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TECHNICAL REPORT NO. 6

USING SIMULATION MODELS FOR PREDICTING THE QUALITY AND QUANTITY OF FISH HABITAT IN RELATIONSHIP TO FLOW VARIATION IN URBAN STREAMS.

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ABSTRACT

Numerous studies have shown that habitat degradation in streams is one of the most critical factors contributing to reduced biological integrity. It is not uncommon for habitat restoration to be incorporated into projects whose major goal is to achieve flood control. Unfortunately, these activities are often considered late in the planning process and are included as “add-ons” to the flow-regime modifications. This often results in a lack of connection between hydraulic flow and the habitat features, especially during low-flow conditions. The purpose of this study is to examine whether hydraulic models can contribute to a better understanding for how to incorporate habitat features into stream restoration designs. We used the Riverine Habitat Simulation (RHABSIM) model to generate predictions of the availability of flow dependent fish habitat for two reaches in a newly restored stream in the Pike River, an urban stream in Racine County, Wisconsin. The two reaches had similar average habitat scores, but differed in that one had few locations of high quality habitat while the other had many locations of lower quality. Predictions from habitat suitability model generated from velocity and depth matched the relationship between the abundance of target species between reaches. Green sunfish were predicted to have better habitat conditions than creek chub for both reaches at low flows, whereas creek chub were predicted to have better habitat at higher flows. At the flows exhibited during summer 2004, Green sunfish were predicted to have the better habitat conditions and they did indeed exhibit higher densities in the reach with the better habitat. In addition, both species were found to have higher abundance and to have better habitat conditions in the reach with the fewer pockets of high-quality habitat, mainly deep pools which provided refuge during low flows. However, when fish habitat quality and quantity predictions were generated using substrate quality in the model, fish abundances between reaches did not correlate with habitat predictions. These findings suggest that substrate quality may be an important constraint and that the creation of smaller amounts of high quality, flow-dependent functional habitat is more successful in restoration design than creating higher amounts of moderate or low quality habitat. Hydraulic models can be a valuable tool predicting functional habitat in stream restoration designs.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

List of Figures

List of Tables

INTRODUCTION

The Clean Water Act of 1977 provided the legislative framework for targeting the nation's water pollution problems. Over subsequent years and amendments the U.S. Environmental Protection Agency was able to focus on point source pollution, and more recently has worked toward nonpoint source pollution improvement through the watershed approach (Novotny et al. 2005). Biological integrity incorporates the physical, chemical and biological parameters of waterways (USEPA 2005). However, even now nearly 30 years later, in states like Wisconsin, there are still many waterways that are not meeting designated uses (WDNR 2004). As such, permits for floodplain channel changes in navigable water's often incorporate provisions for habitat enhancement in efforts to improve biological integrity. This has led to habitat restoration becoming a common practice associated with urban flood control projects.

Flood mitigation projects present opportunities to create multipurpose wetlands, ponds and aquatic habitat features within the design of floodplains and channel modifications. However, flow modification is still the central factor to be controlled and modeled; therefore habitat design often takes a back seat in the design phase of projects and is "added on" once the basic hydraulic and hydrologic modeling is completed.   This approach can default into a "field of dreams" theory on fish habitat; if you build it they will come (Bond and Lake 2003, Suren et al. 2005). This seldom works in urban streams where the functionality of habitat can be significantly reduced by diminished base flow and increased intensity of storm flows (Poff et al. 1997, Wang et al. 1997). As such, flow condition of the stream and flow-dependent habitat performance must be a driving factor in habitat restoration of urban streams (Suren et al. 2005).

Many modeling tools have been developed to predict flood flow and water levels such as HEC-RAS (USACE 2002), SWMM (USEPA 2004), and TR-20 (NRCS 1992). These share the common purpose of allowing the user to simulate the impacts of channel modifications on water conveyance, but they do not incorporate any habitat considerations. Another suite of models include those used during Instream Flow Incremental Methodology (IFIM) (Stalnaker et al. 1995) studies. The IFIM study method, developed by U.S. Fish and Wildlife Service has been used to predict habitat changes that might result from flow reduction caused by proposed water diversions. IFIM has commonly been applied on irrigation and store and release (i.e. peaking) hydropower licensing projects. The concepts behind the combined flow and habitat models derived for IFIM use applied ecological knowledge with modeling output to create sustainable flow conditions for fish. IFIM studies are generally conducted to determine the minimum and maximum stream flow needed to provide conditions suitable for target species in the environment.

Two models that have been developed to assist in IFIM include Physical Habitat Simulation Model (PHABSIM) (USGS 2001) and a modified version Riverine Habitat Simulation Model (RHABSIM) (Payne 1998). These models generate output that integrates stream flow conditions and habitat variables into a parameter described as “weighted usable area” (WUA). The WUA index is the amount of acceptable habitat at a given flow within a specified reach of stream. WUA is a product of the quantity of fish habitat and quality of fish habitat. These habitat simulation models may provide a valuable tool in restoration design. Although it may be tempting to select target flows that maximize WUA, it is critical to understand the coordination between the quality and quantity of fish habitat available in a reach. Additional knowledge of the system; including flow, fish community, and habitat types must be considered when selecting a design or target flow and WUA condition.

This paper presents the results of a study which used RHABSIM to analyze flow-dependent habitat features for fish in a restored urban stream. We test whether predictions of WUA can be used to discern the relationships between quality and quantity of fish habitat with respect to its effect on fish population abundance and distributions. RHABSIM was used to generate WUA predictions for two target species, creek chub (*Semotilus atromaculatus*) and green sunfish (*Lepomis cyanellus*), for two study reaches, each with differing quantity and quality of habitat structure. Relationships between WUA and fish distributions were then tested in a new stream channel that was designed to reduce flooding frequency, but also included features to naturalize the channel, reconnect the floodplain, and generally improve fish habitat.

The objective of the study is to compare predictions of RHABSIM with field observations to evaluate whether the quantity or quality of the habitat is the more important factor in the value of WUA. Both green sunfish and creek chub are common species in the study system (Ehlinger 2002) and are considered tolerant (Becker 1983). Creek chub are considered a sentinel species and as such are a good indicator for acceptable water quality (Fitzgerald et al. 1999). It's expected that these two species will react to the habitat restoration efforts and provide information about preferences to quantity or quality in the study system. This will provide guidance for stream designers as restoration projects continue under the guidance of flood management and WDNR expectations of improved biological integrity.

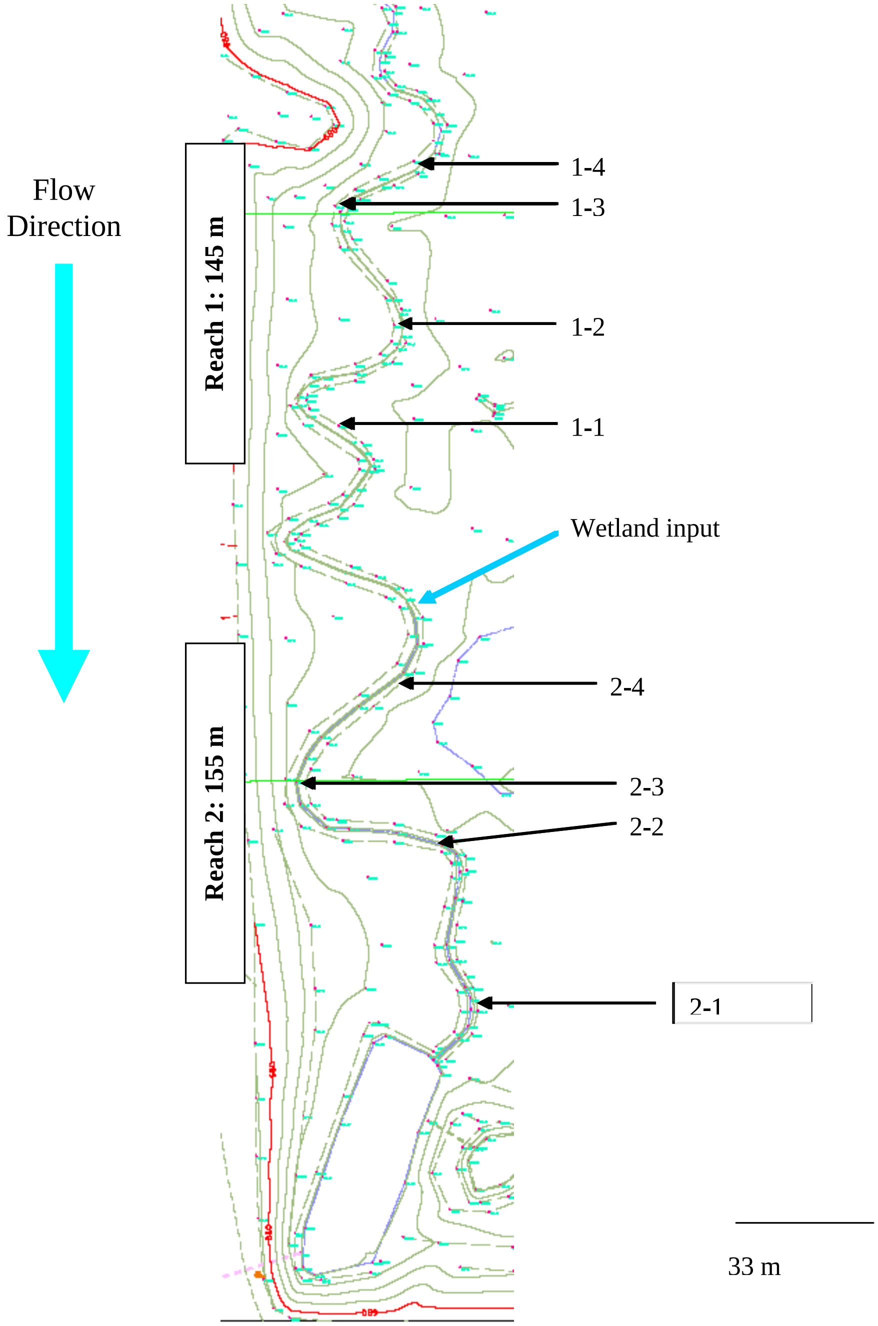
Methods and Materials

Study Area

The entire North branch of the Pike River is approximately 9.15 km of river which drains a 44.9 km^2 watershed in Racine and Kenosha Counties, Wisconsin (SEWRPC 1983). The river channel was dredged and straightened in the late 1800s in order to improve agricultural drainage and allow for earlier spring planting (SEWRPC 1983). As a result, much of the river is incised within a steep-banked channel between 3-7 meters deep. Significant population growth and resultant development in the 1970s and 1980s resulted in increased stormwater runoff and increased frequency of overbank flooding events. A management plan for the river was proposed that included channel deepening and widening to improve conveyance (SEWRPC 1983). Eventually the management plan was modified to include creation of wetland and stream channel restorations along the length of the river (Crispell-Snyder 1997).

Phase I of the multi-phase restoration plan began at the headwaters of the stream and involved channel relocation several meters to the east or west side of the original channel and a large area of wetland/stormwater detention basin system in the middle section of this phase of restoration (Crispell-Snyder 1997). As part of the relocation, a 480 m section of channel was designed and built to meander through the wetland area to better represent a natural stream channel. Two study reaches were selected within this section. A surface water inflow from the wetland complex enters the stream between Reach 1 (upstream) and Reach 2 (downstream). A small pond is inline with the channel at the downstream end of the new meandered channel at the end of Reach 2. This pond was used as a sedimentation pond during construction and is expected to fill in over the next few years (Crispell-Snyder 1997). Reach 1 is 155 m in length and has four bends in all, two less than 45° and two greater than 45°. Reach 2 is 145 m in length and has two large bends greater than 45°. Restoration layout and Reach locations are presented in Figure 1. Each Reach contained four study cross-sections used for collecting data for the habitat simulation model (see below). These cross-sections were chosen to best represent the types and amounts of each habitat type found within a reach. Fish habitat within each reach was assessed using the modified Wisconsin DNR procedures described in Simonson et al. (2000).

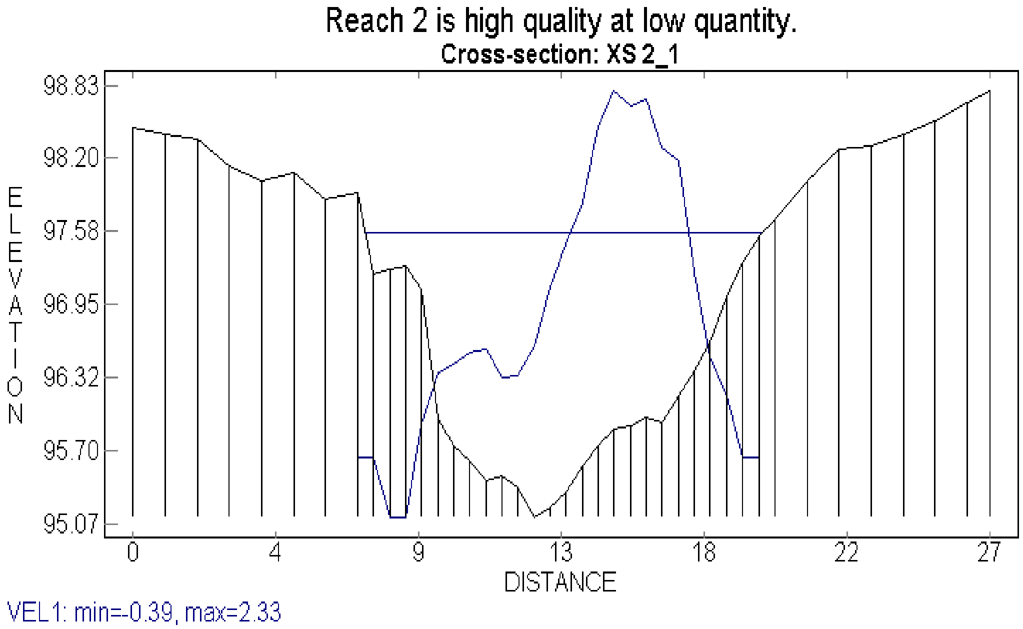
Figure 1: Meandering section (480 m) of North Pike River Restoration Phase 1. Research site layout is identified by Reach location on the left side and cross section labels on the right side.



RHABSIM Model

The Riverine Habitat Simulation (RHABSIM) (Payne 1998) model was used to estimate flow-dependent habitat in the new stream reaches. The program uses habitat attributes (velocity, depth, cover/shade, and substrate) measured from stream cross sections to generate predictions separately for each fish species. Figure 2 is an example of a cross section evaluated and input to the RHABSIM model. Each vertical line indicates a location of assessment for all attributes. These verticals establish the cells of a cross section. Each cell is evaluated for its habitat suitability to the target species. The cell value is multiplied by the flow through that cell to create a weighted usable area (WUA). All cell WUA values are summed to create a reach WUA. This reach value is what is used to estimate the fish habitat in a reach. Habitat attribute values were established through use of Habitat Suitability Index (HSI) criteria curves (see below).

Figure 2: Example of a cross section sampling regime for RHAMSIM surveys. Each vertical represents a data collection po



HSI Development and Criteria Curves

Habitat Suitability Index (HSI) curves (McMahon 1982 and Stuber, Gebhart, and Maughan 1982) were used to establish attribute values for the species criteria curve data in the RHABSIM Model. HSI curves were generated using data collected from prior studies of streams in southeastern Wisconsin between 2001 and 2003 (Ehlinger et al. 2004). Only data where both habitat and fish surveys were conducted simultaneously were used. Streams ranged along a gradient of urban to agricultural land use. The length of stream sampled for both fish and habitat was 35 times the mean stream width of the stream. Fish abundances were standardized by number of fish divided by the total surface area of the stream sampled to generate a catch per area (CPA) index, which is the number of fish caught in the reach divide by the surface area of the reach. Habitat data were plotted against fish CPA and the approximate 95% maximum CPA was used to fit a curve to the data. These curves represent the useful and preferred habitat (based on reach sampling) range for creek chub and green sunfish in southeastern Wisconsin relative to water depth, shading, fish cover, substrates, and velocity. These plots can be found in Appendix A. These data represent the general reach patterns and were not habitat specific. Attributes that are not well served as averages or entire reach values include velocity and depth. These attributes have more significance when evaluated at specific types of cross sections and were therefore derived from the Fish and Wildlife Service HSI plots for creek chub (McMahon 1982) and green sunfish (Stuber et al. 1982). Other features such as shade and cover patterns and substrates were applied as averages for the reach. The HSI values for cover/shade and substrates were assessed using the 95% maximum curves generated from the Ehlinger Lab data and other supporting HSI curves from the Fish and Wildlife Service.

Cross Sectional Data Collection

Water surface elevations were taken at each research cross section. Velocity and depth were measured at the same time at multiple locations for each cross section. These surveys were collected three times for each reach. Cross section bottom elevation survey and substrate characterizations were also conducted once at each cross section.

Surveys were conducted using a fiberglass wading rod and Spectra-Physics Laserplane®, 750. Velocity was taken with an Ott® C1 current meter. Measurements were taken a 0.6*depth unless total depth was greater than 0.76 m. In that case velocity was taken at 0.2*depth and 0.8*depth and were averaged to find the velocity of the cell for use in RHABSIM and discharge calculations.

Model Estimates

In Reach 1 velocity estimates were made as a function of cell flow depth. Water surface elevations for Reach 1 were estimated using Manning's equation for each cross section. For Reach 2, measured velocities were used to calculate Manning's "n" which was then used to estimate flow velocities for cross sections 2-1 and 2-3. For cross sections 2-2 and 2-4 velocity was estimated using its relationship to flow depth. Reach 2 water surface elevations were estimated using the cross sectional stage-discharge relationship.

Fish Surveys

Fish collections were conducted for each reach three times over four weeks in August and September 2004. In addition, a fish survey was taken on September 22, 2004 at each study cross section. The last survey was taken during the lowest flow noted (< 0.006 m^3/s Reach 1, < 0.003 m^3/s Reach 2) and was only conducted at the eight (four per Reach) established RHABSIM cross sections. Section lengths for these fishing events were approximately 3 meters up and down stream of the cross section to observe the full effect of the habitat at that location. All fish samples were collected using a Smith-Root Backpack Pulse Electrofisher®. Samples were identified to the species level and counted for total amounts. Young of year for blue gill and green sunfishes were totaled together.

Data and Statistical Analysis

RHABSIM WUA values were assessed in comparison within and between each reach. Statistical analyses were conducted using SYSTAT 10.2 (SYSTAT Inc. 2002). The paired t-test was used to test for significance between sampling dates for the reaches. Box plots were also generated to identify total range and changes in sampling per reach. HSI curves were created using the plotting routine in Microsoft Excel (Microsoft Corporation 2000) and hand drawn 95% curves. Flow data and WUA plots were transferred from RHABSIM to Microsoft Excel for ease of manipulation and graphing.

Results

Site Characteristics for Flow and Habitat

The general hydrological and physical characteristics for Reach 1 and 2 are shown in Table 1. Information on depth, width, length and area are based on the habitat surveys conducted in accordance to Simonson et al. (1994). Flow data are from the hydrologic cross section surveys conducted for the RHABSIM model. Measured flows ranges from 0.058 – 0.142 m^3s^{-1} in Reach 1 and from 0.07 – 0.29 m^3s^{-1} in Reach 2. Base flows of 0.02 m^3s^{-1} were common mid-summer. Long-term expected variability and range of flow conditions were estimated using USGS gauging data collected from the Pike River in Kenosha, Wisconsin for the period 1972-2001 (http://nwis.waterdata.usgs.gov/usa/nwis/discharge, station number 04087257) (Figure 3). Assuming equal contributions from all areas of the watershed, and using a watershed area draining to the study reaches of 6.8% of the total watershed at the gauging station, the predicted flow exceedence probability curve is presented in Figure 4. The 50% flow exceedence of 0.03 m^3s^{-1} (and greater) is within the range of flows observed during the study.

Table 1: Physical and hydrological characteristics of the North Pike River restoration research site. Data were collected during two types of surveys and is noted in the table.

	Reach 1		Reach 2		Source of Data
	Mean	Std Dev.	Mean	Std Dev.	
Width (m)	1.94	+/- 0.39	1.96	+/- 0.27	Habitat Survey (Simonson et al. 1994)
Length (m)	145		155		
Area (m^2)	281		304		
Depth (m)	0.15	+/- 0.047	0.19	+/- 0.058	
Velocity (m/s)	0.07	+/- 0.038	0.14	+/- 0.097	RHABSIM cross section survey
Average Flow (m^3/s)	0.10	+/- 0.084	0.18	+/- 0.220	
Fine Sediment (%)	85		83		Habitat Survey (Simonson et al. 1994)
Algae (%)	15		10		
Macrophyte (%)	50		46		
Emergent Macrophyte (%)	11		0		
Shading (%)	15		16		
Pool Area (%)	2.8		8.4		
Pool Depth (m)	0.44	+/- 0.167	0.53	+/- 0.155	RHABSIM cross section survey
Riffle Area (%)	0		4.5		Habitat Survey (Simonson et al. 1994)

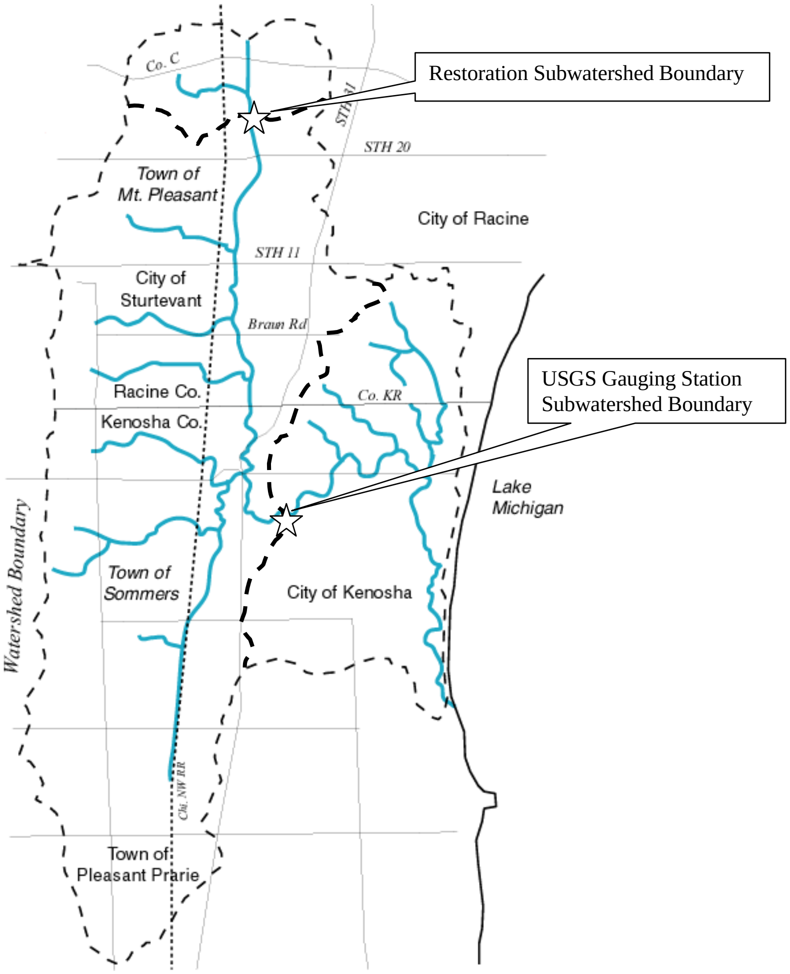
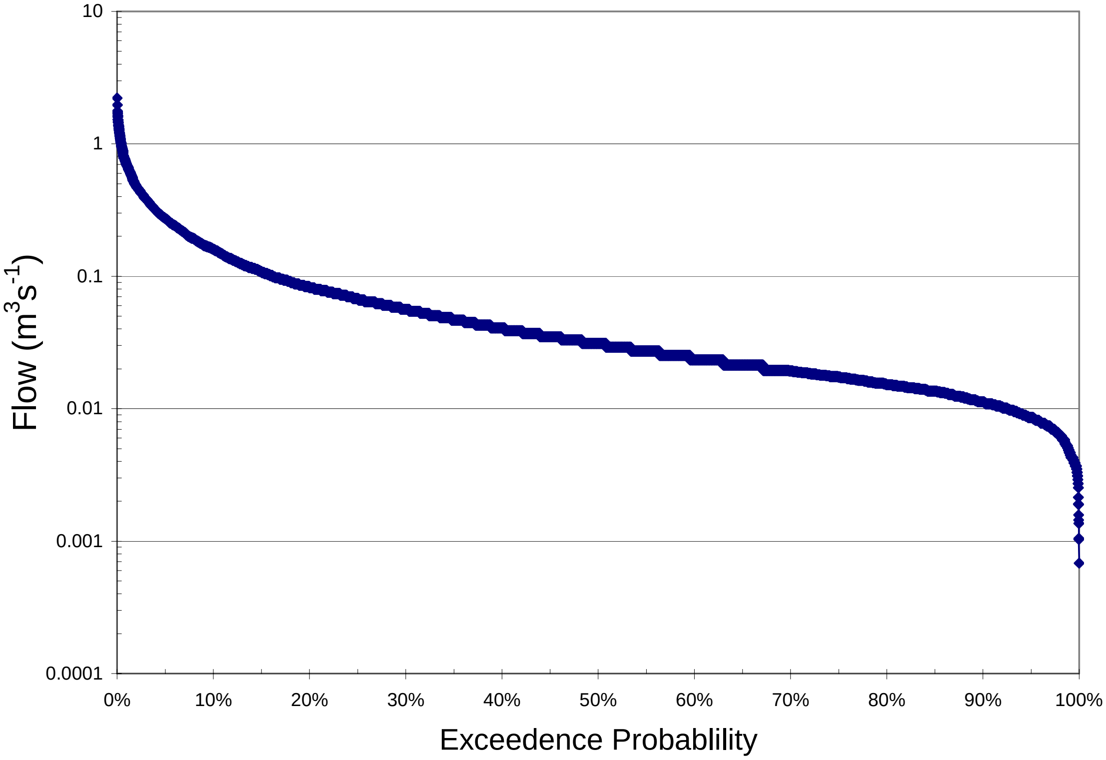


Figure 3: Pike River watershed with delineation of restoration subwatershed (6.9 km^2) and USGS gauging station subwatershed boundary (100.8 km^2).

The higher average flow in Reach 2 is due in great part to surface water input from a ground-water fed wetland created during the restoration which separates the two reaches. This input has the net effect of increasing average flow by 80 percent. In addition, Reach 2 was consistently wider and deeper than Reach 1 during the course of this study. This difference in average flow and depth contributes to the development of different levels of vegetation in the stream channels, with a higher density of emergent macrophytes in Reach 1. The higher level of macrophytes in Reach 1 may also serve to reduce water velocities and contribute to sedimentation (Table 1).

Figure 4: Expected range of flow at North Pike River resotration site based on its relative watershed size to that draining to the USGS gaging station at Racine, WI. Period of flow for gaging station is 1972 through 2001.



Effect of Flow and Habitat Attributes on WUA

Habitat attribute variables in RHABSIM are stream characteristics that are set to a value from 0 to 1 to reflect suitability for particular fish species. When entered together into RHABSIM, the attributes are presented as the "combined suitability factor" (CSF). All weighted usable area (WUA) assessments used velocity and depth as the basic attributes. A third additional attribute was then added to the model to create a three part CSF. For this study three different CSFs were evaluated: (1) Depth and velocity, (2) An integrated cover and shade attribute was combined with depth and velocity for the CSF, and (3) substrate composition combined with depth and velocity. All attribute values are shown in Appendix A.

The effect of variation in stream flow on WUA for creek chub and green sunfish for each of the study reaches are shown in Figures 5a-c. The first simulation considers the effect of flow variation using only depth and velocity (Figure 5a) and holds the other parameters (i.e. substrate or cover/shade) as optimal (considered to be 1). This serves as a measure of the maximum WUA attainable given the physical dimensions and slope of the channel. It is apparent that WUA for green sunfish is maximized at flows less than 0.1 m^2s^{-1} in both reaches, after which, WUA drops off rapidly. On the other hand, WUA for creek chub is not predicted to reach a maximum until flows exceed 0.4 m^2s^{-1} after which it decreases slowly. This difference between species is a reflection of ecomorphological differences and the greater ability of creek chub to live in faster flowing waters (Becker 1983).

The inclusion of the actual amount of cover and shade existing within each reach as an additional attribute in the model did not have any significant effect on the patterns of predicted WUA (Figure 5b) and the WUA was nearly identical to that simulated using only velocity and depth (Figure 5a). Although there is little shade, the higher abundance of bull rushes in Reach 1 and other submerged macrophytes in the stream channel (Table 1) contributed to fish cover attribute scores. Additional simulations using maximum and minimum (0 and 1, respectively) cover and shade level variations in the North Pike restoration sites indicate that they could reduce total WUA by only 5% from the maximum predicted by velocity and depth alone.

Figure 5a: Weighted Usable Area variation with flow for attributes velocity and depth. Measured flows used to estimate the model are noted by the star. From left to righ the first two are the low flows for estimation for Reach 1 and 2 respectively. The third star is the highest flow used to estimate in both Reaches.

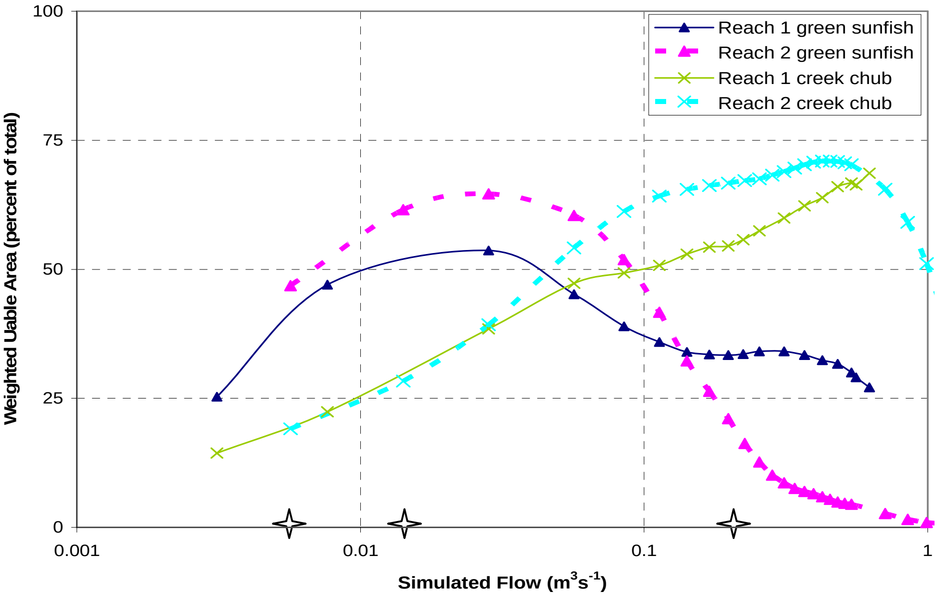


Figure 5b: Weighted Usable Area variation with flow for attributes velocity, depth, and cover/shade

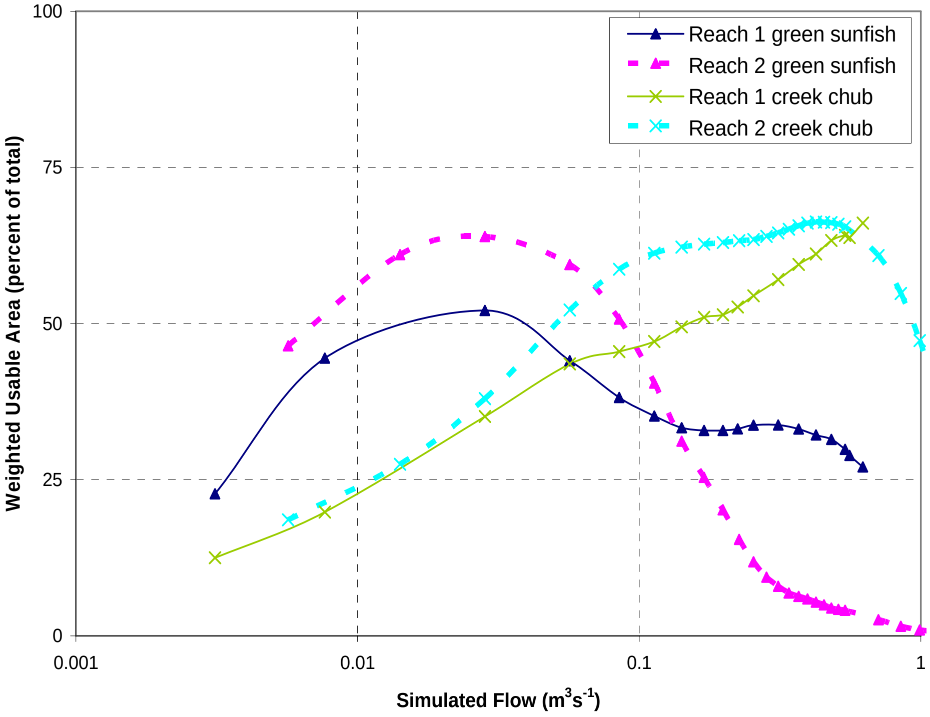
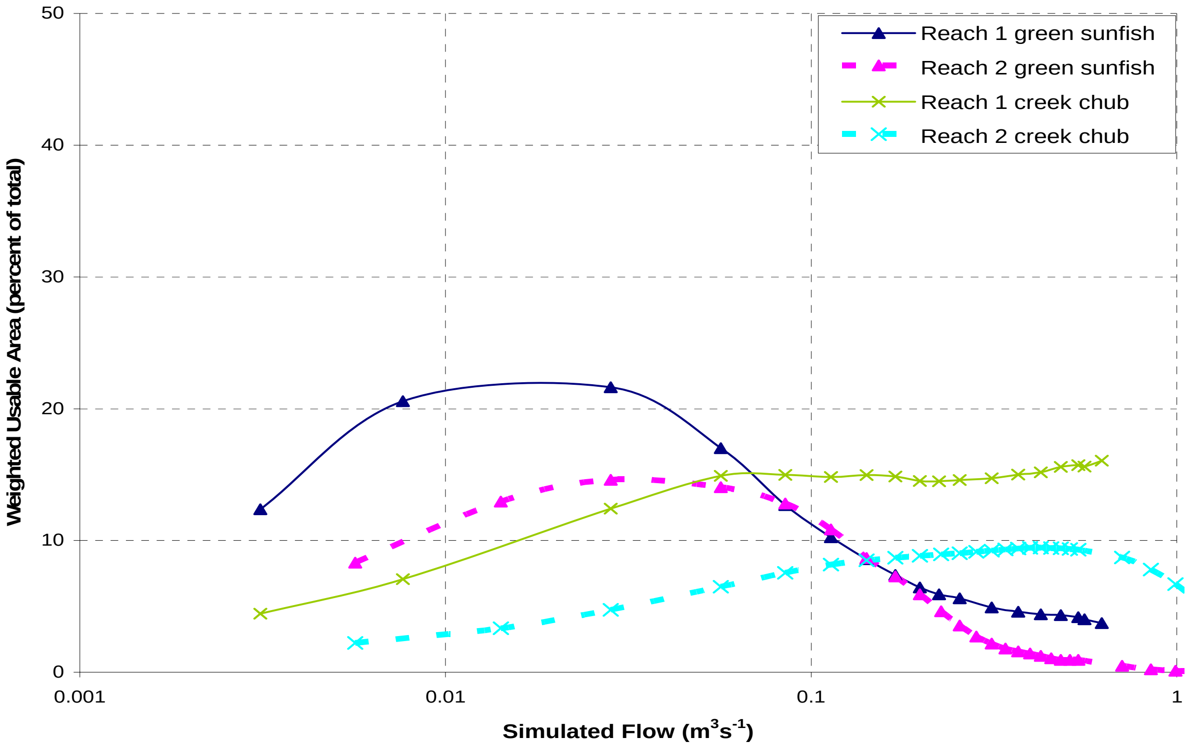


Figure 5c: Weighted Usable Area variation with flow for attributes velocity, depth, and substrates



The inclusion of substrate quality as an attribute for the Pike River has a profoundly negative effect on WUA (Figure 5c). Overall predicted WUA is lower in all reaches for both species. However it is interesting to note that the higher values of WUA are now in Reach 1 for both species, as compared to when substrate quality was not considered (Figure 5a). The suitability index in Reach 1 is consistently greater than Reach 2 at flows less than 0.2 m^2s^{-1}. This is counter intuitive because of nearly equal percent fine sediments shown in Table 1. A partial explanation for this is that Reach 1 has silt combined with gravel and cobble, while Reach 2 cross section substrates are rarely combined with gravel and cobble. Another explanation is that percent fine sediment is evaluated from the entire reach habitat survey and the suitability value was assessed only at the study cross sections. Data for these two surveys were also conducted two months apart with cross section surveys in June and habitat surveys in August. This may have allowed fine sediments to settle into the system and become trapped in Reach 1 from the emergent macrophyte growth. There is also the possibility that the model just does not predict well with confounding factors of substrates. This could be a limitation to the model as it was not created for habitat restoration design.

The Relationship between Flow, WUA and Fish Abundance

The WUA simulations predict that available habitat for green sunfish will be maximized at lower flows (approximately 0.03 m^2s^{-1}) and that creek chub will have better habitat at higher flows (greater than 0.2 m^3s^{-1}, Figure 5a). Furthermore, if fish abundance is related to habitat availability, then at the median flows of 0.03 m^3s^{-1}, it is expected that green sunfish abundance will be higher in Reach 2 compared to Reach 1, and greater than creek chub in both reaches.

The results of the fish surveys are presented in Table 2. In all reaches and sampling dates green sunfish are the dominant fish species, with creek chub and bluegill sunfish less abundant. Reach 2 has the highest abundance for most species on all sampling dates.

Green sunfish were more abundant in Reach 2 (Figure 6, p=0.023, ANOVA). Creek chub were also more abundant in Reach 2 but the difference was only marginally significant (Figure 6, p = 0.069).   However, a few species were more commonly found in Reach 1 (e.g. young of year large mouth bass and brook stickleback), which is most likely due to the higher macrophyte density providing cover from potential predators.

Table 2: Fish Survey Data for Reach 1 and 2 by Date of Sampling

	8/10/2004		8/31/2004		9/15/2004		9/22/2004*	
	Reach 1	Reach 2	Reach 1	Reach 2	Reach 1	Reach 2	Reach 1	Reach 2
black bullhead	1	5	1	7	0	0	0	0
bluegill sunfish	14	40	4	64	2	133	2	48
blue/green sunfish hybrid	0	0	1	0	0	0	0	0
brook stickleback	8	1	3	0	3	0	1	0
creek chub	25	37	5	21	0	32	0	9
fathead minnow	0	1	0	0	0	0	0	0
green sunfish	61	136	96	233	43	254	52	67
mud minnow	3	2	2	4	2	6	0	2
pumpkinseed	0	4	0	7	0	14	0	1
pumpkinseed/bluegill sunfish hybrid	0	0	0	0	0	3	0	3
YOY blue and green sunfish	14	9	22	14	16	21	3	3
YOY large mouth bass	3	0	3	0	2	2	0	0
total fish caught	129	235	137	350	68	465	58	133
shock time (s)	1209	1600	1567	1944	1642	1887	357	321
Total CPA (#/m^2)	0.46	0.77	0.49	1.15	0.24	1.53	1.42	3.99
creek chub CPA (#/m^2)	0.09	0.12	0.02	0.07	0.00	0.11	0.00	0.27
green sunfish CPA (#/m^2)	0.22	0.45	0.34	0.77	0.15	0.84	1.28	2.01

Figure 6: Fish survey results for creek chub and green sunfish. Significant differences were found between reaches for green sunfish (p=0.023) but were insignificant for creek chub (p= 0.069).

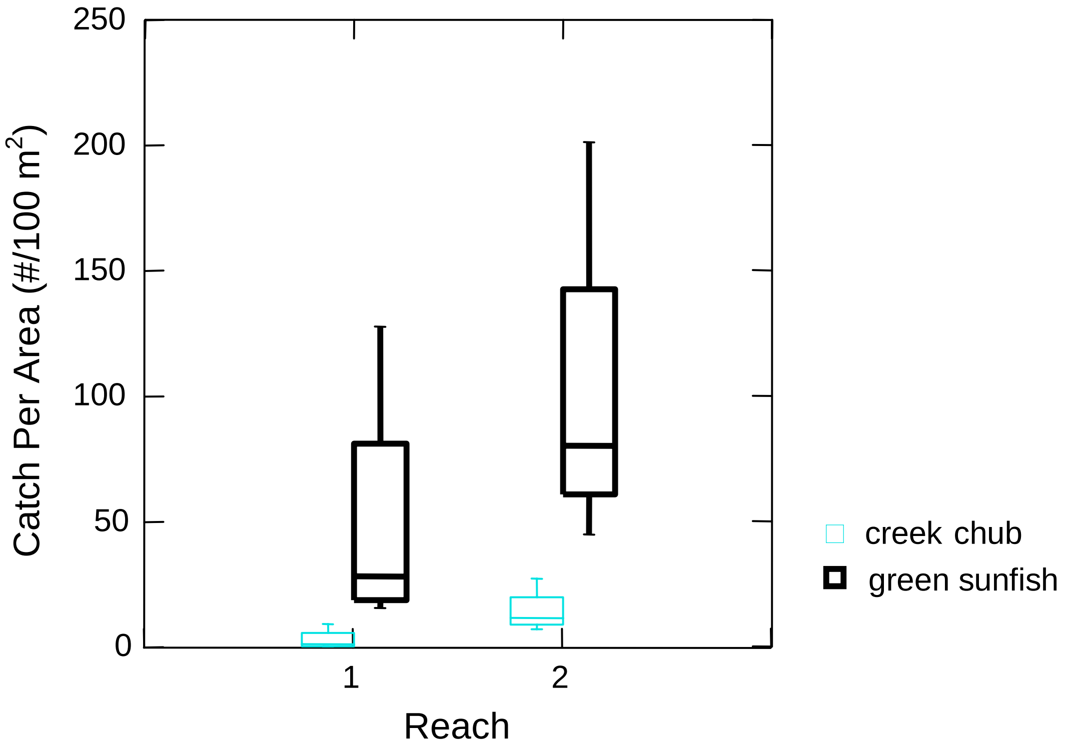


Figure 7a: Changes in Catch per Area along the Weighted Usable Area gradient by Reach for creek chub

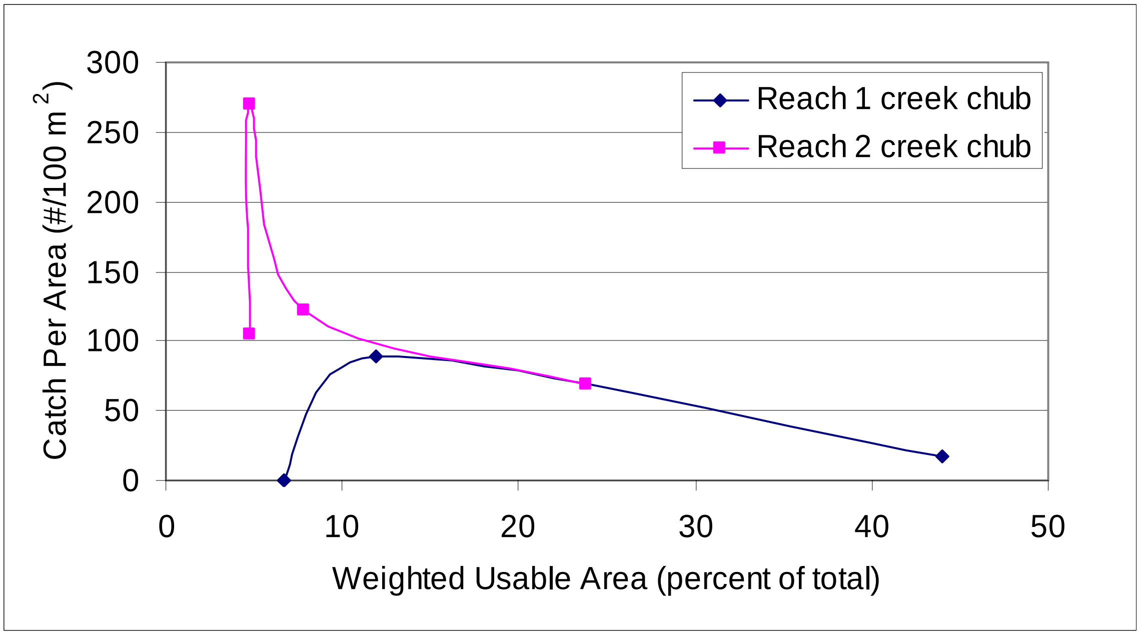
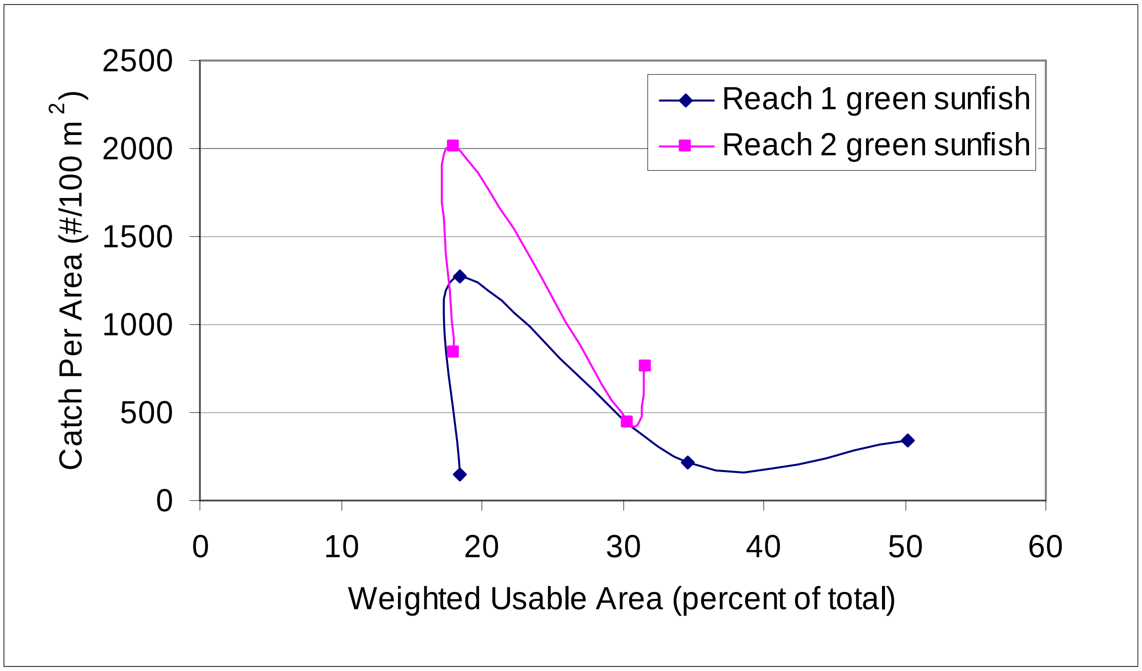


Figure 7b: Changes in Catch per Area along the Weighted Usable Area gradient by Reach for green sunfish



Discussion

RHABSIM accurately predicted the relationship of green sunfish to creek chub abundance and the relationship of Reach 1 to Reach 2. This is strong evidence that RHABSIM, using velocity and depth attributes, can be used as a guide in restoration design by accurately predicting flow dependent habitat. Variation in flow exerts a major influence on variance in predicted available fish habitat. This variation also affects species differently, where green sunfish have higher value at lower flows than creek chub. Higher flows will often be seen during the flooding and storm events, but the daily base flow conditions that dominate may not provide habitat that allows full use of the stream. Substrates, however, greatly reduce the available flow-dependent habitat predicted. Poor substrates in the restoration site may be driving the system into low fish habitat availability.

Modeling restored stream channels with velocity and depth alone results in predictions of WUA which matches the higher abundance of fish consistently found by all measures in Reach 2. Deeper pools and additional flow from the wetland creates more diverse hydraulic conditions in Reach 2 than Reach 1. Even with these improved conditions, flows were generally low, which are more suitable for green sunfish (Becker 1983). As expected green sunfish WUA was much higher and was correlated with increased fish numbers. Conversely, WUAs for creek chub were predicted lower and fish surveys also reflected this relationship. This was a similar trend in both Reach 1 and 2.

The width of the restored sections is highly suitable for creek chub (McMahon 1982), and as such only velocity and depth are the limiting factors of the system and should be altered to improve creek chub habitat. Based on WUA percent in Figure 5a the optimal flow for creek chub is approximately 0.1 to 0.4 m^3s^{-1}. At this point creek chub habitat is predicted to surpass habitat for green sunfish. Creek chub are a less tolerant species than green sunfish and an increase in their abundance will indicate improved habitat and water quality conditions as discussed in Fitzgerald et al. (1999). Improving the quantity and quality of the habitat would increase the WUA percent at lower flows. This would be a more feasible approach to take, since many urban streams are flow limited. However, improved or increased habitat is not a substitute for ensuring connection between flow and habitat, as was shown by Bond and Lake (2003). Under current conditions at North Pike River, improving habitat quality in Reach 1 will likely increase predicted fish WUA, but may have little effect on fish populations in Reach 2 because it has already maximized its potential at the available flows.

Substrate quality had a significant impact on predicted WUA values. When substrates were combined with velocity and depth, the very lowest flows (< 0.01 m^3s^{-1}) predicted higher green sunfish WUA than creek chub WUA. This part of the model corresponded to fish survey results. However, predictions of creek chub WUA between reaches are opposite of previous predictions when using only velocity and depth. Reach 1 is predicted to have higher WUA creek chub values than Reach 2, but surveys show Reach 2 to have higher creek chub numbers. This opposing relationship of predicted fish WUA and surveyed CPA is shown in Figure 7. These figures used flow values from the time of the fish survey to select the WUA value at the corresponding flow as estimated by RHABSIM. This trend provides a clue to understanding the functional habitat relationships between flow and fish abundance. As a less tolerant species, creek chub response to lower substrate quality may be more acute and closely correspond to the creek chubs' lithophilic lifestyle (Fitzgerald et al. 1999).

The WUA model creates predictions based on cross section values selected to represent a reach. However, this does not capture all the habitat variability that fish will respond to within a reach. For example, while WUA was lower in Reach 2, the fish numbers were higher due to the high quality pockets of habitat in deep pools. These pockets provided enough depth for fish to escape the very low flow conditions found in the run dominant reaches. Because pools in Reach 1 were very shallow and generally shorter, there was not enough depth for the fish to persist. Much of this difference could be due to the lack of flow and trapping of sediments in the upstream reach by emergent macrophytes. These emergent macrophytes along with dense algal blooms in the stream could easily trap sediments from the residential watershed draining into the system and block flow. Also, there is less opportunity to escape from higher amounts of fine sediment if there is no hydraulic diversity.

Overtopping of banks was often observed upstream of Reach 1 due to the restricted flow caused by the dense macrophyte growth. This could result in a general decrease in functioning habitat. Reach 2 had higher habitat scores for three reasons, including: 1) Additional flow from the wetland that separates the two reaches, 2) Fewer emergent macrophytes in the system to trap sediments, and 3) Much greater pool depths resulting in more suitable habitat for both the preferred target species creek chub as well as green sunfish.

As base flow decreased over the summer even fewer fish were found in Reach 1 compared to Reach 2 (Table 2), further supporting the importance of deep pools in the restoration design. Through the greater hydraulic diversity of Reach 2, this reach has better functioning habitat. The habitat availability with substrates indicates the raw value of WUA is not what is most important, but the availability of functioning habitat is the vital level of response demonstrated through the fish. The deep pools and increased flow create the hydraulic diversity, which is vital in urban stream restoration (Suren et al. 2005).

Directions for Management

This study demonstrates that simulations of flow-dependent usable habitat for fish can be used to predict how fish abundances respond in restored streams. However, it is essential to note that that a single attribute cannot be considered alone. WUA must be considered together with other factors in the system. In the current study, reaches that are typical for the restored section of the North Pike River were compared to show that a habitat attribute like substrate quality is a limiting factor for creek chub. This can be used both for adaptive management in the restoration process and it allows for the better design of each new reach of restored stream in the project, thereby aiding in its successful use by fishes.

The analyses here also indicate that two other limiting factors in the restored channel are low flow and restricted numbers of pools and their respective depths. This creates a higher proportion of suitable habitat for green sunfish, a less-preferred species for this project. Based upon historical data, flows are expected to be low in this reach. However, designs could be employed that create and maintain localized pools. Patches of increased depth will provide refugia for many species types and may indeed be their only residence during late summer low flow conditions.

Other habitat features associated with the pools can add significantly to functioning habitat (Schmetterling and Pierce 1999, Talmage et al. 2002, and Allouche 2002). For example, in Reach 2, root wads were located adjacent to alternating pools that were created at channel bends. Fish abundance was higher in pools with root wads compared to those without. Furthermore, addition of boulders in runs and addition of gravel to riffles has been shown to increase fish habitat (Simonson et al. 1994) and fish abundance, provided that habitat features do not increase susceptibility to erosion or sedimentation over time. In many urban areas where development physically constrains the width of restored floodplains, the sinuosity of restored channels may be limited, which creates an even greater need for habitat features to provide a diversity of small hydraulic conditions (Aadland 1993).

Green sunfish are considered a tolerant species and are very adept at surviving in poor water and habitat quality (Becker 1983). The presence of green sunfish in the system in and of itself is not an indicator of poor conditions, but the fact that that they dominate the system suggests strongly that the system is under high stress (Lyons 1992). Conditions in the restored reaches of the North Pike River favor green sunfish for several reasons. Based upon the habitat suitability models, green sunfish have the highest preference for low water velocity. Creek chub should do better at higher velocity, but in present circumstances these occur only during high storm flows. It is unlikely, given the pattern of land use and urban development in the North Pike watershed, that creek chub abundance will improve in the future.

Another contributing factor to this is the cross-sectional design for the channels which were created to be overtopped at the 0.25 year occurrence storm event compared to a typical 2 year storm in natural channels. This was done as a way to reduce the amount of bank and bed erosion caused by flashiness and shear forces from stormwater runoff in this rapidly developing watershed, by allowing the flows from small storms to overtop the banks and spread out over the wetland areas. However, the negative side to this trade-off is that the restored channel will have lower water velocity at these lower flows.

The relationship between flow, shading, and nutrient levels in a stream and their impact on oxygen fluctuations is another factor that will change fish communities (Wang et al. 2003 and Wilcock et al. 1998). Photosynthesis and respiration in algae in the North Pike River produce large daily dissolved oxygen (DO) fluctuations (Benson 2005) and green sunfish are better suited to tolerate these changes compared to sensitive species like creek chub or northern pike (Becker 1983). Large algal blooms are known to be associated with poor water quality as a result of intense sunlight conditions (Paul and Meyer 2001). The algae produce extremely high levels of DO during daylight and consume the same large amounts of DO during darkness (Roberts et al. 2004). This creates a diurnal cycle, which less tolerant species will find difficult to tolerate.

During the course of the present study, another project was being conducted examining the effect of shading on stream invertebrates (Benson 2005). Areas of artificial canopy were created using shade cloth, and greater numbers of fish were observed under the shade cloth. Although vegetation has been planted along the banks during the restoration, it has yet to grow enough to contribute significantly to shading and fish cover. Increased shading will not likely have a direct effect of fish populations, but will affect conditions within the stream by helping to reduce dramatic fluctuation in dissolved oxygen from large algal production within the stream. Better effort should be made to shade the stream within short completion of channel modifications. Accounting for these conditions will allow better design at future Pike River restoration projects.

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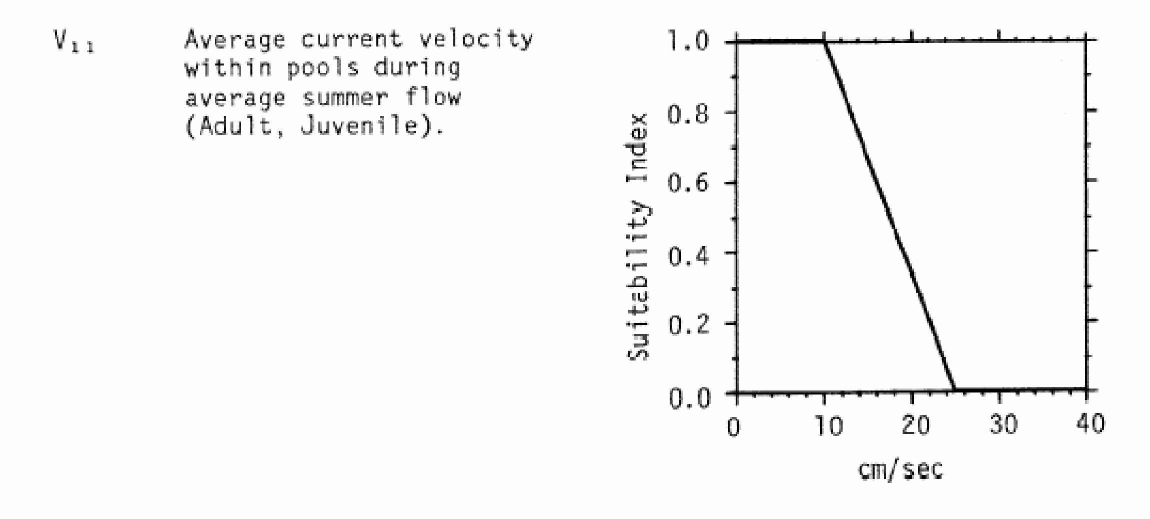
Appendix A: HSI development and values

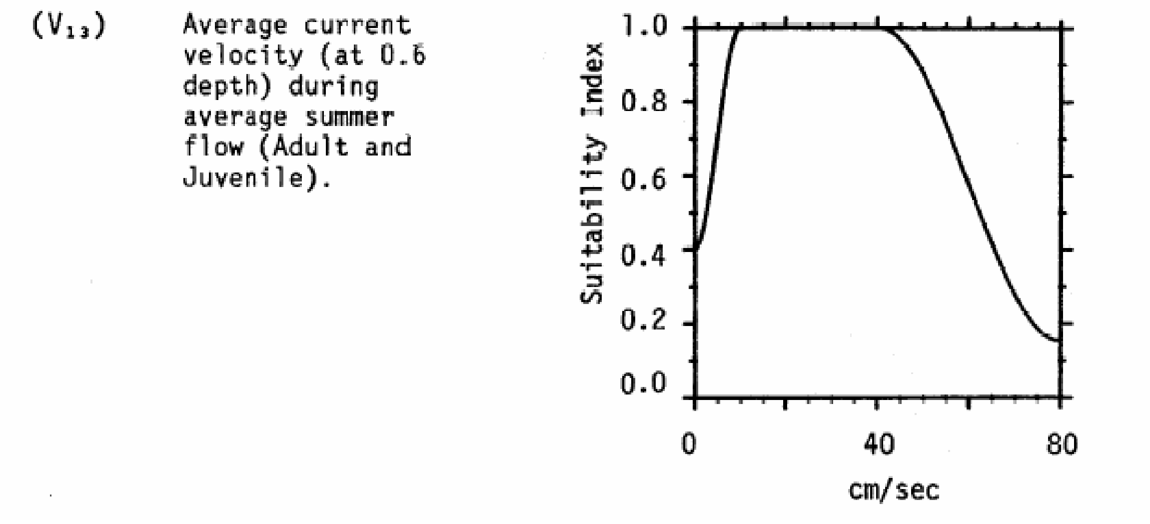
HSI values are derived from plots produced by the US Fish and Wildlife Service (FWS) for creek chub by McMahon (1982) and green sunfish by Stuber et al. (1982). Field data compiled by T.J. Ehlinger at the University of Wisconsin Milwaukee for Southeastern Wisconsin were also used. For Green Sunfish velocity was gathered from the FWS; depth from Ehlinger Lab data; substrate and cover/shade were values assigned based on Ehlinger Lab data and methods outlined in the FWS. For Creek Chub, velocity and depth were gathered from the FWS; substrate and cover/shade were subjective values assigned based on Ehlinger Lab data and information in the FWS document. FWS plots are shown below where direct values were taken. Ehlinger Lab data plots generated and used are also shown below.

Figure A1: FWS Green Sunfish HSI Velocity



V_{11} Average current velocity within pools during average summer flow (Adult, Juvenile).

Figure A2: FWS Creek Chub HSI Velocity



(V_{13}) Average current velocity (at 0.6 depth) during average summer flow (Adult and Juvenile).

Figure A3: FWS Creek Chub HSI Depth

(V_{20}) Average of maximum
stream depths during
average summer flow.

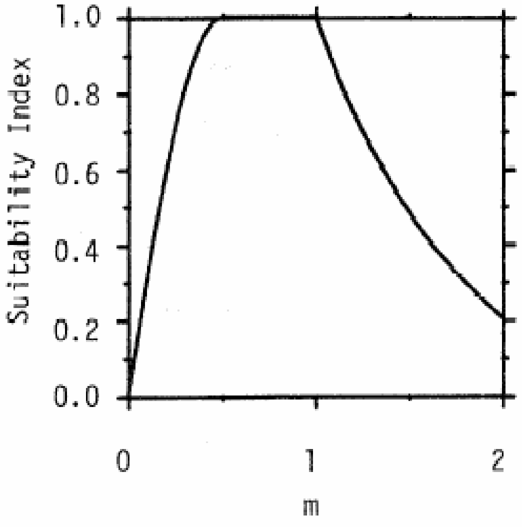


Figure A4: Green Sunfish HSI Depth

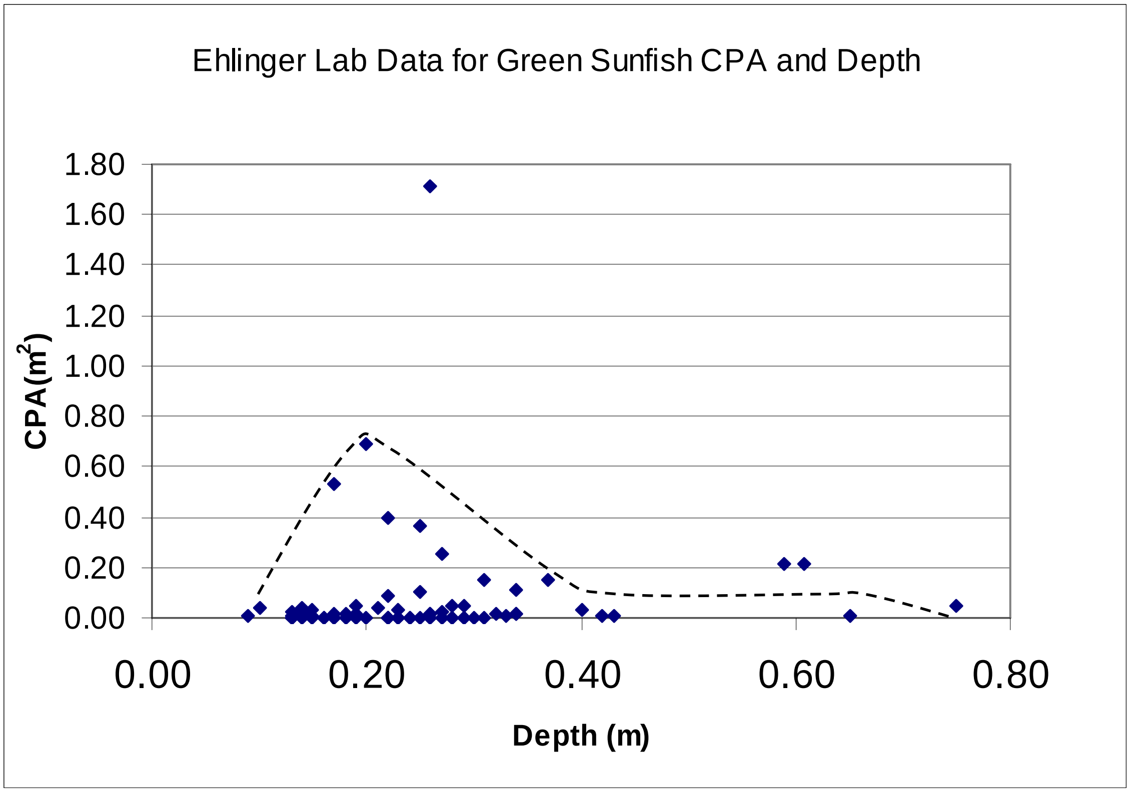
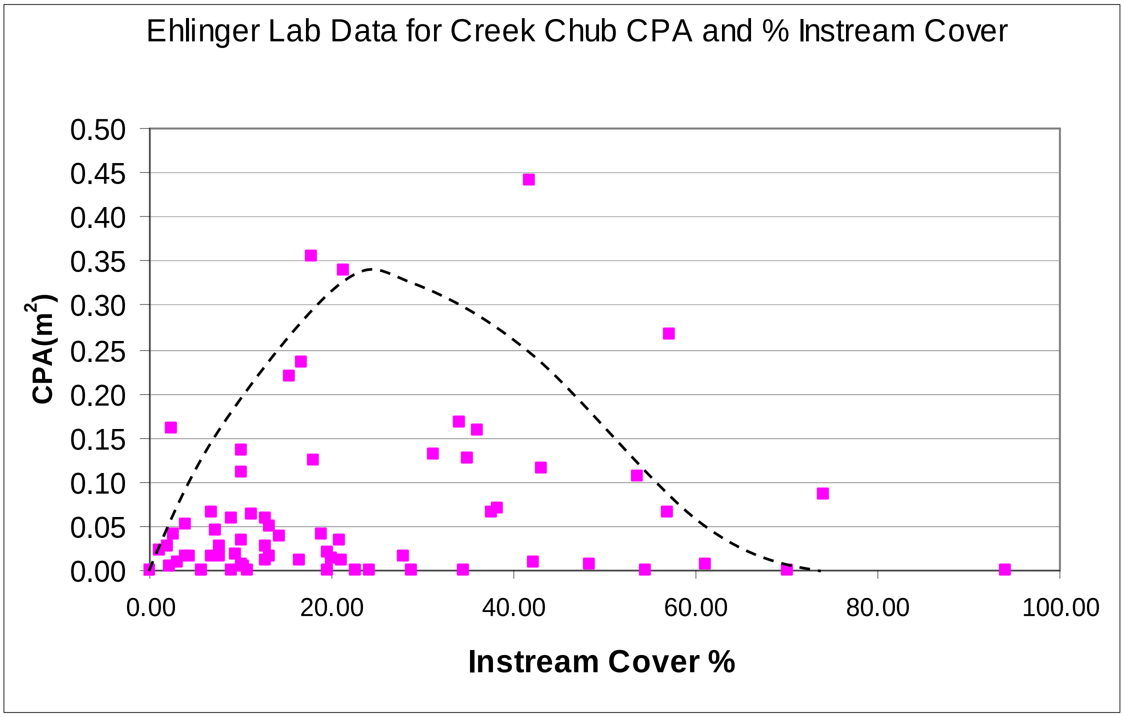


Figure A5: Creek Chub and Green Sunfish HSI Instream Cover



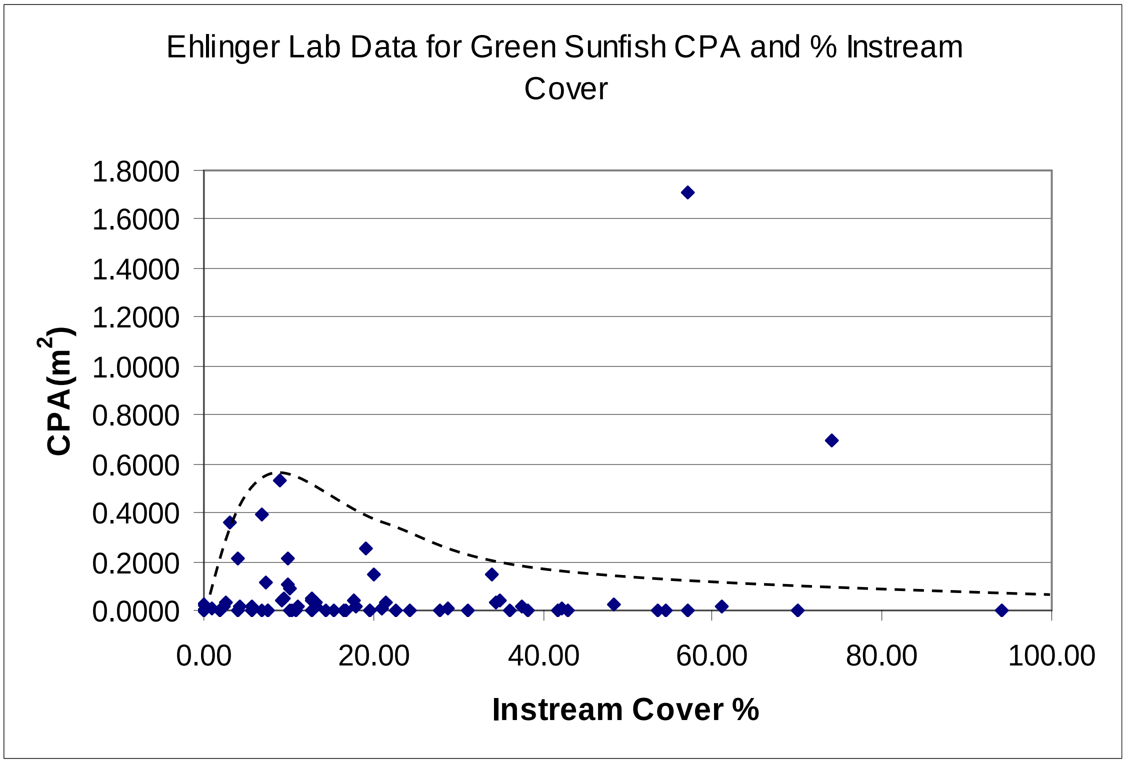
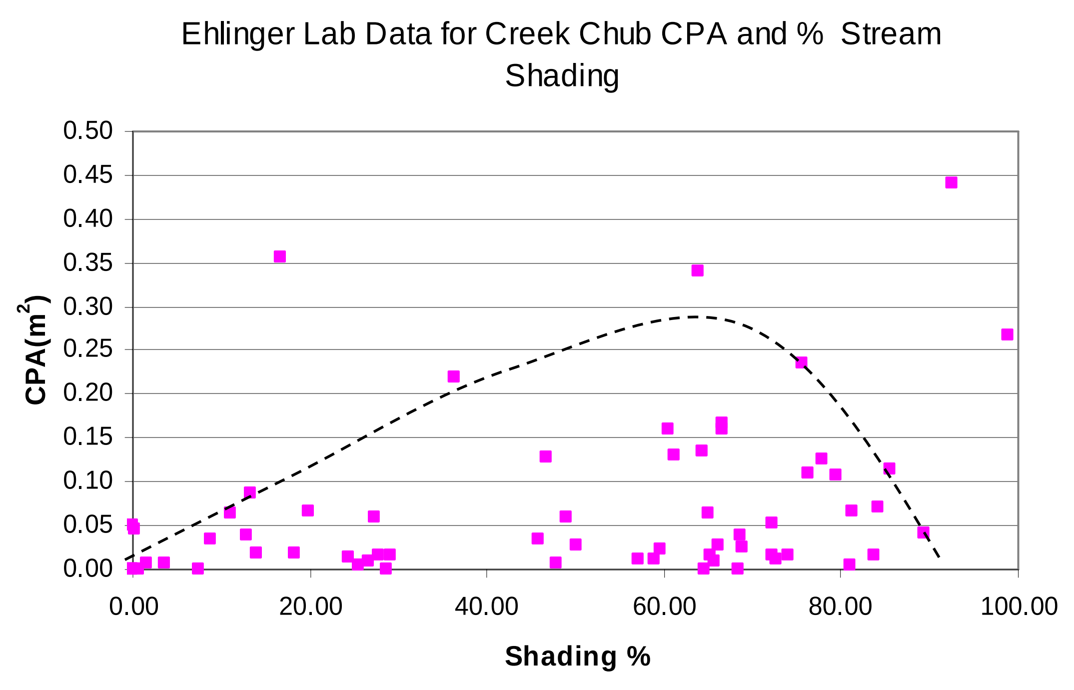


Figure A6: Creek Chub and Green Sunfish HSI Stream Shading



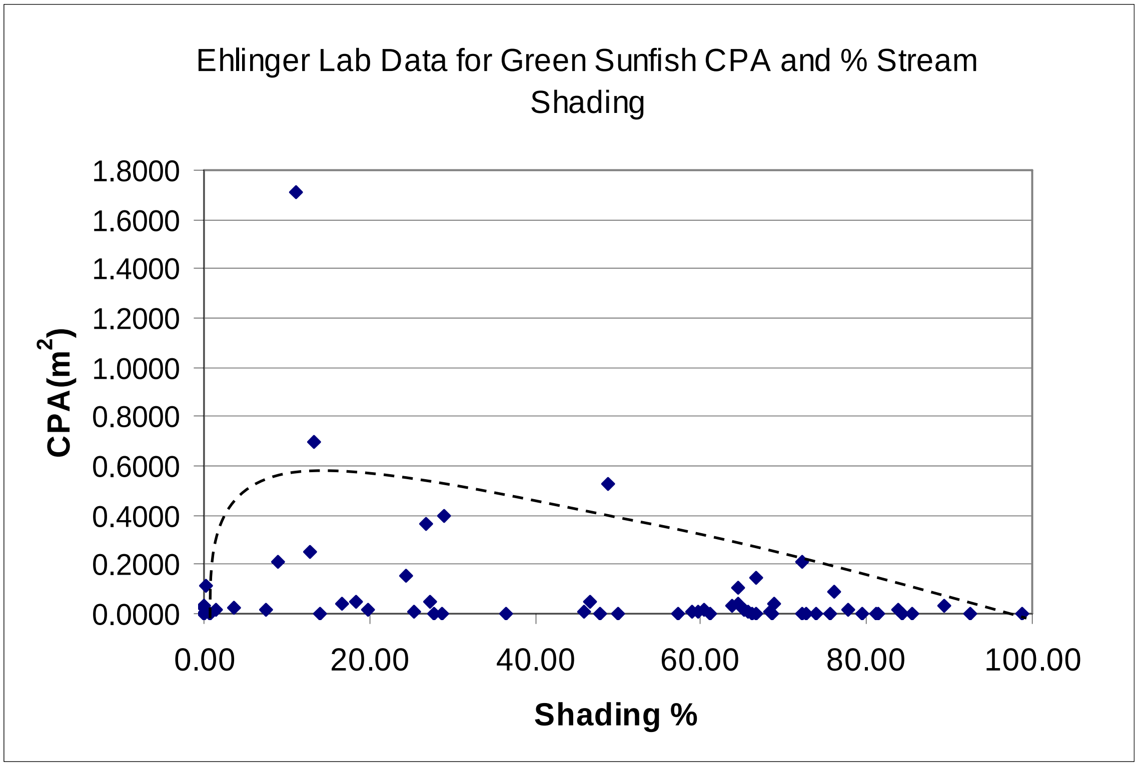


Figure A7: Creek Chub and Green Sunfish HSI for Fine Sediments