# EQUAL AREA LINE-TRANSECT SAMPLING FOR SMALLMOUTH BASS HABITAT SUITABILITY CRITERIA IN THE SUSQUEHANNA RIVER, PENNSYLVANIA

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## ABSTRACT

Two new sampling methods were applied to the collection of data on spawning and rearing smallmouth bass (Micropterus dolomieui) in the mainstem Susquehanna River, Pennsylvania. Both line-transect sampling and equal habitat area sampling are believed to reduce problems inherent with previous methods of collecting data and developing habitat suitability index (HSI) criteria for use with aquatic habitat modeling. The study was designed to minimize the biasing effects of habitat availability, observer subjectivity, and fish disturbance through the use of equal area sampling within habitat type strata, transect randomization, and direct observation of life stages. A 7.5km reach of the Susquehanna River was stratified into five habitat types based on depth, velocity, substrate, and instream cover characteristics. Stratification allowed a controlled distribution of effort with a reasonable assurance that all available habitat characteristics would be sampled. Line-transect sampling is an effective subsampling technique for large rivers that allows random placement and equal effort allocation within habitat type strata. Direct observation of transects using snorkeling or SCUBA gear ensured accurate location and description of chosen microhabitats. Direct observation of 81 transects yielded microhabitat data at focal positions of 50 spawning nests, 196 young-of-year bass, and 129 juvenile and adult bass. Comparison of the Susquehanna River data with habitat suitability models currently in use revealed several important differences in habitat use by smallmouth for spawning and rearing. A close association was observed between instream cover and spawning and fry rearing which could have important consequences for habitat modeling.

KEY-WORDS: Smallmouth Bass/Microhabitat/Habitat Suitability/Instream Flows/Equal-Area/Line-Transect

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## INTRODUCTION

A key component to modeling the relationship between streamflows and fish habitat with the Instream Flow Incremental Methodology (IFIM) is information describing the microhabitat requirements of the affected fish species. In the IFIM context, these requirements are typically described by measurement of water depths, water velocities, bottom substrate materials, and cover characteristics at the focal positions where fish are observed. Analysis and interpretation of these microhabitat observations produce Habitat Suitability Index (HSI) criteria. The biological responses of fish to stream habitat (described by HSI) are interpreted with predicted physical responses of the river to changes in streamflow or surface elevations (by log-log rating, step-backwater, or other hydraulic models) to evaluate potential changes in fish populations.

IFIM results can be very sensitive to differences in HSI (Modde and Hardy, 1992), and HSI in turn are known to be very sensitive to differences in data collection (sampling designs and observation methods, Orth *et al.*, 1982; Bovee, 1986) and analysis (curve smoothing, Cheslak and Garcia, 1988), and in factors that affect fish habitat selection, including fish species and size (Probst *et al.*, 1984), fish behavior (Gosse and Helm, 1982), fish species composition (Schlosser, 1987), season and water temperature (Munther, 1970; Todd and Rabeni, 1989), streamflows (Bain *et al.*, 1982), population densities (Fraser and Sise, 1980), food availability (Wilzbach, 1985), and habitat availability (Orth *et al.*, 1982).

The effects of resource availability on use by organisms has been a long-standing problem in the fields of ecology (Ivlev, 1961; Johnson, 1980), and has been a major topic in the development of HSI where several methods have been employed to account for these effects (Baldridge and Amos, 1982; Rubin *et al.*, 1991). Although disagreement occurs over methods to account for habitat availability in HSI (Morhardt and Hanson, 1988; Bartholow and Slauson, 1990), most researchers acknowledge the potential biases inherent in HSI and many IFIM studies are required to develop site-specific HSI data, or to test the transferability of existing data to the locality in question (Thomas and Bovee, 1993).

This habitat suitability study was conducted on the mainstem Susquehanna River in eastern Pennsylvania at the site of a proposed dam expansion (Figure 1). The proposed development would increase water surface elevations of the Susquehanna by 5m at the dam site and would affect elevations and low-flow depth and velocity characteristics for approximately 7.5km kilometers upstream. The large size and unique habitat features of the study area posed concern over the applicability of published HSI curves for smallmouth bass (*Micropterus dolomieui*), which were developed from smaller streams with different habitat characteristics (Edwards *et al.,* 1983). The objective of this study was to evaluate the applicability of generic HSI criteria for smallmouth bass spawning and rearing for the Susquehanna study area using site specific data collected by unbiased sampling methodologies. HSI data were collected in the Susquehanna according to an equal-area, habitat stratified sampling scheme designed to account for the biasing effects of habitat availability. Direct observation of focal positions along randomly selected strip transects minimized sampling biases associated with observer preconceptions and measurement biases associated with imprecise identification of focal positions.

## STUDY AREA

The study area included the mainstem Susquehanna River from the existing Dock Street Dam at Harrisburg, Pennsylvania, upstream approximately 7.5km to the Rockville Bridge (Figure 1). Limited sampling was also conducted in York Haven Pond located on the Susquehanna 19m downstream of the Dock Street Dam. In the Harrisburg area, the mainstem Susquehanna averaged 1.2km in width and exhibits mean monthly streamflows of 322 to 2,153 cubic meters per second. Despite it's width, the Susquehanna rarely exceeds 2.5m in depth during low-flow conditions and much of the river is less than 1m deep. The expansive shallows with emergent islands and low velocities produce dense beds of aquatic macrophytes (*Justica americana*).

The study area is a highly productive fishery for smallmouth bass, and fish exceeding 2kg are not uncommon in angler catches. Rock bass (*Ambloplites rupestris*), channel catfish (*Ictalurus punctatus*), walleye (*Stizostedion vitreum*), and muskellunge (*Esox masquinongy*) are other sought-after gamefish in the study area. Gizzard shad (*Dorosoma cepedianum*) is the principle forage species. The heavily wooded islands common to the study area provide important nesting habitats for many species of herons and egrets and provide complexity to the aquatic habitat (Figure 1).

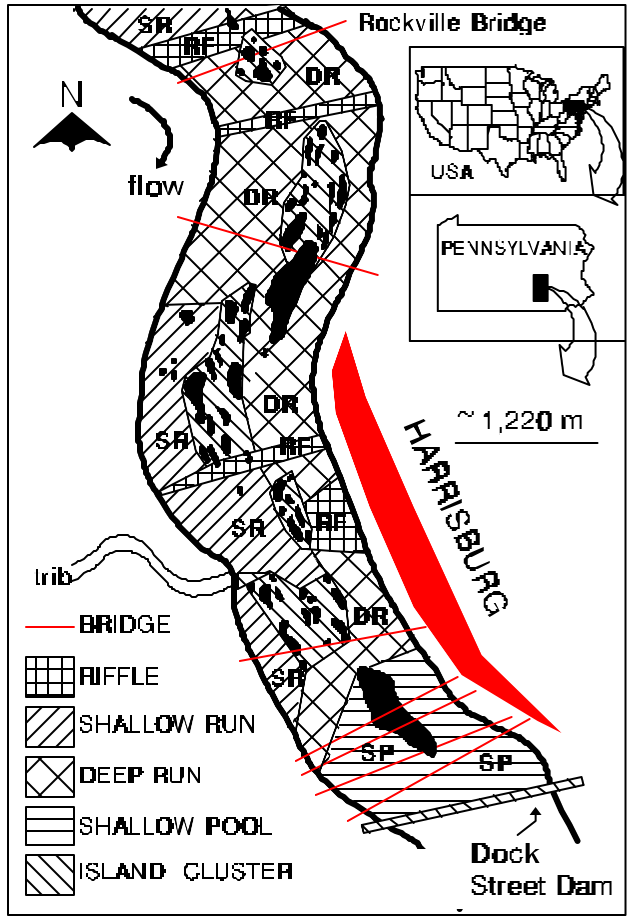


**Figure 1. Susquehanna River study area used for the collection of smallmouth bass HSI criteria, 1989 and 1991.**

## METHODS

A minimum of fifty micro-habitat observations per life stage was desired to verify published HSI criteria for smallmouth bass (Edwards *et al.*, 1983). Randomly selected strip transects were sampled in May 1989 and in May and August 1991 within habitat-type strata by snorkeling or SCUBA diving to identify focal positions of spawning and rearing smallmouth bass.

### Habitat Stratification

The project area was stratified into five macro-habitat types on the basis of depth, velocity, substrate, shoreline, and aquatic vegetation components (Figure 1). Aquatic habitats were generally classified as deep/slow (shallow pool), deep/fast (deep run), shallow/slow (shallow run), and shallow/fast (riffle). Island cluster habitat represented a heterogeneous mixture of the above habitats with a relatively large proportion of shoreline area. Because the project area lacked water exceeding 2m in depth, a sixth habitat stratum (deep pool) was selected from the lower end of York Haven Pond, a Susquehanna River impoundment located downstream of the project area. The inclusion of deep pool habitat was intended to cover a wider range of possible habitat types and to better represent probable post-project habitat conditions. Stratification allowed a controlled distribution of sampling effort with a reasonable assurance that all available habitat characteristics would be represented.

Equal-Area Sampling

The concept of equal-area sampling is based on the supposition that fish densities within a given habitat type will be governed by the suitability of that habitat type. By sampling with equal effort in all available habitat types, pooled HSI data will be weighted by the fish densities present within each type. Consequently, the habitats that are most suitable will be most represented in the pooled data. This methodology is based on several assumptions, including: 1) effective habitat stratification, 2) equal recruitment potential and survival between habitat types, and 3) equal observability between habitat types. The validity of the second assumption in a reach as large as the Susquehanna study area is unknown, however average distances traveled by radio-tagged smallmouth bass in the study area was between 2km and 4km during spring and summer months (Environmental Research and Consulting, 1993), and high flows during the spawning season were expected to distribute fry away from spawning area (Larimore, 1975). Equal recruitment between the mostly free-flowing project area and the impounded York Haven Pond was also assumed, although potential differences prevent a confident interpretation of deep water use by spawning or rearing bass.

Transect Selection

Spawning and rearing observations were made within each habitat strata along randomly located strip transects. The starting point of each transect was selected by locating random coordinate points on a detailed project map. Transect positions were located on-site by triangulating and rangefinding to geographic features. Each transect extended 90m to 150m perpendicular to flow. In 1989, transects were delineated with a weighted cable; in 1991 transects were sampled by following a compass heading.

Field Techniques

After a transect was delineated, a diver wearing snorkeling or SCUBA gear moved slowly along the transect line while searching for rearing fish or spawning nests. Swift water transects required the use of heavy dive weights, a hand-held grapnel anchor, and crampons (ice climbing cleats) to maintain position. Fish exhibiting an alarmed or unnatural behavior were not included in the analysis; focal positions of all other fish or spawning nests were marked with a weighted and numbered buoy. Size of each observed fish was estimated by reference to an underwater ruler. All spawning nests were inspected for the presence of eggs or fry. Fry were classified as sac fry (transparent and benthic), black benthic fry, or black suspended fry.

Focal positions of rearing fish were eye-estimated (height above the substrate), focal positions for all spawning nests were measured 15cm above the substrate. On transects requiring SCUBA, focal velocities were measured by the diver at the estimated focal height with a hand-held pygmy current meter attached to a one meter probe. Adjacent current velocities were also measured at focal height two feet to either side of observed nests. Substrate and instream cover characteristics were evaluated at each fish or nest observation point. Substrate was classified with a continuous code of dominant and adjacent size class composition (Table 1) at the focal position under the observed rearing fish or within the spawning nest. For spawning observations, substrate was also evaluated approximately one foot adjacent to the nest. Instream cover, if present, was identified by type with it's distance and direction from the focal position.

After completion of each transect, the boat or wading crew returned to each marker and measured total depth, mean column water velocity, and focal velocity (for shallow observations). Overhead cover and surface turbulence was also evaluated at each focal position. Additional data recorded at each transect were diver search width, water temperature, water clarity (measured with a Secchi disc), dive time, transect length and direction, weather conditions, and river stage (morning and evening).

**Table 1. Type, size, and code of substrates used to describe focal and nest positions. Code includes the two most dominant size classes, with the percent compostion of the larger size class (i.e. a code 4.3 is 70% sand with 30% gravel; 6.8 is 20% cobble with 80% boulder. From Bovee and Cochnauer (1977).**

| Substrate Type | Size (mm) | Code |
|---|---|---|
| Vegetation | | 1 |
| Mud / Clay | <.05 | 2 |
| Silt | .05-.5 | 3 |
| Sand | .5-6.4 | 4 |
| Gravel | 6.4-76.2 | 5 |
| Cobble | 76.2-304.8 | 6 |
| Boulder | >304.8 | 7 |
| Bedrock | | 8 |

## RESULTS AND DISCUSSION

### Effort Allocation

High flows and poor water clarity during the springs of 1989 and 1991 restricted most of the sampling effort to the middle third of the river channel, making equalization of effort within the macro-habitat strata difficult. In 1989, effort was largely allocated to island clusters and deep pool habitat was not sampled. Total spring sampling effort for the two years was approximately 1,250 lineal meters of transect per macro-habitat type, although deep pools were somewhat under-sampled and island clusters were over-sampled (Table 2). Summer sampling was largely restricted to 1991 due to a heavy algal bloom which occurred in 1989. Summer sampling was conducted along approximately 600 meters per habitat type, except for deep pools and island clusters which were sampled accordingly to produce a combined spring and summer effort of 1,800 meters per habitat type (Table 2). Spawning and rearing transects were distributed throughout most of the study area (Figure 2) and in York Haven Pond.

**Table 2. Allocation of sample effort (in lineal meters of transect) by year, season, and habitat type.**

| | Spring Spawning | | Summer Rearing | | |
|---|---|---|---|---|---|
| **Habitat Type** | **1989** | **1991** | **1989** | **1991** | **Totals** |
| **Riffle** | 305 | 945 | 0 | 610 | 1,860 |
| **Shallow Run** | 610 | 640 | 0 | 610 | 1,860 |
| **Deep Run** | 914 | 245 | 0 | 610 | 1,769 |
| **Shallow Pool** | 802 | 488 | 152 | 457 | 1,899 |
| **Deep Pool** | 0 | 1,067 | 0 | 762 | 1,829 |
| **Island Cluster** | 1,059 | 741 | 0 | 0 | 1,800 |
| **Totals** | 3,690 | 4,126 | 152 | 3,049 | 11,017 |

Environmental Conditions

River discharge differed substantially during the two spawning survey periods. In 1989, streamflows fluctuated between 1,421 and 809 cubic meters per second, whereas stages during the 1991 survey dropped steadily from 849 to 464 cubic meters per second. Water temperatures also differed between years. In 1989, water temperatures generally remained below 20°C. In 1991, a heat wave rapidly increased temperatures from 21°C to 24°C, which appeared to accelerate both spawning and incubation. The wide range of conditions sampled was considered to improve the quality of the data by increasing the variability of habitats available to spawning fish. Spring water visibilities were typically only one to two meters which restricted the location on non-spawning fish. Summer rearing data was collected during stable streamflows of 105 cubic meters per second and a water temperature of 27°C. Visibility was generally less than three meters and sometimes less than two meters due to suspended organic matter and turbid inflow along the Harrisburg shoreline.

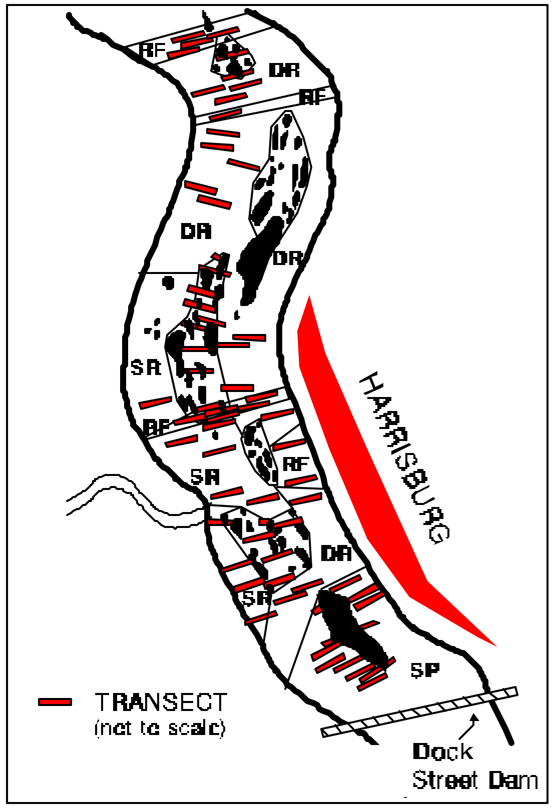

**Figure 2. Approximate location of spawning and rearing transects within the study area.**

Smallmouth Bass Spawning

Fifty nest observations were collected for spawning smallmouth bass in the Susquehanna River. Twenty-two nests were observed in 1989 and another 28 in 1991, two of which were found in the deep water habitat at York Haven Pond (Table 3). Although transect survey methodologies were not designed to yield precise estimates of nest or fish densities (transect search widths were eye estimated), some comparisons between habitat types may be informative.

Overall, a mean of 0.63 nests were observed per 100m$^2$ in the Harrisburg and York Haven areas (Table 3). Estimated nest densities ranged from a low of 0.06/100m$^2$ in deep runs to a high of 1.29/100m$^2$ in island clusters. Despite the large difference in mean densities, transects with no nest observations were common in all habitat types.

**Table 3. Total number and mean density (#/100m$^2$) of smallmouth bass nests observed along spring transects, by habitat type.**

| Habitat Type | # Nests | Mean Nest Density | Density Range |
|---|---|---|---|
| **Riffles** | 9 | 0.80 | 0 - 2.05 |
| **Shallow Runs** | 4 | 0.32 | 0 - 2.87 |
| **Deep Runs** | 1 | 0.06 | 0 - 1.02 |
| **Shallow Pool** | 10 | 0.69 | 0 - 2.58 |
| **Deep Pool** | 2 | 0.30 | 0 - 1.80 |
| **Island Clusters** | 24 | 1.29 | 0 - 5.13 |
| **Totals** | 50 | 0.63 | 0 - 5.13 |

*Nest Activity*

The majority of nests observed in 1989 contained eggs (20 of 22 nests), and no fry were observed.

In 1991 four nests contained eggs and 21 nests contained fry in various stages of development (transparent sac-fry - 2 nests; black benthic fry - 11 nests; and black suspended fry - 8 nests). Three of the 1991 nests contained no eggs, fry, or guarding adult. However, the clean substrate within these nests suggested recent residence and therefore data were collected. Adult bass were observed in the proximity of 12 of 22 nests in 1989 and 13 of 28 nests in 1991. The actual proportion of nests with resident adults was probably underestimated due to disturbance by the diver. The estimated fork length of adult bass found over nests ranged from 15 to 50 cm in 1989 (mean=31.4cm) and 22 to 35 cm in 1991 (mean=27.6cm).

*Nest Depth*

Smallmouth bass nests observed in the Susquehanna ranged in depth from 37cm to 152cm and averaged 102cm in depth (Figure 3). The two York Haven nests occurred at approximately 260cm deep. Nests were typically deeper in 1989 (mean=106cm) than in 1991 (mean= 86cm), possibly due to the higher flows encountered that year. The Susquehanna data showed somewhat higher suitability of shallow water than the HSI curve suggested by the United States Fish & Wildlife Service (FWS, Edwards *et al.*, 1983). Nest observations in York Haven Pool indicated that deep water can be suitable for spawning, but data from the Susquehanna and other waters (Surber, 1943; Stone *et al.*, 1954; Cleary, 1956; Coble, 1975; Monahan, 1991) do not verify keeping suitability maximum to depths of 175 cm, or to infinity as suggested by the FWS clear water option (Edwards *et al.*, 1983).

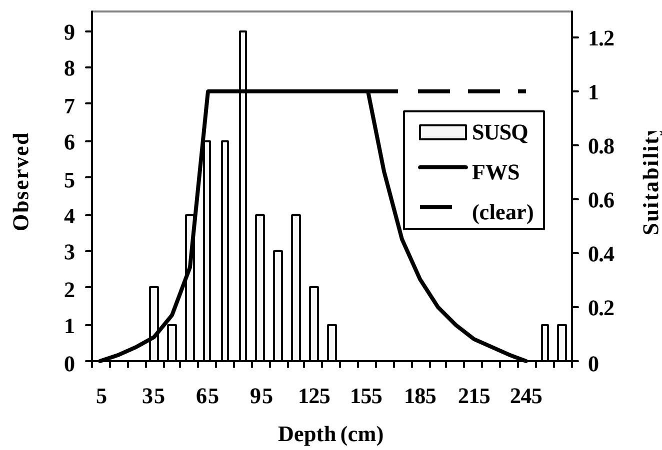


**Figure 3. Depths measured at spawning nests, with FWS HSI curves.**

*Nest Velocity*

Mean column velocities at nest sites ranged from zero to 58cm/s and averaged 16 cm/s (Figure 4). High flows during spawning in 1989 produced much higher nest velocities (mean = 26cm/s) than observed in 1991 (mean = 8cm/s). Despite the observed difference in mean column velocities, bottom velocities at nest sites were similar in 1989 (mean= 6cm/s) and in 1991 (mean = 4cm/s). The low and relatively constant bottom velocities measured at nest sites was largely due to the upstream presence of submerged cover. Smallmouth bass are known to require low bottom velocities for successful reproduction (Surber, 1943; Cleary, 1956; Coble, 1975; Pflieger, 1975; Simonson and Swenson, 1990). Differences in adjacent bottom velocities

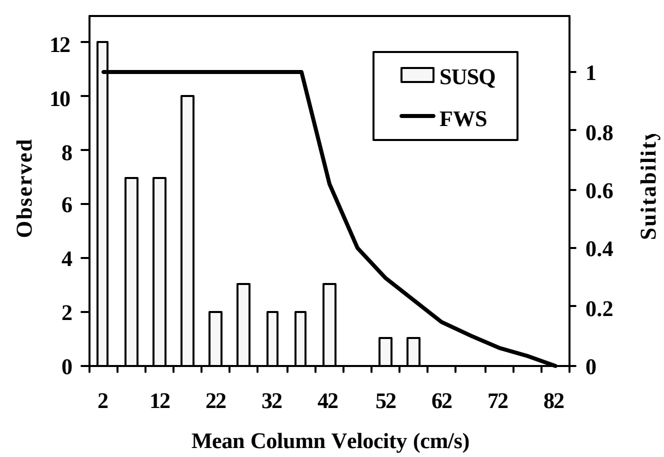


**Figure 4. Mean column velocities measured at spawning nests, with FWS HSI curve.**

measured 60cm to the side of nest cavities in 1991 ranged from zero to 13cm/s (mean = 3cm/s), but were generally less than 5cm/s. The distribution of mean column velocities measured at Susquehanna River nests did not conform to the HSI curve suggested by the FWS (Edwards *et al*., 1985), which indicates much higher suitability for velocities exceeding 25cm/s (Figure 4). In lotic systems, however, bottom velocities at many nest sites may be determined by the upstream presence of instream cover rather than by mean column velocities over the nest. This imprecise association between mean column velocities and bottom velocities, of which the latter is probably most critical for nest selection and success, makes prediction of spawning suitability difficult with current instream flow methodologies.

*Nest Cover*

All but four of the 50 observed nests (92%) were associated with some form of instream cover (Figure 5). Most nests (78%) were located immediately downstream from the cover element. Cover types used by nesting bass were aquatic vegetation (46% - mostly water willow), woody debris and tree branches or roots (14%), boulders (24%), and cobbles (8%). Overhead and turbulence cover were present in 6% and 18% of all nest observations, respectively. Nests were typically located in close proximity to the cover element (mean distance =23cm). Sixty percent of observed nests were less than 20cm from cover (Figure 6).

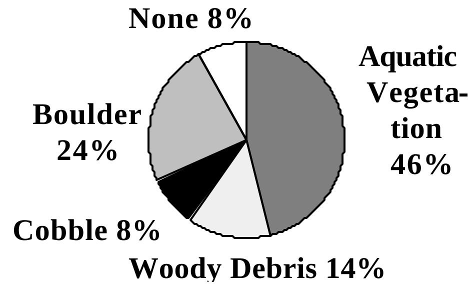


**Figure 5. Percent composition of cover types found near smallmouth bass nests.**

Close proximity to cover was found to be an important aspect of nest sites in both lotic (Simonson and Swenson, 1990) and lentic (Vogele, 1981) environments. Instream cover may provide protection from excessive velocities (see above) or provide security for fry (Livingstone and Rabeni, 1989) or spawning adults (Cleary, 1956).

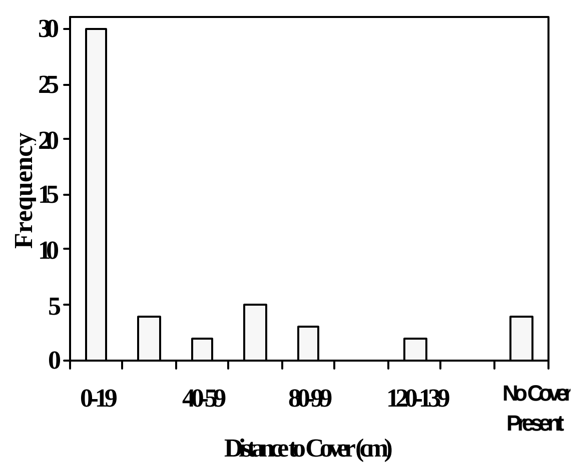


**Figure 6. Distance measured from small-mouth bass nests to the nearest form of instream cover.**

*Nest Substrate*

Gravel was the predominant substrate type within smallmouth bass nests, accounting for 56% of the observations (Figure 7). Cobble was dominant in 12% of nests, vegetation (water willow stems and roots) in 10%, and fines (sand or silt) in the remaining 22%. Differences in substrate composition within and adjacent to nests are readily apparent. The difference in nest and adjacent substrates illustrates the cleaning ability of spawning bass, and the need to account for underlying materials when evaluating substrate suitability (some nests were excavated in 5cm of silt). In general, the substrates found within Susquehanna nests were consistent with those described by the FWS HSI curve (Edwards *et al*., 1985) and with other studies (Coble, 1975; Pflieger, 1975; Vogele, 1981; Monahan, 1991). Susquehanna nests showed more fines (silt) which accumulated in older and recently abandoned nests, and several nests were found with eggs attached to water willow roots.

<ins>Smallmouth Bass Rearing</ins>

*Length Frequency*

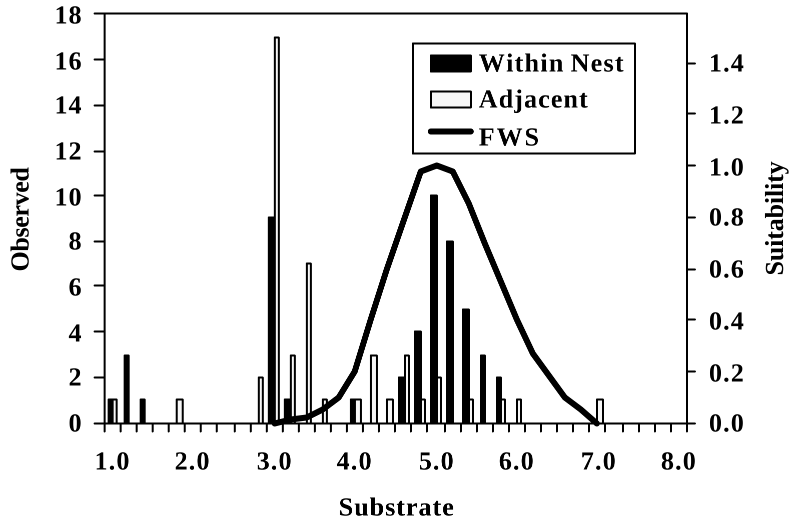


**Figure 7. Substrate characteristics found within and one foot adjacent to smallmouth bass spawning nests.**

Four hundred and fifty-five rearing bass were observed during spring and summer surveys. Observed bass ranged in length from 5cm to 46cm (Figure 8). The dominant size class was composed of young-of-year (YOY) bass (5 - 10.9cm); the remaining fish represented juvenile (*i.e*. yearling, 11-19.9cm) and adult bass (20+ cm). Because juvenile bass were frequently seen in close proximity to adult fish, and because juvenile and adult bass used similar depths and velocities, these fish were grouped together for further analysis (YLG+). Similar findings were made by Orth *et al.* (1982). HSI data were collected at focal positions of 196 YOY and 129 YLG+ bass.

YOY or YLG+ bass were observed on all but two summer transects. Densities of YOY were far higher in riffles than in other habitat types (Table 4). Variability in YLG+ densities between habitat types was much less than observed with YOY. Overall densities were estimated at 10 YOY/100m$^2$ and 3 YLG+/100m$^2$. Qualitative estimates of YOY densities in Courtois Creek averaged approximately one-third of the Susquehanna value (Pflieger, 1975), however estimated YLG+ densities in the Susquehanna were lower than densities reported from many smaller rivers (Paragamian and Coble, 1975).

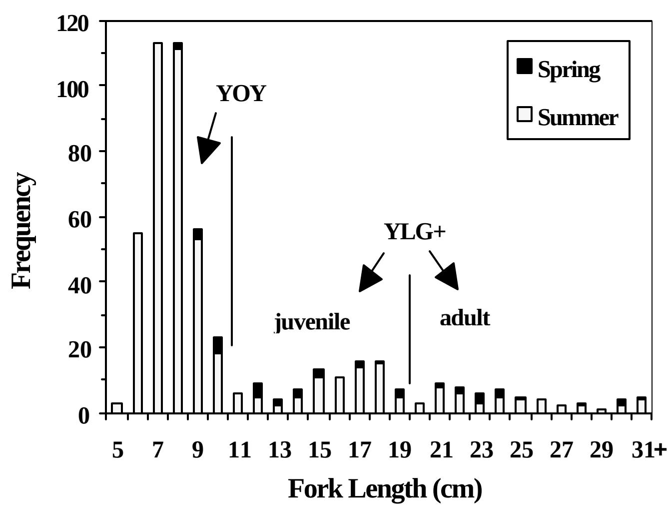


**Figure 8. Length frequency of smallmouth bass observed in the Susquehanna River during spring and summer surveys, 1989 and 1991. Young-of-year (YOY, <11cm fork length) and juvenile+adult (YLG+, >10cm) life stage classifications are shown.**

*Rearing Depth*

The observed depth distributions of YOY and YLG+ bass were noticeably different. Mean depth of YOY focal positions was 53cm (Figure 9), whereas YLG+ fish were observed at a mean depth of 131cm (Figure 10). Although range in depth was similar, YOY frequently inhabited water less than 30cm deep and were uncommon at depths exceeding 150cm. In contrast, YLG+ were not observed in water less than 30cm but were relatively abundant in the deeper depths. The distinct shallow water peak for YLG+ at 35cm is composed of observations from riffle habitats and represents both juvenile and adult bass.

**Table 4. Total number and mean density (#/100m$^2$) of YOY and YLG+ smallmouth bass observed along summer transects, by habitat type.**

| Habitat Type | # YOY | Mean YOY Density | Density Range | # YLG+ | Mean YLG+ Density | Density Range |
|---|---|---|---|---|---|---|
| **Riffles** | 242 | 30 | 10 - 56 | 34 | 4 | 0 - 8 |
| **Shallow Runs** | 54 | 7 | 0 - 22 | 4 | 1 | 0 - 1 |
| **Deep Runs** | 21 | 3 | 0 - 8 | 17 | 2 | 0 - 5 |
| **Shallow Pool** | 24 | 4 | 0 - 9 | 27 | 5 | 4 - 8 |
| **Deep Pools** | 10 | 1 | 0 - 3 | 22 | 3 | 2 - 3 |
| **Totals** | 351 | 10 | 0 - 56 | 104 | 3 | 0 - 8 |

Comparison of Susquehanna data with FWS HSI curves for fry, juvenile, and adult bass show few similarities. Both FWS curves show low suitabilities for depths less than 40cm, where numerous YOY were observed in the Susquehanna. The practice of maintaining maximum suitabilities in deeper water for bass fry does not appear valid for the Susquehanna River. Despite considerable effort in greater depths, few fry were found in the presence of larger bass. Other HSI studies have also suggested low suitability of deeper water for fry (Bain *et al.*, 1982; Monahan, 1991).

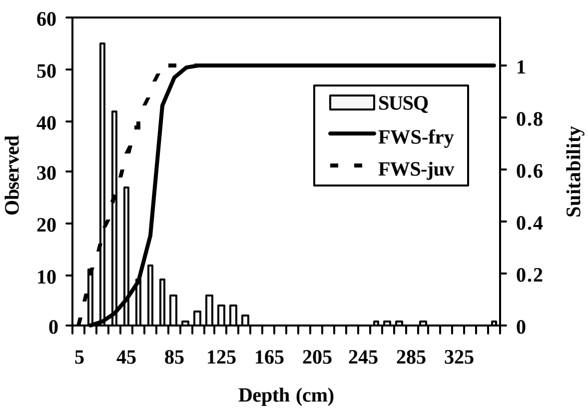


**Figure 9. Depths measured at YOY focal positions, with FWS HSI curves.**

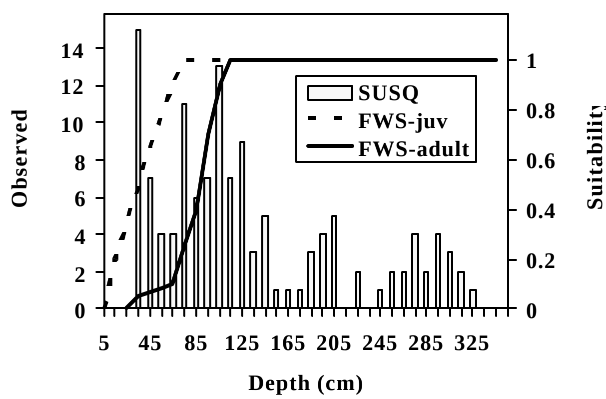


**Figure 10. Depths measured at YLG+ focal positions, with FWS HSI**

The FWS HSI curves for juvenile and adult bass also appear to under-rate the importance of shallow water, where numerous bass of both size classes were observed holding focal positions in riffle habitats (Figure 10). These FWS curves were derived from electrofishing data, which might be expected to disturb large fish away from such exposed positions. Despite the use of electrofishing, Orth *et al.* (1982) also captured numerous adult bass in water less than 50cm. The suitability of shallow water for adult bass may be enhanced in larger river systems, as many of the Susquehanna observations were made hundreds of meters away from the nearest streambank and its associated community of predators. Turbulence cover was also present at many of these shallow water observations. The FWS practice of keeping depth suitability at maximum for juvenile and adult bass may be valid for the Susquehanna. Studies in other large rivers have shown substantial use of deep water by adult bass (Munther, 1970).

*Rearing Velocity*

Mean column velocities measured at focal points averaged 15cm/s for YOY bass and 20cm/s for YLG+ bass (Figures 11 and 12). The frequency distributions were fairly similar, with larger fish somewhat more abundant in faster water.

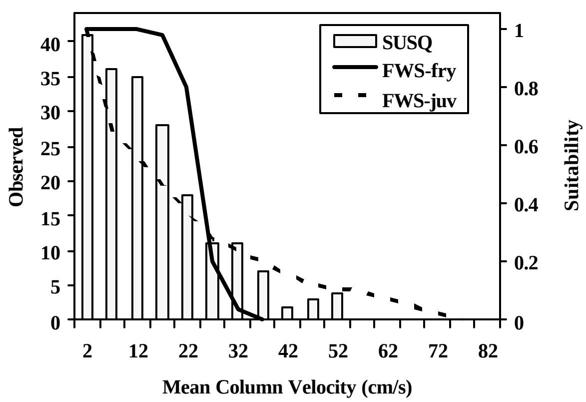


**Figure 11. Mean column velocities measured at YOY focal positions, with FWS HSI curves.**

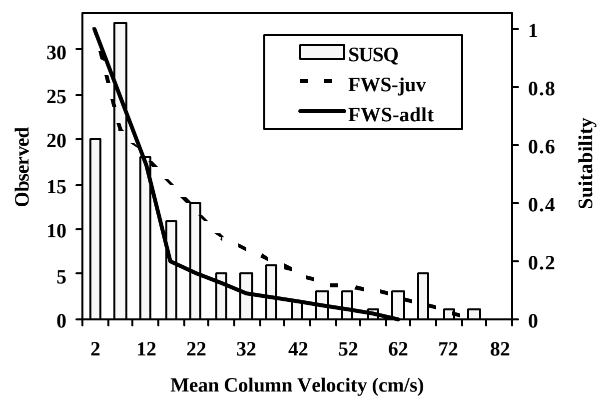


**Figure 12. Mean column velocities measured at YLG+ focal positions, with FWS HSI curves.**

The observed similarities were probably due to the relatively large size of the YOY bass, most of which exceeded seven cm in length. Relatively few YOY or YLG+ were found in velocities exceeding 50cm/s, which is consistent with findings in other rivers (Orth *et al*., 1982; Rankin, 1986; Todd and Rabeni, 1989; Monahan, 1991). Several studies have shown that velocities less than 25cm/s are optimum for bass young-of-year (Bain *et al*., 1982; Simonson and Swenson, 1990). The FWS curve describing velocity suitabilities for fry (Figure 11) matches the Susquehanna data fairly well until approximately 30cm/s, at which point the FWS juvenile curve shows a more similar trend. Because bass often select locations behind submerged objects, these fish can find suitable habitat in mean column velocities thought to exceed critical levels. The observed use of velocities by Susquehanna YLG+ was closely matched by the FWS HSI curve for juvenile bass (Figure 12).

*Rearing Cover*

Young-of-year and juvenile/adult bass were frequently observed in close association with instream cover (Figure 13). The cover association was particularly strong with the YOY population, where only 7% of observations were made in the absence of observable cover (Figure 14). In contrast, 48% of observed YLG+ were observed away from cover. Rock substrates, such as cobbles, boulders, or bedrock ledges, were the most common form of instream object cover observed near focal positions. Instream vegetation (mostly water willow) was the closest source of object cover for 12% of YOY and 6% of YLG+ bass. Woody debris or tree roots were seen near 5-7% of observations. Overhead cover in the form of surface turbulence or overhanging objects was observed at only 2% and 6% of all YOY and YLG+ observations, respectively.

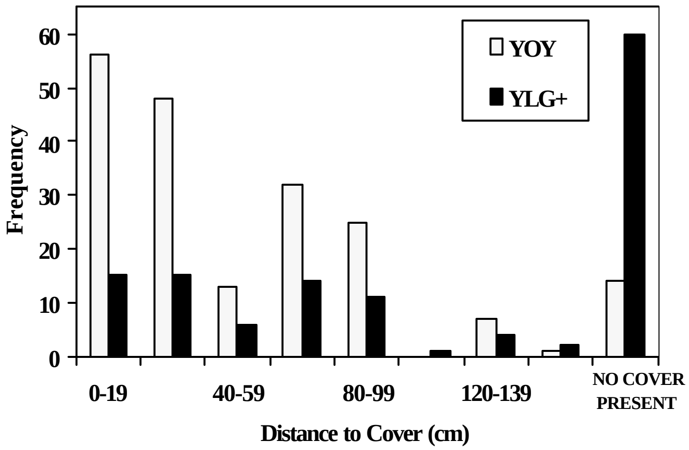


**Figure 13. Distance measured from focal positions of YOY and YLG+ bass to the nearest form of instream cover.**

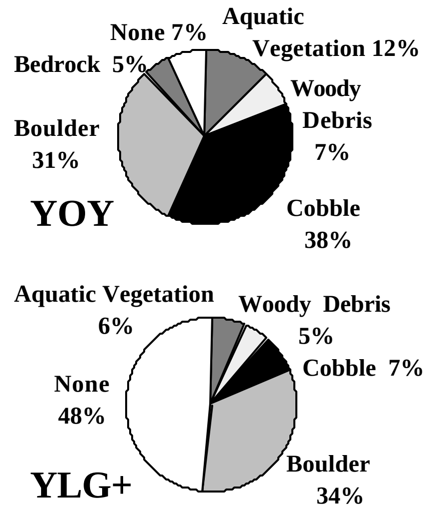


**Figure 14. Percent composition of cover types observed near YOY and YLG+ focal positions.**

Cover is frequently cited as an important habitat component for smallmouth bass (Probst *et al.*, 1984; Todd and Rabeni, 1989). In large rivers such as the Susquehanna, woody debris and other riparian-related cover types are relatively rare and many fish rely on rock substrates and aquatic vegetation for protection from predators or excessive velocities (Munther, 1970; Simonson and Swenson, 1990).

*Rearing Substrate*

Young-of-year smallmouth bass were most frequently seen over sand and gravel substrates, but cobble, boulder, and bedrock were also used (Figure 15). YLG+ bass used a similar range of substrates with a somewhat greater use of the fine substrates characteristic of deeper water (Figure 16). Sand and gravel substrates were more dominant in the Susquehanna data than found in other studies (Munther, 1970; Orth *et al.*, 1982; Rankin, 1986; Todd and Rabeni, 1989, Monahan, 1991). The FWS HSI curves for fry and juvenile/adult bass also emphasized higher

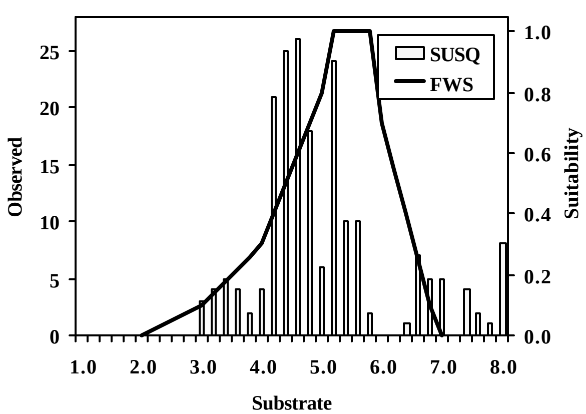


**Figure 15. Substrate characteristics beneath YOY focal positions, with FWS fry HSI curve.**

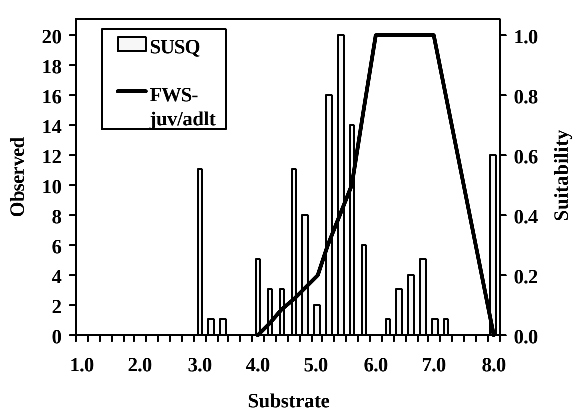


**Figure 16. Substrate characteristics beneath YLG+ focal positions, with FWS HSI curve.**

suitabilities of larger substrate materials. Some of these discrepancies may be due to the procedures used to classify substrate. In the Susquehanna data, substrate was characterized within a 30cm radius of focal positions, which may not have accounted for the presence of larger materials further away. YOY, for instance, were seldom found away from cover components, which often included nearby cobbles and boulders (Figure 14).

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