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COMPARISON OF PREDICTED HABITAT CHANGE AND BROOK TROUT POPULATION RESPONSE TO A SIMULATED IRRIGATION WITHDRAWAL IN HUNT CREEK, MICHIGAN

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ABSTRACT

We withdrew approximately 50% of the summer stream flow from Hunt Creek, MI from 1 June-31 August, 1991-94 to simulate the impacts of a water withdrawal for irrigation on the brook trout *Salvelinus fontinalis* population and to evaluate the Physical Habitat Simulation System (PHABSIM) under controlled conditions. We modeled brook trout diurnal foraging habitat using habitat suitability criteria developed from frequency of use data (use-HSC) and from bioenergetic models (bioenergetic-HSC) based on data collected in Hunt Creek. We also modeled nocturnal resting habitat by application of use-HSC developed from data collected in Hunt Creek. We formulated hypotheses concerning the impact of the withdrawal on the brook trout population based on the PHABSIM model output and tested these hypotheses using Before-After-Control-Impact (BACI) analysis. The PHABSIM model indicated that young of the year diurnal and nocturnal Weighted Usable Area (WUA) increased as a result of the reduced summer stream flow and that yearling and older nocturnal WUA was increased as a result of the reduced stream flow and that yearling and older diurnal foraging habitat decreased only slightly under reduced flow conditions. The PHABSIM model predicted no reduction in density of young of the year or yearling and older brook trout as a result of the reduced flow and these predictions were supported by the BACI analysis. Biannual estimates of brook trout population density in the treatment section of Hunt Creek and in the downstream control sections were very similar in the ten years preceding the withdrawal and during the withdrawal period. The PHABSIM model also predicted that a

summer withdrawal equal to approximately 88% of summer baseflow would be needed to produce a statistically detectable reduction in brook trout density in the treatment section of Hunt Creek and that yearling and older brook trout habitat would be reduced more than young of the year habitat at that level of flow reduction.

Introduction

Changes in stream flow regime can influence the ecology of stream fishes in a variety of ways (Orth 1987). Stream fish ecology can be impacted by changes in stream flow because flows are important in determining reproductive success (Starrett 1951), fish community structure and habitat use (Bain et al. 1988), and habitat availability (Kraft 1972). In midwestern trout streams the input of groundwater is recognized as an important abiotic factor influencing trout populations. For example, Latta (1965) found a significant positive relationship between young of the year brook trout *Salvelinus fontinalis* numbers and groundwater levels during a nine year study on the Pigeon River, Michigan. Similarly, White et al. (1976) determined that trout streams in Michigan and Wisconsin that had the most stable flow regime also had the greatest trout abundance and standing crop. Clearly, protecting flows in midwestern trout streams is important for the maintenance of healthy trout populations.

The Physical Habitat Simulation System (PHABSIM) is the computer based habitat modeling component of the Instream Flow Incremental Methodology (IFIM) that predicts stream habitat quality and quantity as a function of discharge (Milhous et al. 1989). PHABSIM was developed in the western U.S. with the purpose of evaluating the impacts of changes in streamflow on stream habitat. The PHABSIM system is widely used in the western U.S. to evaluate the impacts of water development projects on stream resources and is a legal requirement in the state of California (Reiser et al. 1989). However, the PHABSIM system has only recently been applied to streams in the midwestern U.S. where the geology, hydrology, and composition of the fauna are distinctly different from western streams (Gowan 1984, Bovee et al. 1994).

The PHABSIM system works on the premise that water depth, water velocity, substrate, and cover are the four microhabitat parameters that determine a fish's use of habitat. Data input into PHABSIM are in the form of habitat suitability criteria (HSC) and habitat availability data for these four parameters for the species and life history stage of interest and the stream under investigation (Figure 1) (Milhous et al. 1989). The output of a PHABSIM analysis is a measure of habitat known as Weighted Usable Area (WUA). WUA is a measure of the amount of habitat in a stream that is suitable for the target species and life stage and is calculated for a range of simulated discharges in the stream of interest. The resulting WUA versus discharge relation is used to evaluate proposed changes in the flow regime in a stream and to predict the impacts of altered flows on the fish population(s) in the stream. An assumption of the PHABSIM system is that WUA is linearly and positively related to fish standing crop (Bovee 1978, Orth and Maughan 1982, Mathur et al. 1985). Orth and Maughan (1982) and Milhous et al. (1989) reviewed the computational procedures of the PHABSIM modeling procedure and the assumptions associated with a PHABSIM analysis.

The PHABSIM system has been criticized for several reasons including the technical simplicity of the habitat calculations and the complexity and expense of its application but also for the assumption that WUA is positively related to fish abundance (Mathur et al. 1985, Morhardt 1986, Scott and Shirvell 1987, Morhardt and Mesick 1988, Reiser et al. 1989, Armour and Taylor 1991). Numerous studies have attempted to document a relationship between WUA and fish population parameters with limited success (for example: Orth and Maughan 1982, Gowan 1984, Shirvell and Morantz 1983, Conder and Annear 1987, Scott and Shirvell 1987). However, we are not aware of any PHABSIM studies in which the streamflow was experimentally manipulated and the response of the fish population was compared to a control or a pretreatment period. The objectives were to: 1) evaluate the impacts of a simulated irrigation withdrawal on the brook trout *Salvelinus fontinalis* population in Hunt Creek; 2) evaluate the PHABSIM system in Hunt Creek during a controlled water withdrawal by comparing the output of the PHABSIM analysis to the observed response of the brook trout population; 3) evaluate nocturnal resting HSC and bioenergetically derived HSC for foraging microhabitats (bioenergetic-HSC, Baker and Coon 1995a) to determine if these alter the PHABSIM predictions.

Methods

Study Area

This study was conducted at the Michigan Department of Natural Resources' (MDNR) Hunt Creek Fisheries Research Station in northern Oscoda and southern Montmorency counties of Michigan's lower peninsula. Hunt Creek is a third order stream which drains glacial sands and gravels deposited during the last glaciation of the region, approximately 10,000 years ago (Dorr and Eschman 1970). Hunt Creek and surrounding watersheds have extremely stable discharge and temperature regimes and are some of the most productive trout streams in Michigan (Gaylord Alexander, personal communication). Hunt Creek was chosen as the study stream for this research because the brook trout population in Hunt Creek is naturally reproducing, has been monitored by the MDNR since 1949 and a continuos record of population density estimates exists from spring and fall mark-recapture electrofishing. In addition, the entire Hunt Creek research area has been closed to fishing since 1966. Therefore, any response of the brook trout population to experimental treatment should be attributable to an increase in the natural mortality rate, emigration rate, or some other factor related to the treatment.

The portion of Hunt Creek that flows through the research area is divided into four sections: three nontreatment sections (sections A, C and Z) and a treatment section (section B; Figure 2). Hunt Creek is a second order stream upstream of the confluence with Fuller Creek and is a third order stream through the remainder of the study area.

The brook trout population in Hunt Creek is composed primarily of small fish; approximately 96% of the fish in section B are less than 17.7 cm total length (Alexander and Hansen 1986). The only common fish species in Hunt Creek are brook trout, mottled sculpin *Cottus bairdi* and slimy sculpin *Cottus cognatus* (Alexander and Hansen 1986). In 1989-90 the MDNR excavated a diversion channel around the treatment section and installed bulkheads at the upstream and downstream ends of the treatment section (Figure 2, referred to as the upstream and downstream bulkheads respectively in remainder of text). The bulkheads allowed us to control the flow of water through the treatment section of Hunt Creek. The MDNR also installed inclined screen traps on the bulkheads to monitor downstream fish movement into and out of the treatment section. The traps were operated during each summer of the treatment. In addition, to provide a baseline estimate of fish movement in Hunt Creek, the traps on the AB line bulkhead were monitored during the summer of 1990 before the experiment was initiated. The traps only caught fish moving downstream, and prevented upstream fish movement.

Experimental Design and Data Collection

Beginning on June 1 or 2 and continuing through August 31, 1991-94 we diverted approximately 50% of the summer stream flow around the treatment section of Hunt Creek to simulate the effects of a seasonal water withdrawal for irrigation. During the withdrawal period we monitored the traps on the bulkheads at the upstream and downstream ends of the treatment section (Figure 2) to determine if there was a movement response to the dewatering. We did not operate traps during the period of full flow (September 1-May 31) and therefore, brook trout were free to move upstream and downstream. In addition to the 50% reduction of summer flow, we reduced flow to 25% of summer baseflow (0.11 $m^3 \cdot s^{-1}$) during a three day period in August, 1993 to collect hydraulic data needed to calibrate the hydraulic modeling component of PHABSIM.

We modeled diurnal and nocturnal habitat of young of the year ($\leq$8.9 cm total length) and yearling and older (>8.9 cm total length) brook trout habitat based on several different sets of habitat suitability criteria (use-HSC, Baker and Coon 1995). We used two sets of habitat suitability criteria developed from frequency of use data collected in sections B and C of Hunt Creek in 1991-93 over the range of flows from baseflow (0.46 $m^3 \cdot s^{-1}$) to 25% of baseflow (0.11 $m^3 \cdot s^{-1}$). One set was based on observations of habitat use in diurnal conditions (diurnal use-HSC) and the other set was based on observations of habitat use in nocturnal conditions (nocturnal use-HSC). We also modeled diurnal foraging habitat from habitat suitability criteria based on bioenergetic cost and benefit models (bioenergetic-HSC) from data collected in 1993-94 in section B (Baker and Coon 1995a). Bioenergetic-HSC were size specific for brook trout and were constructed for fish between 5 and 20 cm total length.

We used a representative reach approach for modeling the habitat in section B of Hunt Creek with PHABSIM. To select representative reaches we first measured and marked section B into approximately 50 m contiguous reaches, omitting the small area of impounded water at the downstream end of the section as well as the short reach of disturbed habitat immediately downstream of the diversion bulkhead (Figure 2). We then randomly selected two of the 50 m reaches in section B to model by use of PHABSIM (reaches B2 and B4 in Figure 2). We established transect locations in each of the reaches, and used changes in meso habitat (riffle, run, pool) within the reach to guide transect placement. We classified substrate and cover along each transect by use of the same codes used for the brook trout habitat use observations (Baker and Coon 1995a). The dominant cover type was recorded for each PHABSIM cell. We collected flow data in the two reaches in section B at three discharges; 0.46, 0.23, and 0.11 $m^3 \cdot s^{-1}$. We measured depths to the nearest cm with a wading rod and velocities to the nearest $cm \cdot s^{-1}$ with either a mechanical Pygmy-Gurley or an electronic March-McBirney current meter. We compared velocity measurements obtained from both meters at the same location in Hunt Creek on several occasions and could not detect any differences between the meters. We calibrated the PHABSIM model and simulated habitat over a range of flows from summer baseflow to 0.01 $m^3 \cdot s^{-1}$ (2% of baseflow) for the reaches in sections B.

We collected brook trout population abundance data in cooperation with Michigan DNR staff in all four sections of Hunt Creek by conducting mark-recapture electrofishing in April and September of each year of the study and following the same protocol that has been followed for nearly five decades in Hunt Creek (Alexander and Hansen 1986). The entire length of Hunt Creek was sampled from the downstream end of section Z to the upstream end of section C (approximately 6.5 km of stream). Recapture sampling efforts always followed marking within 72 hours. We measured all fish to the nearest 0.25 cm. We measured weight to the nearest 0.1 g for a subsample of 30 fish per 2.5 cm length interval per section in spring and fall, 1993 and 1994. We used Bailey's modification (Bailey 1951) of the Petersen method to estimate brook trout population density for 2.5 cm length intervals and used the equations in Ricker (1975) to estimate 95% confidence limits.

We measured brook trout lengths and weights during electrofishing sapmling and developed length-weight regressions for each section and season. We tested the length-weight regressions developed from each section, season and year with ANCOVA and determined there were no significant differences between the regressions ($F=0.97$ $df=5,2723$, $p=0.43$). We pooled all the length-weight data, recalculated the regression and used this regression to predict brook trout weights for biomass calculations.

We formulated hypotheses concerning the impact of the withdrawal on the brook trout population numbers and total standing crop in section B (treatment section) based on the predicted relationship between WUA and discharge for section B and the assumed positive linear relationship between WUA and fish population standing stock and population density.

We tested these hypotheses by use of BACI statistics (Stewart-Oaten et al. 1986, 1992). For the analysis we calculated spring and fall mean population density estimates for sections A and Z combined (control section) and determined differences between these estimates and the density estimates for section B for the ten year period preceding the treatment and the four years of treatment. We repeated the analysis for the total biomass data for the same period. We estimated total biomass using the length-weight regression developed from the 1993-94 data. We multiplied the number of fish per 2.5 cm length interval by the weight of a fish at the midpoint of the interval, obtained from the length-weight regression, and summing over all length intervals. We did not include the upstream nontreatment section C in the statistical analysis because the population in section C was influenced by environmental factors that did not impact the population in sections A, B, and Z. We used the Student's t-test to compare pretreatment period mean difference with the treatment period mean difference.

Results

Summer baseflow in section C at the confluence with Fuller Creek (Figure 2) is approximately 0.23 $m^3 \cdot s^{-1}$. Fuller Creek delivers an additional 0.23 $m^3 \cdot s^{-1}$ resulting in a summer baseflow of approximately 0.46 $m^3 \cdot s^{-1}$ through the treatment section (B). A small tributary enters Hunt Creek just downstream of the lower end of the treatment section and delivers approximately 0.11 m^3/s, increasing discharge in Hunt Creek to approximately 0.57 m^3/s. Hunt Creek continues to gain water as it flows downstream and out of the research area.

Characteristics of Study Reaches

Reaches B2 and B4 were 47.1 and 55.2 m long respectively. We established 19 transects and measured habitat availability at 385 locations (cells) in reach B2. We established 21 transects and measured habitat availability at 530 locations (cells) in reach B4. Mean distance between transects was 2.5 m in reach B2 and 2.6 m in reach B4, and the maximum distance between any two transects in reach B2 was 6.6 m and 5.2 m in reach B4.

Several important differences existed between the reaches we selected for habitat modeling which affected the output of the PHABSIM analysis. First, the mean water surface slope at baseflow (0.46 $m^3 \cdot s^{-1}$) in reach B2 (4.2 $m \cdot km^{-1}$) was nearly twice the slope (2.2 $m \cdot km^{-1}$) in reach B4. As a result, the mean water velocities were greater in reach B2: at baseflow the mean of all mean column velocity measurements was 34 $cm \cdot s^{-1}$ in reach B2 and 28 $cm \cdot s^{-1}$ in reach B4. Differences in velocity distributions between the reaches were significant (Mann-Whitney U test, p=0.002). A second difference between the modeled reaches was that the mean channel width in reach B2 (4.15 m) was less than in B4 (5.00 m).

The substrate and cover composition in the two modeled reaches was similar. In both reaches the substrate was composed primarily of small and medium sized gravels less than 2.5 cm diameter. Sand and silt were also common in both reaches. Substrate composition in the reaches differed significantly (C^2=64.1, df=9, p<0.001), primarily due to the presence of more cells in reach B2 with large gravel than in B4 and the greater number of cells in reach B4 with the substrate embedded more than 25%.

The majority of the cells (>93%) in both reaches had cover present, either in the form of a velocity shelter or a combination cover type. Availability of cover composition did not differ between the reaches (C^2=1.13, df=2, p<0.01).

Habitat Suitability Criteria

The HSC developed from frequency of use data and from bioenergetic models are fully presented in Baker and Coon (1995a) and are only summarized here (Table 1). The diurnal use-HSC represent the suitability of foraging microhabitats for brook trout in Hunt Creek because data showed that brook trout were actively foraging on invertebrate drift during daylight hours in Hunt Creek (87% of fish observed during the diurnal period were foraging) and we only included data from actively foraging fish in the construction of diurnal use-HSC. In contrast, nocturnal use-HSC represented the suitability of resting microhabitats (Table 1). Observational data from Hunt Creek showed that 93% of the brook trout were inactive at night and selected microhabitats that allowed the fish to rest on the substrate and minimize energy expenditure. None of the fish observed during the nocturnal period were foraging. Brook trout in Hunt Creek were even observed burrowed into vegetation (primarily watercress, *Nasturtium officinale*) or wedged between sticks at night.

PHABSIM Model Results

The relation between surface area and discharge for the two modeled reaches in section B indicated that a 50% reduction in summer stream flow in the treatment section resulted in a very minor loss of stream surface area (Figure 3). In reach B2 total surface area was reduced from 206 to 195 $m^2 \cdot 100\ m^{-1}$, a reduction of only 5.6%. In reach B4 reducing flow 50%

decreased total surface area from 292 to 275 $m^2 \cdot 100\ m^{-1}$, a reduction of only 5.7%. Model results also predicted that reducing flow in section B by 98% to a discharge of 0.01 $m^3 \cdot s^{-1}$ would decrease total surface area to 132 $m^2 \cdot 100\ m^{-1}$ in reach B2 (35.9% loss) and 176 $m^2 \cdot 100\ m^{-1}$ in reach B4 (39.7% loss). The difference in the total surface area estimates between the two modeled reaches is due to the greater width and lower slope in reach B4.

The 50% reduction of summer stream flow actually resulted in an increase in WUA for young of the year fish based on diurnal use-HSC in reaches B2 and B4 (Figures 4 and 5). Suitable habitat area increased 27% in reach B2 and 16% in reach B4 with a 50% reduction of summer flow. The maximum WUA value over the range of discharges modeled occurred at a discharge of 0.17 $m^3 \cdot s^{-1}$ (37% of baseflow) in both modeled reaches. In reach B2 maximum WUA was 160 $m^2 \cdot 100\ m^{-1}$ and in reach B4 it was 217 $m^2 \cdot 100\ m^{-1}$. The PHABSIM model also predicted that if discharge in section B of Hunt Creek was reduced to 0.01 $m^3 \cdot s^{-1}$ young of the year WUA would only be reduced to 76 $m^2 \cdot 100\ m^{-1}$ in reach B2 and 82 $m^2 \cdot 100\ m^{-1}$ in reach B4. This translates into a reduction in young of the year WUA of 37% and 56% in reaches B2 and B4 respectively with a 98% reduction of summer baseflow.

In contrast to the young of the year WUA estimates, yearling and older diurnal WUA in the two modeled reaches was slightly reduced with a 50% reduction in baseflow (Figures 4 and 5). The yearling and older diurnal WUA in reach B2 decreased from 134 to 132 $m^2 \cdot 100\ m^{-1}$, a loss of only 1.5% of suitable habitat area. Yearling and older WUA in reach B4 decreased from 162 to 159 $m^2 \cdot 100\ m^{-1}$, a reduction of only 1.9%. The model also predicted that a 98% reduction in summer stream flow would reduce yearling and older WUA by 65% in reach B2 and 70% in B4.

Diurnal WUA estimates based on bioenergetic-HSC for brook trout 5 and 7.5 cm total length (length range equivalent to young of the year fish) also increased with the 50% reduction in summer stream flow (Figures 6 and 7). In reach B2 the reduced summer stream flow resulted in increased WUA estimates of approximately 24% and 21% for 5 and 7.5 cm fish respectively. The magnitude of the increase was slightly lower than the 27% increase in young of the year WUA predicted from the diurnal use-HSC. In reach B4 the increases in WUA were approximately 31% and 17% for 5 and 7.5 cm fish respectively. This predicted increase in WUA was slightly higher than the 16% predicted increase in young of the year WUA in reach B4 from diurnal use-HSC. The maximum WUA estimates for 5 and 7.5 cm fish in reach B2 occurred at $Q=0.11\ m^3 \cdot s^{-1}$ and $Q=0.17\ m^3 \cdot s^{-1}$ respectively. This is similar to the predicted discharge of $0.17\ m^3 \cdot s^{-1}$ that yielded maximum WUA for all young of the year fish from the diurnal use-HSC. The maximum WUA values for 5 and 7.5 cm fish in reach B4 occurred at $Q=0.17\ m^3 \cdot s^{-1}$ and $Q=0.23\ m^3 \cdot s^{-1}$ respectively. This is also similar to the results for reach B4 from the diurnal use-HSC which indicated maximum WUA occurred at $Q=0.17\ m^3 \cdot s^{-1}$ for all young of the year fish. Finally, the model indicated that reducing flow 98% ($Q=0.01\ m^3 \cdot s^{-1}$) would reduce WUA in reach B2 for 5 and 7.5 cm fish approximately 75% and 86% respectively and 82% and 91% respectively in reach B4. The magnitude of the WUA reduction based on the bioenergetic-HSC is nearly twice that indicated from the results based on the diurnal use-HSC.

The PHABSIM model results for fish that are equivalent to the yearling and older size indicated that the reduction in flow also increased WUA for brook trout up to 15 cm total length in reach B2. WUA increased 16% for 10 cm fish, 10% for 12.5 cm fish and 2% for 15 cm fish

(Figure 6). In reach B2, WUA was reduced for fish larger than 15 cm and reductions in WUA were 5% and 11% for 17.5 and 20 cm fish respectively. For reach B4, WUA was reduced for all fish 10 cm and larger and reductions in WUA were greater than in reach B2 (Figure 7). The reductions in WUA in reach B4 were between 4% and 37% for fish larger than 10 cm. Losses in WUA with reduced flow were greatest for the largest fish in reaches B2 and B4 (Figures 6 and 7). Finally, the model indicated that WUA for fish between 10 and 20 cm total length would be reduced between 75% and 98% in reach B2 and 82% and 99% in reach B4 if summer stream flow was reduced 98% to 0.01 $m^3 \cdot s^{-1}$.

The PHABSIM model results for nocturnal habitat were similar to the results from diurnal use-HSC. Nocturnal WUA was increased by the 50% reduction in stream flow for both young of the year and yearling and older brook trout in section B (Figure 8). WUA for young of the year fish increased 18% in reach B2 and 29% in reach B4. WUA estimates for young of the year fish at a discharge of 0.01 $m^3 \cdot s^{-1}$ were greater than at baseflow. The 50% reduction in flow increased nocturnal WUA for yearling and older brook trout 9% in reach B2 and 15% in reach B4. In contrast to the results for young of the year nocturnal habitat, the model predicted that a 98% reduction in flow would result in substantial reductions in yearling and older nocturnal WUA. The predicted reduction in yearling and older WUA was 42% in reach B2 and 56% in reach B4.

PHABSIM Predictions

The analysis of the PHABSIM model output yielded two different sets of hypotheses concerning the impact of the 50% flow reduction on the brook trout population. From the model output of diurnal and nocturnal WUA based on the use-HSC, we could expect that young of the year or yearling and older brook trout population standing stock and density would not change in response to the withdrawal. This conclusion stems from the model output which predicted that diurnal and nocturnal WUA was substantially increased in both modeled reaches for young of the year fish, yearling and older diurnal WUA decreased only slightly, and yearling and older nocturnal WUA was increased when summer flow was reduced 50% (Figures 20, 21, and 24). The second hypothesis is based on the PHABSIM output generated from the bioenergetic-HSC. The model output for reach B2 suggests there should not be an impact of the flow reduction (Figure 6), but in reach B4, the standing stock or density of brook trout 12.5 cm and larger should have been decreased by 16-37%, depending on fish size (Figure 7). The expected reduction in brook trout abundance is based on an assumed one to one relationship between WUA and fish standing stock (Bovee 1978).

The predictions of no impact of the withdrawal on both young of the year and yearling and older fish were supported by the BACI statistics. We found no significant change in the mean differences between control and treatment sections of young of the year densities between the pretreatment and treatment period (Figure 9, Student's t=0.43, p=0.65, df=12). Differences in yearling and older density also did not change from pretreatment to treatment period (Figure 10, Student's t=1.21, p=0.28, df=12). We also did not detect any change in total standing crop between the pretreatment and treatment period (Student's t, p=0.97).

We tested the predictions of the PHABSIM model generated from the bioenergetic-HSC using BACI statistics by calculating the densities of brook trout in each of the four sections of Hunt Creek for 2.5 cm length intervals from 5 to 20 cm (e.g. 5-7.49 cm) and testing for impacts on each of these length classes of fish. We found a significant difference between the pretreatment and treatment period differences in densities only for the fish in the 10-12.5 cm length interval (Figure 11, Student's t=4.01, p=0.002, df=12). However, the change in this size group was opposite the predicted change: from 1981-1988, density of 10-12.5 cm brook trout decreased, and from 1989-1993 it increased (Figure 11). For all other length groups of fish we concluded there was no measurable impact from the withdrawal (p values between 0.09 and 0.78).

Because we were interested in the magnitude of the change in fish density that would be needed to detect a difference we calculated the minimum detectable difference and statistical power (Zar 1984) for the BACI analysis. We estimated that a minimum difference of approximately 823.1 and 842.3 fish$\cdot$ha^{-1} between the pretreatment and treatment mean differences would be necessary to conclude there was an impact on young of the year and yearling and older fish respectively. Also, we calculated power estimates of less than 0.20 for the BACI analysis, indicating that if there was an impact of the experimental treatment we only had a 20% chance of detecting it.

We also used the minimum detectable difference estimates to predict the reduction in discharge necessary to produce a measurable impact. For this calculation we subtracted the minimum detectable difference estimate from the mean number of fish$\cdot$ha^{-1} in the control section (AZ) over the pretreatment period to estimate the mean density of fish in the treatment section that would produce a significant result. We then divided that estimate by the mean density of fish in the treatment section during the pretreatment period to estimate the percentage reduction of pretreatment density that would produce a significant result. Then, assuming a one to one relationship between WUA and fish density, we estimated the discharge reduction that would produce the desired reduction in WUA to yield the needed proportional reduction of trout density. The estimated reduction in WUA that would be expected to produce a measurable impact on both young of the year and yearling and older brook trout densities in section B was approximately 50% of the WUA at baseflow (Table 2). The discharge estimates that would be expected to produce a measurable result differed depending on the type of HSC used to calculate WUA. The WUA curves calculated from diurnal use-HSC indicated that flow would need to be reduced to a level between 0.02 to less than 0.01 $m^3\cdot s^{-1}$ to reduce young of the year densities 50% and to a level between 0.03 to 0.05 $m^3\cdot s^{-1}$ to reduce yearling and older densities 50% (Table 2). This represents a reduction in flow of at least 88% before fish densities would be reduced a measurable amount. The discharge needed to produce a measurable impact on fish densities based on the WUA curves calculated from bioenergetic-HSC is between 0.02 and 0.06 $m^3\cdot s^{-1}$ for fish equal to young of the year size and between 0.05 and 0.16 $m^3\cdot s^{-1}$ for fish equal to yearling and older size (Table 2). Because the nocturnal WUA estimates at a 98% reduction in flow were only slightly reduced below those at baseflow it was impossible to evaluate a discharge which would produce a measurable decrease in population standing crop from nocturnal WUA.

Fish Movement

Brook trout moved downstream and out of the treatment section throughout summer, 1990 before the treatment (Table 3). The trap data also indicated that fish movement was relatively steady because the maximum number of brook trout caught on any date was four. Trap data for the treatment period (1991-94) were inconsistent between years and even between the diversion and AB line traps. However, brook trout in section B did not respond to the withdrawal consistently by moving downstream (Table 3). The rate of fish movement into section B was similar to the rate of movement out of the section in 1991-93, and movement into section B exceeded the rate of movement out in 1994 by a factor of four. We are unable to explain this increase in downstream movement of fish in 1994 from section C. Nevertheless, brook trout did not exhibit a change in movement behavior in the treatment section of Hunt Creek during the four years of treatment.

Discussion

The results presented here are very similar to those from a study by Kraft (1972), who evaluated the impact of a seasonal withdrawal on the brook trout habitat and population in a Montana stream. He dewatered a section of stream by up to 90% during the summer months and monitored brook trout population density. Brook trout moved from shallow runs to pools as flow was reduced but trout density of did not change significantly (Kraft 1972). In contrast to this study, brook trout did move out of the dewatered section of the Montana stream but not until the reduction in flow was equal to 90% of mean flow. Also, when the fish moved out of the test section it was in an upstream direction (Kraft

1972). Clothier (1954) reported similar upstream movement of brook trout, brown trout *Salmo trutta*, and rainbow trout *Oncorhynchus mykiss* during extreme irrigation withdrawals in the Gallatin River, Montana. Upstream movement was not possible for the brook trout in section B. We hypothesize the large numbers of brook trout caught in the traps in 1993 was a result of the unusually wet summer. Several heavy rains fell during the summer and each was followed by large numbers of fish caught in the traps. For example, during the three day period of 7 June to 9 June a total of 82 fish were captured in the traps at both the diversion and AB line bulkheads (41 fish at each bulkhead). These three days corresponded to a period of heavy rainfall which ultimately caused the failure of a beaver dam just upstream of section C.

The results presented here demonstrate that the brook trout population in Hunt Creek was not affected by the 50% reduction in summer stream flow. We attribute this to the fact that Hunt Creek is a very stable groundwater fed stream with high quality physical and biotic habitat under summer baseflow conditions. Given the high quality of the habitat under summer baseflow conditions it is not surprising that habitat was not severely impacted by a 50% reduction in baseflow. The results of the PHABSIM modeling support this conclusion because the diurnal WUA estimates for young of the year fish were substantially higher at reduced flow and WUA was only slightly reduced for yearling and older fish. These results were similar whether use-HSC or bioenergetic-HSC were used to estimate WUA. Furthermore, nocturnal WUA was increased for young of the year and yearling and older fish as a result of the reduced flow.

Because the PHABSIM model only varies the depths and velocities when discharge changes, the depth and velocity of the habitats modeled determine the shape of the WUA curve. Therefore, the increased WUA estimates at half of the mean summer stream flow are due to either more locations with improved depth suitability, improved velocity suitability, or both. We suggest that the change in the velocity availability was the primary cause of the increased WUA estimates. This conclusion is based on the observation that the mean column velocity use-HSC indicated that the optimal mean column velocities were less than the mean of the mean column velocity measurements at summer baseflow in section B of Hunt Creek (Baker and Coon 1995A) for young of the year and yearling and older fish. Therefore, as discharge was reduced locations with greater than optimal mean column velocity at summer baseflow would become more suitable because mean column velocity would decrease as discharge decreased.

Although physical habitat is important in determining fish abundance and distribution in a variety of habitats, other biotic and abiotic factors can influence fish abundance and distribution in streams (Chapman 1966, Latta 1965, Sheldon 1968, Gorman and Karr 1978, Finger 1982, Bowlby and Roff 1986). Other factors which could change under reduced flow conditions are predation risk, disease transmission rates, water temperature, competitive interactions, and food availability (Orth 1987). The magnitude of the changes in any of these parameters is almost certainly dependent on the magnitude of the reduction in flow. It does not appear that risk of predation was increased by the reduction in summer stream flow in Hunt Creek because fish numbers in the treatment section were not reduced. Also, although we did not measure disease occurrence during this study, we did not notice any obvious differences in the occurrence of diseased fish between sections during the spring and fall electrofishing sampling. Water temperature also did not appear to increase in the treatment section of Hunt Creek due to the reduced flow. Temperature recorders installed at the upstream and downstream ends of the treatment section indicated the mean daily maximum temperature for June 1-August 31 in 1993 was 0.3° C higher at the downstream end of section B and in 1994 was 0.4° C lower at the downstream end than the upstream end (Michigan DNR unpublished data). These differences could be due to differences in calibration of the recording devices or may be real differences. In either case, there is no evidence for an increase in temperature as a result of the reduced flow. Finally, brook trout food was not reduced as a result of the reduced flow because neither benthic invertebrate density or habitat were impacted by the reduction in flow (Baker and Coon 1995b).

The population data suggest that factors other than mean summer stream flow may serve to determine the density of the brook trout population in Hunt Creek. This contention stems from the fact that there was a large reduction in fall young of the year brook trout density in the upstream section C of Hunt Creek in 1993 which was not observed in the other sections of Hunt Creek (Figure 9). We hypothesize this reduction in fall young of the year density of brook trout was due to the previously mentioned intense rain which caused the failure of a beaver dam just upstream of section C. We were unable to measure water levels or discharge during the spate, however, the flow was over bank full in section C. This occurred during the first week of June when the young of the year brook trout were approximately 2-3 cm total length. We hypothesize this flood event determined fall young of the year density in section C by causing a large mortality or emigration of the young of the year fish, but did not affect the young of the year fish in section B to the same extent because approximately half of the flood flow was diverted through the diversion channel. This large mortality or emigration of young of the year in 1993 also apparently is the cause of the reduction in yearling and older density in fall 1994 (Figure 10).

The alternate HSC showed that an investigator's *a priori* choice of HSC used in modeling habitat can affect the output of a PHABSIM analysis. However, the question still remains as to which type(s) of HSC provide the best prediction of the impacts of a change in flow regime in a PHABSIM analysis. We could not answer that question in this study because the magnitude of the withdrawal was insufficient to produce an impact on the brook trout. However, the fact that the shape and magnitude of the WUA curves differ indicate the analysis based on bioenergetic-HSC may provide a different prediction of impacts. It is worth noting again that the magnitude of the decrease in diurnal WUA predicted at a reduced flow equal to 2% of baseflow was only 37-70% when diurnal use-HSC were used in the calculation of WUA but was 75-91% when bioenergetic-HSC were used to calculate WUA. It is more likely that a 98% reduction in discharge would reduce the suitable drift foraging habitat area approximately the same amount. Therefore, the bioenergetic-HSC may be more accurate predictors of the changes in foraging microhabitat availability in Hunt Creek than diurnal use-HSC.

The differences in the magnitude of WUA between the two methods is likely a result of the more conservative estimates of optimal velocities based on bioenergetic modeling and the interdependence of the suitability of depth to velocity. However, the magnitude of WUA is less important than the shape of a WUA curve in attempting to assess the impacts of a proposed withdrawal on the fish population in a stream (Bovee 1978). In that respect, both types of HSC were accurate predictors of the lack of impact from the reduction of summer stream flow in Hunt Creek. However, we do not consider this an adequate test of the PHABSIM modeling procedure. Rather, we suggest that WUA curves developed from this study be used to establish a withdrawal level expected to produce an impact on the brook trout population in Hunt Creek and the study continued for four more years. Only then can the predictions of the PHABSIM model be tested sufficiently.

It is important to stress that the results of this study are unique to Hunt Creek and are not necessarily applicable to other streams in Michigan or the midwest. The fact that the 50% reduction in summer streamflow did not reduce fish densities in Hunt Creek is probably because Hunt Creek is a very stable stream with high quality brook trout habitat under baseflow conditions. If Hunt Creek was a marginal trout stream the 50% reduction in summer baseflow may have resulted in a reduction in WUA and fish densities. For example, in an evaluation of impacts of irrigation withdrawals on the brown trout population in a marginal trout stream in southern Michigan, the PHABSIM model indicated that a 50% reduction of summer baseflow would reduce brown trout WUA approximately 40% (estimated from figures in Gowan 1984). It is also likely that a 50% reduction of summer stream flow in Hunt Creek would have an adverse impact on the trout in Hunt Creek if the population in Hunt Creek was brown trout or rainbow trout instead on brook trout. We modeled the habitat in section B of Hunt Creek with HSC for brown (Gowan

1984, Raleigh et al. 1986) and rainbow trout (Raleigh et al. 1984). The WUA curves indicated that if brown trout was the only salmonid present in Hunt Creek a 50% reduction in summer flow would reduce adult habitat approximately 8% and would reduce juvenile habitat 12-16%. If rainbow trout were the only salmonid species in Hunt Creek juvenile habitat would be increased approximately 4% and adult habitat would be reduced 14-23% with a 50% reduction in summer flow.

Finally, although there is currently no way to evaluate the effectiveness of the bioenergetic-HSC versus the use-HSC used to calculate WUA estimates for foraging microhabitats, bioenergetic-HSC offer several potential advantages. First, bioenergetic-HSC could be used to construct a spatial model of foraging habitats in the stream of interest which could be used to predict the locations of suitable foraging microhabitats. This information in conjunction with territory size predictions (Grant and Kramer 1990) could be used to predict the actual number of fish in a reach of stream and how that number may change with reduced streamflow. Also, the use of bioenergetic-HSC with a spatial model of stream habitat could also be used to predict fish growth rates (Nielsen 1992) as well as to predict expected changes in growth rates in relation to changes in flow. Information on the expected changes in abundance and growth rates of stream fish in relation to flow could therefore be used to predict changes in biomass as well.

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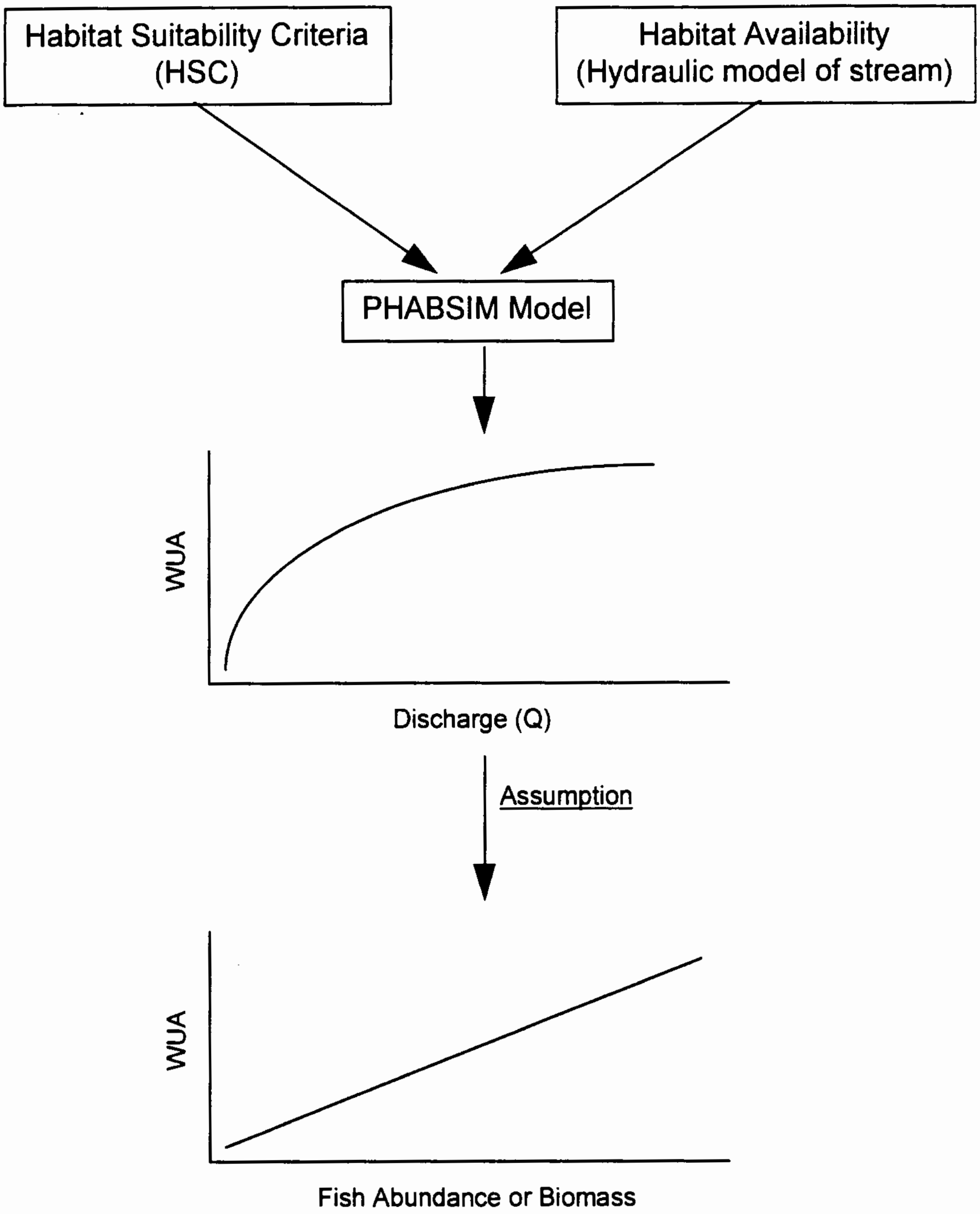

Figure 1. PHABSIM model process including data input and output as well as assumption relating model output to fish population parameters (WUA=weighted usable area).

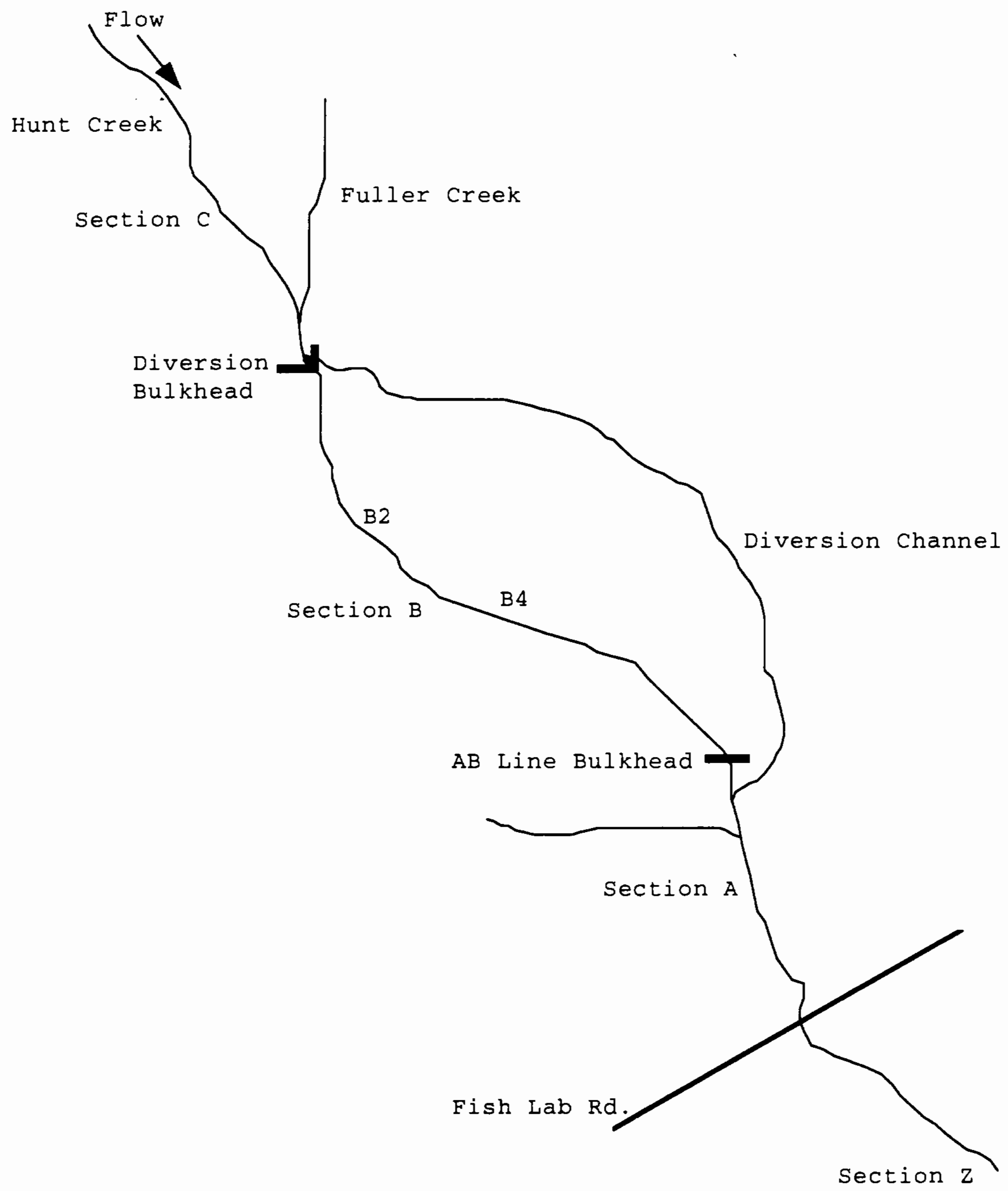

Figure 2. Map of Hunt Creek study area. The upstream bulkhead is the boundary between sections C and B, the downstream bulkhead is the boundary between sections B and A, and Fish Lab Rd. is the boundary between sections A and Z.

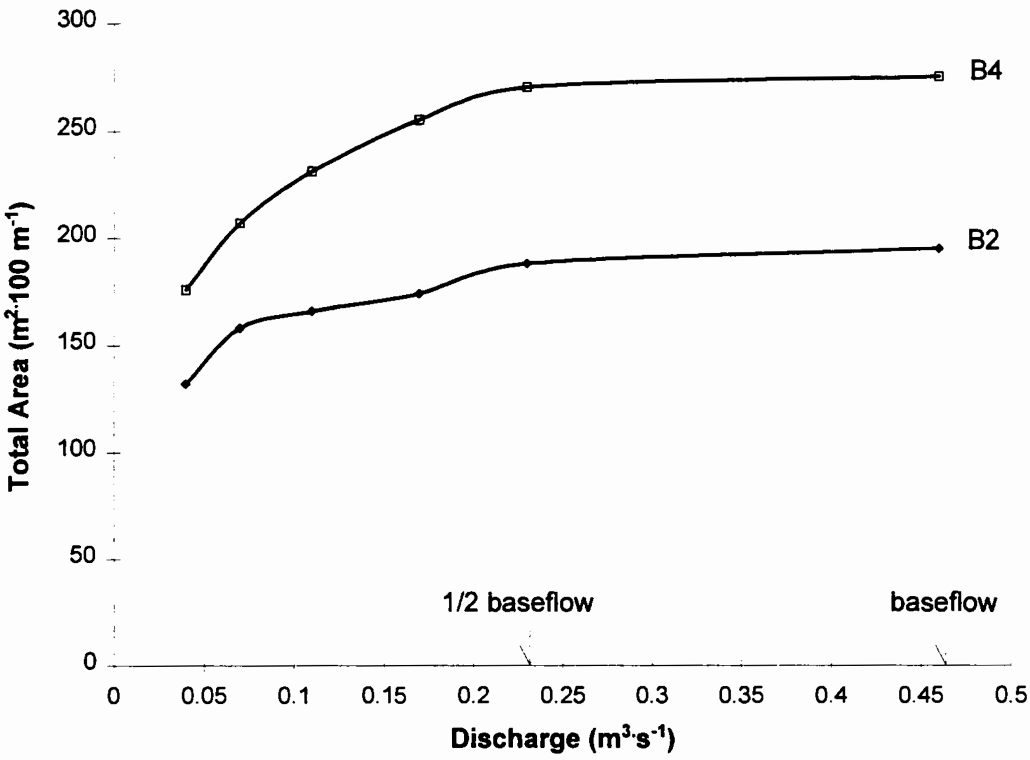

Figure 3. Total area ($m^2 \cdot 100\ m^{-1}$) as a function of discharge ($m^3 \cdot s^{-1}$) for reaches B2 and B4 in Hunt Creek.

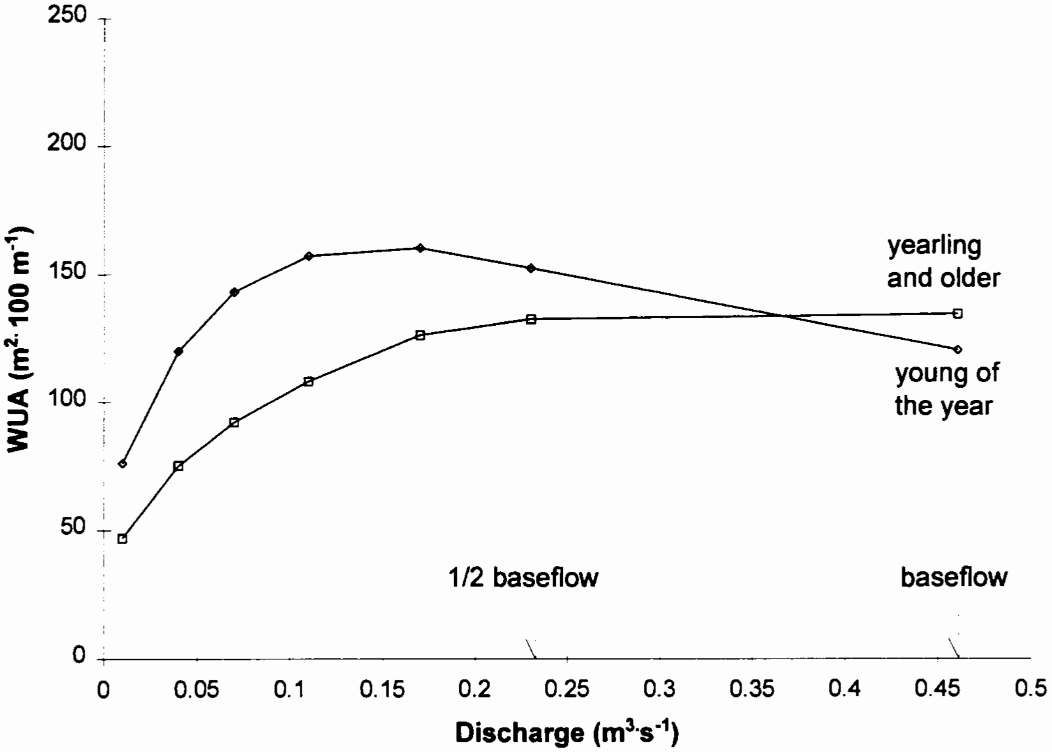

Figure 4. Diurnal WUA ($m^2 \cdot 100\ m^{-1}$) estimates derived from diurnal use-HSC as a function of discharge ($m^3 \cdot s^{-1}$) for young of the year and yearling and older brook trout in reach B2 of Hunt Creek.

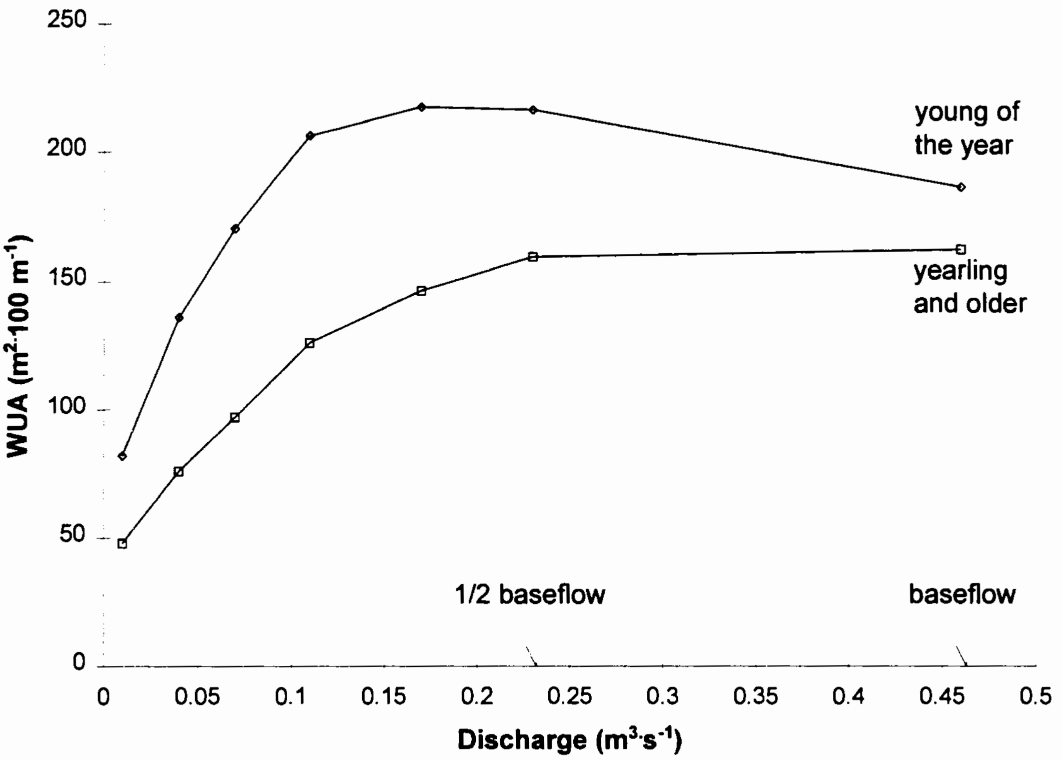

Figure 5. Diurnal WUA ($m^2 \cdot 100\ m^{-1}$ of stream) estimates derived from diurnal use-HSC as a function of discharge ($m^3 \cdot s^{-1}$) for young of the year and yearling and older brook trout in reach B4 of Hunt Creek.

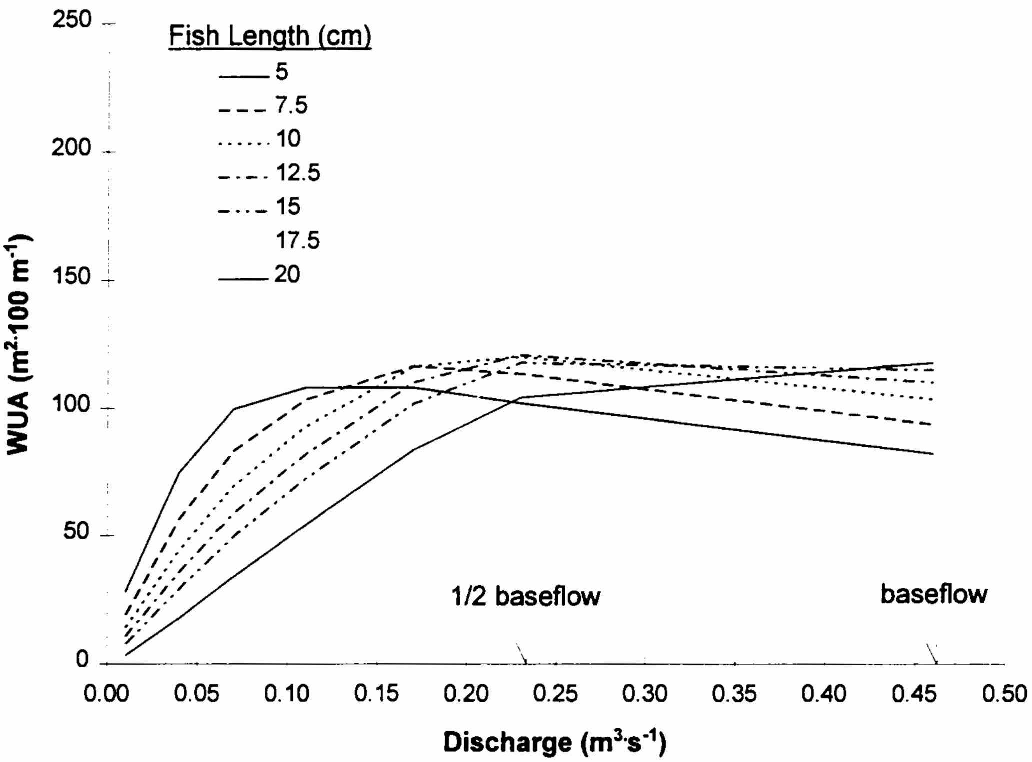

Figure 6. Diurnal WUA ($m^2 \cdot 100\ m^{-1}$ of stream) estimates derived from bioenergetic-HSC as a function of discharge ($m^3 \cdot s^{-1}$) for brook trout in reach B2 of Hunt Creek.

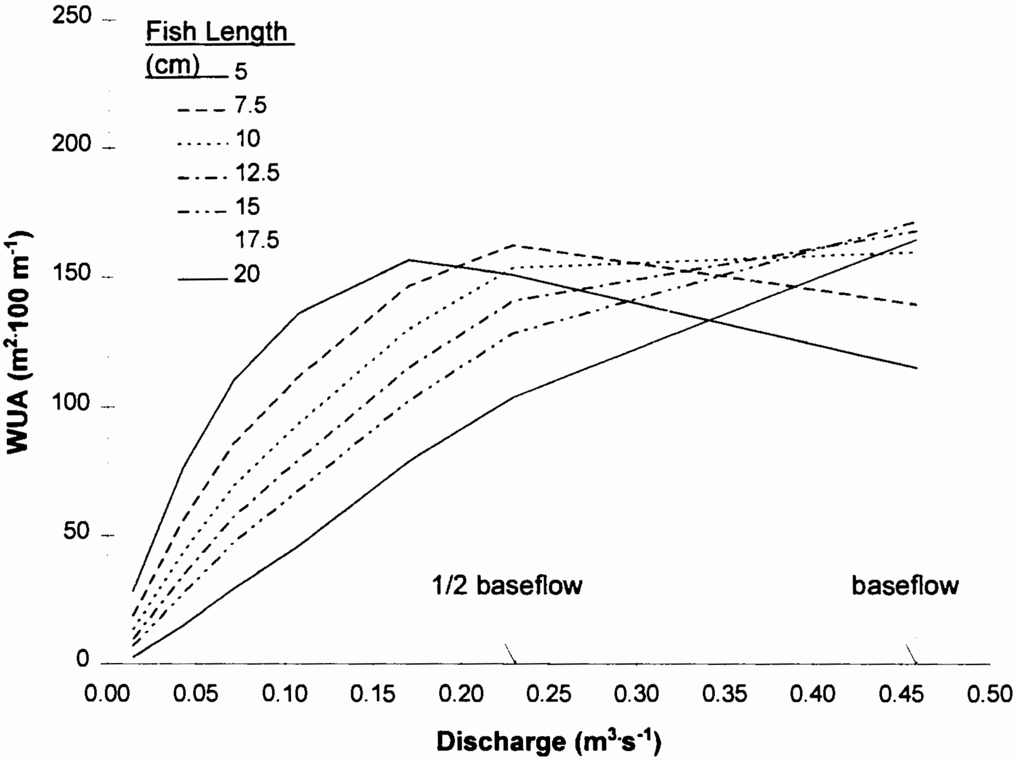

Figure 7. Diurnal WUA ($m^2 \cdot 100\ m^{-1}$ of stream) estimates derived from bioenergetic-HSC as a function of discharge ($m^3 \cdot s^{-1}$) for brook trout in reach B4 of Hunt Creek.

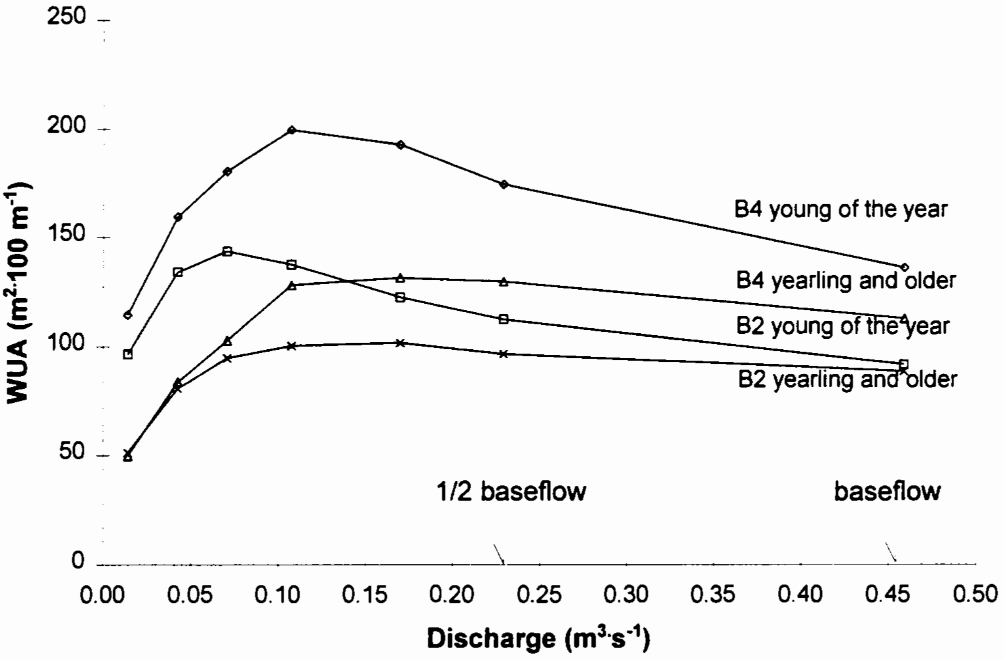

Figure 8. Nocturnal WUA ($m^2 \cdot 100\ m^{-1}$) as a function of discharge ($m^3 \cdot s^{-1}$) estimates for young of the year and yearling and older brook trout in reaches B2 and B4 of Hunt Creek.

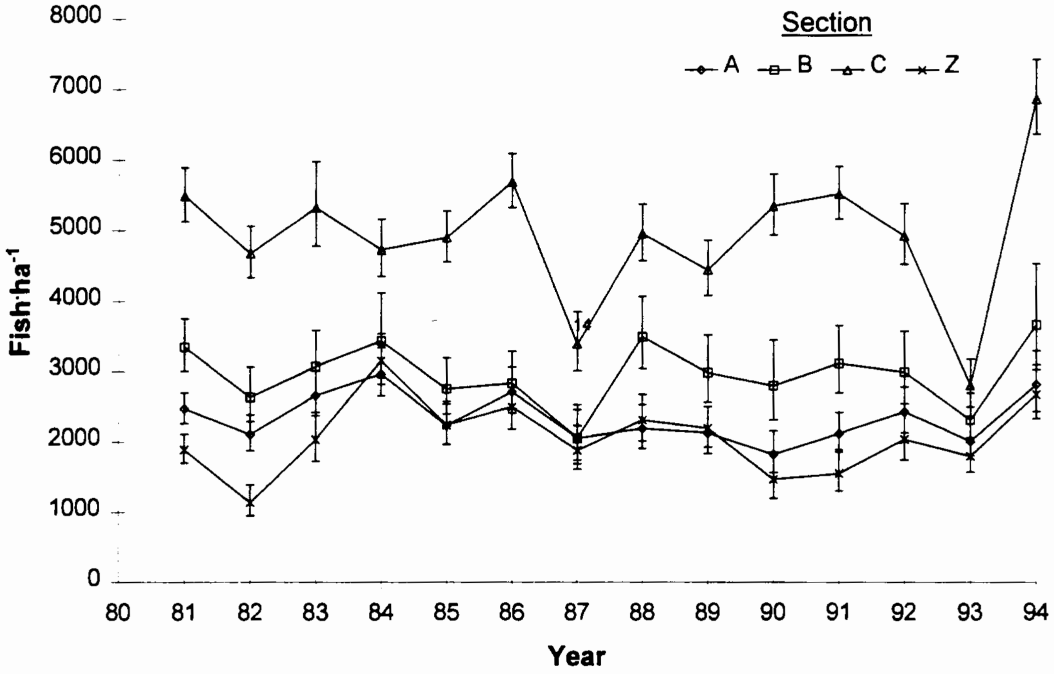

Figure 9. Fall young of the year brook trout population density (fish·ha^{-1}) estimates for sections A, B, C, and Z of Hunt Creek for 1981-1994. The withdrawal period was from 1991-94. Error bars represent 95% confidence limits of the mean.

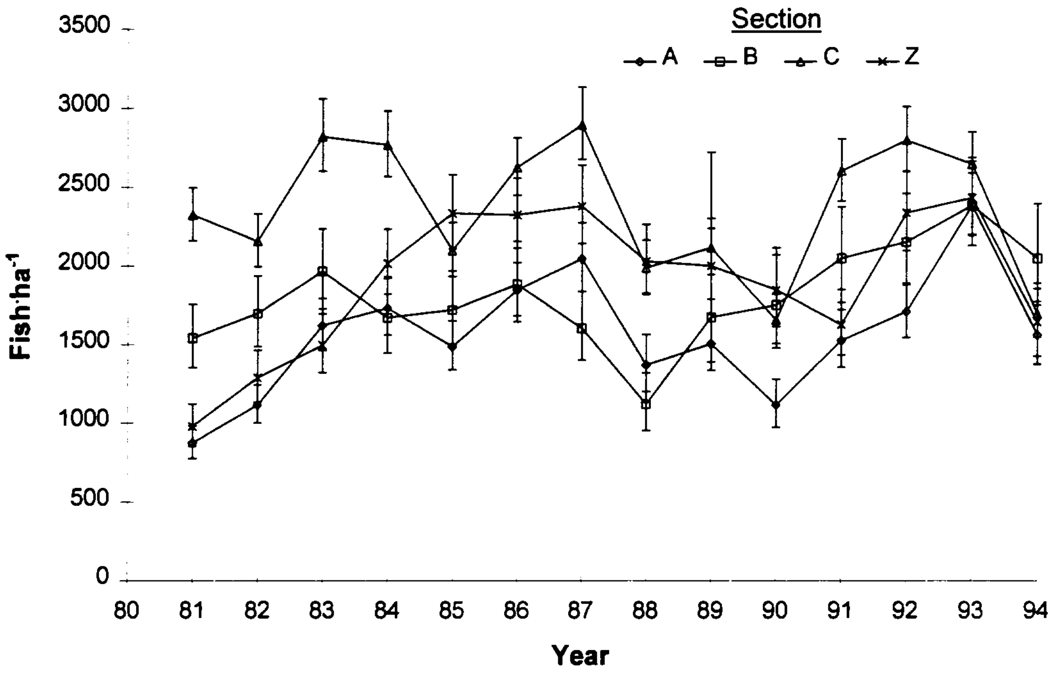

Figure 10. Fall yearling and older brook trout population density (fish·ha^{-1}) estimates for sections A, B, C, and Z of Hunt Creek for 1981-1994. The withdrawal period was from 1991-94. Error bars represent 95% confidence limits of the mean.

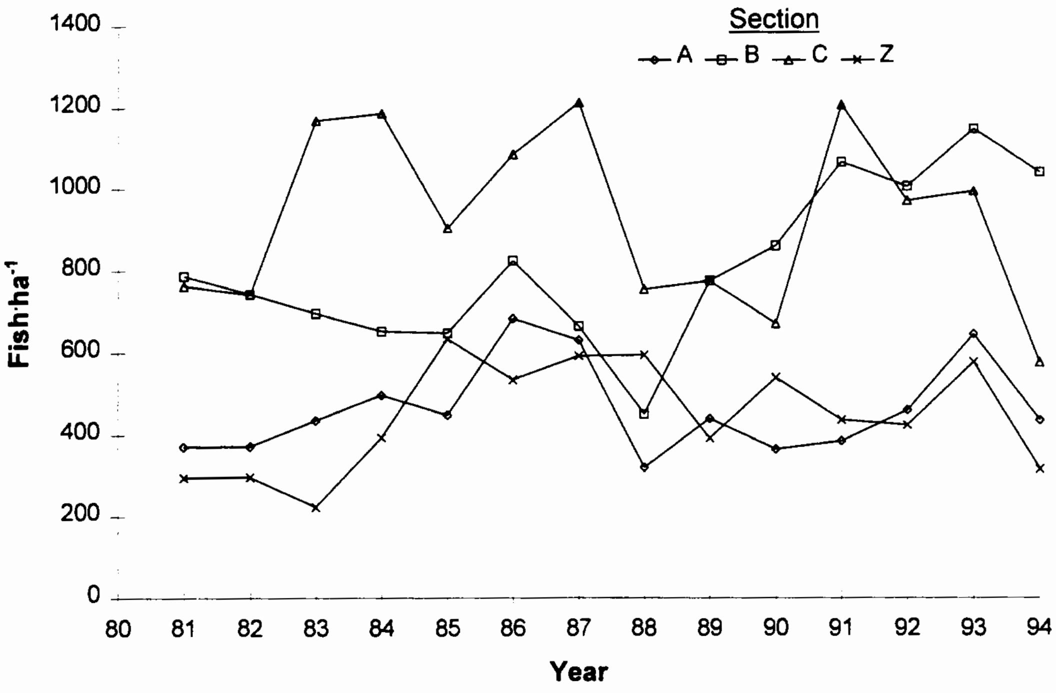

Figure 11. Fall brook trout population density (fish·ha^{-1}) estimates for fish 10-12.5 cm total length in sections A, B, C, and Z of Hunt Creek for 1981-1994. The withdrawal period was from 1991-94.

Table 1. Summary of optimal and suitable habitat suitability criteria curve values for diurnal and nocturnal periods. Data for all HSC are from Baker and Coon (1995a). Bioenergetic-HSC were size specific and are presented here only for 7.5 and 15 cm fish (sizes equivalent to young of the year and yearling and older fish respectively).

		Depth (cm)	**Mean Column Velocity ($cm \cdot s^{-1}$)**	**Substrate**	**Cover**
Diurnal Use-HSC					
young of the year	Optimal Range	15-34	6-30	1-5.4	3
	Suitable Range	3-67	0-66	1-5.4	2 & 3
yearling and older	Optimal Range	27-55	6-27	1-5.4	3
	Suitable Range	12-85	0-98	1-5.4	2 & 3
Diurnal Bioenergetic-HSC					
7.5 cm	Optimal Value	Varies	28	1-5.4	3
	Suitable Range	>1.7	1-46	1-5.4	2 & 3
15 cm	Optimal Value	Varies	41	1-5.4	3
	Suitable Range	>3.3	3-63	1-5.4	2 & 3
Nocturnal Use-HSC					
young of the year	Optimal Range	12-29	5-23	1-5.4	3
	Suitable Range	1-73	0-39	1-5.4	2 & 3
yearling and older	Optimal Range	20-46	4-22	1-5.4	3
	Suitable Range	7-73	0-52	1-5.4	2 & 3

Table 2. Summary of diurnal WUA estimates in modeled reaches of section B, Hunt Creek in relation to summer baseflow discharge (Q) and 50% of summer baseflow and the estimated Q (Q_{50}) at which the WUA estimates would be reduced 50% for fish of each size group.

		WUA ($m^2 \cdot 100\ m^{-1}$) @ summer Q ($m^3 \cdot s^{-1}$)		**WUA ($m^2 \cdot 100\ m^{-1}$) @ 50% of summer Q ($m^3 \cdot s^{-1}$)**		**Q_{50} ($m^3 \cdot s^{-1}$)**	
Reach	**Fish Size**	**Diurnal Use-HSC**	**Bioenergetic-HSC**	**Diurnal use-HSC**	**Bioenergetic-HSC**	**Diurnal use-HSC**	**Bioenergetic-HSC**
B2	**young of the year**	120		152		<0.01	
	5 cm		82		102		0.02
	7.5 cm		93		113		0.04
	yearling and older	134		132		0.03	
	10 cm		103		120		0.05
	12.5 cm		110		121		0.07
	15 cm		115		118		0.08
	17.5 cm		117		112		0.10
	20 cm		117		104		0.12
B4	**young of the year**	186		216		0.02	
	5 cm		115		151		0.03
	7.5 cm		139		162		0.06
	yearling and older	162		159		0.05	
	10 cm		160		154		0.09
	12.5 cm		168		141		0.12
	15 cm		172		128		0.14
	17.5 cm		170		116		0.16
	20 cm		165		104		0.18

Table 3. Size and number of brook trout caught in inclined screen traps during the treatment period (1991-94) and for the summer prior to withdrawal from traps at the upstream and downstream bulkheads.

	Upstream Bulkhead		**Downstream Bulkhead**	
Year	**mean length (cm)**	**n**	**mean length (cm)**	**n**
1990	not recorded		10.9	69
1991	10.2	39	10.3	43
1992	11.3	30	9.0	53
1993	12.6	199	12.6	132
1994	8.5	183	8.3	50