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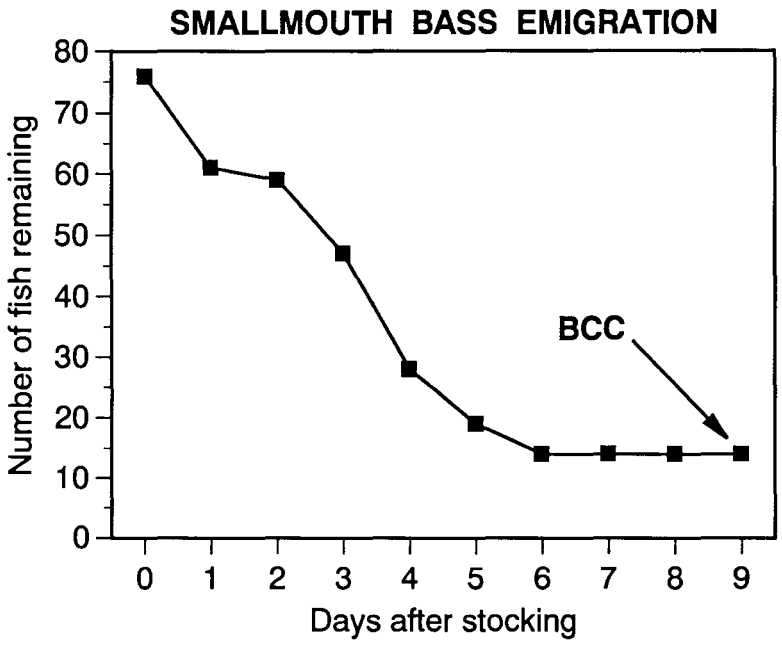
Troy G. Zorn



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The Effect of Streamflow on the Short-Term Carrying Capacity of a Stream for Juvenile Smallmouth Bass: A Test of the Instream Flow Incremental Methodology

by

Troy G. Zorn

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in partial fulfillment of the requirements for
the degree of
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Abstract

The Behavioral Carrying Capacity (BCC) technique was used to test the assumption of the Instream Flow Incremental Methodology (IFIM) that a positive linear relationship exists between fish habitat (Weighted Usable Area or WUA) and fish biomass for smallmouth bass populations at carrying capacity. BCC experiments were performed at various streamflows and WUA was measured at each flow. In each BCC experiment, a section of a stream was over-stocked with juvenile smallmouth bass *Micropterus dolomieui*, excess fish were trapped as they emigrated, and the remaining resident fish were collected after a 10-day period. I found negative relationships between WUA and BCC, and between stream discharge and BCC. High BCC values that occurred during low-flow experiments resulted from less upstream and downstream movement by juvenile smallmouth bass. Such behavioral changes may prevent smallmouth bass populations from being limited by habitat availability during low-flow events. The low-velocity nature of many warmwater streams, and the diverse aquatic habitats and fish communities they contain, are quite different from the high-velocity trout streams where IFIM was developed. As a result, fish populations in warmwater streams are often structured by mechanisms other than habitat availability. In such cases the microhabitat variables (depth, velocity, substrate and cover) typically used in IFIM studies may be inadequate for predicting fish population responses to streamflow alteration for many species and lifestages of fish in warmwater streams.

Introduction

Streams provide many beneficial uses to society. In addition to their inherent aesthetic values, they often support valuable fisheries and other recreational uses, or serve as sources of water for irrigation, industry and municipal use. Demands placed on streams by various users have resulted in conflicts regarding how streamflows should be allocated, i.e. towards instream or offstream uses. In Michigan, current irrigation practices and trends toward increased irrigation (Bedell et al. 1977; Sommers 1977; Bartholic et al. 1983) may make such conflicts a more frequent occurrence. For example, Fulcher et al. (1986) estimated that consumptive uses (primarily irrigation) in the watershed would reduce July and August drought flows (95% exceedence flows) in the River Raisin near Manchester by approximately 85%. Subsequent drought conditions during the summer of 1988 resulted in heated conflict between water users within the River Raisin watershed (R. Van Til, Michigan Department of Natural Resources, Lansing, Michigan, personal communication, 1989).

The Instream Flow Incremental Methodology (IFIM) was developed as a tool to aid fishery biologists and water managers in determining to what extent human activities (such as water withdrawal for irrigation, municipal and industrial use; dam construction and operation; or channel modifications) would affect aquatic habitats of stream-dwelling organisms (Bovee 1982). The IFIM was a technological breakthrough because it allowed managers to quantitatively compare fish habitats at different flow regimes. This is accomplished through the Physical Habitat Simulation Model (PHABSIM), one of the IFIM's primary components. The PHABSIM estimates the amount of usable habitat (Weighted Usable Area or WUA) for a lifestage (egg, larvae, juvenile or adult) of a fish species, as a function of stream discharge. This estimate is produced by combining output from hydrologic models, which relate microhabitat characteristics (depth, velocity, substrate and cover) to stream discharge, with information on the microhabitat preferences of the lifestage of the fish species being studied. There is assumed to be a positive linear relationship between WUA and fish standing crops for populations at carrying capacity (Bovee and Cochnauer 1977). This assumption is based on

studies of density-dependent mortality among salmonids in streams (Chapman 1966) and implies that habitat availability, especially during low-flow periods, is the primary factor limiting fish populations in streams. Since its initial development, other components have been added to the IFIM. These include models of temperature (Theurer et al. 1984), water quality (Brown and Barnwell 1987), physical habitat (Milhous et al. 1990a), hydrology (Milhous et al. 1990b), an analysis of agency involvement (Wilds 1988), and a time-series library (Bartholow and Waddle 1986; Milhous et al. 1990b).

Though the IFIM has enjoyed wide use throughout the United States and Canada (Armour and Taylor 1991) it has been criticized on several counts. Critiques have focused on both the hydrologic components (Wiley et al. 1987; Osborne et al. 1988) and biological aspects (Orth and Maughan 1982; Mathur et al. 1984; Morhardt 1986; Conder and Annear 1987; Orth 1987) of the models used in the IFIM.

Several authors (Mathur et al. 1984; Morhardt 1986) and nationwide surveys of IFIM users (Reiser et al. 1989; Armour and Taylor 1991) have indicated that one of the areas of the IFIM most in need of research concerns the assumption of a positive linear relationship between WUA and fish biomass. In some cases, efforts to validate the method by comparing standing crops of fish to the amount of available habitat have resulted in poor correlations (Orth and Maughan 1982; Conder and Annear 1987; Wiley et al. 1987). This may occur because stream fish populations are often limited by recruitment, rather than habitat availability. The IFIM does not account for the effects of drought and flood events, which often limit recruitment (and subsequent standing crops) of fish in streams. The model actually predicts changes in a stream's carrying capacity (the maximum number of fish that it can support) for a given flow, rather than its standing crop. Tests relating streamflow to carrying capacity are difficult to perform in natural systems because recruitment-limiting events and factors such as predation, competition and food availability often keep population levels below carrying capacity.

Morhardt (1988) devised an innovative method for testing the relationship between stream discharge, WUA and fish biomass at carrying capacity. It involves forcing the fish population to be at carrying capacity of the stream for a short time for the purposes of measurement. This short-term carrying capacity is artificially produced by over-stocking the stream reach, then allowing emigration to deplete the population to a level limited by the habitat characteristics of the reach. Morhardt referred to this endpoint as "behavioral carrying capacity" (BCC) to emphasize that it results from the short-term behavioral responses of the stocked fish. It is expected that "real" carrying capacity would be the result of a more complex set of variables (Orth 1987).

This technique has been used successfully in several artificial stream studies (e.g. Slaney et al. 1974; Wilzbach 1985). Studies using coho salmon *Oncorhynchus kisutch* (Chapman 1962), and Apache trout *Oncorhynchus apache* and brown trout *Salmo trutta* (Mesick 1988) have shown that the suitability of the habitat is the primary factor which controls the number of fish that remain after emigration ceases. Bugert and Bjornn (1991) used BCC to assess habitat use, interactions, and response to cover and predators of subyearling coho salmon and steelhead trout *Oncorhynchus mykiss*. Mesick et al. (1988) found that BCC for brown trout and rainbow trout in a natural stream was positively correlated with the number of rocks providing cover. However, this technique has never been used in field studies of warmwater fish.

I conducted experiments, using the BCC technique at different streamflows, to determine the relationship between streamflow and the short-term carrying capacity of a warmwater stream for smallmouth bass *Micropterus dolomieui*. The objectives of this study were to: 1) Determine if there is a positive linear relationship between WUA and BCC for juvenile smallmouth bass; 2) Determine the relationship between stream discharge and BCC for juvenile smallmouth bass; and 3) Evaluate the effects of low streamflow on the instream distribution of juvenile smallmouth bass. I accomplished this by over-stocking a semi-natural stream reach with juvenile smallmouth bass, trapping emigrating

fish, and measuring BCC of the stream 10 days after it was stocked. This experiment was repeated at different streamflows in order to determine the relationships between WUA, stream discharge and BCC.

Methods

Species Studied

Smallmouth bass were selected for study because they are the dominant predator fish in many warmwater rivers and a favorite target of anglers. Their affinity for cover and streams with moderate gradient closely resembles that of trout, which have been used in all BCC studies to date. Juveniles were selected for several reasons. They were more likely to be drift-feeding insectivores, i.e. similar to trout, than adult smallmouth bass (Becker 1983). Juveniles were readily available from year to year, and sizable numbers of them could be collected with relative ease. Since larger numbers of juveniles could be held in the study reach, changes in the carrying capacity of the stream would be more detectable (in terms of numbers of fish remaining). Strong homing tendencies shown by adult smallmouth bass (e.g. Larimore 1952; Henderson and Foster 1956) also made them a less desirable size group for study. Little information was available on homing and migration behaviors of juvenile smallmouths.

Study Area

I performed BCC experiments in the downstream, unmaintained portion of a millrace that partially drains an impoundment of the River Raisin approximately 4 km northwest of Manchester, Michigan. The millrace and adjacent property are owned by the Sharon Mills Winery. The study stream was approximately 53 m long and 7.6 m wide. It contained two pools (up to .75 m deep) separated by shallow runs (Figure 1). Its substrate consisted of silt and sand (50%), gravel (40%) and cobble (10%), with several large log complexes that provided instream cover. The entire stream

corridor was forested. Streamflow through the study reach was controlled by inserting or removing boards at an upstream dam. A staff gauge was installed in the study stream and cross-sectional measurements used to monitor discharge.

Trapping System

I installed traps at both ends of the study reach (Figure 2). Each trap was a 1- m^3 box constructed with a frame of 5-cm x 5-cm treated lumber and 1.3-cm mesh hardware cloth forming panels. Each trap had a pyramid-shaped throat with a 10-cm x 10-cm square opening that emptied into the center of the trap. A mesh tube was added to the throat opening on the downstream trap in order to prevent trapped fish (which orient themselves in an upstream direction) from swimming between the opening of the throat and the rear panel of the trap. Hardware cloth (1.3-cm mesh) wings extended from the sides of the trap to the streambank. I used sandbags to block openings which occurred between the trap wings and streambed. This kept fish from freely moving into and out of the study stream. The trapping system was visually inspected for openings at the beginning of each experiment. A weir was built above the upstream trap in order to prevent debris from damaging the traps during unexpected high-flow events. It consisted of a 5-cm x 10-cm treated lumber frame, over which was laid chain link fence and 1.3-cm mesh hardware cloth. The weir and traps were cleaned of debris daily.

Experimental Procedures

Once the traps were in place, I removed resident fish from the study section using multiple-pass electrofishing. I removed smallmouth bass (including fry, juveniles and adults), rock bass *Ambloplites rupestris*, northern pike *Esox lucius* and various species of suckers, sunfishes, catfishes and minnows. The fish fauna was very similar to that found in the adjacent River Raisin, indicating that the study stream provided habitats similar to a natural stream.

I conducted experiments between June and September 1990-1992. I attempted to randomize stream discharge levels among experiments in order to eliminate seasonal effects on BCC. I could not strictly adhere to my study design because occasional high-flow events in the main channel of the River Raisin created a backwater in the study stream. As a result, the number and timing of trials varied from year to year (Table 1). I arbitrarily selected streamflows which simulated summer flow conditions ranging from normal to drought flow. Drought flows used were low enough that portions of riffle habitat were dry.

Juvenile smallmouth bass used in each experiment were collected from the River Raisin near Monroe, Michigan. Fish ranged in length from 13 cm to 23 cm, and were typically age I or II (based on unpublished aging of scales). I measured, weighed, and uniquely freeze-branded each fish prior to stocking. The brands allowed me to identify individuals at the end of each experiment and assess their growth during the trial. Depending on their availability, between 68 and 151 (usually about 73) smallmouth bass were stocked in the study stream at the beginning of each experiment (Table 1). In order to allow time for fish to adjust to their new surroundings, emigration traps were not opened until one day after fish were stocked.

Once opened, traps were checked daily, and numbers of emigrating smallmouth bass and other fish caught were recorded. Maximum and minimum air and water temperatures, and stage and discharge levels in the study reach were also monitored daily. Emigrating fish were trapped for at least 8 days before an experiment was terminated.

Prior to collecting fish at the end of each 1991 experiment, I assessed the distribution of the remaining (resident) smallmouth bass in the stream by electrofishing with six pre-positioned electrode arrays. In order to prevent galvanotaxis when sampling, the arrays used 3-phase AC current, produced by a 240-volt generator. Each array consisted of six 30-cm copper electrodes that were placed upright on the streambed, forming a 2 x 3 electrode rectangle which sampled an area of approximately 13.9 m^2. I placed the arrays in the stream on the day before an experiment was to end

(Figure 1). Arrays were electrified the following day in a "semi-random" order at 20-minute intervals between 0900 and 1130 hours. The order was "semi-random" because after an array was electrified, the arrays immediately upstream and downstream of it would not be electrified next. The 20-minute interval served as a recovery period for fish that may have been disturbed as workers collected stunned fish.

The remaining resident fish were collected from the study stream by making multiple passes with DC electrofishing gear. Electrofishing passes were made upstream until two consecutive passes failed to produce bass. The number of trapped and shocked fish collected during an experiment often did not equal the initial number of fish stocked (on average, 96% of fish stocked were recovered during experiments). I assumed that BCC for an experiment equalled the number of smallmouth bass collected by electrofishing. I recorded the length, weight, and brand of each individual collected. I assessed the diet of resident fish by flushing out their stomach contents with a modified, hand-operated garden pump-sprayer.

For two days following collection of fish from the study stream, I measured instream microhabitat conditions for the recently completed trial. Maximum depth, mean velocity, substrate, and cover were measured at 61-cm intervals along cross-sectional transects located at 3-m intervals along the entire length of the study stream. Mean velocity was measured at 0.6 of maximum depth using a Price model 622 current meter. Dominant and subdominant substrate types were determined visually (Table 2), and cover types occurring within 30 cm of each cell were also recorded (Table 3).

I did not make habitat measurements for the experiments ending on August 20, 1991 and August 19, 1992 because rainstorms occurring at the end of these experiments raised the stream to atypically high levels. Data from experiments using similar, but more constant, streamflows (July 24, 1991 and July 9, 1992, respectively) were used to estimate microhabitat conditions for these experiments.

Data Analysis

Depth, velocity, substrate, and cover measurements for each cell were assigned values ranging between 0 and 1 based upon their suitability for juvenile smallmouth bass (1 being the most suitable). Habitat suitability data for juvenile smallmouth bass in the Huron River (Monahan 1991), a watershed adjacent to the River Raisin, were used to assign suitability values to the transect data. Two sets of suitability curves were generated from Monahan's data. The first set of curves (Appendix A) was based on daytime observations of juvenile smallmouth bass using all habitat types during the summer. The second set of curves (Appendix B) was generated from a subset of the daytime-summer observations, and represents suitability of high-cover run habitats (commonly found in the study stream) for juvenile smallmouth bass. I wrote a computer program, in the BASIC language, to estimate WUA from the transect data obtained for each experiment (Appendix C). WUA values were calculated as follows.

$$WUA = \sum_{i=1}^{n} D_i \, V_i \, S_i \, C_i \, A_i$$

D_i = Depth suitability for cell *i*

V_i = Velocity suitability for cell *i*

S_i = Substrate suitability for cell *i*

C_i = Cover suitability for cell *i*

A_i = Area of cell *i* (1.86 m^2)

Component WUA values (sum of the products of each suitability value times the cell's area) for depth, velocity, substrate and cover variables; and percent WUA (total WUA divided by stream area) were calculated for each experiment (Appendix D). Mean and maximum depths and velocities were also recorded (Appendix D).

I used the SYSTAT computer software package (Wilkinson 1989) to perform statistical analyses. Unless otherwise stated, hypotheses were tested using simple linear regression techniques and an $\alpha = 0.05$. I tested the following hypotheses:

1. There is a positive linear relationship between WUA and BCC for juvenile smallmouth bass.
2. There is a positive relationship between stream discharge and BCC.
3. There is no relationship between pre-positioned electrode catch and BCC, i.e. fish do not become concentrated in certain microhabitats as BCC levels increase (juvenile smallmouth bass are territorial and do not tolerate crowding).

I used the Mann-Whitney U statistic to compare the mean size of emigrants with that of residents in order to determine if body size affected whether fish established residency in the study stream. I also performed simple linear regression tests to determine if the following factors affected the outcome of the BCC experiments:

1. Number of fish stocked at beginning of experiment.
2. Number of large (>19 cm) or small (<19 cm) fish stocked.
3. Time period during which the experiment occurred (expressed as the number of days since June 30).
4. Mean daily temperature during the experimental period.
5. Median river stage during the experimental period.
6. Possible changes in the availability of food items in the study stream over the course of the summer, expressed for each experiment as the percentage of resident fish containing food in their stomachs.

The significance (P) values presented are for statistical tests using BCC defined as biomass of fish. However, when statistical tests using BCC expressed as numbers of fish produced conflicting results, they are also discussed.

Results

Emigration patterns and establishment of residency

Emigration of stocked smallmouth bass typically began as soon as the traps were opened. By the sixth day after stocking (5 days of trapping), over 95% of the emigrants had left the study stream (Figure 3). During the last few days of each experiment, there was little (if any) emigration. Seventy-five percent of emigrants left the stream via the upstream trap. The number and biomass of fish establishing residency ranged from 3 (171 g) to 38 (3230 g) (Appendix D).

BCC tests

The IFIM assumes a positive linear relationship between WUA and fish biomass for fish populations at the stream's carrying capacity. Instead, I found negative relationships between WUA and BCC, indicating that available habitat (measured as WUA) did not limit the BCC of the study stream for juvenile smallmouth bass. The negative relationship was significant when WUA was calculated from suitability curves based on observations of smallmouth bass using all habitat types (n=102) (Figure 4). There was no significant relationship (P = 0.10) between WUA and BCC when WUA was calculated from curves based on observations of fish using high-cover run habitats (similar to those encountered in this study), but the general trend was also negative. Similarly, there were negative relationships between stream discharge and BCC, expressed as fish biomass (Figure 5) or

fish numbers (Figure 6). None of the component WUA values were positively correlated with BCC (Appendix D).

Resident smallmouth bass appeared to prefer certain habitats in the study stream. Relatively shallow (<40 cm) sites without cover (sites B and F on Figure 1) failed to produce fish in any experiments, while those with woody cover (sites C, D and E) or deeper (>50 cm) water (site A) usually contained fish (Figure 7). The pre-positioned electrode catch of smallmouth bass at these sites appeared to increase with BCC (possibly indicating that fish would concentrate in these areas during droughts), but the relationship between numbers of fish caught and BCC was not significant ($P = 0.10$) (Figure 8). The lack of a significant relationship may result from a small sample size (n=5).

Effects of Other Factors

Other factors examined did not appear to affect the outcome of the BCC experiments. There were no significant relationships between the total number of fish stocked ($P = 0.20$), the number of large ($P = 0.74$) or small ($P = 0.46$) fish stocked, and the resulting BCC values obtained for the experiments. In seven of eight experiments, there were no significant differences between the mean sizes of resident and emigrant fish (Table 4), indicating that emigration was not size-selective. For the experiment in which there was a difference, the mean size of residents was calculated from only 3 fish. The time period of each experiment's occurrence and mean daily temperatures for the experiments were not significantly correlated with BCC values ($P = 0.12$ and $P = 0.89$). BCC, expressed as numbers of fish however, was significantly affected by the time period of each experiments occurrence ($P = 0.03$). This may have resulted from my inability to completely randomize streamflows for all experiments, i.e. no high flow experiments were performed late in the summer. The percentage of residents with food items in their stomachs did not change significantly ($P = 0.65$) over the course of the summer (Table 5), indicating that the availability of food items did

not appear to affect the outcome of BCC experiments. The relationship between river stage and BCC was not significant ($P = 0.16$) (Figure 9).

Discussion

One of the major assumptions of the IFIM is a positive linear relationship between WUA and standing crops of fish for streams at carrying capacity. Using BCC as a surrogate for carrying capacity, I found a negative relationship between WUA and standing crops of juvenile smallmouth bass in a semi-natural stream. In other words, the stream supported fewer fish as instream habitat conditions became more "suitable" (by IFIM standards) for occupation. In field tests of the IFIM on smallmouth bass, Orth and Maughan (1982) found no relationship between WUA and standing crops of juvenile and adult smallmouth bass, and Wiley et al. (1987) found no relationship between low-flow percent usable area and the population density of adult smallmouth bass. Orth and Maughan (1982) felt that recruitment-limiting events (spring floods and sport angling) might have reduced smallmouth bass populations to the extent that they would not be limited by habitat. Interpreting the results of these studies is difficult because standing crops of fish could be limited by factors other than habitat availability. By over-stocking the study stream with fish, the BCC technique eliminated the potential effects of these factors. Consequently, my results indicate that low streamflows and habitat availability, as defined by WUA, did not limit populations of juvenile smallmouth bass, at least in the short term.

The higher BCC values which I observed for low-flow experiments indicated that juvenile smallmouth bass exhibited less upstream and downstream movement under these conditions. Reduced movement during drought periods may be a behavioral adaptation for living in warmwater streams, since these streams have naturally-variable flow regimes and undergo droughts. During periods of low water, fish using shallow habitats, especially those without cover, may be more susceptible to avian and terrestrial predators (Larimore et al. 1959; Alexander 1976). It is probably

much safer for fish to move into deeper waters, or waters with cover, and remain there until higher streamflows return. This may explain why two of my pre-positioned electrode sites, sampled relatively shallow (< 40 cm) habitats without cover (sites B and F), never contained smallmouth bass. While not statistically significant, the pre-positioned electrode catch data (Figure 7) suggested that fish may concentrate in certain areas, especially pools and runs with cover, under low flow conditions. These microhabitats also produced the majority of bass collected during multiple-pass electrofishing runs, further supporting this conclusion. Similarly, Kraft (1972) found that brook trout subjected to low flows left run habitats and concentrated in deeper pools.

Other studies of warmwater fishes subjected to drought flows have shown little movement between pools. Only minnows showed extensive movement between pools during drought flow conditions in an Illinois stream (Larimore et al. 1959). Bayley and Osborne (1993) found no downstream movement of fish from desiccated streams to permanent streams during the drought of 1988. Fish movement may be greater during high water periods because they may provide greater safety from predation, increase the availability of food items, or serve as recolonization periods in which fish seek out new, hopefully more profitable, habitats (Larimore et al. 1959; Bayley and Osborne 1993).

Lower BCC values for smallmouth bass subjected to increased streamflows suggests that more upstream-downstream movement occurs as stream discharge increases. A laboratory study by MacCrimmon and Robbins (1981) found that activity levels of 3 to 12 month-old smallmouth bass increased with streamflow. Rankin (1983) found that smallmouth bass spent less time in "fast" (usually >12 cm/s) microhabitats, and more time in "slow" (usually <8 cm/s) microhabitats. He also observed that smallmouth bass rarely foraged in fast microhabitats, and usually just moved through them. In my study, increasing streamflows (and current velocities) appeared to cause smallmouth bass to be more mobile, resulting in higher numbers of fish being caught in the emigration traps, and fewer fish taking up residency in the study stream. This may partially have been the case for

experiments conducted on July 31, 1990 and July 11, 1991 which had both the highest mean current velocities (24 cm/s) and WUA values (Appendix D).

Decreased agonistic activity between individuals undergoing low flows may also be a drought adaptation. I observed at least eight fish actively foraging together in a 3-m x 3-m area during a low-flow experiment, and saw no obvious agonistic interactions. Rankin (1983) stated that agonistic encounters between smallmouth bass rarely occurred. Klauda (1975) found that adult bass in a semi-natural stream habitat exhibited relatively little aggressive behavior, but that agonistic interactions provided the basis for establishing a dominance hierarchy. Possible changes in fish behavior in response to drought would complicate applications of the IFIM in warmwater streams. Habitat availability during short-term drought events may not limit the abundance of species such as smallmouth bass, which can tolerate being temporarily crowded.

Applicability of the IFIM to Low-Gradient Warmwater Streams

In applying the IFIM to warmwater streams, model users assume that fish populations in warmwater streams are controlled by mechanisms similar to those operating in coldwater streams where the model was developed. However, some factors affecting fish populations differ considerably between coldwater and warmwater streams. These factors may influence application of the IFIM to warmwater streams.

The IFIM was initially developed for use in high gradient, coldwater streams in the western United States. These streams contained few species and were dominated by salmonids. The "territorial" spacing behaviors of trout, especially smaller individuals, is well documented in the literature (Kalleberg 1958; Chapman 1962; Bachman 1984). Bachman (1984) observed that brown trout chose foraging sites (often associated with rocks) which minimized the energetic cost of maintaining position while feeding on drift in the stream. The strong relationship between microhabitat characteristics (availability of foraging sites) and their use by trout provides some basis

for the general conclusion that at high densities, fish populations in streams are space- or habitat-limited (Smoker 1953; Chapman 1966; Lewis 1969) . Therefore, flow modelers assumed that there is a positive relationship between WUA and fish biomass for populations at carrying capacity, and for many trout streams this appears to be the case (Conder and Annear 1987; Binns and Eiserman 1979; Wolff et al. 1990).

The energetic cost of living in high velocity (high-gradient or high-discharge) habitats requires fish to select microhabitats that allow for efficient foraging. Trout commonly use a passive "sit and wait" foraging strategy which allows them to avoid the energetically-costly current while taking advantage of invertebrates drifting downstream (Bachman 1984). Kalleberg (1958) demonstrated importance of water velocity in the behavior and habitat use of Atlantic salmon and brown trout. When the current was fast, fish stayed close to the streambed and used strictly localized feeding stations which they defended. In this situation, coarse substrates on the streambed generated turbulence, providing fish with low-velocity flows at or near the streambed. Fish associated themselves closely with these substrates and the streambed in order to avoid the current while foraging. As the current velocity was reduced, fish moved up off of the streambed, into the water column, and eventually formed schools. The streambed's functional role as a shelter from high velocity water declined as the current velocity (and energetic cost of foraging in the current) was reduced. In a similar study, Godin and Rangeley (1989) found that Atlantic salmon attacked food items further away from them as current velocity (and energetic cost of moving in the current) declined. Such changes in habitat use and foraging behavior may occur for many species. Smallmouth bass, being found in both lakes and streams, may also exhibit such behavioral flexibility. The actual velocity at which these transformations occur probably varies with the body form, feeding habits and size of the fish being studied.

The microhabitat variables (depth, velocity, substrate and cover) used in IFIM studies may work adequately for high-gradient trout streams, because velocity constrains fish to selecting

microhabitats which minimize the energetic costs of drift-feeding. For example, Hill and Grossman (1993) found that rosyside dace *Clinostomus funduloides* and rainbow trout selected current velocities which maximized their net energy gain and ability to capture prey. The importance of current velocity in determining which microhabitats are used by fish may change with the velocity (gradient or discharge) of streams. Conder and Annear (1987) suggested that WUA estimates for trout streams with gradients less than 0.8% may be invalid, because factors other than water velocity had a greater influence on trout density (microhabitat use). Warmwater streams in the Midwest have gradients considerably lower than those found in western trout streams. The gradient of warmwater streams in Michigan is commonly less than 0.2% (G. Whelan, Michigan Department of Natural Resources, Lansing, Michigan, personal communication, 1993). If factors other than water velocity become more important in microhabitat selection, then the microhabitat variables used in IFIM studies may produce WUA values which are not positively correlated with fish biomass.

Several observations suggest to me that microhabitat selection by many species of fish in low-gradient warmwater streams, particularly those in Michigan, is not constrained by velocity. First, the low-gradient nature and low summer discharges, characteristic of most warmwater streams, essentially provide lentic conditions during the growing season. As a result, many warmwater streams support true lentic species, such as northern pike, largemouth bass *Micropterus salmoides*, bluegill *Lepomis macrochirus* and other centrarchids. These fishes have highly elongated or compressed body forms which provide high maneuverability in static water, but are inefficient in lotic environments (Alexander 1974). These species thrive in warmwater streams, despite their body forms, because these streams often do not have enough current velocity during the growing season to exert a significant energetic cost on their bodies. Their body forms contrast with the extremely efficient, streamlined bodies of trout, which are adapted for foraging in streams that have swift currents (due to high gradients and base flows) during the growing season.

The use of active foraging strategies by many species of fish in warmwater streams is further evidence that current velocity may not be the primary factor determining microhabitat selection by fish. Smallmouth bass, for example, actively "search" for (Rankin 1983) and "pursue" (Klauda 1979) their main prey, crayfish and fish (Becker 1983; Probst et al. 1984). Active foraging strategies would be energetically costly in streams that have high velocities during the growing season. If velocity was the major factor influencing microhabitat selection by fishes in warmwater rivers, I would expect these streams to be dominated by species that have streamlined bodies and use more passive foraging strategies.

If velocity is not the primary factor determining microhabitat selection by fishes in low-gradient warmwater streams, then questions arise regarding the relative importance of the microhabitat variables used in IFIM studies. For example, several studies have shown that smallmouth bass abundance was more strongly correlated with the presence of boulders than other habitat characteristics, like depth and velocity (Paragamian 1981; Wiley et al. 1987; McClendon and Rabeni 1987; Todd and Rabeni 1989). This may be due to the importance of boulders as habitat for crayfish, a dominant component in smallmouth bass diets. Fish may congregate in areas with boulders, under a variety of depth and velocity conditions, because of their value as foraging habitat. Similarly, the strong association of smallmouth bass with cover, particularly woody structures (Probst et al. 1984; McClendon and Rabeni 1987; Beam 1990; Zorn personal observation), suggests that cover is functionally important to these fish, possibly in providing a velocity shelter or place to hide from prey or predators. On the other hand, if the availability of cover does not limit smallmouth bass populations, it is not a useful variable for IFIM studies. In this study, substrate and cover conditions probably did not vary enough among treatments to establish their effects on BCC (Appendix D). The importance of microhabitat parameters used in IFIM studies may vary considerably depending on the species and lifestage of fish being studied (Wiley et al. 1987; Bain and Boltz 1989). If this is the case, assigning equal weighting to every microhabitat variable used in IFIM studies would be inappropriate.

Given that there is variation in the importance of microhabitat features to fish, I suspect that the relationship between IFIM outputs (WUA) and fish biomass may be weak for many species and lifestages of fish in warmwater rivers.

Despite the drawbacks to the IFIM mentioned above, significant positive relationships between WUA and fish biomass may occur for certain species and lifestages. Reproductive success of many species in warmwater streams is strongly related to the timing of high and low flow events (Starrett 1951; Moyle and Li 1979; Grossman et al. 1982). The IFIM may be useful in predicting the extent to which changes in the flow regime of a stream will affect recruitment of these species.

Correlations between usable habitat and fish abundance appear to exist for riffle-dwelling fishes in warmwater streams. Orth and Maughan (1982) found significant relationships for the freckled madtom *Noturus nocturnus*, the central stoneroller *Campostoma anomalum* and the orangebelly darter *Etheostoma radiosum*, and Wiley et al. (1987) reported similar results for the rainbow darter *Etheostoma caeruleum*. These riffle-dwelling species are obligate stream fishes (whose selection of microhabitats may more likely be constrained by velocity), unlike smallmouth bass which are adapted to both lake and stream environments. Orth and Maughan (1982) supported the use of WUA-discharge relationships in recommending instream flows for riffle-dwelling fishes since they found a positive relationship between WUA and standing stocks for these species. The lack of a relationship between WUA and standing stocks of smallmouth bass in their work, that by done by Wiley et al. (1987), and this study suggest that the use of WUA-discharge curves in recommending instream flows for smallmouth bass is not justified.

Orth and Maughan (1982) also pointed out that riffle-dwelling species used similar microhabitats for feeding and resting, while smallmouth bass used different habitats for feeding and resting. Large brown trout in Michigan's Au Sable River system also used different feeding and resting habitats, and moved largely between them (Clapp 1988). In such cases, separate habitat

suitability curves may need to be developed and IFIM simulations performed for each habitat type in order to determine which type of habitat (if any) is limiting fish populations.

Use of BCC Studies in Testing the IFIM

The following assumptions and biases were encountered in applying the BCC technique to test the IFIM's assumption of a positive linear relationship between fish biomass and WUA. First, this study did not address some of the biological effects of flow reduction, such as changes in interspecific competition, intraspecific competition (between size classes) or predation. The extent to which smallmouth bass became concentrated during low-flow experiments may not reflect natural conditions, because only one species and size-group of fish (smallmouth bass, 13-23 cm long) were used in this study. Schlosser (1987) found that the threat of predation from large smallmouth bass in pools caused smaller fishes to shift from using preferred pool habitats to shallow riffle and raceway refuges. Future BCC studies, involving small fish and large piscivores, would be useful in determining the extent to which small fish might concentrate under low-flow conditions. Assessments of competition and predation by piscivores could be incorporated into a BCC study by stocking more than one fish species or lifestage.

The size of a study stream should also be large enough that it will encompass the home range of the individuals being studied. For species with relatively small home ranges, such as small trout (Bachman 1984; Regal 1992), fairly short stream reaches may be suitable for BCC studies. I assumed that my study reach was large enough to accommodate the home range of juvenile smallmouth bass since little information was available on their movement patterns. However, I found that fish used in this study appeared to be more mobile at higher streamflows. One may interpret the low BCC values obtained from my high flow experiments as a result of the study stream not being large enough to accommodate the increased movements of fish at these flows. This may explain why an unexpected

15-cm increase in stream stage during one experiment (not included in this study) coincided with the emigration of 15 "resident" fish in one day. On the other hand, if the size of the stream was inadequate for tests at higher flows, I would have expected fish to be emigrating, and be caught in the traps, throughout the entire course of high flow experiments. In all experiments, the number of residents remained nearly constant for the last 4 or 5 days of the study. Finally, if smallmouth bass home ranges do change with streamflow, my results indicate that low flows may cause the home range of smallmouths to shrink so that they may tolerate drought periods.

Several studies recommend the use of site-specific habitat suitability data in IFIM analyses (Orth and Maughan 1982; Larimore and Garrels 1985; Wiley et al. 1987). In order to calculate WUA, I used suitability data obtained from juvenile smallmouth bass in the Huron River (Monahan 1991), an adjacent watershed. Poor visibility and the small number of fish used in this study precluded my obtaining habitat suitability data for fish in the study stream. The locations of fish collected at the end of each experiment indicated to me that fish in the study stream used microhabitats similar to those used by smallmouth bass in the Huron River. In addition, I found negative relationships between WUA and BCC using various sets of suitability curves (unpublished data).

BCC studies do not address the effects of long-term factors such as siltation, food availability and changes in the thermal and chemical regimes of streams subjected to flow alteration. I was concerned that repeatedly over-stocking the study stream with fish may deplete the food supply to the extent that it would affect the outcome of BCC experiments occurring late in the summer. Fortunately, this did not appear to have occurred. In fact, the highest BCC values were obtained late in the summer when food resources, i.e. crayfish, should have been at their lowest. The effects of low flows on temperature and dissolved oxygen were not realistically simulated in this study because the study stream received water that flowed over the dam of an upstream impoundment. These and other environmental changes may significantly affect lotic fish communities, and deserve to be

addressed through long-term studies of streams subjected to altered flow regimes. The value of BCC studies, however, lies in their use as a relatively quick and inexpensive way to determine relationships between the "quality" of stream habitats and their potential to support fish populations (carrying capacity).

Management Implications

Warmwater streams provide diverse habitats such as emergent and riparian marshes, submersed macrophytes, oxbows, seasonally flooded bottomlands, etc. Associated with these habitats is an equally diverse fish fauna, with sites frequently containing >25 species (Funk 1975; Smith et al. 1981). Their fish communities have a complex trophic structure which includes piscivores, insectivores, detritivores, herbivores, and omnivores (Moyle and Li 1979; Becker 1983). Some species may be considered habitat specialists, thriving under a narrow range of conditions, while others are habitat generalists.

Maintaining a diverse fish community requires that the habitat needs of all fishes be met. Managers may attempt to accomplish this using any of several approaches to flow modelling. Each species can be modelled individually, with the resulting WUA-stream discharge curves for all species being combined to determine an optimum flow. This approach can be costly, with redundant data being collected for species with similar habitat requirements, and interpretation of the data may be confusing due to the volume of curves generated (30 species x 4 lifestages = 120 curves) and the presence of conflicting preferred flows for species or lifestages (Bain and Boltz 1989).

Another approach involves grouping fish species and/or lifestages into guilds based upon similarities in their use of particular habitats (Leonard and Orth 1988; Bain and Boltz 1989; Lobb and Orth 1991). Species representing each guild are selected and model simulations are performed on them. The resulting stream discharge-WUA curves are used to select an optimum flow level for the stream. Data requirements for this approach are lessened because species are lumped into

habitat-use guilds, but there are drawbacks to using guilds in IFIM studies. First, the approach used in selecting target species can have a considerable effect on the recommended optimum flow that results from the study (Leonard and Orth 1988). Another problem that may occur with this approach can be seen in Leonard and Orth's (1988) stream discharge-WUA curves which showed that guilds can have opposite reactions to increased stream discharge, i.e. WUA for riffle and run guilds increased dramatically with streamflow while WUA for the pool guild declined dramatically with streamflow. Consequently, flows much greater or less than their recommended discharge were quite detrimental to certain guilds. The guild approach may be useful for comparing the effects different flows on individual guilds, but conflicting responses of guilds to increased streamflow make this approach less valuable for assessing the effect of streamflow alteration on the entire fish community.

Another problem in using the IFIM in warmwater streams is that many of species are not obligate riverine fishes. In large, low-gradient rivers, which characteristically have extensive reaches of pool habitat separated by short riffles and runs, riverine species may be in the minority. This is further complicated by the fact that the economically important gamefishes (Centrarchids and Esocids) live in both lake and stream environments, and the obligate riverine species (Catostomids and darters) are not an important part of the angler's creel. For the manager most interested in "improving" the sport fishery, IFIM studies may recommend low flow conditions to benefit smallmouth bass and northern pike that are detrimental to much of the stream community. Such recommendations would probably adversely impact riffle areas which may be important for a variety of reasons (including production of forage fish).

The diverse habitats and complex aquatic communities of warmwater streams should be preserved for the enjoyment of future generations of people. Maintaining diversity and complexity in these systems should be the goal of policies used to protect warmwater streams. The high cost, site-specific nature of input data and model outputs, and questions regarding the predictive capabilities of the IFIM for fish populations suggest that less costly, simpler approaches may be equally (or more)

effective at protecting fish communities in warmwater streams. This seems especially true for agricultural states, such as Michigan, where many watersheds may be affected by irrigation activity and IFIM studies of each affected stream are not feasible.

The state of Kansas, for example, developed their own method for recommending minimum desirable streamflows for the state's rivers (Layher and Brunson 1992). They had previously used the IFIM, but when water planning efforts required expedient development of flow recommendations for several streams, they chose not to use it. Instead, they modified the Habitat Evaluation Procedure (U.S. Fish and Wildife Service 1980), developing relationships between total fish standing crops, microhabitat characteristics (means of stream width, depth and velocity) and stream discharge. This allowed them to use existing data on stream fish populations and long-term hydrological records from permanent U.S. Geological Survey gauging stations as a basis for making streamflow recommendations. The effectiveness of their recommended flows in protecting fish communities has yet to be determined.

For warmwater streams impacted by irrigation during the growing season, fish species belonging to riffle and stream margin guilds will be more adversely affected by low flows than pool and run guilds (Orth and Maughan 1982; Schlosser 1987; Leonard and Orth 1988). A wetted perimeter method (Morhardt 1986) may be effective in recommending minimum flows that will provide habitats for all guilds. These methods involve plotting the wetted perimeter (the distance from water's edge to water's edge along the stream bottom) versus stream discharge. Cross-sectional transects are usually placed in riffle areas, which dry up first during drought flows. Inflection points on the curve (streamflows below which the wetted perimeter of the stream declines dramatically) represent minimum recommended flows. Orth and Maughan (1982) found that flow recommendations based on the wetted perimeter method were similar to those generated by the IFIM for the low-flow season (July to December). Such relatively simple methods may hold promise for the development of flow protection measures for Michigan's warmwater streams.

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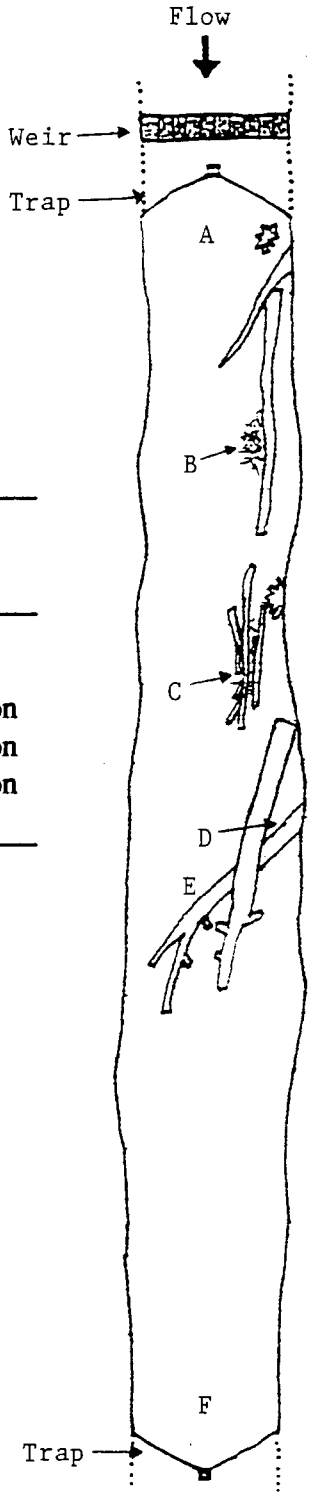
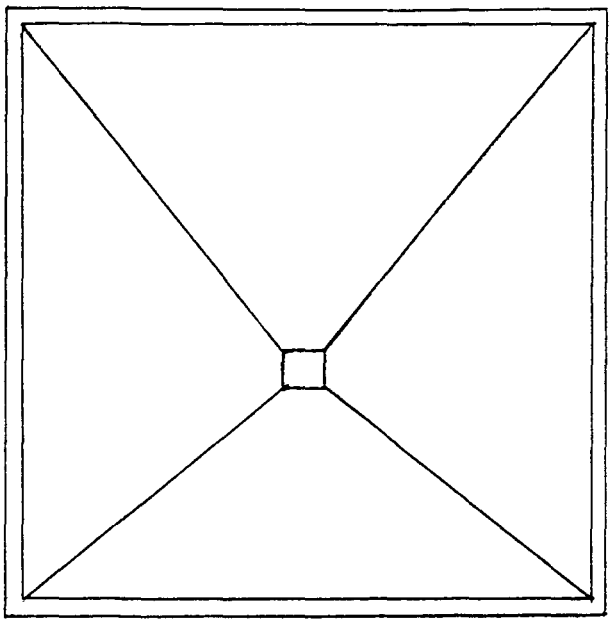


5 m

Electrode Site	Depth (cm)	Cover Type
A-pool	61	None
B-run	24	Visual Isolation
C-run	34	Velocity Shelter, Visual Isolation
D-pool	40	Velocity Shelter, Visual Isolation
E-run	40	Velocity Shelter, Visual Isolation
F-pool	40	None

Figure 1. Sketch of the study stream at an intermediate discharge with locations and descriptions of pre-positioned electrode sites. Objects in the stream represent woody debris (logs, stumps, brush).

Front View



Overhead View

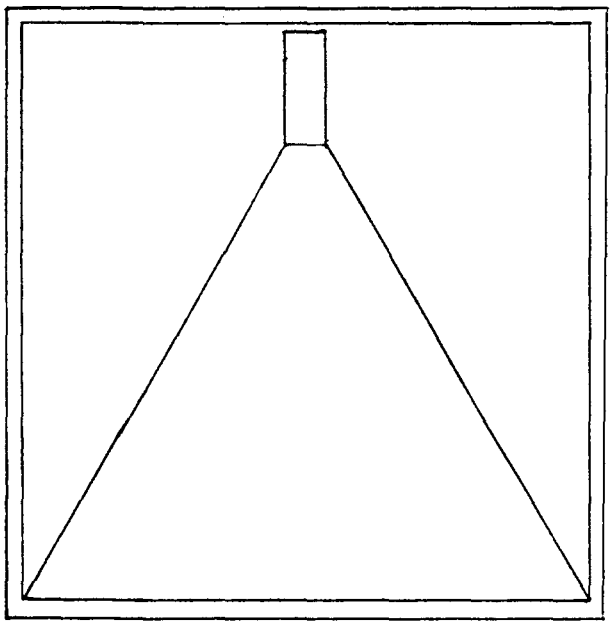


Figure 2. Sketch of trap used to catch emigrating smallmouth bass. Wings extended from opening of trap to shore.

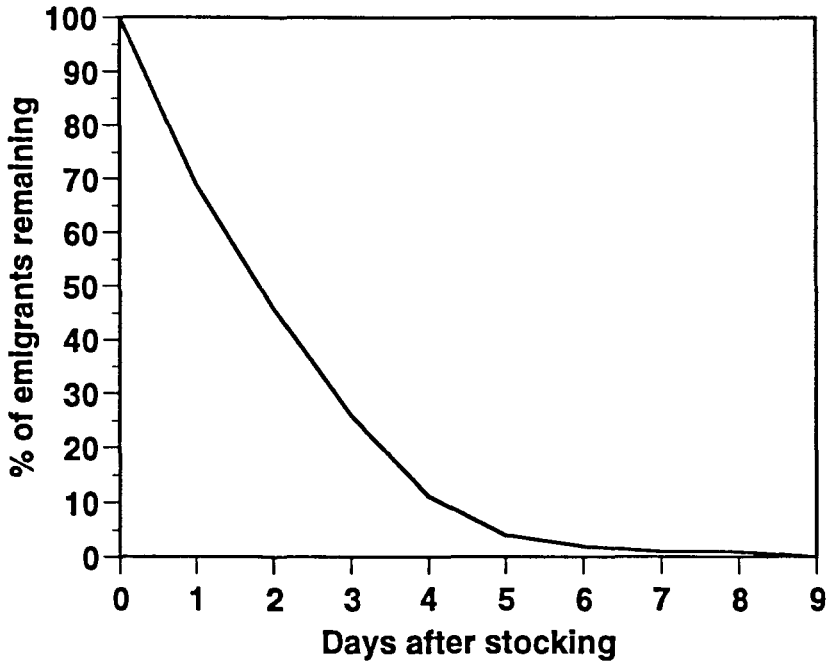


Figure 3. Emigration pattern for juvenile smallmouth bass stocked into study stream. Curve (based on data from all trials) shows the percentage of emigrating fish that remain in the stream as experiments progressed.

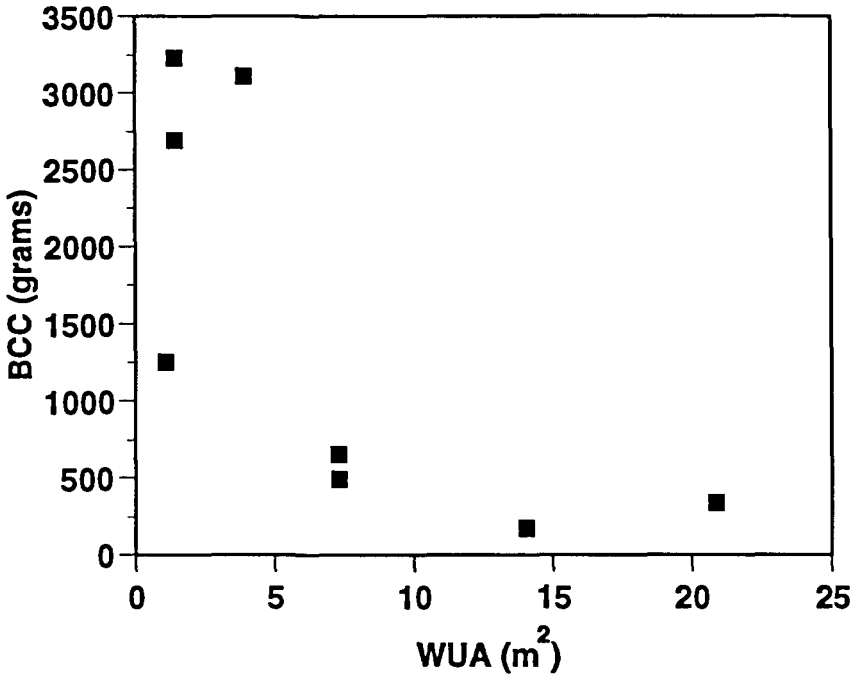


Figure 4. Relationship between WUA and BCC for juvenile smallmouth bass in the study stream. Negative relationship was significant (P = 0.05). WUA was estimated using suitability data based on daytime observations of juvenile smallmouth bass using all habitat types in the Huron River, Michigan (Monahan 1991).

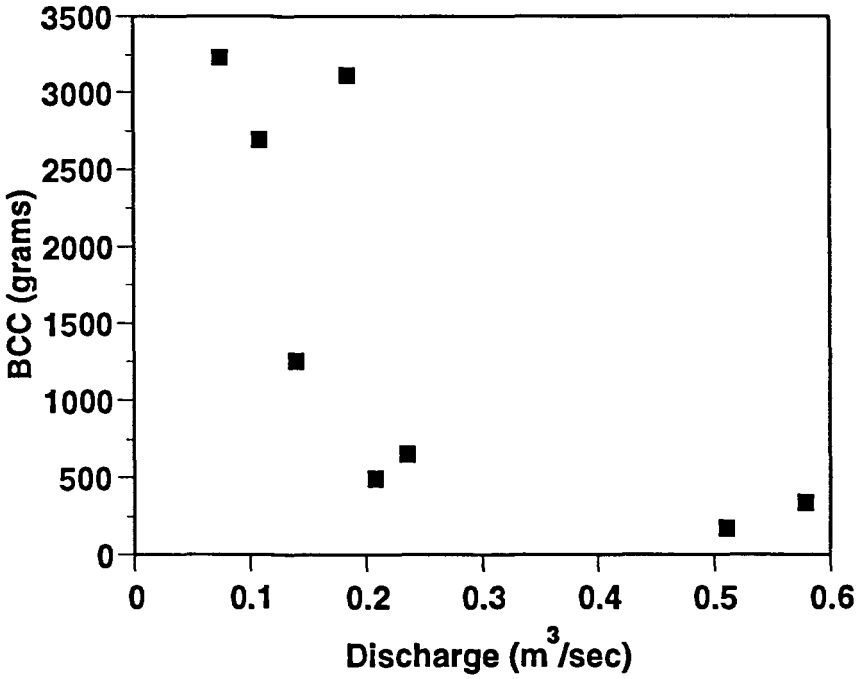


Figure 5. Relationship between stream discharge and BCC (expressed as biomass) for juvenile smallmouth bass in the study stream. The negative relationship was significant (P = 0.05).

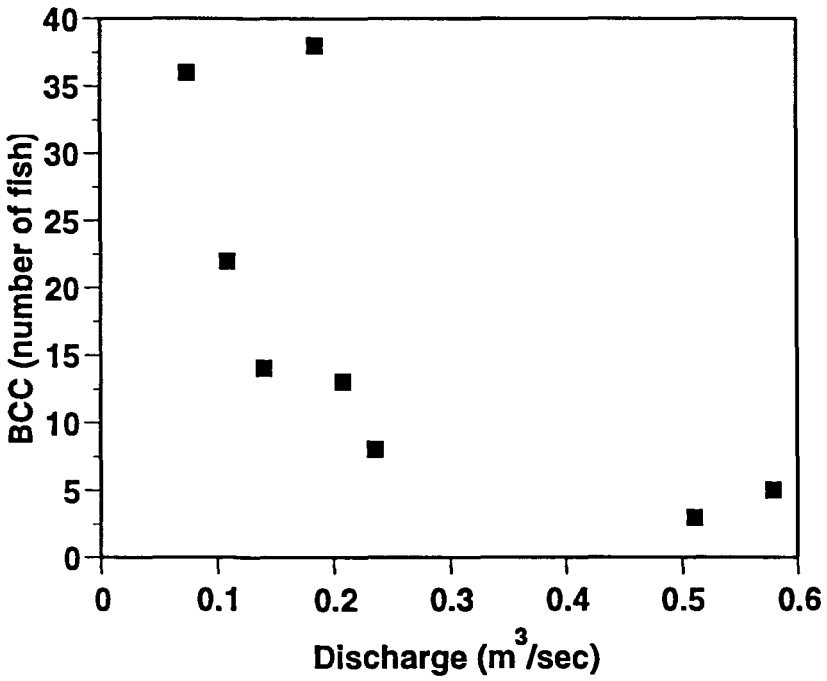


Figure 6. Relationship between stream discharge and BCC (expressed as numbers of fish) for juvenile smallmouth bass in the study stream. The negative relationship was not significant (P = 0.06).

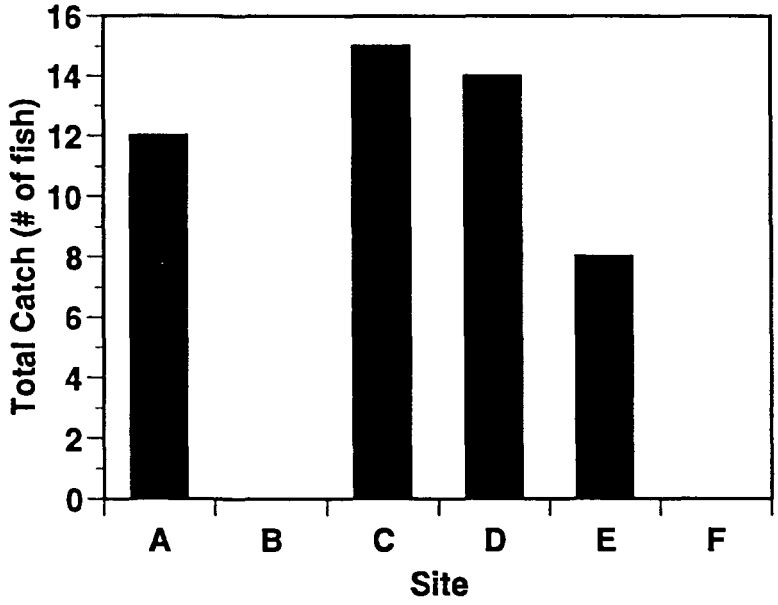


Figure 7. Number of resident smallmouth bass caught at pre-positioned electrode sites for five BCC experiments conducted in 1991. Smallmouth bass were collected from sites with deep (> 50 cm) water (site A) or large woody debris (sites C, D and E).

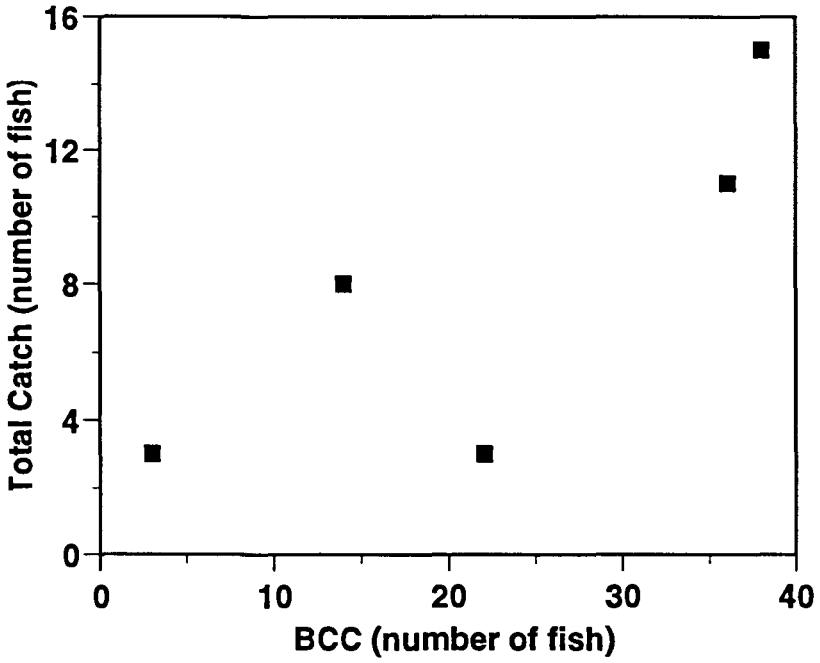


Figure 8. Relationship between total catch by pre-positioned electrodes and BCC for juvenile smallmouth bass in the study stream. Relationship was not significant (P = 0.10).

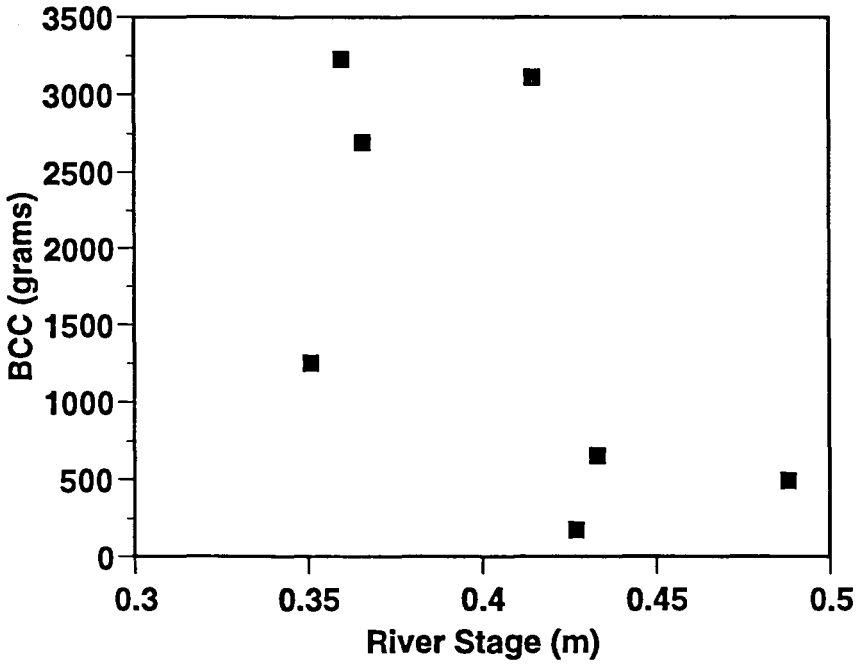


Figure 9. Relationship between the median river stage and BCC for juvenile smallmouth bass in the study stream. Relationship was not significant (P = 0.16).

Table 1. Date, streamflow, number and mean size (two standard deviations shown in parenthesis) of smallmouth bass stocked during BCC experiments.

Date	Streamflow (m^3/s)	Number Stocked	Mean Size (mm)
31 Jul 90	0.578	151	175 (27)
11 Jul 91	0.510	72	212 (54)
24 Jul 91	0.108	68	201 (73)
8 Aug 91	0.139	76	177 (62)
20 Aug 91	0.074	73	179 (39)
12 Sep 91	0.184	68	184 (45)
9 Jul 92	0.235	79	167 (69)
19 Aug 92	0.207	92	147 (25)

Table 2. Definition of substrate classes used in this study. Classification is based on a modified Wentworth classification (Bovee 1982).

Code	Classification	Particle Size (mm)
1	Vegetation, Detritus	---
2	Clay	---
3	Silt	---
4	Sand	< 2
5	Small Gravel	2 - 8
6	Medium Gravel	8 - 25
7	Large Gravel	25 - 51
8	Small Cobble	51 - 152
9	Large Cobble	152 - 305
10	Small Boulder	305 - 610

Table 3. Description of cover categories identified within the study reach (Monahan 1991).

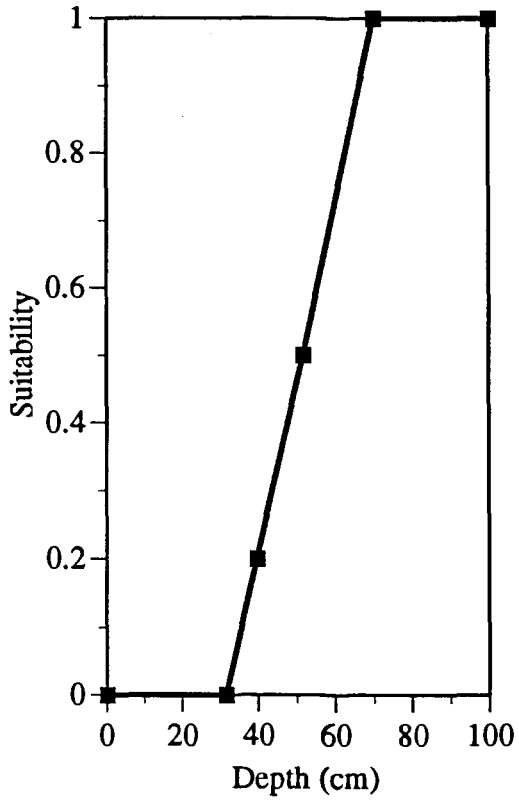
Code	Assumed Function	Description
1	No Cover	---
2	Velocity Shelter	Blunt object protruding >305 mm above substrate
3	Velocity Shelter and Visual Isolation	Individual logs (>152 mm) and complexes of two or more logs
4	Visual Isolation	Root wads and dense clusters of sticks (<152 mm) which fish could hide within

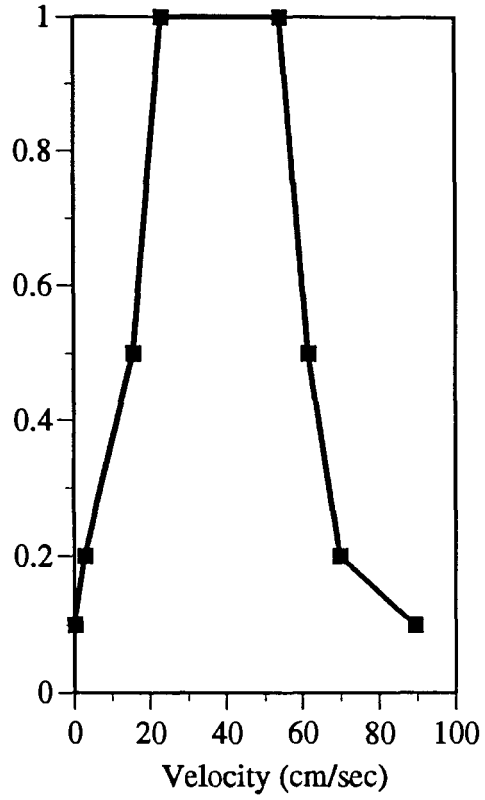
Table 4. Mean lengths of emigrant and resident smallmouth bass. Number of fish is shown in parentheses. * indicates a significant difference at $\alpha = 0.05$.

	Mean Length (mm)	
Date	Emigrants	Residents
11 Jul 91 *	214 (69)	162 (3)
24 Jul 91	200 (48)	202 (19)
8 Aug 91	176 (61)	180 (15)
20 Aug 91	179 (40)	179 (31)
12 Sep 91	185 (30)	184 (38)
9 Jul 92	167 (71)	170 (8)
19 Aug 92	147 (92)	144 (13)

Table 5. Percentage of resident smallmouth bass containing food items and dates when stomachs were sampled. The percentage of fish containing food was not correlated with the number of days after June 30 (P = 0.65).

Date of Sample	Days after June 30	Percent with food	Sample Size
6 Jul 92	6	88	8
12 Jul 90	12	53	19
2 Aug 90	33	80	5
14 Aug 90	45	83	6
15 Aug 90	46	89	9
19 Aug 91	50	86	29
19 Aug 92	50	77	13
9 Sep 91	71	47	20

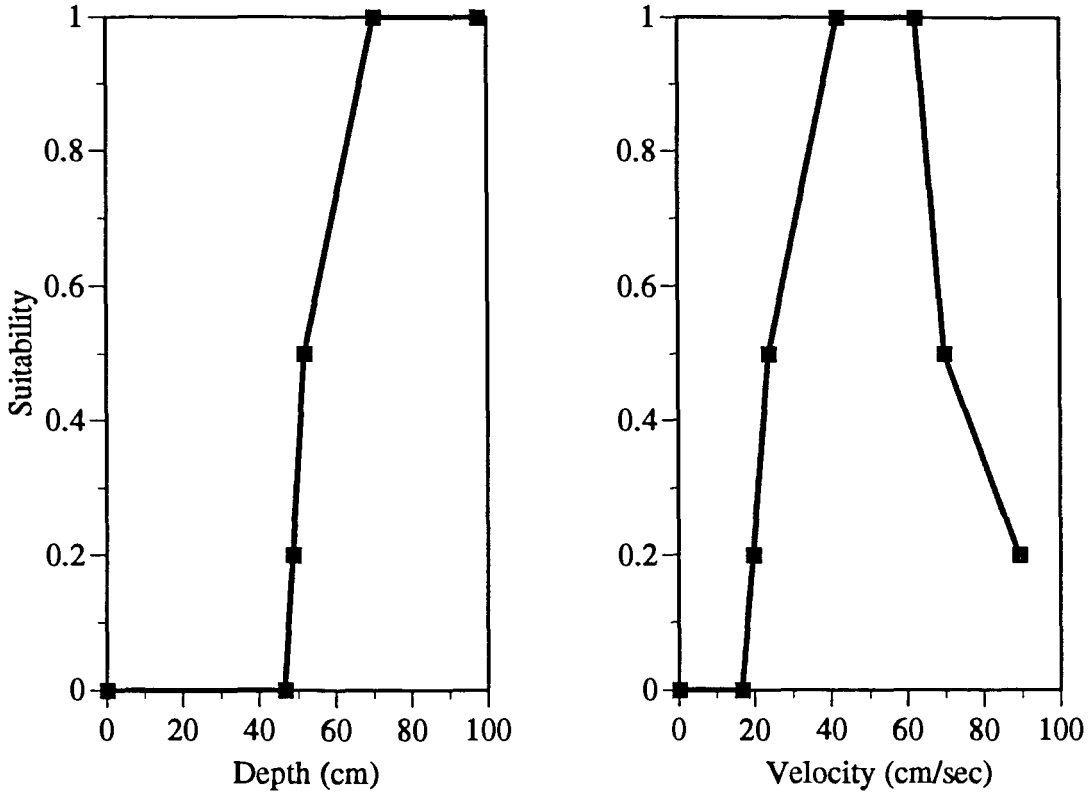




Substrate	Suitability
Silt / Sand	0.25
Gravel	0.71
Cobble	1
Boulder	0

Cover	Suitability
None	0.97
Velocity Shelter	1
Visual Isolation	0.03
Combined	0.5

Appendix A. Habitat suitability data based on daytime observations of juvenile smallmouth bass using all habitat types in the Huron River, Michigan (Monahan 1991).



Substrate	Suitability
Silt / Sand	0.25
Gravel	0.71
Cobble	1
Boulder	0

Cover	Suitability
None	0.97
Velocity Shelter	1
Visual Isolation	0.03
Combined	0.5

Appendix B. Habitat suitability data based on daytime observations of juvenile smallmouth bass using high-cover run habitats in the Huron River, Michigan (Monahan 1991).

Appendix C. BASIC programs used to calculate WUA from microhabitat data collected during the experiments.

```
10 REM    PROGRAM FOR CALCULATING WEIGHTED USABLE AREA
20 REM    FOR JUVENILE SMALLMOUTH BASS AT SHARON MILLS.  INPUT FILES
30 REM    ARE DEPTH, VELOCITY, SUBSTRATE, AND COVER MEASUREMENTS
40 REM    MADE AT 2' INTERVALS ALONG TRANSECTS SPACED 10' APART.
50 REM    SUITABILITY DATA ARE FOR HURON RIVER JUVENILE
60 REM    SMALLMOUTHS.  DIURNAL-SUMMER (N=100 TO 102)
70 REM
80 REM
90 DIM T(200),D(200),V(200),S(200),C(200)
100 LET C=1
110 INPUT "ENTER NAME OF FILE WITH TRANSECT DATA (e.g. C:HI071191.DAT)";N$
120 PRINT "TRANSECT","DPREF", "VPREF", "SPREF", "CPREF"
130 OPEN "I", #1, N$
140 INPUT #1, T(X), D(X), V(X), S(X), C(X)
150 IF T(X)= -99 THEN GOTO 730
160 REM
170 REM    DETERMINE DEPTH SUITABILITY VALUE
180    IF D(X)<1.03 THEN DPREF=0
190    IF D(X)>=1.03 THEN IF D(X)<1.7 THEN DPREF=.75*D(X) - .775
200    IF D(X)>=1.7 THEN IF D(X)<2.3 THEN DPREF=.833*D(X) - .917
210    IF D(X)>=2.3 THEN IF D(X)<=3.6 THEN DPREF=1
220    IF DPREF<0 THEN DPREF=0
230 REM
240 REM   DETERMINE VELOCITY SUITABILITY VALUE
250    IF V(X)<=9.000001E-02 THEN VPREF=1.111*V(X) + .1
260    IF V(X)>9.000001E-02 THEN IF V(X)<=.51 THEN VPREF=.714*V(X) + .143
270    IF V(X)>.51 THEN IF V(X)<=.76 THEN VPREF=2*V(X) - .52
280    IF V(X)>.76 THEN IF V(X)<=1.78 THEN VPREF=1
290    IF V(X)>1.78 THEN IF V(X)<=2.04 THEN VPREF=(-1.93*V(X)) + 4.423
300    IF V(X)>2.04 THEN IF V(X)<=2.29 THEN VPREF=(-1.2*V(X)) + 2.948
310    IF V(X)>2.29 THEN IF V(X)<=2.93 THEN VPREF=(-.156*V(X)) + .558
320    IF V(X)>2.93 THEN PRINT "VELOCITY BEYOND SUITABILITY DATA RANGE"
330    IF VPREF<0 THEN VPREF=0
340 REM
350 REM   DETERMINE SUBSTRATE SUITABILITY VALUE
360    IF S(X)<0 THEN PRINT "SUBSTRATE VALUE TOO LOW"
370    IF S(X)>=1 THEN IF S(X)<=4 THEN SPREF=.25
380    IF S(X)>=5 THEN IF S(X)<=7 THEN SPREF=.71
390    IF S(X)>7 THEN IF S(X)<=9 THEN SPREF=1
400    IF S(X)=10 THEN SPREF=0
410    IF S(X)>10 THEN PRINT "SUBSTRATE VALUE TOO HIGH"
420    IF SPREF<0 THEN SPREF=0
430 REM
440 REM   DETERMINE COVER SUITABILITY VALUE
```

```
450    IF C(X)=1 THEN CPREF=.974
460    IF C(X)=2 THEN CPREF=1
470    IF C(X)=3 THEN CPREF=.513
480    IF C(X)=4 THEN CPREF=.026
490 REM
500 REM   CALCULATE WUA BY COMPONENT
510    DWUA= DWUA + DPREF*20
520    VWUA= VWUA + VPREF*20
530    SWUA= SWUA + SPREF*20
540    CWUA= CWUA + CPREF*20
550 REM
560 REM   DETERMINE MINIMUM PREFERENCE VALUE FOR CELL
570    LET MINPREF= DPREF
580    IF VPREF<MINPREF THEN MINPREF=VPREF
590    IF SPREF<MINPREF THEN MINPREF=SPREF
600    IF CPREF<MINPREF THEN MINPREF=CPREF
610 REM
620 REM   CALCULATE TOTAL WUA BY VARIOUS FORMULAS
630    PRODWUA= PRODWUA + DPREF*VPREF*SPREF*CPREF*20
640    PDVSWUA= PDVSWUA + DPREF*VPREF*SPREF*20
650    PDVCWUA= PDVCWUA + DPREF*VPREF*CPREF*20
660    AVEWUA= AVEWUA + ((DPREF+VPREF+SPREF+CPREF)/4)*20
670    MINWUA= MINWUA + MINPREF*20
680    TOTWUA=TOTWUA + 20
690 PRINT T(X),USING "#.###        "; DPREF, VPREF, SPREF, CPREF
700 X=X + 1
710 GOTO 140
720 REM
730 REM   PRINT FINAL RESULTS
740    LPRINT "*****************************************************"
742    LPRINT "WUA FROM HURON RIVER DIURNAL CURVES (n=102)"
750    LPRINT "FILE NAME:   ";N$
760    LPRINT "PRODUCT WUA (sq ft,m):  ";PRODWUA, PRODWUA*.092903
770    LPRINT "PRODUCT WUA     (%):  "; USING "##.##";100*(PRODWUA/TOTWUA)
780    LPRINT "PRODDVS WUA (sq ft,m):  ";PDVSWUA, PDVSWUA*.092903
790    LPRINT "PRODDVC WUA (sq ft,m):  ";PDVCWUA, PDVCWUA*.092903
800    LPRINT "AVERAGE WUA (sq ft,m):  ";AVEWUA, AVEWUA*.092903
810    LPRINT "MINIMUM WUA (sq ft,m):  ";MINWUA, MINWUA*.092903
815    LPRINT "TOTAL AREA (sq ft,m):   ";TOTWUA, TOTWUA*.092903
820    LPRINT " "
830    LPRINT "WUA BY COMPONENTS (sq ft,m)"
840    LPRINT "-------------------------"
850    LPRINT "DEPTH:       "; USING "####.#";DWUA, DWUA*.092903
860    LPRINT "VELOCITY:    "; USING "####.#";VWUA, VWUA*.092903
870    LPRINT "SUBSTRATE:   "; USING "####.#";SWUA, SWUA*.092903
880    LPRINT "COVER:       "; USING "####.#";CWUA, CWUA*.092903
890    LPRINT : LPRINT
```

```
10 REM    PROGRAM FOR CALCULATING WEIGHTED USABLE AREA
20 REM    FOR JUVENILE SMALLMOUTH BASS AT SHARON MILLS.  INPUT FILES
30 REM    ARE DEPTH, VELOCITY, SUBSTRATE, AND COVER MEASUREMENTS
40 REM    MADE AT 2' INTERVALS ALONG TRANSECTS SPACED 10' APART.
50 REM    SUITABILITY DATA ARE FOR HURON RIVER JUVENILE
60 REM    SMALLMOUTHS.  STRATIFIED TO RUN-HIGH COVER (n=29).
70 REM
80 REM
90 DIM T(200),D(200),V(200),S(200),C(200)
100 LET C=1
110 INPUT "ENTER NAME OF FILE WITH TRANSECT DATA (e.g. C:HI071191.DAT)";N$
120 PRINT "TRANSECT","DPREF", "VPREF", "SPREF", "CPREF"
130 OPEN "I", #1, N$
140 INPUT #1, T(X), D(X), V(X), S(X), C(X)
150 IF T(X)= -99 THEN GOTO 740
160 REM
170 REM    DETERMINE DEPTH SUITABILITY VALUE
180    IF D(X)<1.53 THEN DPREF=0
190    IF D(X)>=1.53 THEN IF D(X)<1.7 THEN DPREF=3*D(X) - 4.6
200    IF D(X)>=1.7 THEN IF D(X)<=2.3 THEN DPREF=.833*D(X) - .917
210    IF D(X)>2.3 THEN DPREF=1
220    IF DPREF<0 THEN DPREF=0
230 REM
240 REM   DETERMINE VELOCITY SUITABILITY VALUE
250    IF V(X)<=.547 THEN VPREF=0
260    IF V(X)>.547 THEN IF V(X)<=.78 THEN VPREF=2.143*V(X) - 1.171
270    IF V(X)>.78 THEN IF V(X)<=1.37 THEN VPREF=.847*V(X) - .161
280    IF V(X)>1.37 THEN IF V(X)<=2.04 THEN VPREF=1
290    IF V(X)>2.04 THEN IF V(X)<=2.29 THEN VPREF=(-2*V(X)) + 5.08
300    IF V(X)>2.29 THEN IF V(X)<=2.93 THEN VPREF=(-.469*V(X)) + 1.573
310    IF V(X)>2.93 THEN PRINT "VELOCITY BEYOND SUITABILITY DATA RANGE"
320    IF VPREF<0 THEN VPREF=0
330 REM
340 REM   DETERMINE SUBSTRATE SUITABILITY VALUE
350 REM    SAME AS FOR n=102
360    IF S(X)<0 THEN PRINT "SUBSTRATE VALUE TOO LOW"
370    IF S(X)>=1 THEN IF S(X)<=4 THEN SPREF=.25
380    IF S(X)>=5 THEN IF S(X)<=7 THEN SPREF=.71
390    IF S(X)>7 THEN IF S(X)<=9 THEN SPREF=1
400    IF S(X)=10 THEN SPREF=0
410    IF S(X)>10 THEN PRINT "SUBSTRATE VALUE TOO HIGH"
420    IF SPREF<0 THEN SPREF=0
430 REM
440 REM   DETERMINE COVER SUITABILITY VALUE
450 REM   SAME VALUES AS FOR n=102
460    IF C(X)=1 THEN CPREF=.974
470    IF C(X)=2 THEN CPREF=1
```

```
480    IF C(X)=3 THEN  CPREF=.513
490    IF C(X)=4 THEN CPREF=.026
500 REM
510 REM   CALCULATE WUA BY COMPONENT
520    DWUA= DWUA + DPREF*20
530    VWUA= VWUA + VPREF*20
540    SWUA= SWUA + SPREF*20
550    CWUA= CWUA + CPREF*20
560 REM
570 REM   DETERMINE MINIMUM PREFERENCE VALUE FOR CELL
580    LET MINPREF= DPREF
590    IF VPREF<MINPREF THEN MINPREF=VPREF
600    IF SPREF<MINPREF THEN MINPREF=SPREF
610    IF CPREF<MINPREF THEN MINPREF=CPREF
620 REM
630 REM   CALCULATE TOTAL WUA BY VARIOUS FORMULAS
640    PRODWUA= PRODWUA + DPREF*VPREF*SPREF*CPREF*20
650    PDVSWUA= PDVSWUA + DPREF*VPREF*SPREF*20
660    PDVCWUA= PDVCWUA + DPREF*VPREF*CPREF*20
670    AVEWUA= AVEWUA + ((DPREF+VPREF+SPREF+CPREF)/4)*20
680    MINWUA= MINWUA + MINPREF*20
690    TOTWUA= TOTWUA + 20
700 PRINT T(X),USING "#.###         "; DPREF, VPREF, SPREF, CPREF
710 X=X + 1
720 GOTO 140
730 REM
740 REM   PRINT FINAL RESULTS (CONVERTED TO METRIC)
750    LPRINT "**************************************************"
760    LPRINT "WUA FROM HURON RIVER - RUN, HIGH COVER CURVES (n=29)"
770    LPRINT "FILE NAME:  "; N$
780    LPRINT "PRODUCT WUA (sq ft,m):  ";PRODWUA, PRODWUA*.092903
790    LPRINT "PRODUCT WUA (%):        "; USING
       "##.##";100*(PRODWUA/TOTWUA)
800    LPRINT "PRODDVS WUA (sq ft,m):  ";PDVSWUA, PDVSWUA*.092903
810    LPRINT "PRODDVC WUA (sq ft,m):  ";PDVCWUA, PDVCWUA*.092903
820    LPRINT "AVERAGE WUA (sq ft,m):  ";AVEWUA, AVEWUA*.092903
830    LPRINT "MINIMUM WUA (sq ft,m):  ";MINWUA, MINWUA*.092903
835    LPRINT "TOTAL WUA (sq ft,m):    ";TOTWUA, TOTWUA*.092903
840    LPRINT " "
850    LPRINT "WUA BY COMPONENTS (sq ft,m)"
860    LPRINT "---------------------------"
870    LPRINT "DEPTH:       "; USING "####.#";DWUA, DWUA*.092903
880    LPRINT "VELOCITY:    "; USING "####.#";VWUA, VWUA*.092903
890    LPRINT "SUBSTRATE:   "; USING "####.#";SWUA, SWUA*.092903
900    LPRINT "COVER:       "; USING "####.#";CWUA, CWUA*.092903
910    LPRINT
920    LPRINT
```

Appendix D. Flow conditions, BCC values, and microhabitat measures for the BCC experiments in this study. BCC values for experiments on 20 Aug 91 and 19 Aug 92 are 3230 g and 494 g, and 36 and 13 fish, respectively. Microhabitat measurement data from experiments on 24 Jul 91 and 9 Jul 92 were used for experiments on 20 Aug 91 and 19 Aug 92.

Date	31 Jul 1990	11 Jul 1991	9 Jul 1992	12 Sep 1991	8 Aug 1991	24 Jul 1991
BCC (g of fish)	335	171	653	3110	1250	2692
BCC (# of fish)	5	3	8	38	1422	
Streamflow (m^3/sec)	0.578	0.510	0.235	0.184	0.139	0.108
Maximum Depth (cm)	79	76	79	70	58	58
Mean Depth (cm) 35	34	33	30	22	25	
Maximum Velocity (cm/sec)	65	65	30	30	44	30
Mean Velocity (cm/sec)	24	24	11	11	11	9
Total Reach Area (m^2)	351	346	347	349	314	316
WUA from suitability curves in Appendix A						
Product WUA (D*V*S*C)	20.86	14.02	7.26	3.90	1.05	1.41
Percent WUA	5.94	4.06	2.09	1.12	0.33	0.45
Depth Component	61.0	51.3	45.1	34.5	13.0	16.9
Velocity Component	250.2	248.1	154.6	150.3	139.8	115.5
Substrate Component	181.0	167.8	157.8	153.7	140.0	154.4
Cover Component	296.1	302.1	304.6	301.3	266.8	264.2
WUA from suitability curves in Appendix B						
Product WUA (D*V*S*C)	3.68	3.04	0.27	0.00	0.00	0.00
Percent WUA	1.05	0.88	0.08	0.00	0.00	0.00
Depth Component	30.6	24.0	22.3	18.2	5.6	5.2
Velocity Component	145.1	145.0	27.0	25.1	37.0	10.0
Substrate Component			same as above			
Cover Component			same as above			