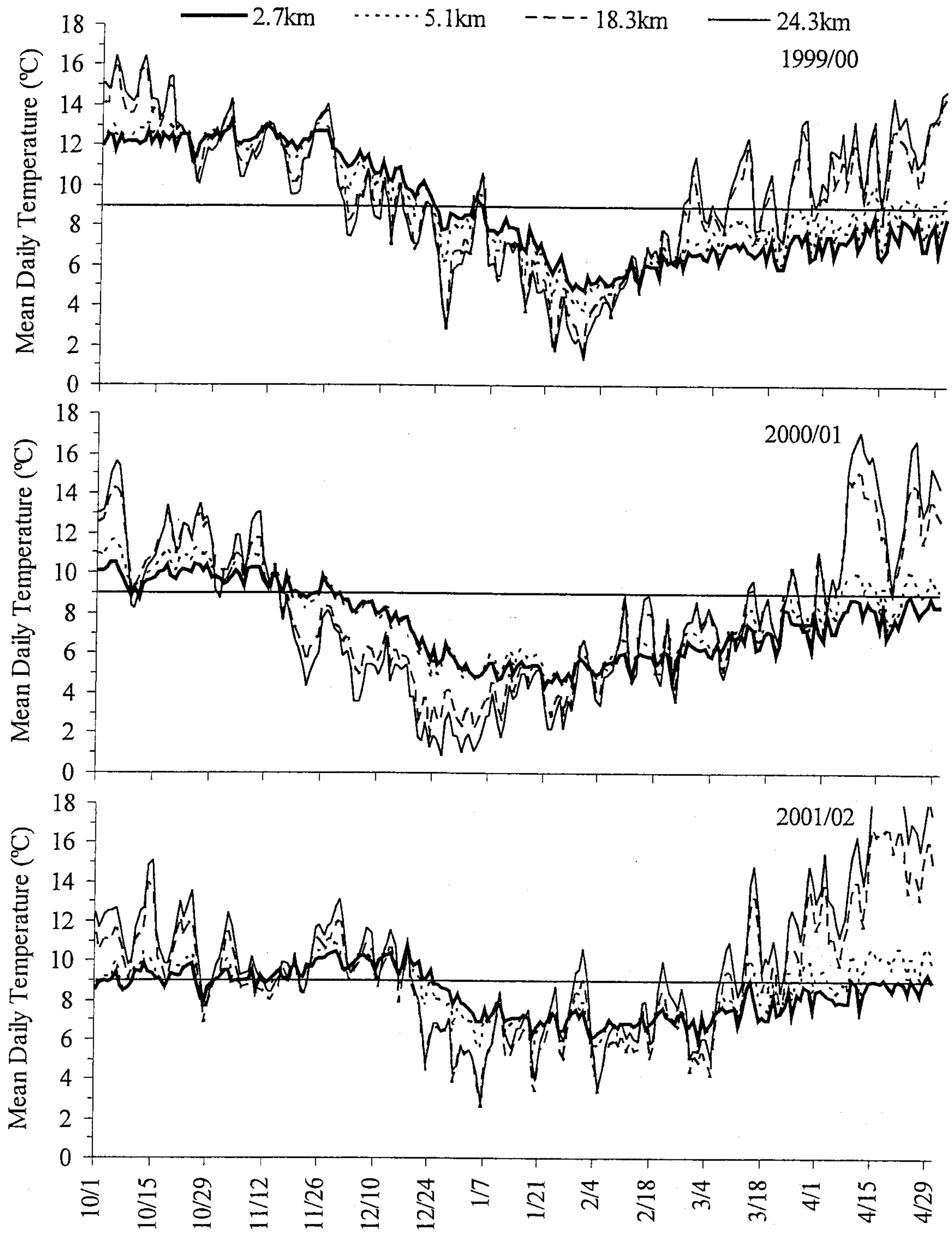


Figure 2. Mean daily water temperature (°C) during brown trout spawning, incubation, and emergence period at 2.7, 5.1, 18.3, and 24.3 km below Philpott dam in the Smith River, VA during 1999/00, 2000/01, and 2001/02. Horizontal line displays 9°C, which is the temperature believed to initiate spawning.

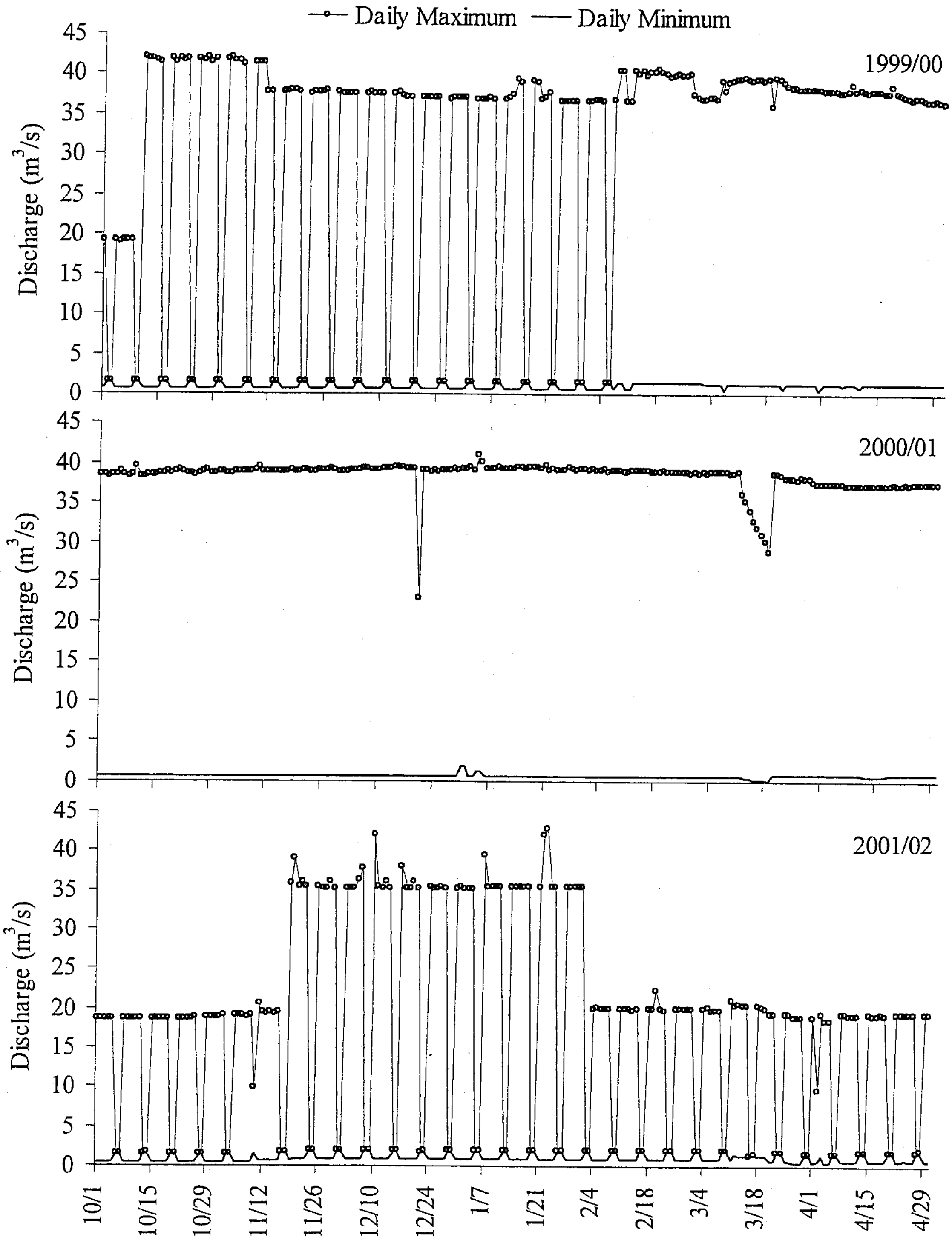


Figure 3. Daily maximum and minimum discharge (m^3/s) during brown trout spawning, incubation, and immergence period at 0.5 km below Philpott dam in the Smith River, VA during 1999/00, 2000/01, and 2001/02.

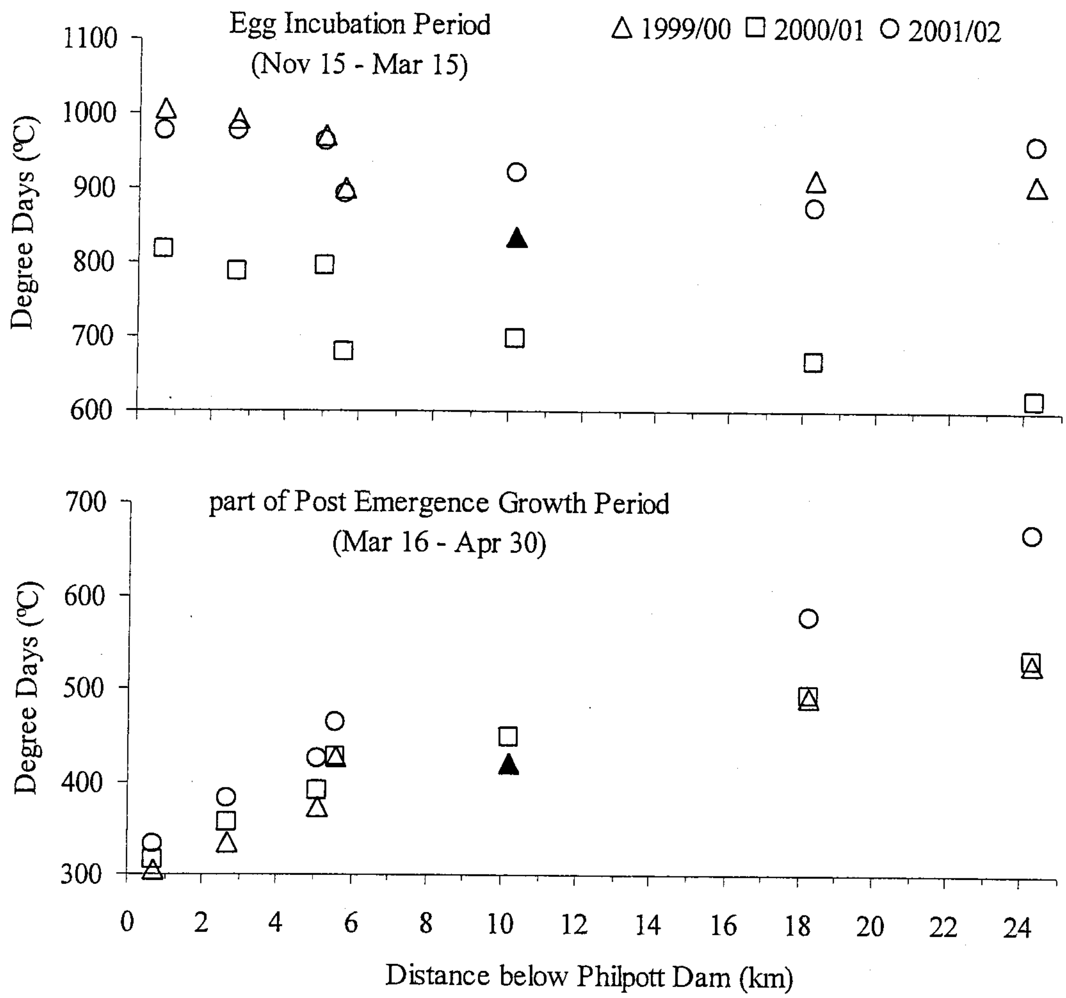


Figure 4. Degree days (°C) (sum of daily mean water temperature) at 0.7, 2.7, 5.1, 5.6, 10.2, 18.3, and 24.3 km below Philpott dam in the Smith River, VA during the typical egg incubation period (11/15 - 03/15) and part of the growth period after emergence (03/16 - 04/30) during 1999/00, 2000/01, and 2001/02. Open symbols represent data logger recorded data and solid symbols represent model (RQUAL) predict values where logger data is missing. Data is currently unavailable for the 2001/02 post emergence period.

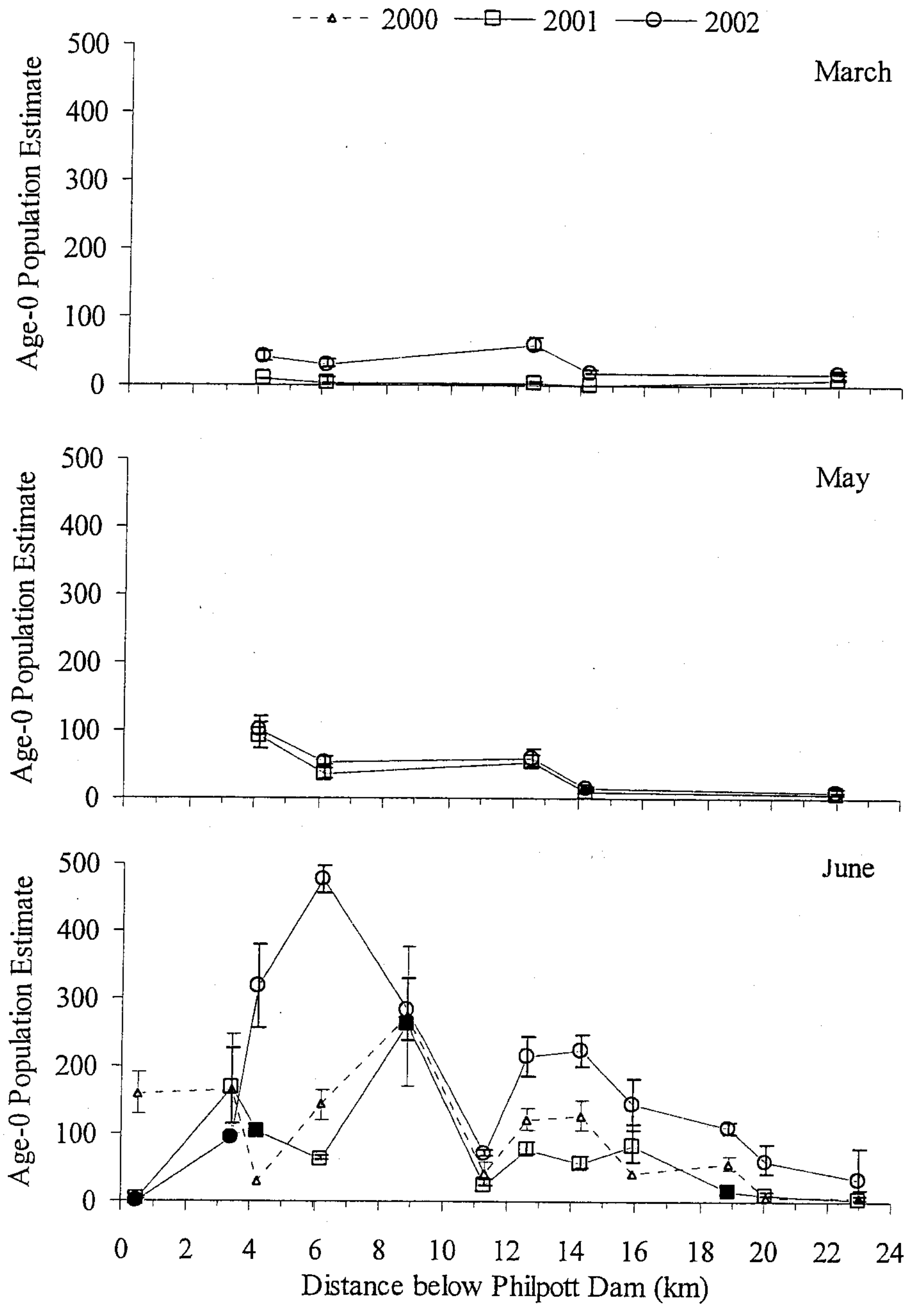


Figure 5. Population estimates (Microfish software) for age-0 brown trout sampled by 3-pass depletion electrofishing in March and May of 2001 and 2002, and June of 2000, 2001 and 2002. Error bars represent upper and lower 95% confidence intervals. Solid symbols indicate that the actual number of fish sampled is presented, not a population estimate, because of non-descending catch data. Direct comparison of population estimates between June and May or March should be done with cautiously as different sampling protocol and gear were used.

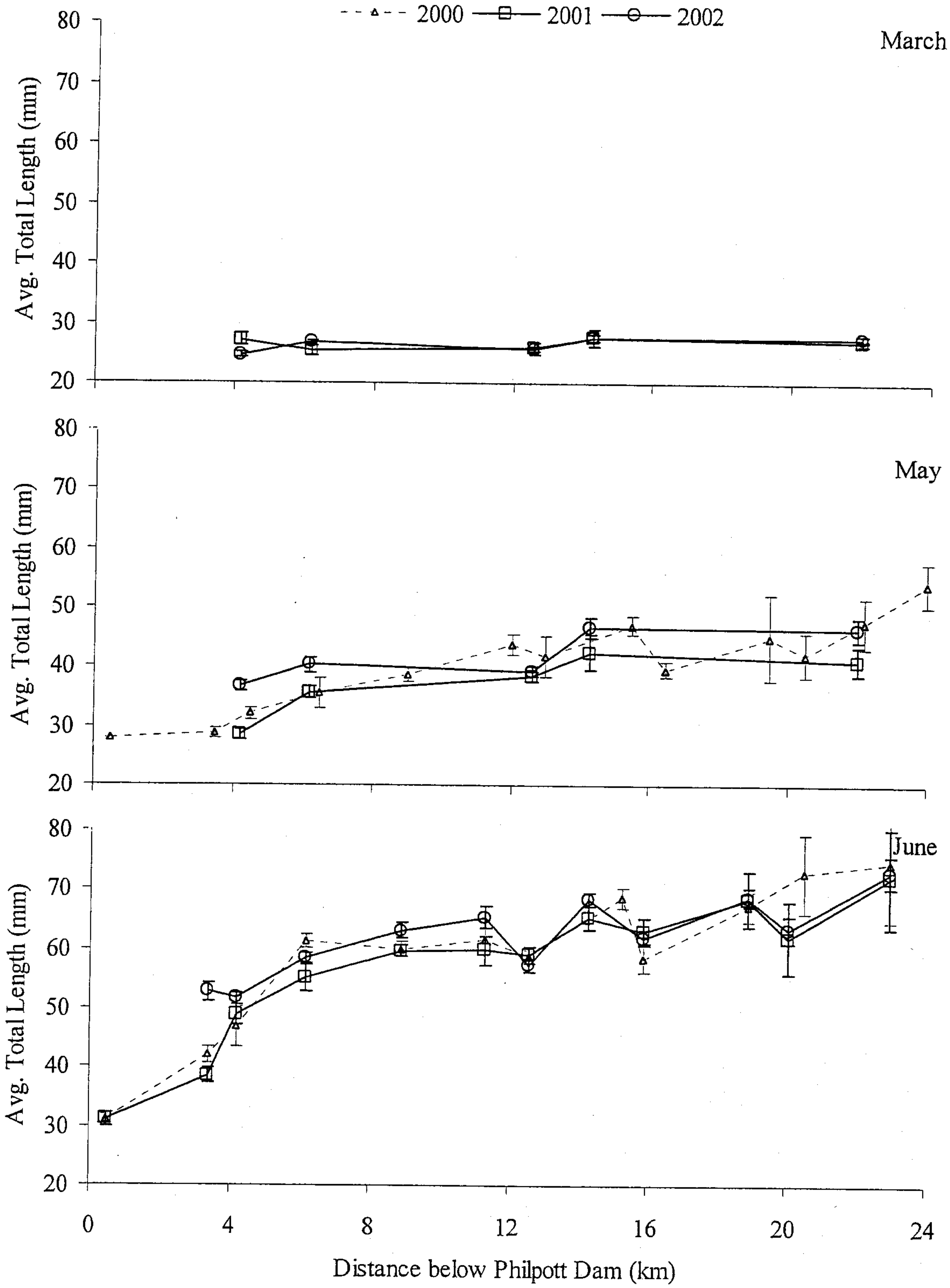


Figure 6. Average total length (mm) of age-0 brown trout sampled during March, May, and June of 2000, 2001, and 2002 in the Smith River, VA. Error bars represent ±2SE.

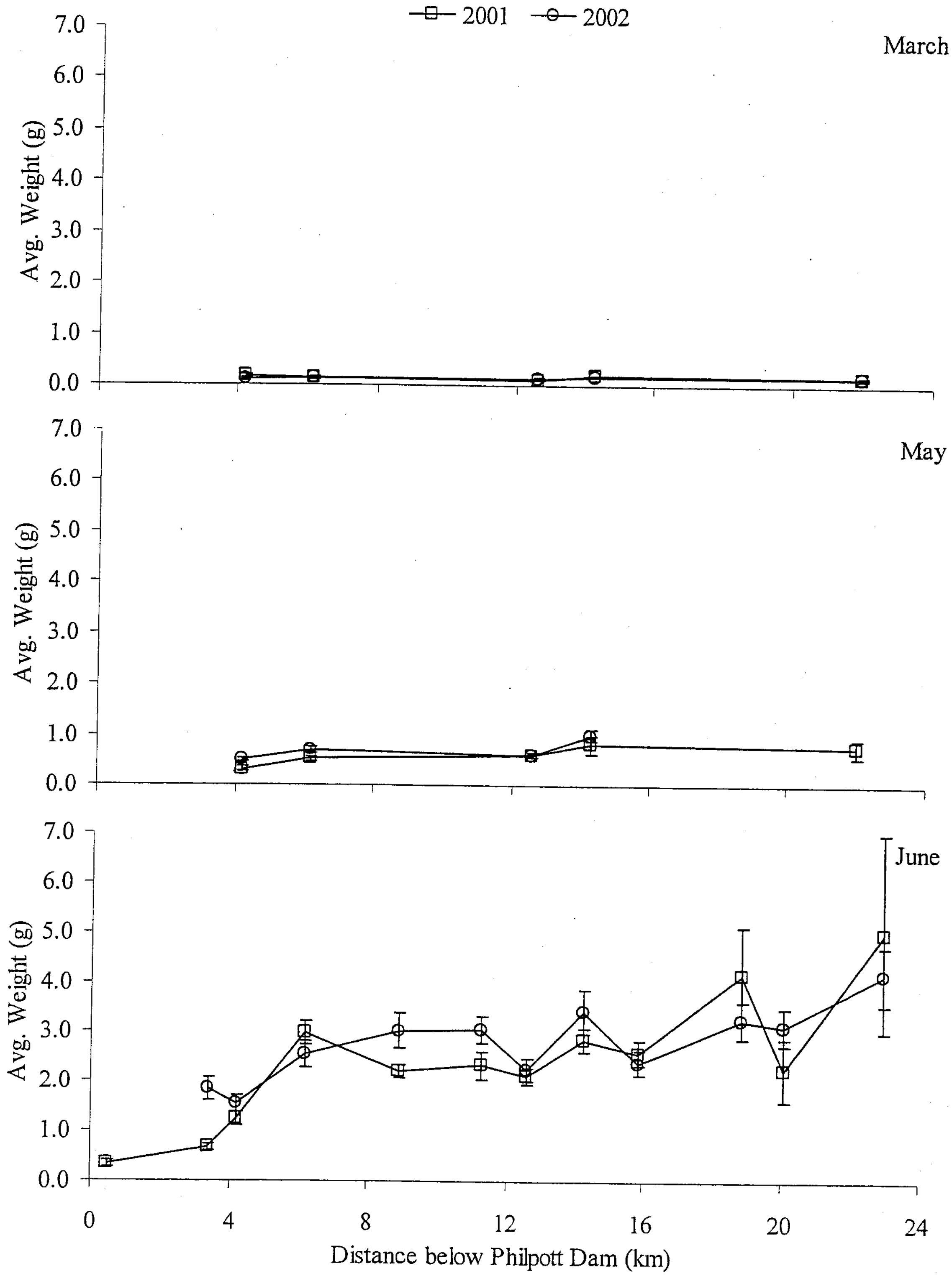


Figure 7. Average weight (g) of age-0 brown trout sampled during March, May, and June of 2001 and 2002 in the Smith River, VA. Error bars represent ±2SE.

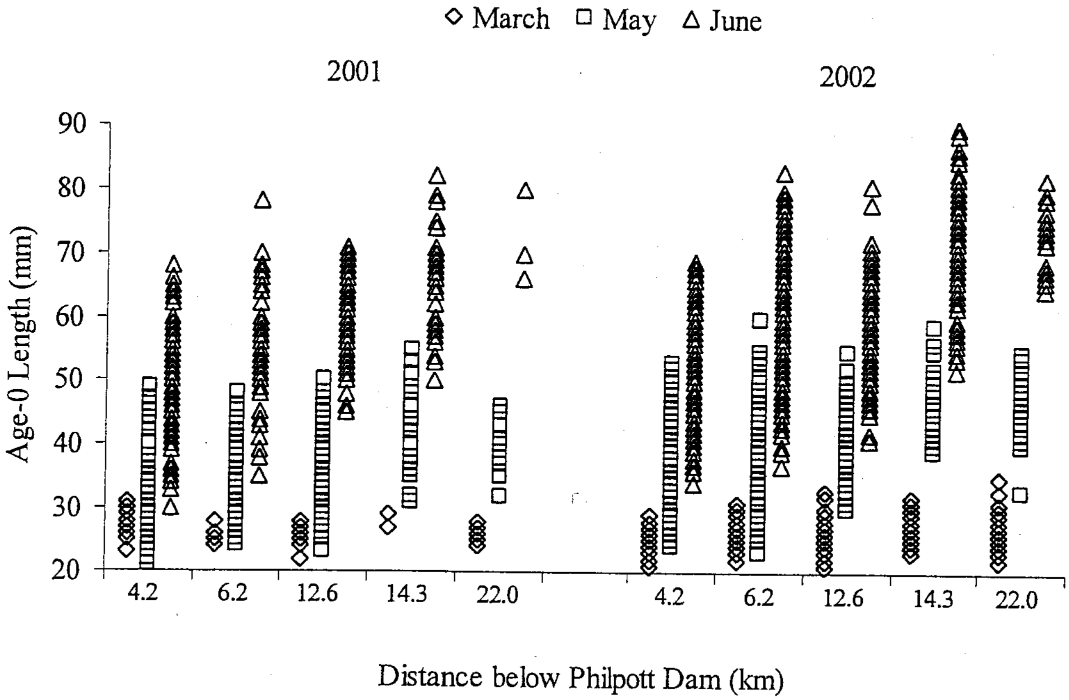


Figure 8. Total length (mm) of individual age-0 brown trout sampled during March, May, and June 2001 and 2002 at five locations downstream of Philpott dam, Smith River, VA.

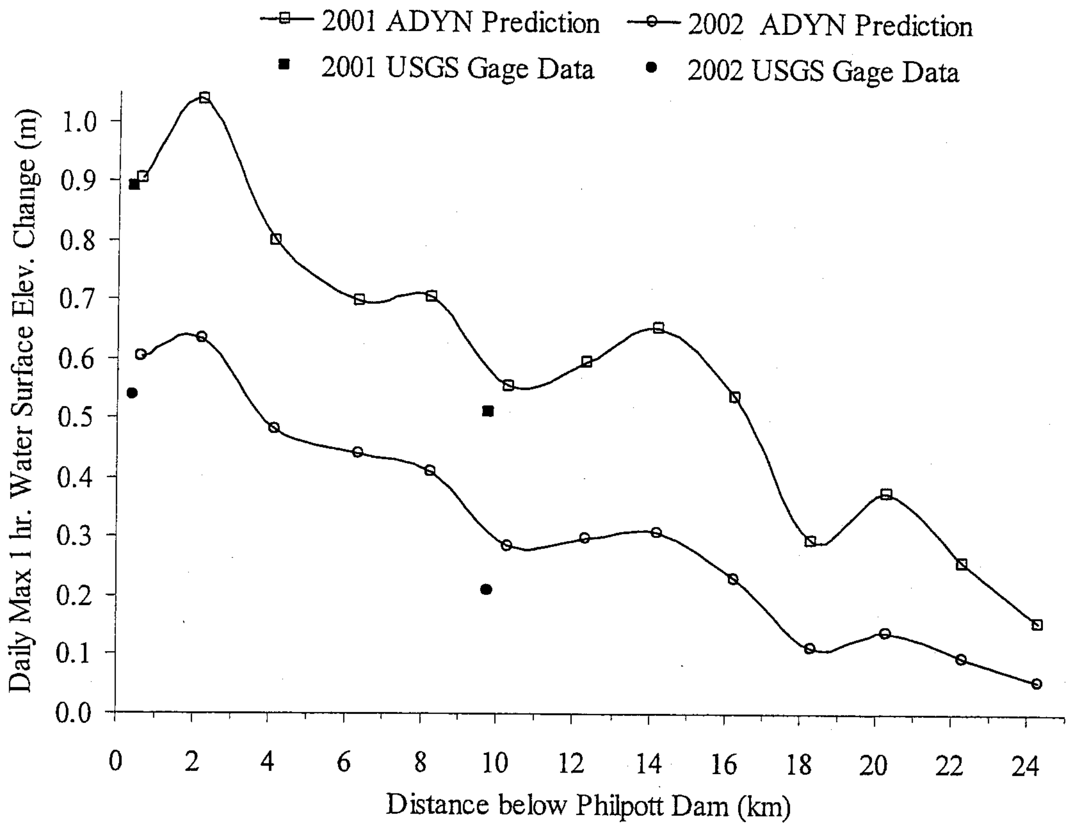


Figure 9. Daily maximum hourly water surface elevation change (m) averaged from March 15 to April 23 for 2001 and 2002 (excluding non-generation weekends) at 2 km intervals below Philpott dam for ADYN model predictions and USGS gage data. Data derived from ADYN hydraulic model predictions assumed lateral inflow to be constant representative flows over the predicted time period.

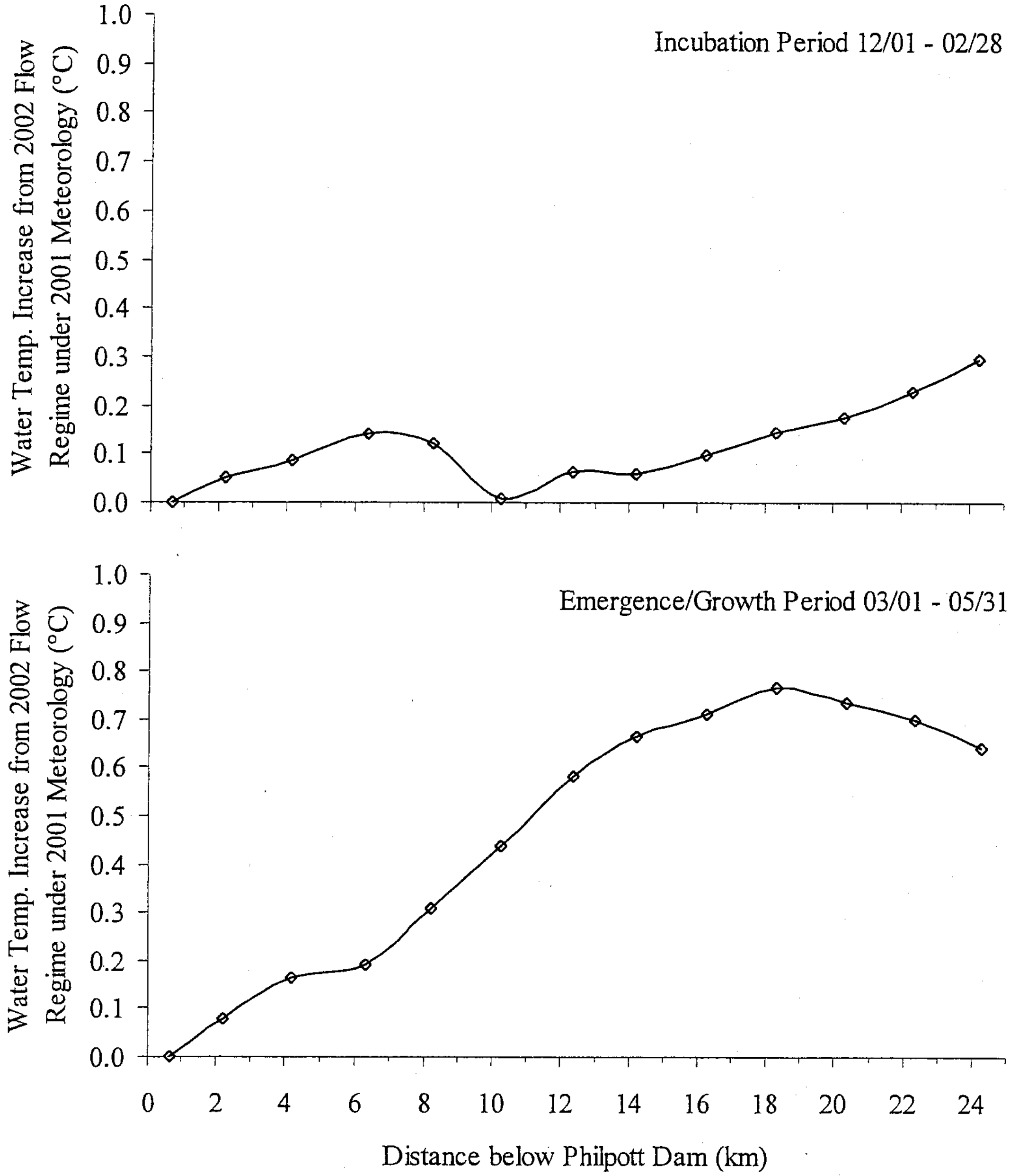


Figure 10. Average change in water temperature (°C) predicted with the ADYN & RQUAL model if the 2002 Smith River flow regime occurred during 2001 (i.e., under 2001 meteorological conditions). This modeling exercise shows that the 2002 flow regime produces warmer water temperatures than the 2001 flow regime regardless of meteorological conditions.

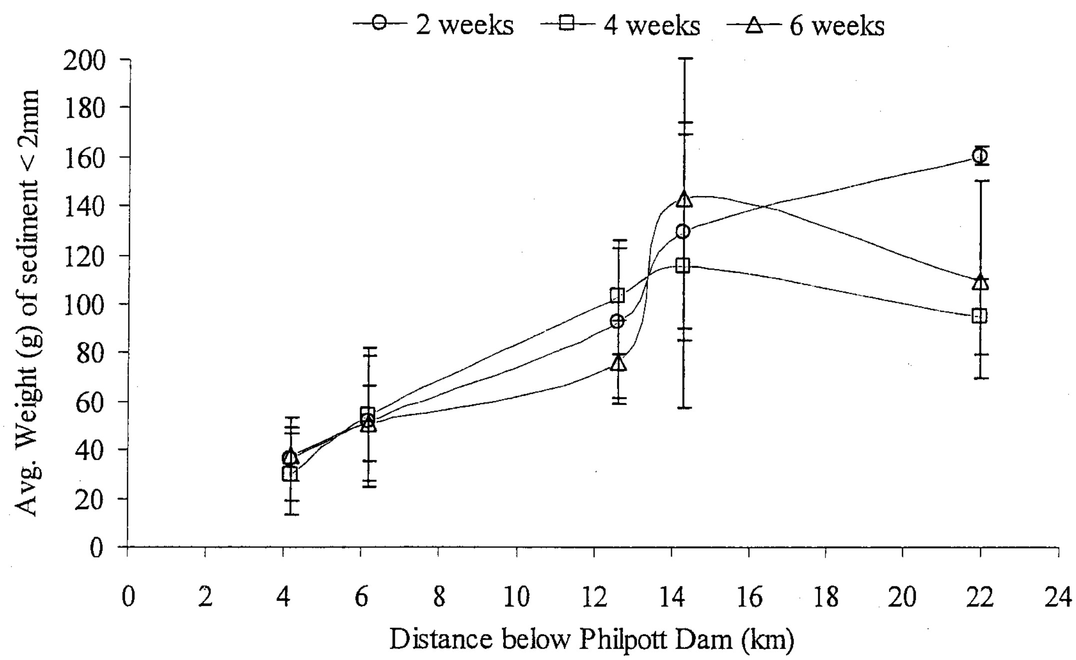


Figure 11. Average weight (g) of sediment <2 mm intruded over 2, 4, and 6 weeks (summer 2002) into vibert boxes at 4.2, 6.2, 12.6, 14.3, and 22.0 km below Philpott dam, Smith River, VA. Error bars represent ±2SE.

Job 2: Determinants of Brown Trout Growth and Abundance and Patterns of Nongame Abundance and Distribution

Job Objective: To collect biological data to quantify relative abundance of trout and nongame fishes in Smith River from Philpott Dam to Martinsville, quantify temperature limits on fish occurrence, and monitor annual variation in brown trout recruitment success. To evaluate the bioenergetic constraints on trout growth under existing temperature regimes. To evaluate longitudinal patterns of nongame fish abundance in relation to biological and physical components.

Job 2 has several objectives that aim to assess the brown trout population and the nongame fish community. These objectives seek to evaluate the factors that influence the community structure and population dynamics of fish in the tailwater.

Several specific objectives have been determined under Job 2 to evaluate the brown trout population and the possible constraints on the population. These objectives include; assessment of longitudinal trends in population dynamics of brown trout in the Smith River, evaluation of seasonal diets of the brown trout in the tailwater, evaluation and modeling of forage and thermal constraints on the brown trout, and to assess the metabolic response of brown trout under two acutely fluxing thermal regimes.

Within the Smith River tailwater, thermal and flow regimes are predicted to influence the brown trout population. However, environmental variations can also influence food availability and ultimately the amount of food that trout can consume. In addition, brown trout diet composition can vary on spatial and temporal scales. To determine the role that food consumption is having in structuring the growth rates of trout, a study was initiated to determine daily consumption rates of brown trout in four reaches, which will be used in subsequent bioenergetics models. The inclusion of the diet study will lead to a greater understanding of the limitations in the tailwater.

Understanding patterns of nongame fish abundance and diversity in the Smith River tailwater will aid in management choices to maintain a healthy fishery. There are four working hypotheses that will be assessed. First, the community structure of nongame fish persists over time with a stable pattern of abundance and diversity along a longitudinal gradient both annually and seasonally. A spatial pattern of recovery, in terms of increased numbers and diversity of fish, occurs at tributary junctions, or areas in the mainstem that are adjacent to tributaries. The highest abundance and diversity of nongame fish is present in areas with high levels of primary productivity. Finally, the highest levels of primary productivity will occur in areas directly below tributary confluences.

Procedures

Fish collection - Brown trout and nongame fish populations were assessed at 12 locations from Philpott Dam to Martinsville beginning in June 2000 and continuing through June 2002. Fish were sampled in June and October 2000, April, June, and October 2001, and April and June 2002. Fish were collected with multiple mobile anode pulsed DC barge electrofishers. During the June sampling periods, three-pass depletion electrofishing was conducted on 100-m sections at each location that were enclosed with block nets, while single pass electrofishing was conducted on other sampling dates. Maximum-likelihood population estimates and 95% confidence intervals were calculated for the June sampling periods based on the catch rates from the three passes using Microfish 3.0 (Van Deventer and Platts 1983).

During June 2000, brown trout larger than 100 mm were implanted with PIT (Passive Integrated Transponder) tags (Biomark™, Inc.). Because tag recapture rates were low during the June 2001 sampling period, additional tagging of brown trout (>70 mm) occurred during October 2001 (Table 1). All trout during each sampling period were measured to the nearest mm (total length), weighed to the nearest 1 gram, and scanned for the presence of a PIT tag.

Chlorophyll a - The rate of primary production at 20 sites in the Smith River tailwater was estimated by collecting rock samples and extracting chlorophyll a. The sites chosen correspond with the 12 fish sampling sites and 8 additional sites, one above and below each of the 4 main tributary junctions. Five rocks were collected from a riffle in each site the last week of June 2002. The rocks were frozen and transported to a lab facility at Virginia Tech where the upper surface of the rock was scrubbed to remove any plant or algae growth. Laboratory protocols were followed to extract the chlorophyll a. A spectrophotometer was used to read the optical density of each sample and absorbance readings were converted into ug/cm^2 of chlororphyll a present. Due to high quantities of filamentous plant growth on a portion of the rock samples, chlorophyll a was not extracted for some sites including: below Towne Creek, site 4 (6.2 RKM), and site 12 (23 RKM).

<u>Analyses</u>

Brown trout cohorts - The 12 sampling sites were assigned to four reaches based on current management regulations and gross morphometric habitat variations between the reaches (Table 2). To observe patterns in trout growth, brown trout from each reach were divided into cohorts prior to further analysis. Brown trout were divided into cohorts based on length-frequency analysis, and recaptured fish with PIT tags validated cohorts. Trout otoliths were used to validate length-at-age for the cohorts. Otoliths were removed from trout, adhered to microscope slides, and sanded to allow light to pass through the otolith. The otolith was then viewed using an imaging system (Image Pro-Plus ® software), which allowed the digital enhancement of the image to aid in identification of the annuli. Each cohort was analyzed for significant differences in length based on sampling date and reach using analysis of variance (ANOVA; GLM procedure) using SAS Version 8.0. Relationships were considered significant at a 0.05 alpha level. If significant differences were found among the reaches, a mean separation test was used to determine which reaches were significantly different from one another.

Brown trout diet composition - On February 5 and 8 (winter) and May 21 and 23 (spring), 2002, a total of 80 age-1 and older brown trout were collected each season to obtain stomach content samples. During each season, in each reach, five trout were collected every six hours over a 24-hour period using a backpack electrofisher. Trout were sacrificed to obtain stomachs and otoliths. Stomach contents were preserved in 10% formalin and returned to the laboratory for further analysis. Stomach contents were identified, enumerated, and weighed to the nearest 0.001 grams.

Regression analysis - Nongame fish data collected during June/October 2000 and April 2001 was analyzed using multiple linear regression. Relative abundance of nongame fish (# of fish per 100m) over the three time periods was the dependent variable for the regression model. The predictor variables used in the full model include: brown trout relative abundance, mean monthly temperature, tributary location, maximum hourly temperature flux, and difference between maximum and minimum daily flow. A stepwise regression procedure was used to reduce the model. Model reduction was employed in order to achieve the fewest variables that explain the highest amount of variability in nongame abundance. Nongame fish data for the time periods June/October 2001 and April/June 2002 were not analyzed because complimentary temperature data is not available at this time.

Results and Discussion

Brown trout cohort assessment - Growth rates can vary over the lifespan of fish, so comparisons of trout growth among the reaches needed to be assessed by cohorts. By comparing individual cohorts, differences in growth, based on fish age, was accounted for. Cohort analysis also allowed for the comparison of different age-classes among the years to test for yearly differences. The following descriptions of the cohorts describe the mean total lengths of trout over time from the individual reaches.

1998 Cohort: The 1998 cohort was 2-years of age when sampling began in June 2000. Significant differences were found in the mean total length of the brown trout between the reaches ($P<0.0001$). Reaches were also significantly different for all sampling periods ($P<0.0001$). A mean separation test determined that trout in the Dam reach were significantly smaller during all time periods, with the two downstream reaches (Bassett and Kohler) having trout that are significantly larger during the sampling periods (Table 3).

1999 Cohort: The 1999 cohort was 1-year of age when sampling began in June 2000. Significant differences were found in the mean total length of the brown trout between the reaches ($P<0.0001$). Reaches were also significantly different for all sampling periods ($P<0.0001$). Mean separation tests determined that the trout in the Dam reach were significantly smaller during all time periods, with the two downstream reaches (Bassett and Kohler) yielding significantly larger trout during the sampling periods (Table 4).

2000 Cohort: Collection of the 2000 cohort began when the trout were age-0 during June 2000. Significant differences in mean total length were found between reaches ($P<0.0001$). Further analysis revealed that all reaches were significantly different based on sampling dates ($P<0.0001$). Based on mean separation tests, brown trout from the Dam reach were significantly smaller than trout from the two farthest downstream reaches (Table 5).

2001 Cohort: Collection of the 2001 cohort began when the trout were age-0 in April 2001. Significant differences in mean total length of brown trout were found between reaches ($P<0.0001$). Further analysis revealed that mean total length was not significantly different between reaches during the April, 2001, sample (P=0.694); however, all reaches were significantly different based on sampling dates for all other sampling periods (P<0.0001). Based on mean separation tests, brown trout from the Dam reach were significantly smaller after the April 2001, sample than trout from the two farthest downstream reaches (Table 6).

<u>2002 Cohort</u>: Collection of the 2002 cohort began when the trout were age-0 in April 2002. Significant differences in mean total length of brown trout were found between reaches (P<0.0001). Further analysis revealed that mean total length was not significantly different between reaches during the April, 2002, sample (P=0.545); however, all reaches were significantly different based on sampling dates for all other sampling periods (P<0.0001). Based on mean separation tests, brown trout were significantly larger in the Kohler reach than in all other reaches after the April 2002, sample (Table 7).

Analysis of the mean total length of trout from the reaches indicated that trout from the Dam Reach were significantly smaller than trout from the other three reaches; however, no significant differences were found in mean total length of trout in the 2001 and 2002 cohort when the trout were initially sampled in April. By June, however, significant differences were observed in the mean total length of trout. It appears that significant differences in growth occur during the April to June time period, which may account for differences in mean total length during the June time period.

Age Analysis - Because significant differences were found between reaches in the cohort analysis, statistical analyses were conducted on age-0 and age-1 from each cohort from each reach. In the analysis of age-0 trout, the 2000, 2001, and 2002 cohorts were examined. For the analysis on age-1 trout, the 1999, 2000, and 2001 cohorts were examined.

<u>Age-0 brown trout</u>: Within the Dam Reach, significant differences were observed between the three cohorts (P<0.0001; Figure 1). Separation tests conducted on the age-0 year class from the Dam reach indicated that mean total length of age-0 trout was significantly higher in 2002, with smaller age-1 trout being observed with the 2000 cohort (P<0.0001; Table 8). In the Special Regulations reach, significant differences were observed (P=0.0352; Table 8), with larger age-0 trout occurring in the 2000 cohort. Mean total lengths of age-0 brown trout were significantly different in the Bassett reach (P=0.0221; Table 8), with smaller lengths in the 2001 cohort. In the Kohler reach, no significant differences were observed in mean total length of age-0 trout from the three cohorts (P=0.2326; Table 8).

<u>Age-1 brown trout</u>: Within the Dam Reach, significant differences were observed between the three cohorts (P<0.0001; Figure 1). Separation tests conducted on the age-1 year class from the Dam reach indicated that mean total length of age-1 trout was significantly higher in 1999, with smaller age-1 trout being observed with the 2000 cohort (P<0.0001; Table 9). In the Special Regulations reach, significant differences were observed (P=0.0005; Table 9), with larger age-0 trout occurring in the 2000 cohort. Mean total lengths of age-1 brown trout were significantly different in the Bassett reach (P<0.0001; Table 9), with smaller lengths in the 2001 cohort. In the Kohler reach, significant differences were observed in mean total length of age-1 trout from the three cohorts (P<0.0001; Table 9), with the largest trout being observed in the 2000 cohort.

Analysis of length-at-age data from the different cohorts indicated that significant differences were observed among the different years. Further analysis is needed to determine which factors contributed to differences among the years.

Brown trout abundance - Population estimates were calculated for the 12 sampling sites using the 3-pass depletion data obtained in June 2000, June 2001, and June 2002. Trends in population estimates were similar in 2000 and 2001; however, in 2002, trends were inconsistent with previous sampling years (Figure 2). Population estimates for age-1 and older brown trout at the site 0.5 km downstream of Philpott Dam are higher than in previous years, while population estimates at distances of 3.4, 4.2, 6.2, and 8.9 km downstream of Philpott Dam are lower than in previous years (Figure 2). For age-0 trout, the population estimates were much higher in 2002 than in previous years (Figure 2).

Brown trout diet analysis - Eighty brown trout were collected from each of the two sampling seasons. Initial analysis on trout collected during the winter, indicate that trout in all reaches are consuming Ephemeroptera. Isopoda are an important diet item for trout in Reach 1. Plecoptera, Trichoptera, and Diptera are also present in the diets. One sample contained fish. Only one stomach of the 80 collected was empty. During the spring sample, only one stomach of the 80 was empty. A variety of items were observed in the stomach contents including terrestrial insects and crayfish. Five fish out of 80 had fish in their stomach contents.

Nongame regression model - A correlation matrix of the six variables in the nongame regression model aided our understanding of the linear relationship between the variables as well as the strength of that relationship. The relationships marked by strong correlations are those of tributary location, mean monthly temperature, and brown trout abundance with nongame fish abundance as well as brown trout abundance with mean monthly temperature (Table 10). The correlation matrix is also important because it reveals a collinearity problem if one of the pairwise correlations exceeds 0.9 or several exceed 0.7. Variables should be removed from the model if collinearity is present in order to prevent redundant variables being present in the model (i.e. those sharing too much information). No variables used in the multiple linear regression model for this report have such high pairwise correlations.

The model chosen by the stepwise regression procedure is a 3-regressor model including the variables brown trout relative abundance, mean monthly temperature, and tributary location. This model explains 60% of the variance in nongame fish abundance at a significant level ($p = < 0.0001$). The parameter estimates from the model were used to predict nongame abundance using the following equation:

$$\text{nongame abundance} = -48.72 + \text{tributary}\ (65.35) + \text{mean temperature}\ (3.35) + \text{brown trout abundance}\ (-0.39)$$

Figure 3 shows the changes in the response of the variables mean monthly temperature and brown trout abundance across the range of the observed values for those variables. By holding two of the variables constant in the above equation, the effect of one variable on nongame abundance is shown, conditional on the other variables being fixed at their mean values. Using this method, predicted values of nongame abundance are plotted with real numbers of nongame abundance. Mean monthly temperature influences nongame fish abundance in that as temperature increases, nongame numbers increase. Conversely, as brown trout numbers decrease, nongame numbers increase (Figure 3). The change in the response of tributary location is not plotted with respect to the other two variables, due to the binary nature of tributary location. Instead, nongame abundance is plotted with distance from the dam and the tributary locations are highlighted (Figure 4). Tributary locations are consistently marked with higher numbers of nongame fish.

The chlorophyll a extractions from 17 sites in the Smith River do not show a distinct general trend of high levels of chlorophyll a in sites directly below tributary confluences, or of any longitudinal trend such as increasing chlorophyll a content with increasing distance from the dam (Figure 5, Table 11). Instead, the highest level of chlorophyll a was found at site 1 (RKM 0.5), directly below the dam. The second highest level occurred at site 8 (RKM 15.3), and a marked change in chlorophyll a content occurred between the sites above and below Jordan Creek. The site below Jordan Creek at 21.2 RKM showed higher levels of chlorophyll a content than the site above the tributary.

Roanoke logperch update - A complete table of catch data for the Roanoke logperch is included showing the date of catch, number caught, and location over all sampling periods (Table 12). The complete data set for Roanoke logperch catch indicates that there does exist an extant population of this endangered species in the mainstem of the Smith River. No Roanoke logperch has been caught above site 5 (RKM 8.9).

Conclusions

Cohort analysis determined that brown trout are significantly smaller in the Dam reach, while significantly larger brown trout occur in the lower reaches of the river, particularly the Bassett and Kohler reaches. Significant differences were found for every time period except for April 2001, for the 2001 cohort and April 2002, for the 2002, indicating that trout emerge at the same size within the tailwater; however, between the April to June time period, growth of age-0 brown trout increases rapidly downstream of the Dam reach, causing significant differences in total length of trout in subsequent sampling periods. Closer evaluation of age-0 brown trout during the April to June time period may lend insight into the reasons for the increased growth at lower reaches.

In 2002, the number of age-0 brown trout increased in addition to being significantly larger. This may be related to the reduction in generation peaking flows. However, the reduction may have also altered the invertebrate community, which could lead to increased forage for the trout. Based on the diet analysis, it appears that aquatic macroinvertebrates (in the winter) and terrestrial insects (in the spring) are important components of the trout diets, so if the macroinvertebrate community were to improve due to altered flow regimes, the brown trout may benefit. Invertebrate samples were collected in July 2002 to determine if there have been changes in the invertebrate community since 2001.

Multiple linear regression analysis allows the selection of variables that are significant predictors of nongame abundance in the presence of one another. The primary utility of this analysis is *inference* about what biological mechanisms most influence nongame abundance. The problems of "data dredging" or "overfitting" commonly associated with stepwise regression can lead to false parameter estimates or nonimportant variables included in the resulting model (Burnham 1998). In order to make a valid inference, careful consideration was made of what variables to include in the model and what form these variables should take. If anything, the resulting model is not a product of overfitting, but "underfitting" or possible exclusion of other pertinent variables.

A stable pattern of nongame community structure has emerged over time with peaks of both abundance and diversity at tributary junctions. Based on the regression results, tributary location plays an influential role in nongame fish numbers. The conclusion is that a tributary effect is present in the Smith River such that nongame community structure is affected at tributary junctions. From the chlorophyll a preliminary results, this effect does not appear to be based on bottom-up trophic dynamics. The original working hypothesis that the highest abundance and diversity of nongame fish should be present in areas with high levels of primary productivity is false. Also, the highest levels of chlorophyll a were not present below tributaries. The same result was found in another study measuring chlorophyll a both above and below tributaries in order to distinguish a tributary effect (Cushing 1983). The June 2002 chlorophyll sampling will be compared with a July 2002 extraction from all 20 sites to see if there is continuity between results. Ash-free dry mass (AFDM) will be calculated for all 20 sites in order to include the 3 sites in the analysis that have high levels of filamentous plant growth.

In addition to a tributary effect, temperature and brown trout abundance drive mechanisms shaping the response of nongame numbers. An evolutionary stable strategy for a nongame fish would be to reside in an area of the Smith River tailwater that provides less extreme thermal habitat. Very few nongame fish are found in the first 4 RKM below the dam with the exception of the green sunfish and white sucker. The majority of the nongame fish must be choosing to not occupy this area because they have adopted a better strategy that will increase their chances of surviving and reproducing. The inference from the strong relationship between nongame abundance and temperature is that these fish survive better in warmer temperatures downstream from the dam.

Nongame fish do not reside in areas with high numbers of brown trout. Preliminary stomach analyses show that few nongame fish have been consumed by brown trout. Thus, patterns of nongame fish abundance do not appear to be driven by predation pressure. Rather, the inverse relationship between nongame abundance and brown trout abundance could be more a function of habitat, whether thermal or composition of substrate.

In conclusion, multiple causes often interact to produce biological processes and patterns. For the nongame fish in the Smith River, tributary effect and temperature prove to be the most influential (based on multiple linear regression results) and biologically-meaningful factors that influence nongame abundance.

Future Research and Job Schedule

Future research activities on brown trout include the continuation of the diet analysis study with additional diet sampling in the fall and spring. This will allow the comparisons of diet composition and consumption across all seasons. In addition, a laboratory study on the oxygen consumption rates of brown trout under two acutely fluxing thermal regimes will allow for a greater understanding of the effects of fluxing temperatures on brown trout. Both the diet information and the oxygen consumption parameters will be combined in a bioenergetics model to fully evaluate potential constraints and predict trout growth under alternative thermal regimes. In addition, regression analysis will be used to evaluate the potential factors (including temperature variables, flow variables, trout and nongame fish abundance, and habitat variables) on growth limitations. Continuation of trout sampling in October 2002, and April and June 2003 will allow for further analysis of differences in growth rates among years.

Future research activities on nongame fish include single species analyses with additional regression models for the four most common species in the Smith River: bluehead chub, fantail darter, white sucker, and spottail shiner. An additional chlorophyll a extraction from July, 2002 rock samples will be performed using the same procedures as for the June extraction. Finally, data collected from the bluehead chub and fantail darter spawning surveys will be analyzed for the April-July 2002 spawning location habitat variables and habitat availability data.

Job 2 Schedule. The following table is an overview of the Job 2 Schedule including activities related to brown trout and nongame components of the study (mainstem and tributaries). All aspects of Job 2 are on schedule with no significant changes anticipated. Reporting period extends to bold line.

Calendar Year	1999	2000				2001				2002				2003				2004			
Project Year	Year 1			Year 2				Year 3				Year 4				Year 5					
Quarter	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
Focus: Brown trout																					
3-pass depletion				X				X				X				X					
PIT tagging				X					X				X								
Habitat mapping				X					X	X											
Data analysis				X	X	X	X	X				X	X	X	X	X	X	X			
Recapture				X	X		X	X	X		X	X	X		X	X	X				
Stomach sample collection										X	X	X	X								
Diet analysis										X	X	X	X	X							
Monthly temp monitoring								X	X	X	X	X	X	X							
Otolith preparation and aging								X	X	X	X		X	X	X						
Bioenergetics modeling									X	X			X	X			X				
Fluxing thermal regime (lab)										X	X	X	X	X	X						
Work plan preparation						X	X														
Annual report				X				X				X				X					
Dissertation writing																	X	X	X		
Manuscript preparation																	X	X	X		
Focus: Nongame species																					
Habitat sampling								X	X												
Chlorophyll a sampling									X	X	X	X									
Fish sampling									X	X	X	X	X		X	X	X				
Spectrophotometry labwork										X	X	X									
Spawning surveys											X	X									
Data analysis										X	X	X									
Report writing								X	X	X	X	X	X								
MS Thesis												X	X								
Manuscript preparation												X	X								

Table 1. Number of brown trout tagged in June 2000, number of recaptured in June 2001 that were originally tagged in June 2000, the number of brown trout tagged in the 12 study sites in October 2001, and the number of trout recaptured in June 2002 that were tagged in October 2001 in the Smith River, Virginia, tailwater.

Distance from Philpott Dam (km)	Number tagged in June 2000	June 2001Recaptures for trout tagged in June 2000	Number tagged in October 2001	June 2002 Recaptures for trout tagged in October 2001
0.5	77	6	105	26
3.4	252	46	235	114
4.2	423	71	238	75
6.2	235	44	238	49
8.9	270	65	317	56
11.3	170	14	226	55
12.6	17	3	147	26
14.3	101	6	112	20
15.9	90	1	89	6
18.9	71	22	91	6
20.1	82	0	56	12
23	86	6	98	21

Table 2. Location in the tailwater, Virginia Department of Game and Inland Fisheries (VDGIF) management regulation (creel limit and minimum length limit), and general habitat description of the four reaches in the Smith River, Virginia. Non-game abundances and standard errors (SE) are mean values from 3-pass depletion estimates in June 2000 (Orth 2000).

Reach	Location from Philpott Dam (km)	Sampling sites in reach	VDGIF trout regulation	General habitat	Non-game abundances in number per 100 m (SE)
Dam	0-5.3	1,2,3	6 trout; 178 mm	Short riffle:run segments; substrate dominated by bedrock, boulders, and cobble	17 (10.9)
Special regulations	5.3-10	4,5	2 trout; 406 mm	Short riffle:run segments; substrate dominated by bedrock, boulders, cobble, and pebbles	290 (25.5)
Bassett	10-15.9	6,7,8	6 trout; 178 mm	Long run segments; substrate dominated by pebbles and sand	384 (86.7)
Kohler	15.9-24	9,10,11,12	6 trout; 178 mm	Long, deep pools and short riffles; dominant substrate is silt and sand; few boulders	347 (100.3)

Table 3. Mean total length for the 1998 brown trout cohort beginning in June 2000, and continuing through June 2002 from 4 sampling reaches in the Smith River, Virginia. Brown trout were collected using paired multiple anode barge electrofishing units. Mean total lengths with the same letter for the sampling period are not significantly different between reaches.

	Reach			
	Dam	Special Regulation	Bassett	Kohler
June 2000	229.9 c	247.1 b	276.0 a	277.8 a
October 2000	243.4 d	256.9 c	295.7 b	302.2 a
April 2001	254.9 d	271.4 c	294.0 b	310.6 a
June 2001	258.4 d	275.3 c	311.8 b	334.6 a
October 2001	270.6 c	291.1 b	346.6 a	334.8 a
April 2002	272.6 c	293.4 b	350.5 a	336.8 a
June 2002	276.9 c	310.0 b	335.0 a	344.3 a

Table 4. Mean total length for the 1999 brown trout cohort beginning in June 2000, and continuing through June 2002 from 4 sampling reaches in the Smith River, Virginia. Brown trout were collected using paired multiple anode barge electrofishing units. Mean total lengths with the same letter for the sampling period are not significantly different between reaches.

	Reach			
	Dam	Special Regulation	Bassett	Kohler
June 2000	148.5 c	171.4 b	185.7 a	188.6 a
October 2000	178.8 d	196.2 c	219.5 b	225.4 a
April 2001	196.8 d	230.3 c	242.2 b	253.5 a
June 2001	212.6 d	239.5 c	255.4 b	270.7 a
October 2001	227.0 d	254.2 c	271.3 b	262.9 a
April 2002	243.9 c	268.5 b	285.2 a	287.7 a
June 2002	249.6 c	274.3 b	285.8 a	294.0 a

Table 5. Mean total length for the 2000 brown trout cohort beginning in June 2000, and continuing through June 2002 from 4 sampling reaches in the Smith River, Virginia. Brown trout were collected using paired multiple anode barge electrofishing units. Mean total lengths with the same letter for the sampling period are not significantly different between reaches.

	Reach			
	Dam	Special Regulation	Bassett	Kohler
June 2000	37.2 c	60.6 b	63.4 a	64.2 a
October 2000	82.6 d	108.6 c	114.4 b	123.7 a
April 2001	116.3 d	143.3 c	150.1 b	163.2 a
June 2001	136.3 d	176.8 c	183.0 b	197.6 a
October 2001	169.1 d	206.2 c	211.8 b	217.5 a
April 2002	193.8 c	231.4 b	233.4 b	247.5 a
June 2002	207.0 c	235.0 b	238.9 b	245.7 a

Table 6. Mean total length for the 2001 brown trout cohort beginning in April 2001, and continuing through June 2002 from 4 sampling reaches in the Smith River, Virginia. Brown trout were collected using paired multiple anode barge electrofishing units. Mean total lengths with the same letter for the sampling period are not significantly different between reaches.

	Reach			
	Dam	Special Regulation	Bassett	Kohler
April 2001	31.0 a	27.2 a	30.3 a	*
June 2001	43.0 d	58.8 c	61.3 b	64.2 a
October 2001	82.2 d	110.0 c	114.6 b	117.6 a
April 2002	121.1 c	149.8 b	153.5 a	155.6 a
June 2002	139.1 c	173.4 b	178.6 a	176.2 ab

*No brown trout from the 2001 cohort were collected in the Kohler Reach in April 2002.

Table 7. Mean total length for the 2002 brown trout cohort beginning in April 2002, and continuing through June 2002 from 4 sampling reaches in the Smith River, Virginia. Brown trout were collected using paired multiple anode barge electrofishing units. Mean total lengths with the same letter for the sampling period are not significantly different between reaches.

	Reach			
	Dam	Special Regulation	Bassett	Kohler
April 2002	30.5 a	28.8 a	28.3 a	33.8 a
June 2002	52.0 d	60.1 c	63.5 b	65.6 a

Table 8. Mean total lengths of age-0 brown trout from the 2000, 2001, and 2002 cohorts during June 2000, 2001, and 2002, respectively, from four reaches in the Smith River, Virginia, tailwater. Means within the reach with the same letter are not significantly different between cohorts.

	Cohort		
	2000	2001	2002
Dam Reach	37.2 c	43.0 b	52.0 a
Special Regulations Reach	60.6 a	58.8 b	60.1 ab
Bassett Reach	63.4 a	61.3 b	63.5 a
Kohler Reach	64.2 a	64.2 a	65.6 a

Table 9. Mean total lengths for age-1 brown trout from the 1999, 2000, and 2001 cohorts during June 2000, 2001, and 2002, respectively, from four reaches in the Smith River, Virginia, tailwater. Means within the reach with the same letter are not significantly different between cohorts.

	Cohort		
	1999	2000	2001
Dam Reach	148.5 a	136.3 c	139.1 b
Special Regulations Reach	171.4 b	176.8 a	173.4 b
Bassett Reach	185.7 a	183.0 a	178.6 b
Kohler Reach	188.6 b	197.6 a	176.2 c

Table 10. Correlation matrix for six parameters related to Smith River, VA. Significantly correlated variables at the 0.05 level are in bold.

	Nongame abundance	Tributary location	Temperature flux	Mean daily temperature	Difference in maximum and minimum flow	Brown trout abundance
Nongame abundance	*	**0.61** **< 0.0001**	- 0.01 0.966	**0.63** **< 0.0001**	0.05 0.766	**- 0.48** **0.003**
Tributary location		*	- 0.14 0.420	0.29 0.091	- 0.03 0.859	- 0.20 0.251
Temperature flux			*	**0.42** **0.012**	- 0.04 0.836	0.04 0.824
Mean daily temperature				*	0.13 0.467	- 0.42 0.010
Difference in maximum and minimum flow					*	0.22 0.189
Brown trout abundance						*

Table 11. Chlorophyll a extraction numbers by location.

Site	Distance from dam (km)	Chlorophyll a (ug/cm^2)
1	0.5	0.242
2	3.4	0.060
3	4.2	0.031
5	8.9	0.079
6	11.3	0.119
7	13	0.087
8	15.3	0.187
9	15.9	0.082
10	18.9	0.110
11	20.5	0.116
Upstream Towne Creek	5.3	0.146
Upstream Blackberry Creek	13.3	0.061
Downstream Blackberry Creek	13.5	0.063
Upstream Reed Creek	18.5	0.139
Downstream Reed Creek	18.7	0.133
Upstream Jordan Creek	21	0.031
Downstream Jordan Creek	21.2	0.100

Table 12. Roanoke Logperch, *Percina rex,* occurrence in twelve sites below Philpott Dam. Sampling periods included are June and October 2000, April, June, and October 2001, and April and June 2002.

Roanoke Logperch	Sampling Date	Location (km below dam)	Number Caught
ROL	June 2000	13	2
ROL	June 2000	20.5	3
ROL	April 2001	8.9	1
ROL	April 2001	11.3	1
ROL	April 2001	15.3	1
ROL	April 2001	18.9	1
ROL	April 2001	20.5	1
ROL	April 2001	23	1
ROL	June 2001	20.5	3
ROL	June 2001	23	7
ROL	October 2001	18.9	2
ROL	October 2001	20.5	4
ROL	April 2002	8.9	1
ROL	April 2002	15.9	1
ROL	April 2002	18.9	2
ROL	April 2002	20.5	2
ROL	April 2002	23	1
ROL	June 2002	15.9	1
ROL	June 2002	18.9	3
ROL	June 2002	20.5	1
ROL	June 2002	23	1

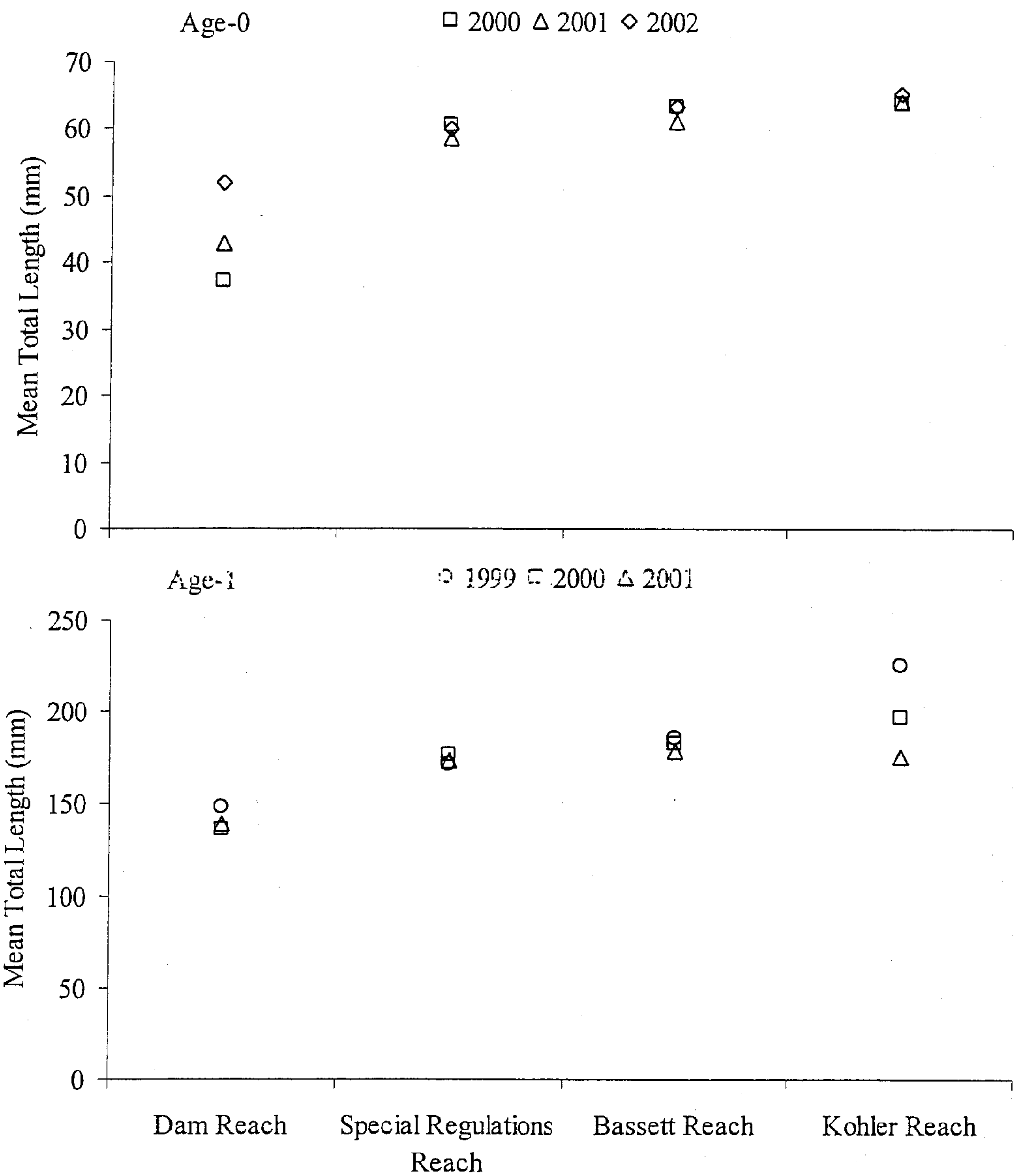


Figure 1. Mean total lengths of age-0 (top panel) and age-1 (bottom panel) brown trout from three cohorts collected from four reaches in the Smith River, Virginia, tailwater. Sampling was conducted in June 2000, June 2001, and June 2002 for the cohorts.

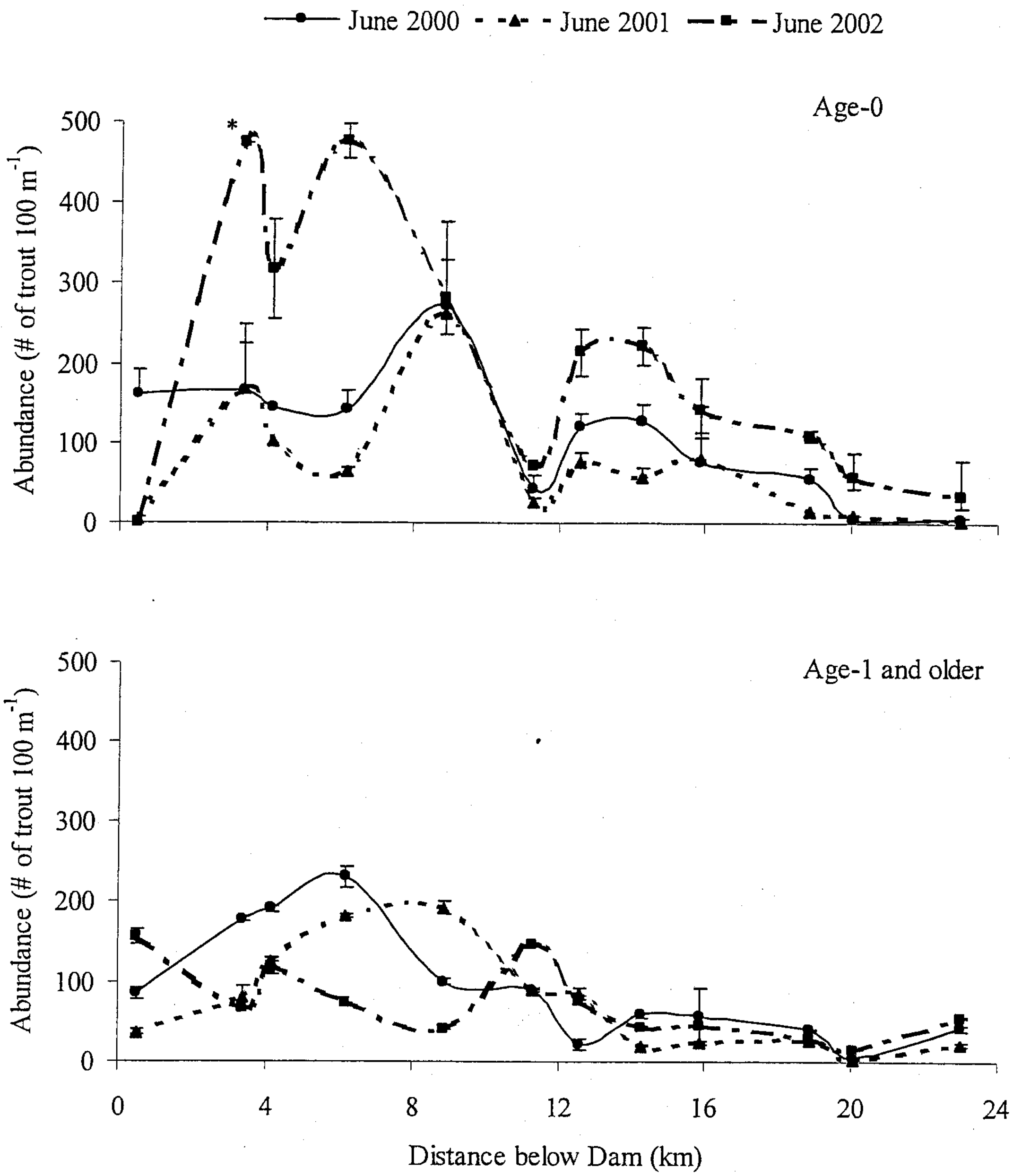


Figure 2. Population estimates (with 95% confidence intervals) for age-0 (lower) and adult (upper) brown trout from the Smith River, Virginia, sampled from 12, 100-m sections by 3-pass depletion electrofishing in June 2000, June 2001, and June 2002. Asterisk indicates that the population estimate for the site is not reliable because of non-descending catch data.

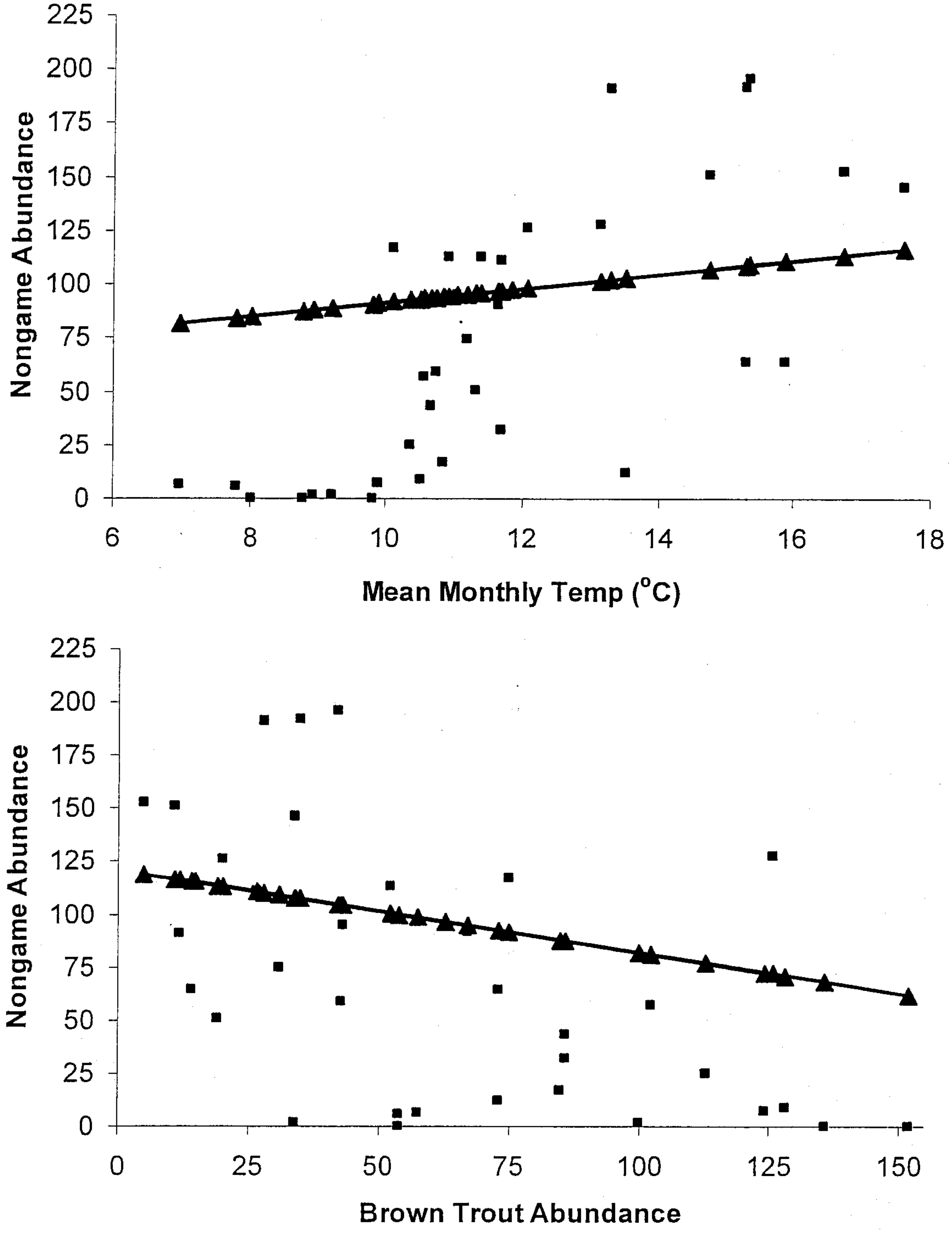


Figure 3. The relative abundance of nongame fish is plotted with mean monthly temperature and brown trout relative abundance using data from June, October 2000 and April 2001. A line is fitted to nongame abundance that was predicted using the best multiple linear regression model.

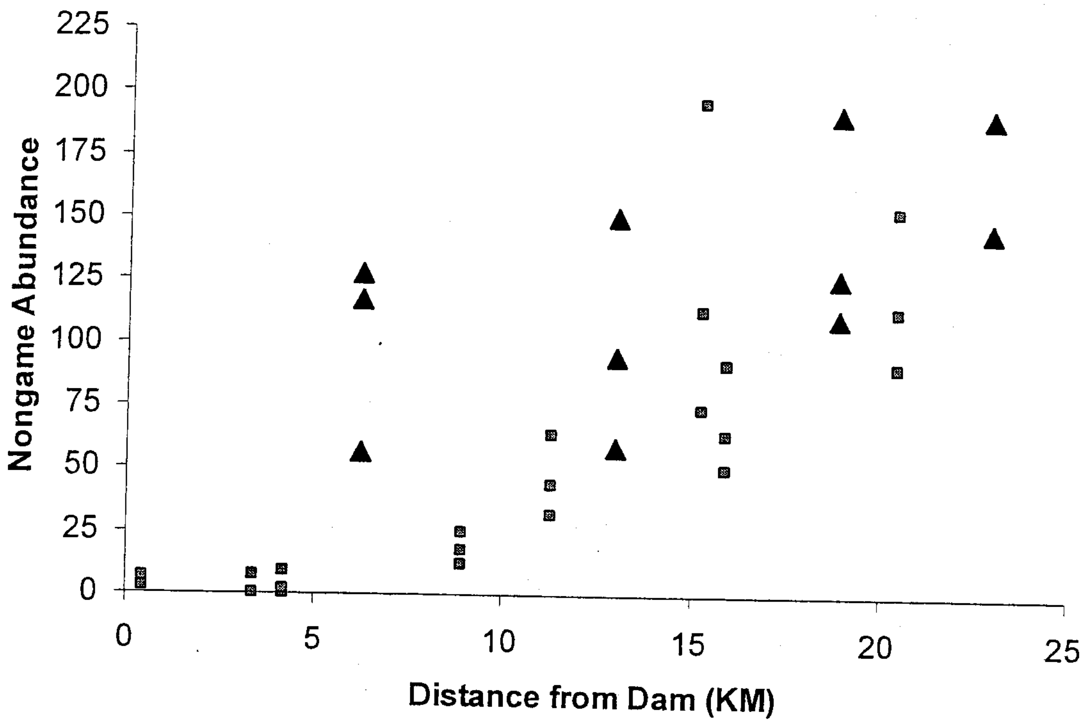


Figure 4. The relative abundance of nongame fish is plotted with distance from the dam using data from June, October 2000 and April 2001. The triangles represent those sites which are adjacent to a tributary junction.

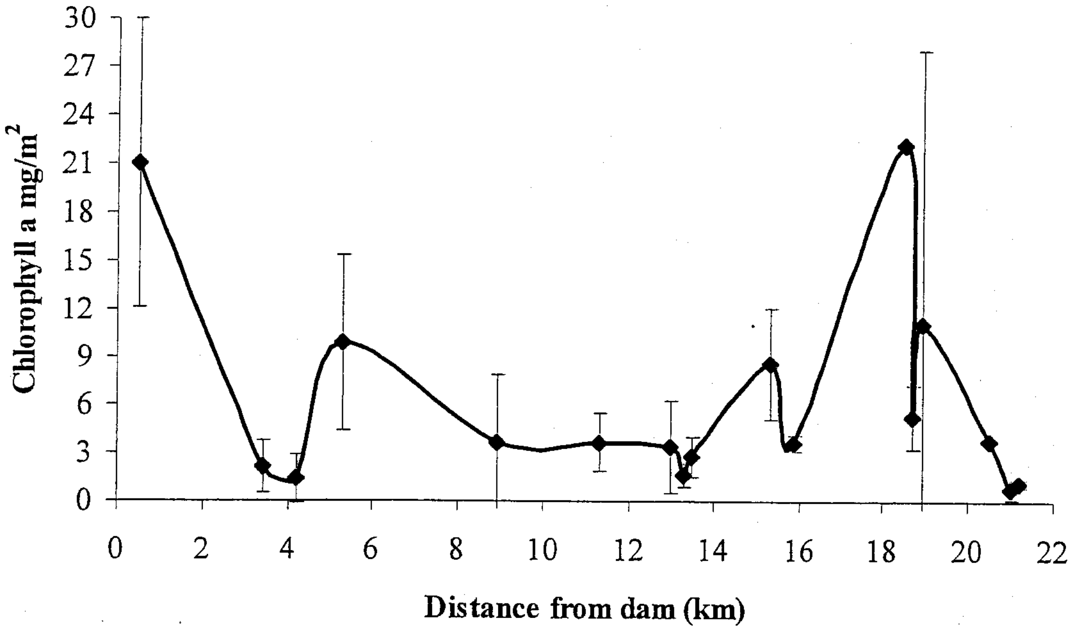


Figure 5. Results from chlorophyll a extractions are shown for 17 sites below the dam. Bars represent ± 2SE.

Job 3. Hydraulic Model Development and Application to Smith River Tailwater

<u>Job Objective</u>: To design a field survey and modeling protocol to measure effects of varying flows on the shear stress, mobilization of streambed gravels, and relate discharge to the amount of redd scouring or brown trout fry displacement that would occur at sites in the tailwater. This information coupled with flow records should permit prediction of catastrophic year-class failures and flow ranges that provide for acceptable reproduction.

One-Dimensional Numerical Method for Spawning Habitat Evaluation

PHABSIM (Physical HABitat SIMulation) is a part of the Instream Flow Incremental Methodology and has been widely used in North America for instream flow investigations (Shirvell 1989). From the measurements of water depth, water velocity, substrate, cover and temperature, PHABSIM is able to predict Weighted Usable Area (WUA), which is used as an indicator of fish habitat quality. Some studies suggested that good relationships between habitat predicted by this model and observed fish population (Orth and Maughan 1982) exist, while other studies have shown the opposite. The validity of the PHABSIM method has long been debated across the country. The purpose of this study is to check the relationship between brown trout spawning habitat and WUA predictions from PHABSIM at one site in the Smith River, Virginia.

Two-Dimensional Hydraulic Modeling for Physical Habitat Simulation

Growing evidence suggests that different aquatic organisms use, and surround themselves with, flow patterns that are not readily quantifiable or differentiable using standard habitat metrics (depth, velocity and substrate data) (Crowder and Diplas 2002a & b). For example, Kondolf et al. (2000) argued that fish often respond to features in their hydraulic environments, such as velocity gradients, over small length scales. Disturbed flows downstream of boulders and other obstructions are used by trout as feeding stations and influence the abundance and diversity of flora and fauna in a stream after floods.

Compared with one-dimensional models (e.g. PHABSIM), two-dimensional models hold the promise of providing a spatially explicit solution of the flow field (Waddle 2000). In the past a few years, two-dimensional hydraulic models have being intensively studied to assess stream habitat (Ghanem et al. 1996; Guay et al. 2000; Crowder and Diplas 2002a & b). Guay et al. (2000) evaluated the ability of 2-D numerical habitat models to predict the distribution of juveniles of Atlantic salmon. Waddle (2000) performed the comparisons of velocity and water surface elevation between PHABSIM and a 2-D finite element model.

To better understand the relationship between fish activity and their surrounding hydraulic environment, some hydraulic metrics with spatially explicit characteristics were tested and are discussed here. Froude number (Fr), which can be employed to distinguish between supercritical and subcritical flows, is a measure of the ratio of the kinetic energy to potential energy within a river, and provides an objective way to classify and analyze habitat units. Reynolds number, which can be used as a criterion to distinguish between laminar and turbulent flow, is another important parameter that influences drag forces acting on fish body. Bed shear stress (τ) is an important parameter since it is related to scour, sediment transport and redd stabilities. In addition, those spatial habitat metrics proposed by Crowder and Diplas (2000 & 2002a), were evaluated based on the results obtained from a two-dimensional numerical hydraulic model for the selected study site. These habitat metrics include kinetic energy, vorticity and circulation.

Flow Unsteadiness Parameter Analysis of Smith River fluctuations

The Smith River flow regime is characterized by long periods of steady discharge values, but interrupted by short periods of unsteady flows. Current habitat modeling approaches do not explicitly consider this dynamic aspect. In fact, peaking regimes impose abnormally unstable habitat conditions for fish due to rapid changes in flow on a daily basis (Cushman 1985). For spawning habitat, it is believed the instability of flow conditions has negative consequences on the reproductive success of trout. Sudden increases in discharge can destroy the redd constructions through unusually high shear stress and confuse female fish, which can dig several redds without attempting to spawn in any of them. When the peaking flow returns to baseflow the rapid decrease in discharge can force spawners to move out of the spawning sites.

Although in practice some researchers analyze the unsteady flow as quasi-steady, a sequence of increasing steady state flows with time, the validity of such an assumption under a variety of conditions is doubtful. For example, Rowinski et al. (2000) claimed that the traditional formula of friction velocity (U_*) is not acceptable for unsteady river flows, because the maximum values of bed shear stress (τ_0) which is closely related to U_* are several times larger than the values for base flow. Hence, in order to correctly characterize the unsteadiness of the Smith River flow patterns, three hydraulic parameters are considered: acceleration parameter ($\O$ Clauser parameter) and unsteadiness parameters Γ and α. If the calculated values for these parameters are beyond certain ranges, the influence of the Smith River transient flow regimes might be significant; otherwise, the flow may be approximated as being quasi-steady.

Procedures

One-Dimensional Numerical Method for Spawning Habitat Evaluation

The necessary physical and hydraulic data were collected from the previous year's investigation (Figure 1). For convenience and to simplify our problem, only four typical transects were included for the PHABSIM study. Cell boundaries were established halfway between adjacent measurement points, so that the center of each cell was at a measurement point. At the modeling site 4.2 km below Philpott dam, measurements of water velocity at 0.6 m depth, water depth, and substrate were made at various locations along the transects for a discharge of 1.8 m^3/s.

Hydraulic modeling - Average water column velocities, water surface elevations, riverbed elevations, cell substrate categories, and site discharge were entered into PHABSIM to create hydraulic models for each transect.

Given adequate topographical and water surface profile observations, the normal procedure for hydraulic simulation in PHABSIM is to use a backwater step model (WSP) which employs the Manning equation and a technique known as energy balancing to predict water surface elevations. Then, the Velocity Simulation program (VELSIM) of PHABSIM is utilized to distribute velocities across the channel.

Habitat modeling - The hydraulic and structural elements of a river are then translated into indices of habitat quality using Habitat Suitability Criteria (HSC curves) (Figure 2). These suitability indexes are aggregated mathematically to determine the composite suitability of the cells, usually expressed on a scale ranging between 0 and 1. When the composite suitability is multiplied by the surface area of the cell, the product is known as WUA.

Two-Dimensional Hydraulic Modeling for Physical Habitat Simulation

The data for focal point velocity and depth were provided by the simulation results of RMA2V, a 2-dimensional hydrodynamic model. The redd locations were surveyed during previous field trips. The definitions of several hydraulic parameters and habitat metrics are provided below:

1. Fr number:

$$Fr = \frac{V}{\sqrt{gh}}$$

   where
   V = focal point velocity
   g = acceleration of gravity
   h = focal point depth

2. Re number:

$$\mathrm{Re} = \frac{Vh}{\nu}$$

   where
   V = focal point velocity
   h = focal point depth
   ν = kinematic viscosity of water

3. For estimating the shear stress (τ) Dean's method has been adopted

$$C_f = 0.073\,\mathrm{Re}^{-0.25}$$

$$\tau = C_f \rho V^2$$

   where
   C_f = friction factor/correlation

4. Kinetic energy gradient

$$\frac{\partial(V^2/2)}{\partial s} = V_{ave}\frac{V_2 - V_1}{\Delta s}$$

This parameter represents the spatial change in a flow's kinetic energy per unit mass and unit length. The reason for choosing this parameter is that kinetic energy per unit mass multiplied by a drag coefficient provides the drag force acting on the fish.

5. Relative Kinetic energy gradient

$$\frac{\dfrac{\partial(V^2/2)}{\partial s}}{V_{\min}{}^2/2} = \frac{2V_{ave}\dfrac{V_2 - V_1}{\Delta s}}{V_{\min}{}^2}$$

This and the previous parameters relate to the energy a fish will expend if it moves a distance Δs. As Crowder and Diplas (2000) suggested though, this parameter is more useful, because it considers the environment surrounding the fish (normalized by V_{min}).

6. Velocity gradient
Fish often respond to features in their hydraulic environments, such as velocity gradient. Fausch and White (1981) and Hayes and Jowett (1994) suggest that velocity gradients are important features of brown trout and brook trout feeding stations.

7. Vorticity
For a two-dimensional flow field, the vorticity vector may be represented as

$$\bar{\xi} = 2\bar{\omega} = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

This parameter measures the rate at which a tiny fluid element rotates around its axes.

8. Circulation
The mathematical expression for the circulation value per unit area follows:

$$\frac{\Gamma_{ABS}}{A_{TOT}} = \frac{\sum|\bar{\xi}|\Delta A}{A_{TOT}}$$

where Γ_{ABS} is the modified circulation parameter and A_{TOT} is the total wetted area over which Γ_{ABS} is being computed.

Flow Unsteadiness Parameter Analysis for Smith River fluctuations

Figure 3 illustrates a typical velocity hydrographs obtained at the Philpott & Bassett gage stations. These two hydrographs are used to compute the flow unsteadiness parameters.

Acceleration parameter Ø (Clauser parameter; Shuy 1996) -

$$\phi = \frac{2D}{f_s V^2}\frac{dV}{dt} \tag{1}$$

where steady friction factor f is related to the Darcy-Weisbach wall shear stress τ_w by

$$f_s = \frac{8\tau_w}{\rho V^2} \tag{2}$$

In pipe flows, D is the pipe diameter. When equation (1) is used for open channels, D should be replaced by 4R, where R is the hydraulic radius of the channel cross section (for wide streams, R ≈ water depth). For steady flow, $\tau_w = \rho g R S$, where S is the riverbed bottom slope (uniform flow) or water surface slope (non-uniform flow). After substituting equation (2) into equation (1), we get,

$$\phi = \frac{1}{gS}\frac{dV}{dt} \tag{3}$$

Natural river channels are irregular in shape, and the stage-discharge relationship may not be well approximated by simple rectangular channel approximation. Therefore, to accurately calculate the wetted area in the Smith River, the cross-section has been modified as one trapezoidal cross-section with side slopes and off-channel storage (Figure 4). After considering the real-world channel geometry of the two study sites in Smith River and relating the wetted area (A) to their corresponding water (h) depth, the relation shown in Table 1 is obtained.

Flow unsteadiness parameters Γ and α (De Sutter 2001) - One possible error that needs to be considered when estimating Γ, is due to the unknown location of the bed elevation (Z_b). By using the gage height H instead of water depth h, we will overshoot the real friction velocity (u_{*b}) and therefore underestimate parameter Γ.

$$\Gamma_{Philpott} = \frac{1}{u_{*b}}\frac{\Delta h}{\Delta T} = \frac{1}{\sqrt{gHS}}\frac{\Delta H}{\Delta T} = \frac{1}{\sqrt{9.81 \times 2.21 \times 0.3048 \times 0.000685}}\frac{0.557784}{1800} = 4.6 \times 10^{-3}$$

$$\Gamma_{Bassett} = \frac{1}{u_{*b}}\frac{\Delta h}{\Delta T} = \frac{1}{\sqrt{gHS}}\frac{\Delta H}{\Delta T} = \frac{1}{\sqrt{9.81 \times 1.49 \times 0.3048 \times 0.00257}}\frac{0.1524}{5400} = 2.6 \times 10^{-4}$$

$$\alpha_{Philpott} = \frac{h_m - h_b}{T_r} \Big/ \frac{U_m + U_b}{2} = 0.00031/0.323 = 0.00096$$

$$\alpha_{Bassettt} = \frac{h_m - h_b}{T_r} \Big/ \frac{U_m + U_b}{2} = 0.0000282/0.863 = 0.000033$$

Results and Discussion

One-Dimensional Numerical Method for Spawning Habitat Evaluation

The profiles shown on Figure 5 illustrate the accuracy with which the water surface and velocity profiles were simulated at the calibration discharge (1.8 m^3/s) using PHABSIM. The mean absolute calibration error for the water surface elevation among the four transects was only 0.0025 m.

Figure 6 shows the 3-D prediction results of PHABSIM. Four typical cross sections, 3, 5, 6, and 8 are shown together for comparison.

To examine in detail the correlation between the predicted WUA and spawning density locations at 4.2 km below the dam, we compare the computed WUA for each transect with redd locations and density (Figures 7, 8 and Table 2).

A positive relationship can be found from these results. Three of the four cross sections at 4.2 km below the dam show significant correlation between WUA and redd locations at the mesohabitat scale. Among them, only one cross section shows no relationship between redd location and simulated WUA.

Also, we found a strong correlation between the number of redds and the WUA values (Table 2 and Figure 8). From table 2, we can see that mesohabitats with more redds have higher WUA values. Figure 8 shows that those cells with higher WUA (shown in red color) have more redds than those with lower WUA (shown in yellow color).

Two-Dimensional Hydraulic Modeling for Physical Habitat Simulation

Figures 9, 10 and 11 show the computed range of several hydraulic parameters (Fr, Re, τ) for the brown trout spawning area. Figures 9, 10 and 11 show the frequency distributions of these items. Table 3 includes the statistical comparison results of the whole river reach and the fish spawning areas. The lower standard deviation values of all the three hydraulic parameters at the redd location indicate that fish may prefer a specific hydraulic environment when spawning.

As far as Fr number is concerned, from Figure 9, we can estimate that all of its values are between 0.1 and 0.2, which is much lower than the critical value (1.0). So it is suggested that brown trout would prefer strongly subcritical flow conditions in the locations where they build their redds.

The illustration of Figure 9 is consistent with the argument made by Jowett (1993). He analyzed 1,112 stream sites in New Zealand and showed Fr values for pools to be less than 0.18 and Fr values for riffles to be greater than 0.41. As brown trout redds are found predominantly near pool sites, this result is in agreement with our findings in Smith River.

Reynolds number is related to flow type and is an indicator of the drag force experienced by the fish. As shown in Figure 10, Re numbers in the vicinity of redds are typically very high.

It is obvious that shear stress is another important parameter which can influence redd construction. If the shear stress is too large, not only it will transport too much sediment, but will also destroy redd structure and wash away the eggs (Figure 11 and Table 3).

Figures 12 through 14 show the calculated habitat metrics for the two study sites. At the site 4.2 km below the dam, Figure 12 (lower panel) shows that although the high flow discharge is much larger than the low flow rate (about 10 times as high), the velocity gradient distributions are nearly the same. We think this is because the velocity gradient is primarily influenced by the geometry of the selected river. These results suggest that this metric can potentially be used to analyze the complexity of the river bed topography.

The distribution of the energy metric values (kinetic energy gradient and relative kinetic energy gradient), as a proportion of the entire study reach's wetted area, is shown in Figure 13. An analysis of the data in Figure 13 (upper panel) shows that in all the three simulations, more than 60% of the entire reach has energy gradient values ranging from 0.01 to 0.03 $J \cdot kg^{-1} \cdot m^{-1}$. From Figure 13 (lower panel), 80% of the relative kinetic energy gradient values have magnitudes less than 0.6 m^{-1}. Sites with values of relative kinetic energy gradient larger than 2.0 are located in areas with very low velocity adjacent to much faster moving fluid. These places typically exist next stream banks, island edges and downstream of boulders. The range of computed vorticity values plotted in Figure 14 is from -0.11 to 0.17 s^{-1} for 80% of the wetted area. This result shows that a narrow range of vorticity values dominates most of the area in both study sites.

Table 4 shows the calculated circulation values for the two study sites under three different flow conditions. The base flow reflects the regulated low discharge released and the median flow from a peak flow generated by peaking release. All of these three flows meet the minimum flow rate requirement for the brown trout. For the 4.2 km site, we can find that the circulation value of the base flow is higher than that of the high flow without changing the riverbed geometry. If we compare the unit circulation values ($\Gamma_{ABS} / A_{TOT}(s^{-1})$) of these two sites under the base flow condition, the value obtained at the 4.2 km is larger than that at 12.6 km. Hence, the results serve to illustrate the point that circulation metrics, to some extent, can be used to measure complex flow patterns.

Flow Unsteadiness Parameter Analysis for Smith River fluctuations

The slope values ($^{dV}/_{dt}$) calculated from the rising limbs of these two velocity hydrographs (Figure 3) are 0.0009 ft/s^2 and 0.00031 ft/s^2 , respectively. Since it is an unsteady flow with non-uniform characteristics, we use slopes of water surface elevations instead of riverbed bottom slopes for these two sites, which are 0.685‰ and 2.57‰, respectively. The final computed Clauser parameters are shown as following:

$$\varnothing_{Philpott} = 0.04 < 0.3$$
$$\varnothing_{Bassett} = 0.004 < 0.3$$

Because the slope of the descending limb of a hydrograph is generally smaller than that of the rising limb, we can estimate its corresponding Clauser parameter should be smaller than that of the rising flow (<0.3). Hence, considering the calculated Clauser values above, we can conclude that this selected flow can be approximated as quasi-steady state. In other words, the corresponding unsteady friction factor (or shear stress) should be very close to the corresponding steady state friction factor (or shear stress) in both study sites.

The calculated Γ and α values of the 4.2 km site fall into the experiment data ranges got by Rowinski et al. (2000) and De Sutter (2001), whereas the unsteadiness factors at 12.6 km below the dam are one order of magnitude lower than their results. Due to the damping effect along the channel, it is reasonable that the unsteadiness factor of the 12.6 km site is always smaller than that of the 4.2 km. Because only the gage height data instead of water depth are used, we could expect that there must be higher values for both unsteadiness parameters in the real world.

Based on results from De Sutter (2001), it is possible that the 4.2 km site's transient flow regime will affect the sediment transport rate, because its unsteadiness factors are located within the transition category (between influence and no influence strip) obtained by De Sutter (2001). On the other side, for the 12.6 km site, the influence of dynamic flow to sediment transport perhaps becomes negligible. Therefore, the flow of the 12.6 km site can be treated as a sequence of steady state or gradually varied flow.

Preliminary Conclusions

One-Dimensional Numerical Method for Spawning Habitat Evaluation

In this study, positive correlations between predicted WUA and brown trout spawning areas at the mesohabitat scale have been found in one selected site of Smith River. However, WUA predicted by PHABSIM are the potential fish habitat areas which might be used by brown trout. In other words, it is also possible for the fish only occupy part of the total WUA for spawning while leave others untouched. Other error sources associated with the PHABSIM approach might be the influence of the vertical velocity, meandering channel, transverse flow and eddies, etc.

Two-Dimensional Hydraulic Modeling for Physical Habitat Simulation

The results of a two-dimensional finite element hydraulic model from two selected study reaches of Smith River tailwater suggest that the spatially explicit habitat metrics are potentially useful for detecting complex flow patterns with ecological importance. Those highest habitat metrics are found in the immediate vicinity of exposed boulders, along the banks and close to the island edges. The locations with similar depth and velocity but surrounded by different flow patterns can be differentiated with these metrics.

The proposed hydraulic parameters provide stream biologists and managers important tools for use in a quantitative way. These quantitative descriptions allow people to evaluate the stream habitat environment quality through comparison among different flow features. However, input from fish biologists is needed to help determine the best and most appropriate use of such metrics.

Flow Unsteadiness Parameter Analysis for Smith River fluctuations

The calculated physical meaning of acceleration parameter (*Ø*) is the ratio of the force necessary to change the flow and the corresponding boundary share stress. This is very close to the original format of Strouhal number; whereas the unsteadiness parameters Γ and α are more straightforward and relatively easy to be measured. From the ecology point of view, the denominator of *Ø* parameter formula has a relationship with resistance force acting on a specific actionless organism (Crowder and Diplas 2000). Whereas the numerator of *Ø* parameter expression relates to the inertial force when this organism moves with a relative acceleration. The acceleration parameter *Ø* provides a measure of how much additional force a fish undertakes if the flow surrounded changes from steady to unsteady state. Hence, it has the potential to be employed in a two dimensional unsteady model which can estimate the flow fluctuation effect on fish activity.

Future Research and Job Schedule

Future research should be focused on the influence of unsteady flow released by Philpott Dam. Different flow hydrograph with different unsteadiness characteristics should be surveyed and then analyzed in detail. The flow patterns will be measured with an acoustic Doppler profiling system (SonTek RiverCat) and input into the computer models (HEC-RAS and RMA-2V) for further study. An enhanced two-dimensional sediment transport model will be utilized to evaluate the bank erosion and sand deposition.

Job 3 Schedule. All aspects of Job 3 are on schedule with no changes anticipated at this time. Reporting period extends to bold line.

Calendar Year	1999			2000				2001				2002				2003				2004	
Project Year	Year 1			Year 2				Year 3				Year 4				Year 5					
Quarter	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
Bathymetric surveys					X	X	X				X										
Hydraulics measurements				X						X	X										
Model calibration														X	X						
Time series analysis												X	X								
Data analysis and graphics						X	X				X			X							
Manuscript preparation								X	X			X	X	X	X						

Table 1. The simplified formula of reach cross section's wetted area (A) and their corresponding water depth (h) for modeling sites 4.2 and 12.6 km below Philpott dam, Smith River, Virginia.

4.2 km	$h < WS_{critl} = 0.17$	$A = 5h + 3.32h^2$
	$h > WS_{critl} = 0.17$	$A = 23.63h^2 - 1.91h + 0.587$
12.6 km	$h < WS_{critl} = 0.51$	$A = 5h + 14.5h^2$
	$h > WS_{critl} = 0.51$	$A = 14.5h^2 + 9.83h - 2.318$

Table 2. Data summary for year 2000 at 4.2 km (high spawning area) below Philpott dam, Smith River, Virginia.

Cross Section	Total area (m^2)	WUA (m^2)	WUA/TotArea	No. of redds
8	457.5	39.73	8.7%	6
6	683.7	66.3	9.7%	8
5	606.1	51.5	8.5%	0
3	373.5	44.3	11.9%	8

Table 3. Statistics data for *Fr*, Re, and shear stress (τ) at 4.2 km below Philpott dam, Smith River, Virginia (Q = 1.83 m^3/s).

	Fr	Re	τ
Range (Reach)	0.71	275031	1.817
Mean (Reach)	0.104	65051	0.193
Standard Deviation (Reach)	0.069	46916	0.187
Range (Spawning Area)	0.06	58734	0.177
Mean (Spawning Area)	0.153	124066	0.364
Standard Deviation (Spawning Area)	0.017	16286	0.054

Table 4. Comparison of circulation metric values at 4.2 and 12.6 km below Philpott dam, Smith River, Virginia, under various flow regimes.

	4.2 km below dam (High trout spawning area)		12.6 km below dam (Low trout spawning area)
	Base Flow ($1.78\ m^3/s$)	Median Flow ($15.3\ m^3/s$)	Base Flow ($1.8\ m^3/s$)
A_{TOT} Wet Area (m^2)	4040.25	4562.90	4248.56
Γ_{ABS} (m^2/s)	197.14	130.86	181.96
Γ_{ABS} / A_{tot} (s^{-1})	0.05	0.03	0.04

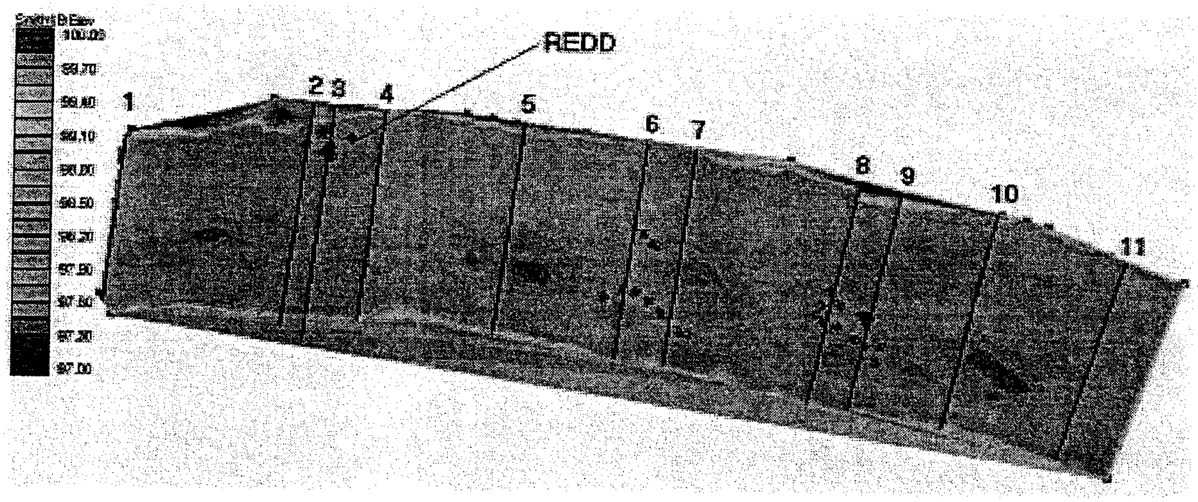


Figure 1. Location of wild brown trout redds spawned in year 2000 in relation to 11 cross sections of the Smith River at 4.2 km below Philpott dam, Smith River, Virginia.

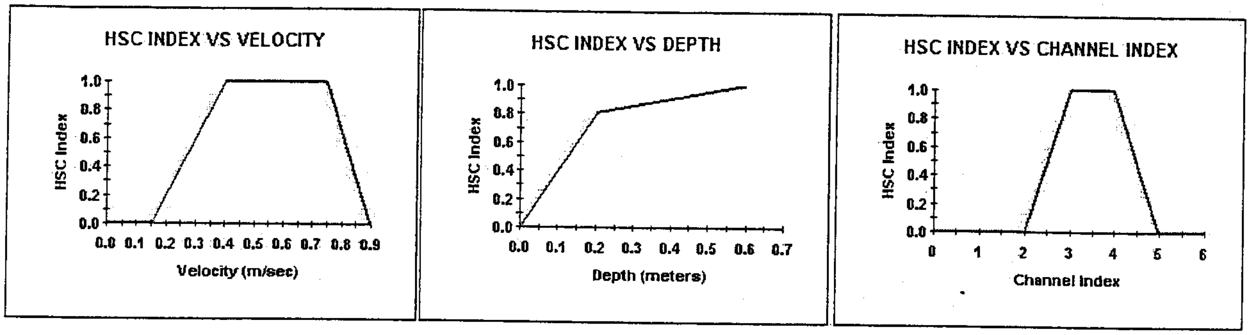


Figure 2. Three HSC models considered in this PHABSIM model.

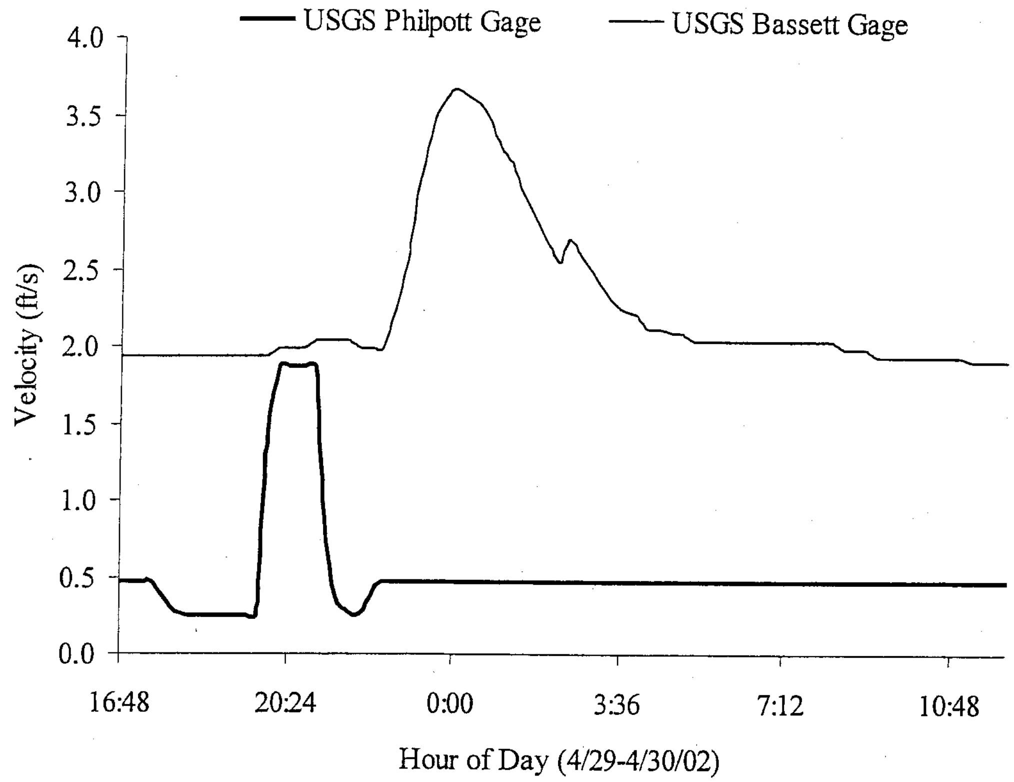


Figure 3. Typical velocity hydrographs from Philpott & Bassett USGS gage stations, Smith River, Virginia.

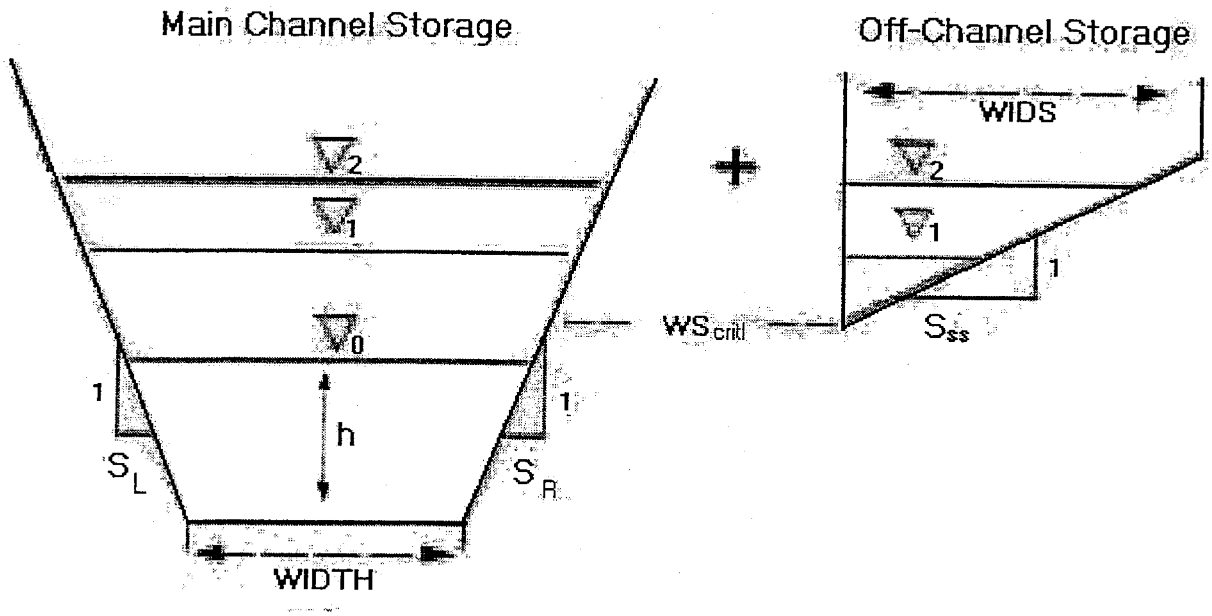


Figure 4. A representative cross section of channel storage and off-channel storage.

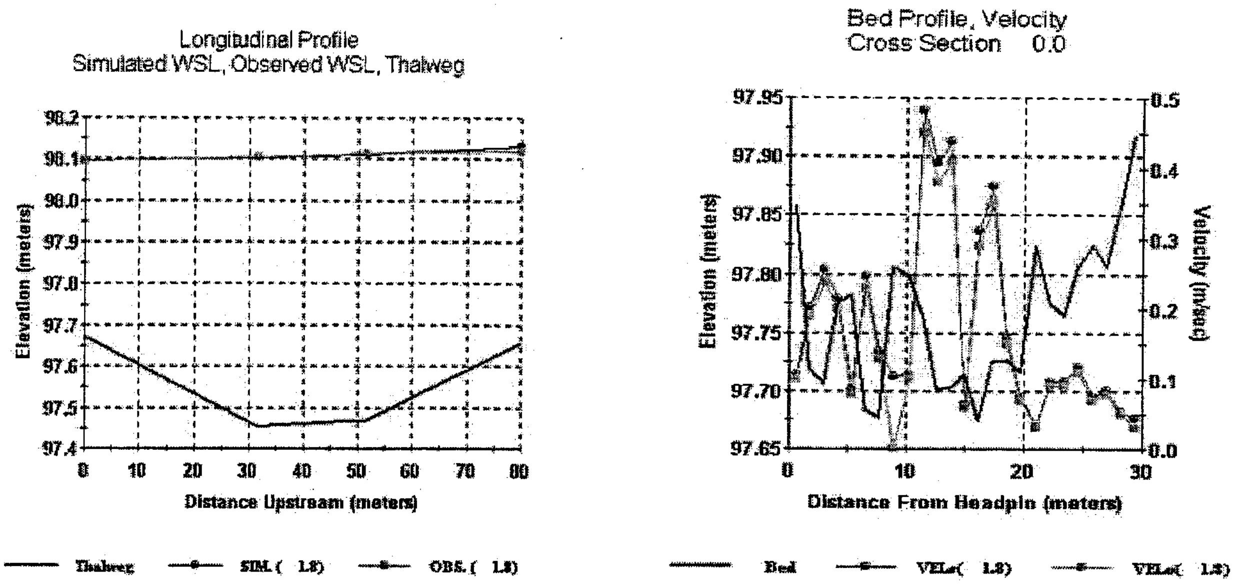


Figure 5. Simulated water surface elevation (WSL), measured WSL, simulated velocities, and observed velocity distribution along transect #8 (Figure 1) at 4.2 km below Philpott dam, Smith River, Virginia.

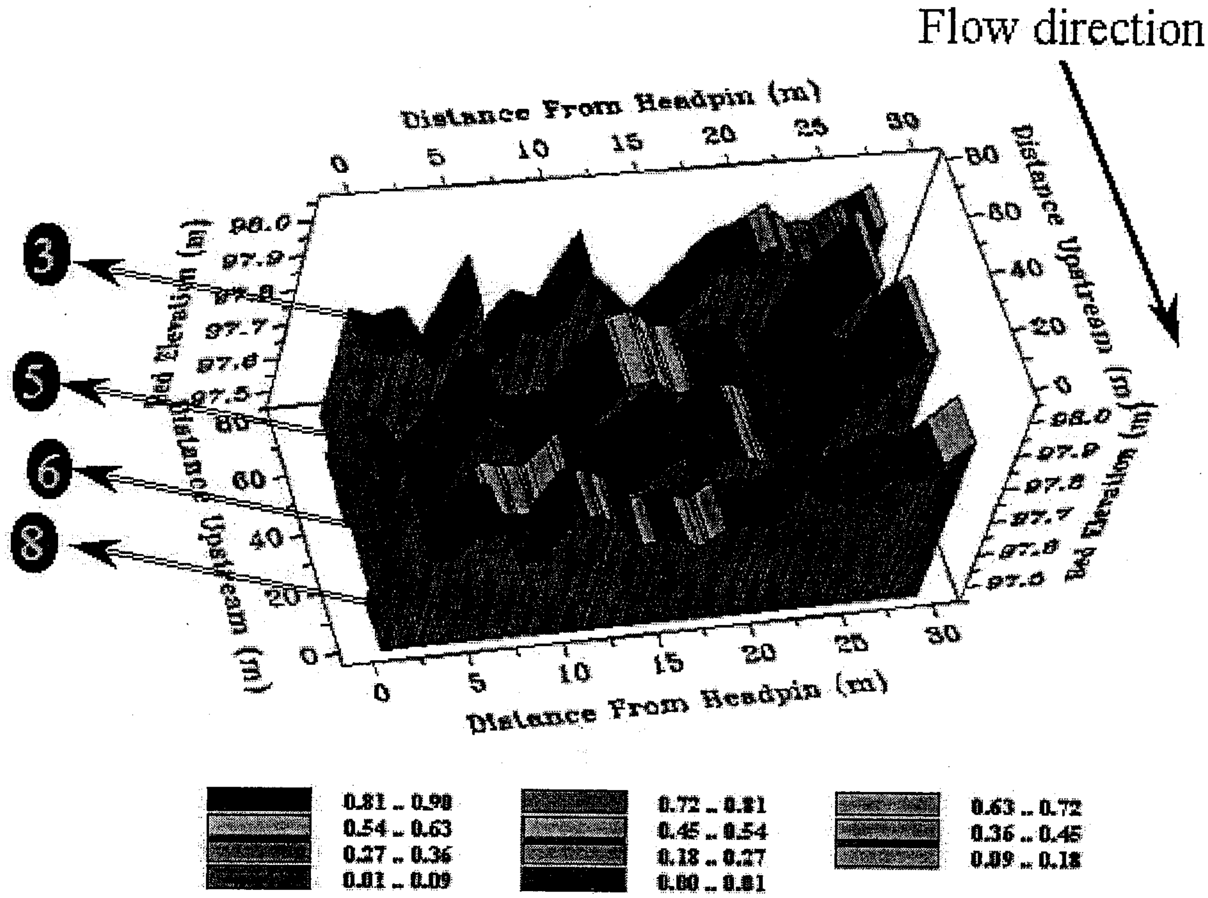


Figure 6. HABTAE output for combined suitability indexes (0.0 ~ 1.0) at 1.8 m^3/s for brown trout at spawning life stage. HABTAE is a model of PHABSIM, which allows integration of biological requirement of target species and life stages represented in the form of HSC with hydraulic simulation results to generate a number of indices of available habitat quantity and quality

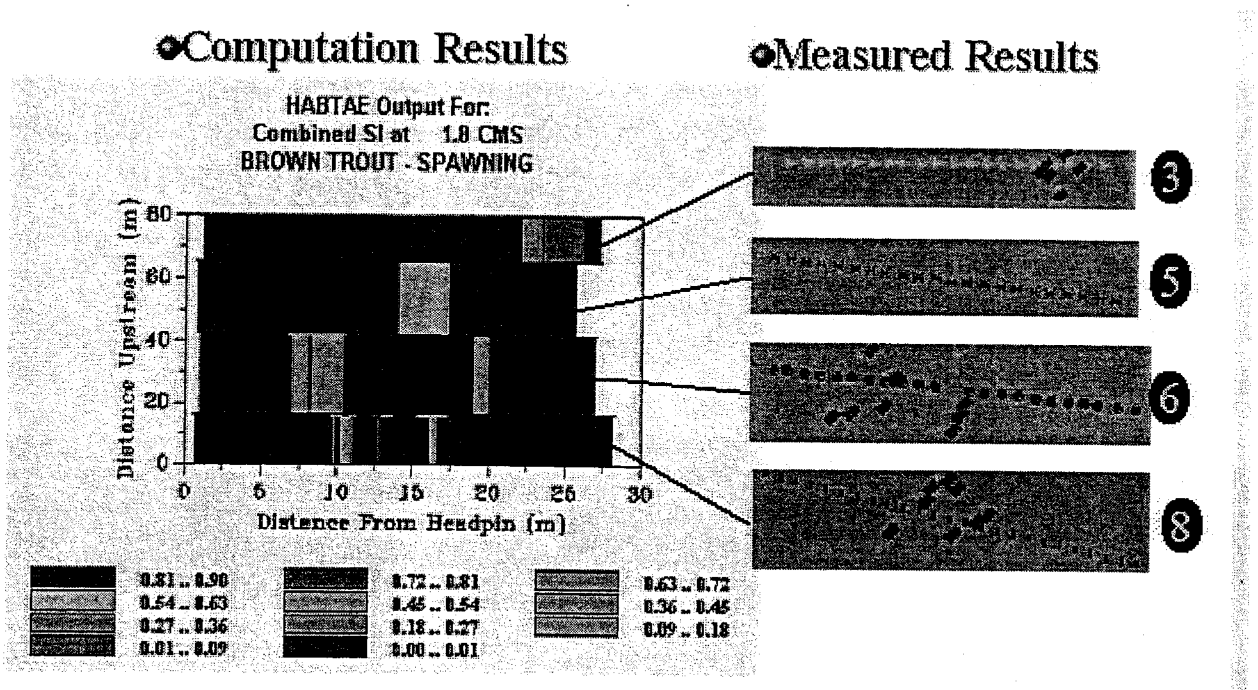


Figure 7. Computation results compared with field data shows the location of redds.

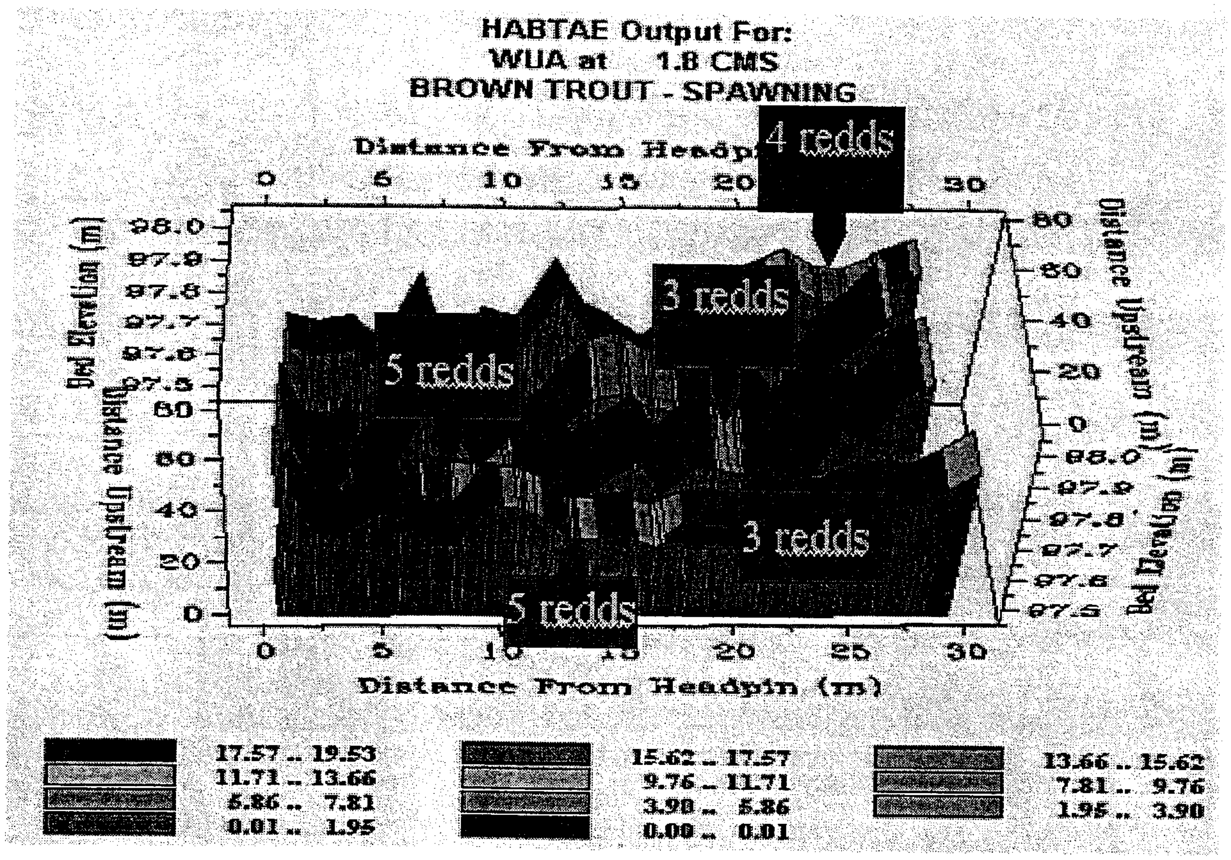
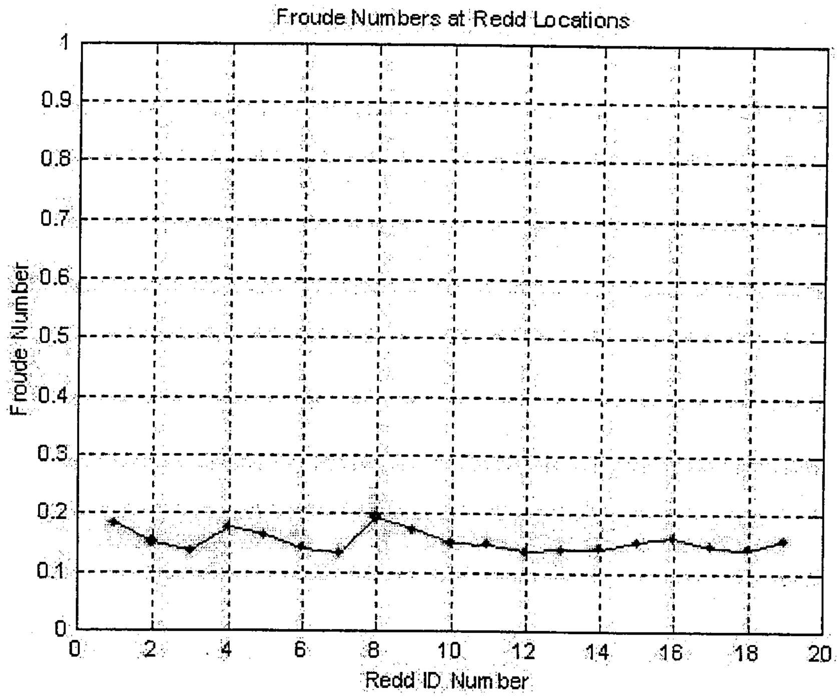


Figure 8. Weighted usable area and redds numbers at the microhabitat level.



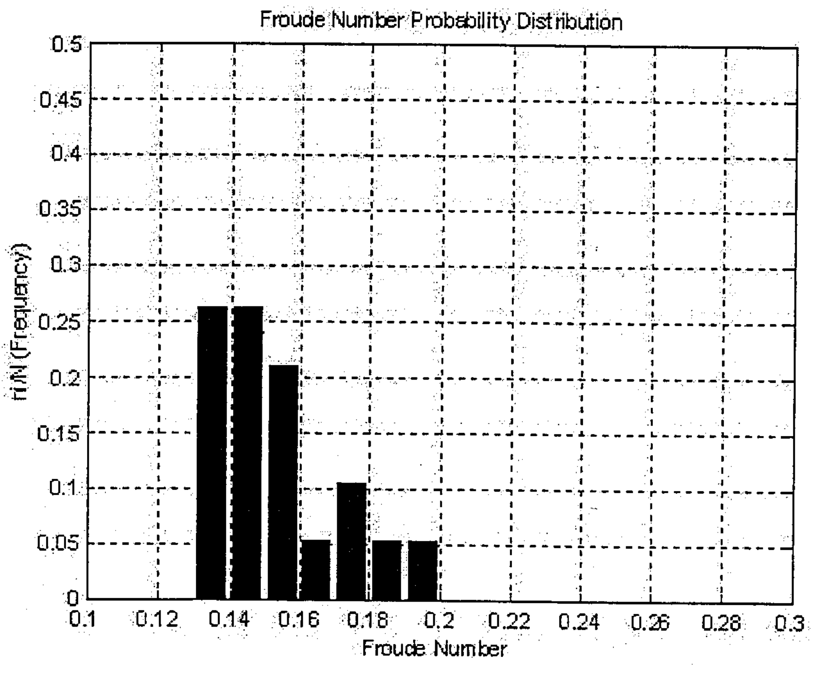
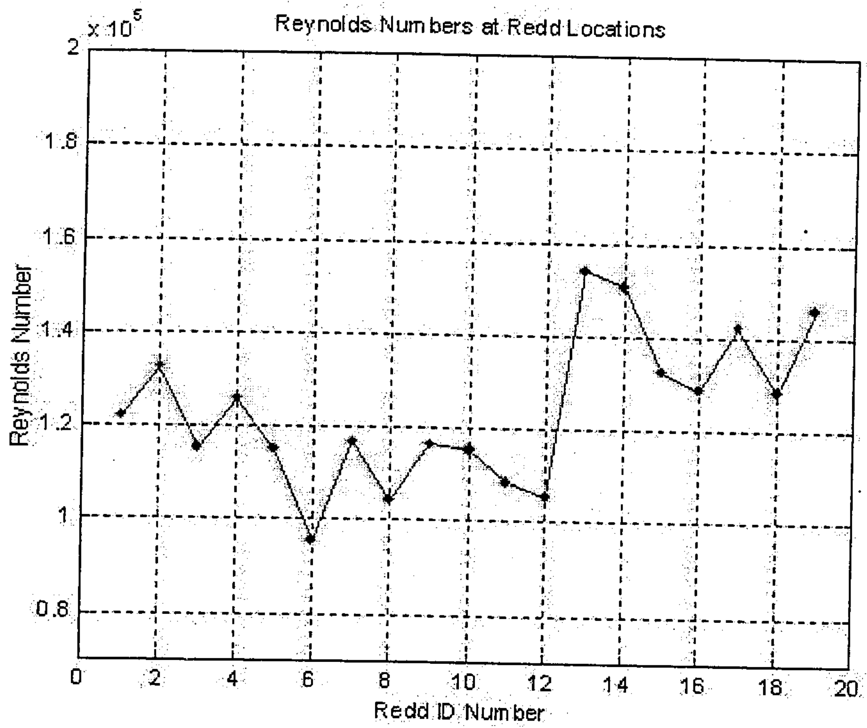


Figure 9. Calculated Froude number and frequency distribution at selected redd locations in the site 4.2 km below Philpott dam, Smith River, Virginia at a discharge of 1.83 m^3/s.



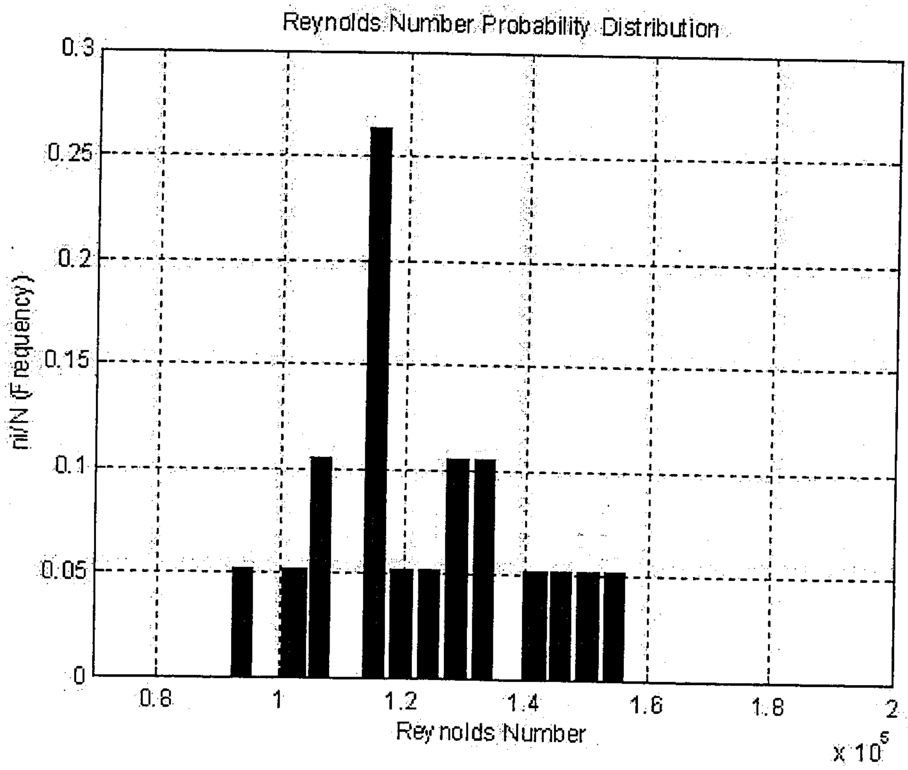
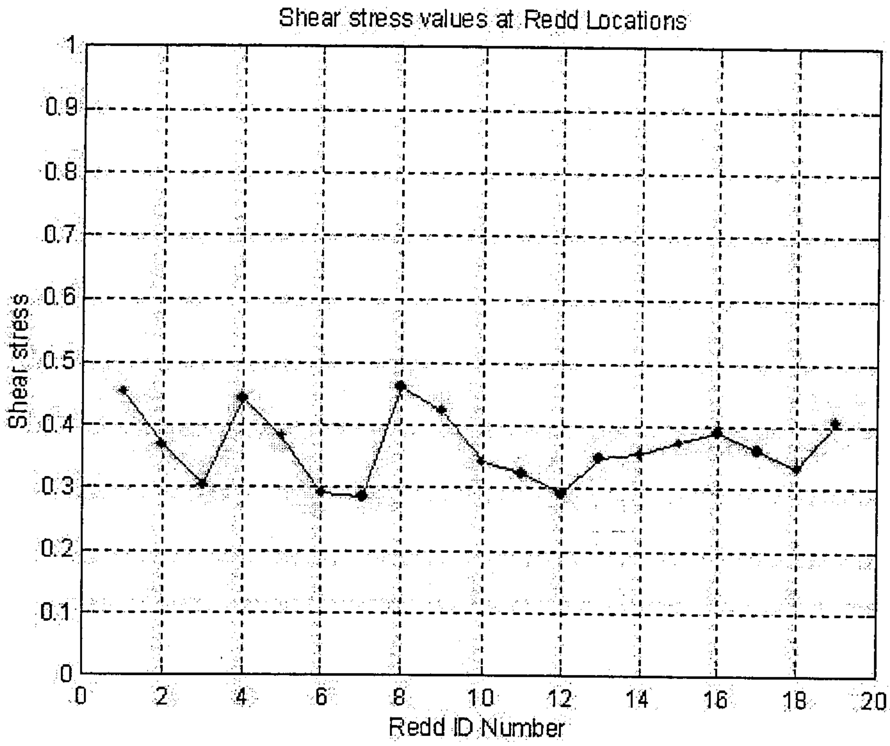


Figure 10. Calculated reynolds number and frequency distribution at selected redd locations in the site 4.2 km below Philpott dam, Smith River, Virginia at a discharge of 1.83 m^3/s.



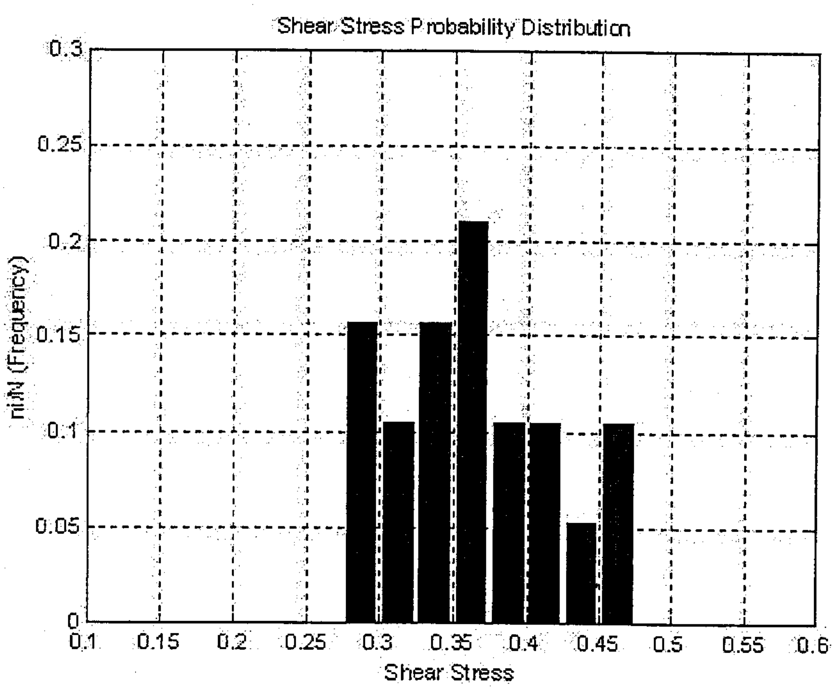


Figure 11. Calculated shear stress and frequency distribution at selected redd locations in the site 4.2 km below Philpott dam, Smith River, Virginia at a discharge of 1.83 m^3/s.

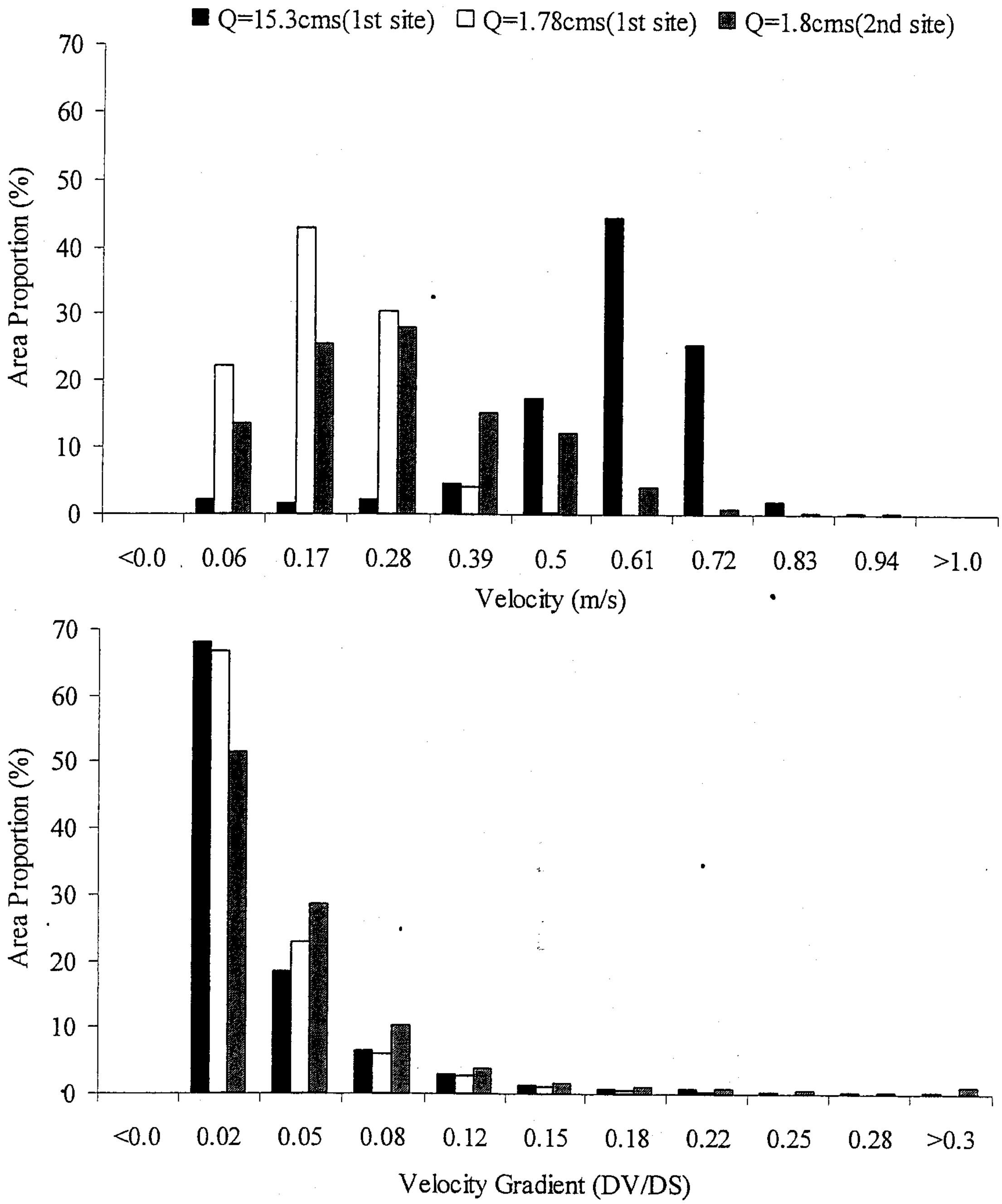


Figure 12. Velocity (m/s) and velocity gradient (DV/DS) at 4.2 km (1st site) and 12.6 km (2nd site) below Philpott dam, Smith River, Virginia at discharges of 15.3 and 1.78 m^3/s (1st site), and 1.8 m^3/s (2nd site).

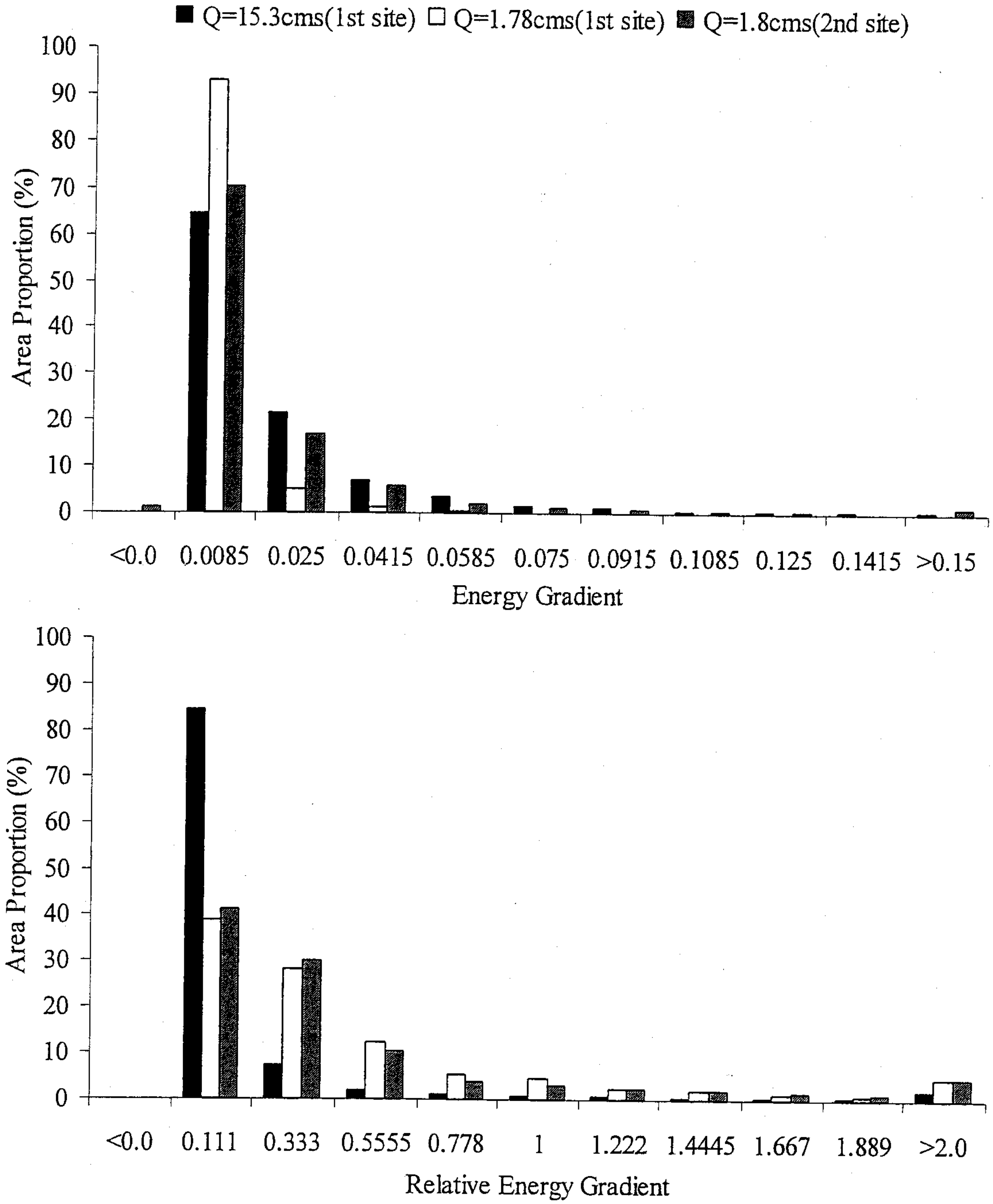


Figure 13. Energy gradient and relative energy gradient at 4.2 km (1st site) and 12.6 km (2nd site) below Philpott dam, Smith River, Virginia at discharges of 15.3 and 1.78 m^3/s (1st site), and 1.8 m^3/s (2nd site).

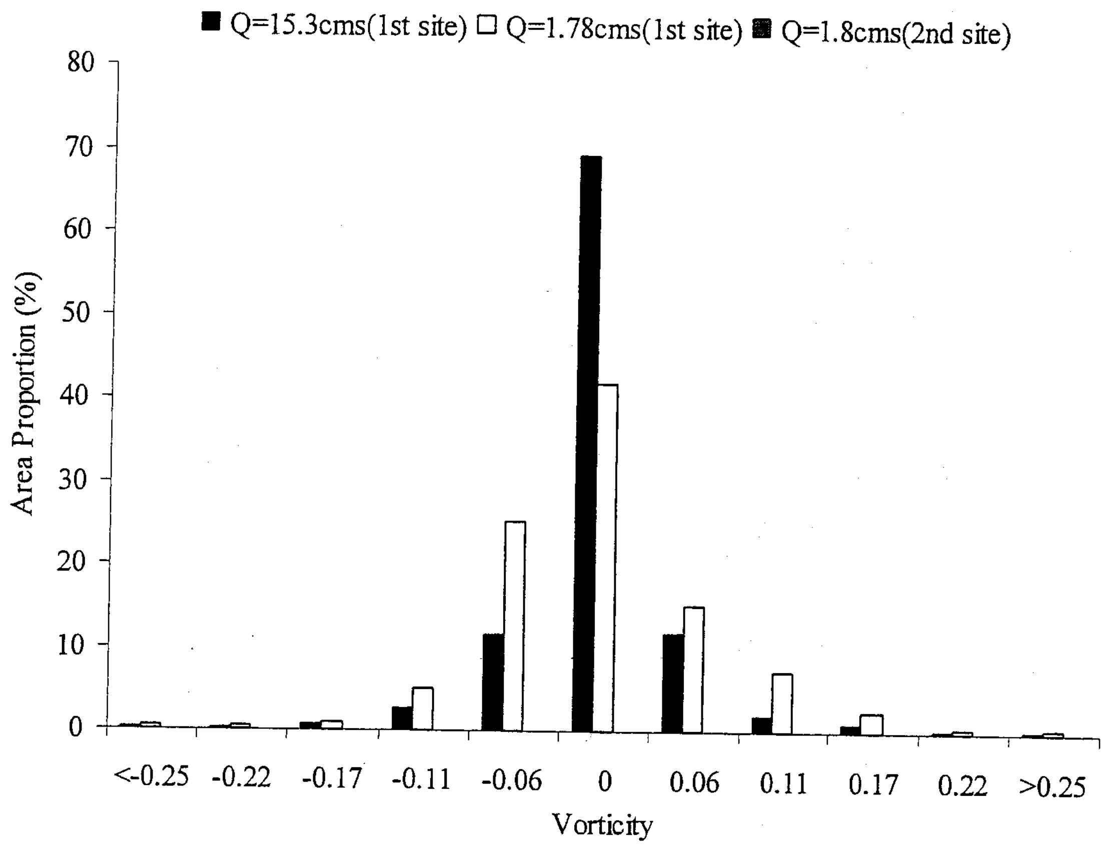


Figure 14. Vorticity at 4.2 km (1st site) and 12.6 km (2nd site) below Philpott dam, Smith River, Virginia at discharges of 15.3 and 1.78 m^3/s (1st site), and 1.8 m^3/s (2nd site).

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Appendix A. The following presentations were made in 2001 - 2002 by Smith River Study researchers.

1. Anderson, M. R., T. J. Newcomb, and D. J. Orth. 2002. Growth Rates of Brown Trout in the Smith River, Virginia, Tailwater. American Fisheries Society 132nd Annual Meeting, Baltimore, Maryland.

   Abstract: The Smith River tailwater below Philpott Dam is a highly valued naturalized brown trout fishery in southwestern Virginia. The tailwater historically produced trophy-sized brown trout. Today, however, trout rarely attain lengths (>356 mm) desired by managers and anglers. Our goal was to evaluate proximate and ultimate factors on brown trout growth for 24 km of the tailwater. Brown trout were captured by electrofishing in June 2000, tagged with passive integrated transponder tags, and recaptured in August and October 2000 and April and June 2001. Absolute growth rates in length (mm day^{-1}) and weight (g day^{-1}) were significantly different among sampling sites ($P<0.0001$) with lowest growth rates near the dam and increased growth rates at intermediate sites. Growth rates varied seasonally ($P<0.0001$) with highest growth rates from June to October, and lowest growth rates occurred during October to April. No linear trend in growth rates was observed with increasing distance from the dam. We developed multivariate, nonlinear models to identify factors that were contributing to observed growth patterns at different locations in the river. Determination of limiting factors will provide much needed information for improving brown trout growth and thus the fishery.

2. Hunter, A. K., and C. A. Dolloff. 2002. Longitudinal Patterns of Community Structure for Stream Fishes in a Virginia Tailwater. American Fisheries Society 132nd Annual Meeting, Baltimore, Maryland.

   Abstract: Artificial disturbances in flow impose changes outside the natural range experienced by most stream fishes, limiting their distribution and abundance. Such high environmental variability provides an opportunity to understand mechanisms shaping fish community structure in a regulated river. Philpott Dam located on the Smith River, VA is a peaking, hydropower facility with flows fluctuating from 30 to 1400 cfs and a hypolimnetic release which creates great thermal flux. A primary objective of our research is to describe nongame species distribution, abundance, and diversity and to relate these patterns to environmental conditions. Our study examines how brown trout abundance, mean monthly temperature, maximum hourly temperature flux, tributary location, and the difference between maximum and minimum daily flow explain longitudinal patterns of community structure for stream fishes in the Smith River tailwater. Understanding relationships between environmental gradients and fish community structure in regulated rivers will improve efforts to manage streamflow and preserve aquatic life.

3. Krause, C. W., T. J. Newcomb, and D. J. Orth. 2002. Thermal Habitat Assessment of Alternative Flow Scenarios in a Tailwater Fishery, American Fisheries Society 132nd Annual Meeting, Baltimore, Maryland.

Abstract: The Smith River tailwater (Patrick County, VA) offers a self-sustaining brown trout fishery managed for trophy trout (>406 mm), however trophy sized fish are rare. Limited food resources, physical habitat, and thermal habitat likely cause slow growth and small size. We assessed the potential for thermal habitat improvement with a one-dimensional hydrodynamic model coupled with a water temperature model. Temperature predictions from fifteen alternative flow regimes were evaluated for occurrence of optimal growth temperatures (12-19°C) and compliance with Virginia DEQ daily maximum (21°C) and hourly temperature change (2°C) standards. Optimal growth temperatures were increased by releasing water in the morning, decreasing duration of release, and maintaining existing baseflow. Maximum temperatures were decreased by releasing every day to prevent elevated temperatures on non-generation days, increasing baseflow, increasing duration of release, and releasing in the morning rather than evening. Hourly temperature change was decreased by increased baseflows, morning releases, and decreased release duration. Despite conflicting adjustments to improve all criteria concurrently, a 7-day, 7 am, 1-hour release regime improved all criteria compared to existing conditions. Integrating habitat assessment with hydropower operations via cost-benefit analysis could not be done because hydropower planning and operations at this ACOE impoundment are divorced from environmental planning.

4. Hunter, A. K., and C. A. Dolloff. 2002. Longitudinal Patterns of Community Structure for Stream Fishes in a Virginia Tailwater. Southern Division American Fisheries Society Midyear Meeting, Little Rock, Arkansas.

   Abstract: Artificial disturbances in flow impose changes outside the natural range experienced by most stream fishes, limiting their distribution and abundance. Such high environmental variability provides an opportunity to understand mechanisms shaping fish community structure in a regulated river. Philpott Dam located on the Smith River, VA is a peaking, hydropower facility with hypolimnetic releases that create flows fluctuating from 30 to 1400 cfs. A primary objective of our research is to describe nongame species distribution, abundance, and diversity and to relate these patterns to environmental conditions. Preliminary results indicate that temperature regimes and tributaries influence nongame fish community patterns. Species distributions show a general trend of increasing abundance as distance increases from the dam and as temperature increases along the longitudinal gradient. However, peaks in fish abundance and diversity occur at tributary junctions. Tributary junctions may provide localized benefits to mainstem biotic communities, thereby increasing the likelihood that nongame species will persist in the Smith River tailwater. Understanding such mechanisms behind fish community structure in regulated rivers will improve efforts to manage streamflow and preserve aquatic life.

5. Krause, C. W., T. J. Newcomb, and D. J. Orth. 2002. Modeling Optimum Growth Temperatures for Trout in a Tailwater Fishery, 2002 Conference on Water Resources Planning and Management Proceedings, Roanoke, Virginia.

   Abstract: The Smith River tailwater (Patrick County, VA) offers a self-sustaining brown trout fishery managed for trophy trout (406+ mm), however trophy sized fish are rare.

Slow growth and small size are likely caused by any one or a combination of limited food resources, physical habitat, and thermal habitat. To evaluate the potential for thermal habitat improvement, temperature changes resulting from 15 alternative hydropower generation flows released from Philpott dam were assessed with a one-dimensional hydrodynamic model coupled with a water temperature model. Simulated temperatures at 13 river locations under each flow scenario were assessed for occurrence of optimal growth temperatures. Increased occurrence of optimal growth temperatures resulted from releasing water in the morning, decreasing the duration of release, and maintaining existing baseflow. A 7-day/week, morning, one hour release regime caused the greatest increase in occurrence of brown trout optimal growth temperatures compared to existing conditions.

6. Newcomb, T. J., C. W. Krause, and D. J. Orth. 2002. Evaluation of Alternative Flow Regimes in a Hydropeaking Tailwater: What to do when the fog doesn't lift until noon. Invited Presentation. National Instream Flow Council meeting. Linville, North Carolina.

   Abstract: Southeastern tailwaters can provide high quality, unique trout angling experiences and they can be economically important to the communities that surround them. However, tailwater management operations can produce challenges to fish growth resulting from limited food resources, highly variable physical habitat, and quickly fluxing stream temperatures. We assessed the potential for thermal habitat improvement for a naturalized brown trout population in a Virginia tailwater by use of a one-dimensional hydrodynamic model coupled with a water temperature model. Temperature predictions from fifteen alternative flow regimes were evaluated for occurrence of optimal growth temperatures (12-19°C) and compliance with Virginia DEQ daily maximum (21°C) and hourly temperature change (2°C) standards. Optimal growth temperatures were increased by flow scenarios that released water in the morning and by decreasing the duration of the release. Maximum daily temperatures in the summer were decreased by changing the daily and diurnal schedule of releases and by increasing baseflow. Hourly temperature flux was decreased by increasing baseflows, releasing in the morning, and reducing the release duration. Despite conflicting adjustments to improve all criteria concurrently, a 7-day, 7 am, 1-hour release regime improved all criteria compared to existing conditions. It appears possible to improve conditions in this tailwater by altering the thermal regime through flow releases, however other biological limitations should be considered to prioritize alternative modes of enhancement. Would altering the thermal regime be worth the cost? Integrating habitat assessment with hydropower operations via cost-benefit analysis could not be done because hydropower planning and operations at this ACOE impoundment are divorced from environmental planning.

7. Orth, D. J. 2002. When will we start adaptive management? Update on the Smith River-Philpott dam tailwater study. Instream Flow Council Biennial Meeting, Crossnore, North Carolina. May 19-22.

8. Hunter, A. K. In Press. Fishing for trout, but what about those rough fish?, The Complex Nature of Managing a Tailwater. Fisheries. American Fisheries Society.

Student essay 2nd place winner: In the 1970s, the Smith River tailwater in Virginia became well known among anglers prompted by the catch of a state record brown trout, weighing 14 lbs. 6 oz. This trout fishery continues to gain attention from anglers as a choice destination to fish a self-sustaining population of brown trout, or "wild" brown trout. The interest of anglers to catch bigger brown trout and the potential economic value of this resource has spurred Virginia Tech and the Virginia Department of Game and Inland Fisheries to team together to perform research necessary to answer pressing questions about the future productivity of the tailwater. The main question managers wish to answer is how to enhance the fishery to produce bigger brown trout.

The tailwater, created by the construction of the Army Corps of Engineers' Philpott Dam in 1952, is home to 35 fish species among which are brown trout, stocked rainbow trout, and 33 different nongame fish, including one federally endangered species, the Roanoke logperch. These fish are exposed to high fluctuation in flows and temperature because of Philpott's water releases. Though nongame fish are not the target species of managers, these fish are recognized to play an important ecological role in the tailwater and portray an array of diverse strategies to feed, reproduce, and survive.

There is much to learn about the community of nongame fish and how they are able to persist in such a changing environment. I seek to evaluate the patterns of nongame fish abundance in relation to environmental factors such as fluctuating temperature, available substrate, and predator and prey abundance. My research will aid managers in understanding the processes that most influence nongame fish abundance.

Speaking with anglers, naturalist groups, and youth about "rough" fish, as they call them, has demonstrated to me that there is interest among the public to know more about the nature of nongame fish that cruise, hide, and dart through the water. Their curiosity is understandable because the fishes I study grow bumps on their bodies, wear vibrant colors, and even have large fleshy lips. People who have not seen the portrudible lips of a sucker or heard the story of a *Nocomis* mound-builder or an egg-clustering darter are intrigued, especially youth. Forging an appreciation and awareness of such rich aquatic fauna is valuable for the future of the resource.

The majority of the nongame fish of the Smith River tailwater are warmwater species and make up a remnant assemblage from the days before the dam. Today, a dichotomy of warmwater (nongame) and coldwater (trout) fish exists. Improving the biological function of this fishery provides a unique challenge, primarily because of the complex nature of the tailwater environment. Tailwaters change Mother Nature's original blueprint for ecosystem function and create artificial conditions for fish. Managing for increased productivity in such artificial ecosystems will require consideration of multiple species and their ecological roles.

9. Anderson, M. R., C. Krause, and G. M. Buyoff. 2002. Fish Sampling in the Smith River, Virginia. Bassett Middle School, June 28, Bassett, Virginia.

10. Orth, D. J., M. R. Anderson, A. K. Hunter, C. W. Krause, and T. Smith. 2001. Summary of nongame species and life history in the Smith River. Martinsville Naturalists Club Meeting, November 27.

11. Anderson, M. R., and A. K. Hunter. 2001. The Smith River tailwater: feast or famine? Roanoke Chapter of Trout Unlimited, September 19, Roanoke, Virginia.

12. Novinger, D. C., and D. J. Orth. 2001. Spatial and Temporal Patterns in Spawning/Growth of Brown Trout in Relation to Environmental Conditions. American Fisheries Society 131st Annual Meeting, Phoenix, Arizona

Abstract: Brown trout demonstrate spatial and temporal patterns in spawning, abundance, and growth in relation to temperature and flow conditions below a hydropower dam in the Smith River, Virginia. Longitudinal trends in temperature and physical habitat correlated with spawning site location, spawning and emergence dates, and characteristics of redds. Most redd construction (78%) took place in the upper 3-8 km of the tailwater where spawning substrates were retained in bends in the river channel. Estimated median spawning dates occurred in early November downstream and late December upstream. However, mean temperatures during the week preceding median spawning dates varied within a tight range regardless of calendar date or distance downstream (mean=7.9°C, Se=0.2, n=19). We also found that redds were larger and located in faster water in downstream spawning sites. Earlier spawning and emergence of age-0 downstream allowed for a broader window for growth and attainment of larger sizes compared to age-0 upstream. This size difference is apparently maintained into maturity. Our conclusion is that temperature plays a strong role in determining the timing of spawning. Differences in spawning dates between upstream and downstream sites ultimately have important implications for survival and growth of age-0 brown trout in this tailwater.

Appendix B. The following table lists research funding awarded in support of Smith River related research at Virginia Tech (research beyond current project scope).

Funding Source	Amount
Coosa Valley Chapter of Trout Unlimited Research Grant Project use: brown trout diet study	$2000
George L. Disborough Award from the Kalamazoo Chapter of Trout Unlimited	$3000
TOTAL:	$5000

Appendix C. The following reports and presentations have featured research in conjunction with (but not funded by) the Smith River Study.

1. Crowder, D.C. and P. Diplas. 2002. Vorticity and circulation: spatial metrics for evaluating flow complexity in stream habitats, Canadian Journal of Fisheries and Aquatic Sciences, 59(4):633-645.

2. Krause, C. W. 2002. Evaluation and Use of Stream Temperature Prediction Models for Instream Flow and Fish Habitat Management, Department of Fisheries and Wildlife Sciences Thesis Seminar, Virginia Tech.

   Abstract: The SNTEMP (U.S. Fish and Wildlife Service), QUAL2E (U.S. Environmental Protection Agency), and RQUAL (Tennessee Valley Authority) stream temperature prediction models were evaluated. All models had high predictive ability with the majority of predictions, >80% for Back Creek (Roanoke County, VA) and >90% for the Smith River tailwater (SRT) (Patrick County, VA), within 3°C of the measured water temperature. Sensitivity of model input parameters was found to differ between model, stream system, and season. The most sensitive of assessed parameters, dependent on model and stream, were lateral inflow, starting-water, air, and wet-bulb temperature. All three models predicted well, therefore, selecting a model to assess alternative water management scenarios was based on model capabilities. The RQUAL model, used to predict SRT temperatures under alternative hydropower release regimes, illustrated potential thermal habitat improvement for brown trout (*Salmo trutta*) compared to existing conditions. A 7-day/week morning 1 hr release was determined to best concurrently increase occurrence of brown trout optimal growth temperatures (+10.2% mean), decrease 21°C (state standard) exceedances (99% prevention), and decrease hourly changes in temperature (-1.6°C mean) compared to existing thermal conditions. The SNTEMP model was used to assess thermal habitat under flow, shade, and channel width changes occurring from future urbanization within the Back Creek watershed. Predictions reveal that additional urban development could limit thermal habitat for present fish species by elevating summer mean daily temperature up to 1°C and cause 31°C (state standard) exceedances compared to existing conditions. Temperature impacts were lessened by single rather than cumulative changes suggesting mitigation measures may maintain suitable thermal habitat.

3. Krause, C. W., T. J. Newcomb, and D. J. Orth. 2001. Ability of Three Models to Predict Water Temperature in an Unregulated Stream and Hydro-peaking River, 2001 Virginia Water Research Symposium, Charlottesville, Virginia.

   Abstract: Stream temperature models can be used to predict thermal regimes following changes in watershed hydrology, land use, and riparian conditions. To produce accurate predictions and answer chosen management questions the appropriate model must be used. We evaluated the performance of three software packages that model stream temperature (SNTEMP, QUAL2E, and TVA River Modeling System) for use on two stream networks (a third-order stream and hydropeaking tailwater). We assessed model predictive ability, parameter sensitivity, data collection requirements, and user friendliness. Steady-state models, SNTEMP and QUAL2E, predicted similarly for both the third-order stream where

daily flow was relatively constant, as well as for the hydropeaking tailwater where flow fluctuated daily. Though SNTEMP required more collection of data than QUAL2E, SNTEMP had fewer limitations, which makes it better for evaluating alternate shade and flow scenarios. The TVA model, a dynamic model, was better suited to model the rapidly changing flows of the tailwater by predicting hourly rather than daily temperature. The TVA model required the most intensive data collection therefore it was less efficient for use in the third-order stream. Each model had sensitive parameters, air temperature, relative humidity, and starting water temperature, which required accurate collection for optimal predictive ability. Consideration of stream type and modeling objectives are imperative factors for choosing a stream temperature modeling approach.

4. Krause, C. W., T. J. Newcomb, and D. J. Orth. 2001. Choosing the Appropriate Stream Temperature Prediction Model, American Fisheries Society 131st Annual Meeting, Phoenix, Arizona.

   Abstract: Stream temperature models can be used to predict thermal regimes following changes in watershed hydrology, land use, and riparian conditions. To produce accurate predictions the appropriate model must be chosen. We evaluated the performance of three software packages that model stream temperature (SNTEMP, QUAL2E, and TVA River Modeling System) for use on two stream networks (a third-order stream and hydropeaking tailwater). We assessed model predictive ability, parameter sensitivity, data collection requirements, and user friendliness. Steady-state models, SNTEMP and QUAL2E, predicted better for the third-order stream where daily flow was relatively constant. Though SNTEMP required more collection of data than QUAL2E, SNTEMP predicted more days correctly and had fewer limitations, which makes it better for evaluating alternate shade and flow scenarios. The TVA model, a dynamic model, was better suited to model the rapidly changing flows of the tailwater. The TVA model required the most intensive data collection therefore it was less efficient for use in the third-order stream. Each model had sensitive parameters, air temperature, relative humidity, and starting water temperature, which required accurate collection for optimal predictive ability. Consideration of stream type and modeling objectives are imperative factors for choosing a stream temperature modeling approach.

5. Hanna, K. A., T. J. Newcomb, and M. R. Anderson. 2001. Macroinvertebrate Forage for Brown Trout in the Smith River: Feast or Famine? Southeastern Association of Fish and Wildlife Agencies, Louisville, Kentucky.

   Abstract: Benthic macroinvertebrates were sampled at 12 sites in the Smith River below Philpott Dam in July 2000 and April 2001. One riffle in each site was stratified into upstream, middle, and downstream transects and Surber samples were collected at two randomly selected locations on each transect. Macroinvertebrates were identified to family and each sample was measured for wet weight. Family richness was calculated and simple linear regression was used to evaluate longitudinal trends in mean abundance and wet weight with increasing distance from the dam. We found low values of family richness near the dam but richness more than doubled by 4.2 km downstream. Mean wet weight and abundance of macroinvertebrates were higher in April than in July and Ephemerellidae proportionately dominated the samples in April. Overall, abundance of aquatic invertebrates in this tailwater was lower than expected for a stream of this size in Virginia. No strong pattern was found between distance from the dam and macroinvertebrate abundance. However, isolated peaks in abundance of macroinvertebrates at spatially discrete locations suggest that localized channel characteristics improved some areas for macroinvertebrate colonization downstream of Philpott Dam.

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Virginia

DJ Grant F-121-R-3

Influences of Fluctuating Releases on Stream Fishes and Habitat in the Smith River, Below Philpott Dam

July 1, 2001 to June 30, 2002

96pp.

Performance Report

State: Virginia **Grant No:** F-121-R-3

Grant Type: Research **Date:** September 2002

Grant Title: Influences of Fluctuating Releases on Stream Fishes and Habitat in the Smith River, below Philpott Dam

Grant Period: July 1,2001 to June 30, 2002

Grant Objectives:

To conduct research to validate and discover new fish-population and habitat relationships and provide defensible fish-habitat relationships to be used for developing specific management actions to improve the fisheries resources of the Smith River tailwater. Job 1 **Characteristics of Spawning and Rearing Habitats for Brown Trout.** To characterize the instream habitat conditions in areas where successful spawning and juvenile rearing of brown trout occurs. Job 2 **Determinants of Brown Trout Growth and Abundance.** To collect biological data to quantify abundance of trout and nongame fishes in Smith River from Philpott Dam to Martinsville, quantify temperature limits on fish occurrence, and monitor annual variation in brown trout recruitment success. To evaluate the bioenergetic constraints on growth under existing temperature regimes. Job 3 **Hydraulic Model Development and Application to Smith River tailwater.** To design a field survey and modeling protocol to measure effects of varying flows on the shear stress, mobilization of streambed gravels, and relate discharge to the amount of redd scouring or brown trout fry displacement that would occur at sites in the tailwater.

Activities: See attached report submitted by Dr. Donald Orth et al.

Target Date for Completion: June 30, 2004

Significant Deviations: None

Segment No. 3

Costs:

State	Federal	Total
$50,783.34*	$152,350.00	$203,133.34

* Virginia Tech waived indirect costs as third (3rd) party in-kind match.