A Larval Striped Bass Habitat Index for Chesapeake Bay Tributaries

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ABSTRACT

A Larval Striped Bass Habitat Index (LSBHI) was developed to assess the suitability of annual environmental conditions in three Chesapeake Bay tributaries with the respect to recruitment of striped bass larvae. LSBHI values were calculated for the Potomac, Patuxent and Choptank Rivers for each year from 1986 through 2000, using Maryland water quality and zooplankton monitoring data from the Chesapeake Bay Program. The LSBHI is intended to provide an indicator of the quality and potential of each tributary's striped bass spawning and nursery habitat for each year of available data. The LSBHI incorporates components of the Individual Based Model (IBM) of Rose and Cowan (1993) to score annual conditions with regard to initial spawning success, early survival of eggs and pre-feeding larvae, and feeding larval growth and production as a function of zooplankton availability. The annual LSBHI for a tributary is composed of three sub-indices, each calculated for regional semi-monthly cohorts: 1) a spawning sub-index, 2) an early survival sub-index, and 3) a zooplankton (food) availability sub-index. The spawning sub-index uses temperature and salinity data, as well as literature based relationships of these parameters to striped bass spawning to determine the suitability of the habitat for a successful spawn. The early survival sub-index uses temperature to assess the habitat with respect to egg and early larval survival. The zooplankton availability sub-index is based on a comparison of the available zooplankton (a function of zooplankton abundance and predator searching ability given relative sizes of predator versus prey and water clarity), the minimum food requirement based upon metabolic relationships, and the maximum consumption possible. To independently verify the LSBHI, annual values were quantitatively compared with annual juvenile abundance measures from beach seine surveys conducted by Maryland Department of Natural Resources. Application of the LSBHI was successful for the Potomac River ($R=0.62$, $p<0.01$), Patuxent River($R=0.55$, $p=0.03$), but did not correlate well with the beach seine data for the Choptank ($R=-0.14$, $p=0.61$). Possible reasons for this lack of fit and recommendations for expanding the LSBHI to include additional factors (e.g. flow, pH) are discussed.

INTRODUCTION

The largest stock of Atlantic striped bass typically occurs in the Chesapeake Bay, and its reproductive success depends upon successful recruitment of dominant year-classes (ASMFC 1990, 2000). Recruitment strength of a particular year-class is established by the end of the first year of life (Goodyear 1985, Uphoff 1989, Houde et. al 1990), and is followed from that time forward by fisheries managers (e.g., MFS 1998). A number of studies have demonstrated that recruitment may be fixed early in the larval stage of development (Cowan et. al 1993, Rutherford and Houde, 1995, Rutherford et al. 1997, Uphoff 1989). Important and interrelated factors for the success of a striped bass year-class include size of the spawning population, water quality conditions in the spawning area, egg and larval survival, and the availability of food. A number of field and laboratory studies have been conducted to help quantify these factors (e.g., URI 1976, Morgan et. al 1981, Eldridge et. al 1982, Boreman 1983, Tuncer 1988, Chesney 1989, Uphoff 1989, Uphoff 1997, MacKenzie et. al 1990, Houde et. al 1990, Houde et. al 1997, Kimmerer et al. 2001,Versar, 2002). Results from a model based upon studies of this nature support the view that much of the variability in recruitment may be explained by environmental conditions during spawning and the first few weeks of life (Rose and Cowan 1993, Cowan et. al 1993). The goal of this study is to better understand what environmental conditions lead to successful recruitment for a year-class of the Chesapeake Bay stock, and develop an index to measure the relative importance of these factors. The development of such an index is intended to identify nursery and spawning habitat requirements that may or may not be able to be addressed by management actions.

Our approach is to follow the example of the individual based model (IBM) of Rose and Cowan (1993). The IBM uses information from field and laboratory studies of the effects of environmental conditions on spawning and the early life history of striped bass to predict the survival and production of a year class of striped bass. The survival, growth and production of individual larva were modeled under various environmental scenarios, and the results for the individual larvae were combined and used to assess the impact of the environmental conditions at the population level (Rose and Cowan 1993, Cowan et. al 1993). They used this approach "…as a framework for synthesizing available information and for evaluating the interactive effects of factors that influence various life stages" (Rose and Cowan 1993). Their modeling approach resulted in findings that in our opinion were quantitative, objective and definitive. We hope to accomplish the same objective by adapting their philosophy and certain of their methods to construct an index for assessing the environmental quality of annual spawning and nursery habitats within the tributaries of the Chesapeake Bay.

The index is called the Larval Striped Bass Habitat Index (LSBHI), and we used it to assess the suitability of annual conditions in selected tributaries of the Chesapeake Bay for the successful recruitment of that tributary's year-class. The LSBHI is composed of three sub-indices: 1) a spawning sub-index, 2) an early survival sub-index, and 3) a zooplankton (food) availability sub-index. The spawning sub-index requires salinity and temperature data to determine the suitability of the environment for a large spawn. The early survival sub-index uses temperature to score the habitat's ability to support egg and pre-feeding (yolk-sac) larval survival. The third sub-index models the feeding requirements and capabilities of the striped bass larvae and assesses the sufficiency of the available zooplankton biomass to meet these needs. Included in the zooplankton availability sub-index is the average striped bass larval reaction distance based upon its most likely length, the predominant zooplankton (prey) length, and the clarity of the water. Conditions were assessed for each of these three sub-indices for semi-monthly cohorts of striped bass from regions within these tributaries. These results were then combined to produce the annual LSBHI value.

To determine the utility of the LSBHI we estimated the index's value for several year-classes, and then compared the year-to-year patterns in the LSBHI to an independent measure of striped bass recruitment. This independent measure of striped bass recruitment to the juvenile stage has been determined by the Maryland Department of Natural Resources for several years through their beach seine survey program. The environmental data requirements of the LSBHI included a time-series of water quality and zooplankton data, which were obtained from the Chesapeake Bay Monitoring Program. Since 1985 this program has monitored several areas in the Chesapeake Bay and its tributaries, including sites in or near striped bass spawning habitat.

Using the LSBHI, we assessed annual environmental conditions for three Maryland tributaries of the Chesapeake including the Potomac River, the Patuxent River, and the Choptank River. LSBHI values were calculated and then evaluated by comparing each tributary's year-class values with the annual juvenile recruitment measure from that river. This comparison was made by use of a non-parametric correlation analysis of each measure's annual rankings.

METHODS

LSBHI Overview

The steps in the calculation of a tributary's annual value for the larval striped bass habitat index (LSBHI) are summarized in Figure 1. The process begins with the calculation of average measurements for salinity, water temperature, secchi depth, and zooplankton (both meso- and micro-) abundance for semi-monthly (i.e., about two weeks) time periods within salinity-based regions in the tributary. Each combination of semi-monthly time period and region is assumed to represent a potential striped bass cohort. Thus, this method tracks several cohorts during a given year within the tributary. The semi-monthly period (rather than weekly or daily) was the smallest period supported by the frequency of field sampling. The average measurements are used to calculate values for each regional semi-monthly cohort of the three sub-indices that underlie the LSBHI: 1) the spawning sub-index, 2) the early survival sub-index, and 3) the zooplankton (food) availability sub-index. Each sub-index was scored with an integer on a scale of 0 to 4, providing 3 sub-index scores per cohort.

The final LSBHI score for the regional semi-monthly cohort is based on the minimum of the three sub-indices' values. The minimum sub-index value for a particular cohort is used because any one of the three sub-index conditions may act to serve as the limiting factor. The annual LSBHI value is then calculated by summing the scores of the individual LSBHI values from all of that year's cohorts.

LSBHI Details

1) <u>Spawning Sub-Index</u> The first sub-index is associated with spawning conditions (Figure 2.) For striped bass spawning to occur, water temperatures must be gradually rising, and salinity must be less than 0.5 ppt (ASMFC 1990). Therefore, it was assumed that a semi-monthly period within a river segment will be associated with a spawned cohort if a) the average salinity in the segment is less than 0.5 ppt, b) the average water temperature is no less than the temperature in the preceding semi-monthly period, and c) the water temperature is between 11.4 C and 22.3 C. The value of 11.4 C was the minimum water temperature for which an observed spawn was observed in the Potomac River (Houde et al., 1988), while spawning is reported to cease at temperatures above 22.3 (ASMFC 1990). In addition, if the temperature was less than 17.5 C it was assumed that the cohort was spawned by large females, who spawn at colder temperatures (ASMFC 1990) and produce larger and more viable eggs (Rose and Cowan 1993). We limited the extent of spawn by large females by assuming no more than two semi-monthly cohorts by large females within a year and tributary. If conditions were acceptable for spawning to occur, a spawning index value of 1 was given to the cohort. If large females were responsible for the spawn, the sub-index value was elevated to 4. Otherwise, the semi-monthly period received a sub-index value of 0.

2) <u>Early Survival Sub-Index</u> The second sub-index is related to early life stage survival, and is calculated as the product of the survival rates of egg and yolk-sac larvae: each a function of the average water temperature. The estimated egg survival (Morgan et al. 1981, Setzler et al. 1980, Rose and Cowan 1993) is set to 0 if the water temperature is less than $12°C$, and otherwise is calculated as:

$$S_e = \left[1 - \left((1 + 2.04 - 0.30\,T + 0.0083\,T^2)(\frac{1}{LS_e}) + 0.5 \right) \right]^{LS_e}$$

where

T = the average water temperature ($°C$), and

$LS_e = 10.77\, e^{-0.0934\,T}$ = the life stage duration for eggs (Rogers et al. 1977).

This function is plotted in Figure 3-a.

The estimated survival of yolk-sac larvae (URI 1976, Rose and Cowan 1993) is calculated as:

$$S_y = \{1 - [\ (0.00955\,T - 0.088) + 0.15\ ]\ \}^{LS_y}.$$

where

$LS_y = 14.95 - 0.453\,T$ = the life stage duration for yolk-sac larvae (Boreman 1983).

This function is also plotted (Figure 3-b).

The early life stage survival is calculated as the product of the egg and yolk-sac survival estimates (Figure 3-c). The range of early life stage survival (zero to the maximum observed in the tributary) is then divided into four quartiles. Then an early survival sub-index score of zero is assigned to the cohort if the estimated early life stage survival is zero, or a value of 1,2,3, or 4 is assigned based on the quartile of the observed survival.

<u>3) Zooplankton (food) Availability Sub-Index</u> The third sub-index is related to the availability

of food for striped bass larvae. Its calculation has five steps:

i) estimation of the minimum food requirement for the striped bass larvae (mg/d) for each region and semi-monthly time period,

ii) estimation of maximum consumption rate (mg/d) for each region and semi-monthly time period,

iii) estimation of zooplankton available for each region and semi-monthly time period (mg/d),

iv) use of the regional per-period results from the first three steps to estimate the minimum and maximum food requirements, and zooplankton availability values for each regional semi-monthly cohort, and

v) comparing the zooplankton available to the cohort with the minimum and maximum requirement values, and setting the value for the sub-index for the cohort.

i) *Minimum Consumption.* The minimum food consumption requirement for striped bass larvae (mg/d) is the least amount of food needed each day to avoid weight loss, and is equivalent to the total metabolic dry-weight rate identified by Rose and Cowan (1993) adjusted for utilization efficiency:

$$Min = \frac{R_{tot}}{A},$$

where

R_{tot} = total metabolic dry-weight rate, and

A = 0.7 = utilization efficiency value (Houde 1989, MacKenzie et al. 1990) - the fraction of consumption available for growth and metabolism.

The total metabolic dry-weight rate of Rose and Cowan 1993 (R_{tot}) has a routine component (R_r) dependant upon larval weight and water temperature, and an active component which is represented as a multiplier of routine metabolism during feeding:

$$R_{tot} = \left[R_r + (ACT - 1) \bullet R_r \bullet FF\right] \bullet \delta$$

where

$R_r = 0.303 \bullet G(T)$ = the routine component of metabolism (Eldridge et al. 1982), with

$G(T) = e^{0.1\,[\log_e(Q_{10})] \bullet (T - T_r)}$ (the parameters Q_{10} and T_r are set to values of 20°C and 1.9, respectively, after Rose and Cowan 1993),

ACT = 2.5 = the activity multiplier of routine metabolism for striped bass larvae (Rombough 1988),

FF = fraction of day in which metabolism is active (as per Rose and Cowan 1993, larvae are assumed to be active for all daylight hours, regardless of consumption activity) = day-light fraction (DL):

$DL = 0.51 + 0.11 \bullet \cos[0.0172\,(day - 173)]$ (Dalton 1987), and

δ = an adjustment to metabolism under conditions of less-than-maintenance consumption (always set equal to 1 for our purposes).

ii) Maximum Consumption. The maximum consumption (mg/d) is the largest amount of food that can be consumed by striped bass in forced-feeding situations. The relationship used in this study was also used by Rose and Cowan (1993), Tuncer (1988), Hewett and Johnson (1987), and Moore (1988). Maximum consumption is calculated as:

$$\text{Max} = 0.55 \bullet W^{0.96} \bullet F(T)$$

where

W = 4.92 mg = the weight of an individual striped bass larvae as calculated by:

$$W = e^{\left(\frac{\log(L)-\log(8.84)}{0.332}\right)}$$

(after Tuncer 1988), assuming an average length (L) of 15 mm, and

$$F(T) = \left(\frac{T_m - T}{T_m - T_o}\right)^X \bullet E^X\{1 - [(T_m - T)/(T_m - T_o)]\},$$ given T is the water

temperature, and $X = 0.0025 \bullet \log_e(\theta)^2 \bullet (T_m - T_o)^2$

$$\bullet \left[1 + \sqrt{1 + \frac{40}{\log_e(\theta)(T_m - T_o + 2)}}\right]^2.$$

The parameter values used for optimal temperature ($T_o = 22°C$), the curve parameter ($\theta = 2.2$), and the maximum temperature ($T_m = 30°C$) were selected to be consistent with past work (Rose and Cowan 1993, MacKenzie et al. 1990, Houde 1989).

iii) *Zooplankton (food) Availability.* The available food (mg/d) is calculated as the biomass of zooplankton (food) per liter, multiplied by the volume swept by a striped bass larva in one day under environmental conditions:

$$AV = Z \bullet S,$$

$$S = \pi (RD \bullet F_{RD})^2 (sp \bullet L \bullet FF \bullet 3{,}600 \bullet 24) \bullet \frac{10^{-6}\ L}{mm^3},$$

where,

Z = mean zooplankton biomass (mg/l),

S = search volume (l/day, see Figure 4),

RD = reaction distance (mm),

F_{RD} = decimal fraction accounting for turbidity,

sp = swimming speed (1 body length/second, Rose and Cowan 1993, Bowles et al. 1976),

L = average striped bass larval length (assumed to be 12 mm), and

FF = fraction of the day spent feeding (daylight fraction, Rose and Cowan 1993).

The reaction distance (RD) is a function of prey length (*PL);* (Rose and Cowan 1993, Breck and Gitter 1983):

$$RD = \frac{PL}{2 \bullet \tan(\alpha/2)},$$

$$\alpha = 0.0167 \bullet e^{9.14 - 2.4 \bullet \log_e(L) + 0.229 \bullet \log_e(L)^2},$$

where the prey length is calculated based on the average length of zooplankton.

The function for the decrease in reaction distance due to turbidity (F_{RD}) was calculated by inserting the observed secchi reading into a fitted function. The function is an exponential curve fit to the hinged line model provided by Rose and Cowan (1993), and is based on Chesney (1989) and Vinyard and O'Brien (1976):

$$F_{RD} = 0.8 \bullet e^{k \bullet RD},$$

$$k = k_e \bullet \frac{s_p}{s},$$

where

$k_e =$ the estimated exponential decay parameter (-0.035854),

$s_p =$ the average secchi depth in the Potomac River based on monitoring data from 1986-1996 (0.7867 m), and

$s =$ the average secchi depth for the region during the semi-monthly period.

An observed secchi depth (s) that is larger than the average for the Potomac River (s_p) results in a smaller value for k, leading to a smaller fractional reduction in the striped bass larva reaction distance (F_{RD}) and a corresponding larger search volume (*S*).

iv) Calculate Values per Cohort Using per Period Results from Steps i,ii, and iii. Minimum food requirements (Min), maximum consumption values (Max), and micro and meso food availability estimates (AV) were calculated for each semi-monthly time period (*i*) within each region (r). For each cohort, the minimum ($\text{Min}^*_{r,i}$) and maximum ($\text{M}ax^*_{r,i}$) consumption estimates were calculated as weighted averages over the three consecutive periods:

$$\text{Min}^*_{r,i} = \frac{(2 \bullet \text{Min}_{r,i}) + (4 \bullet \text{Min}_{r,i+1}) + (2 \bullet \text{Min}_{r,i+2})}{8}, \text{ and}$$

$$\mathrm{Max}^{*}_{r,i} = \frac{(2 \bullet \mathrm{Max}_{r,i}) + (4 \bullet \mathrm{Max}_{r,i+1}) + (2 \bullet \mathrm{Max}_{r,i+2})}{8}.$$

Less weight is given to the early period to reflect less feeding by the cohort early on when some larvae are still in the yolk-sac stage, and less weight is given to the late period to reflect reduced consumption of zooplankton when larvae are switching over to other food sources. Note that in the equations above, and in those that follow, that starred (*) terms indicate per-cohort values in contrast to the input terms which are on a per-period basis.

The food availability for a cohort was calculated as a weighted average of micro- and mesozooplankton availability measurements. A greater weighting factor was given to microzooplankton (copepod nauplii and rotifer biomass) very early in the life stage when striped bass larvae require smaller prey:

$$AV^{*}_{r,i} = \frac{(2 \bullet Mi_{r,i}) + (1 \bullet Mi_{r,i+1}) + (3 \bullet Me_{r,i+1}) + (2 \bullet Me_{r,i+2})}{8},$$

where

$Mi_{r,i}$ = microzooplankton biomass in segment r and period i, and

$Me_{r,i}$ = mesozooplankton biomass in segment r and period i.

v) Set Value for Zooplankton Availability Sub-Index. The food availability sub-index is calculated by comparison of the cohort food availability value to the corresponding minimum and maximum consumption values. A food availability value below the minimum consumption level receives a score of 0, while a food availability value above the maximum consumption level receives a score of 4 (Figure 5). The interval from the minimum consumption to the maximum consumption was divided into three equally sized sub-intervals, with a score of 1, 2, or 3 associated with a food availability occurring in the lowest, middle, or highest sub-interval, respectively.

LSBHI Score for Cohort Based on all three indices, each cohort receives a combined score equal to the minimum of the three index values associated with the cohort. Note that because any one of the three factors may be limiting, all three factors must be acceptable (i.e., index scores greater than zero) for a cohort to receive a non-zero combined score.

Annual LSBHI Value The final index for a given year is calculated as the sum of all of the cohort-specific LSBHI scores.

Validation and Evaluation of Annual LSBHI Values The success of the LSBHI for each tributary was validated by comparing the rankings of the LSBHI for the years 1986 through 2000 with the rankings from the results of Maryland beach seine sampling programs for striped bass juveniles. This was quantified by use of Spearman's rank correlation method.

If the LSBHI for a tributary had a meaningful correlation with the results from the juvenile sampling programs, then the sub-indices' values underlying the low LSBHI values for that tributary were evaluated to see which of the three factors was most responsible, for any given year.

Data Sources

Data were obtained for 1986-2000 from the Chesapeake Bay Program for stations in spawning areas of the Patuxent, Potomac and Choptank Rivers. Water quality data collections generally consisted of monthly sampling events in January and February, and semi-monthly sampling events from March through June. Water quality parameters used to produce the LSBHI were salinity, temperature, and secchi depth. Within each tributary, zooplankton monitoring was conducted at least monthly at one station within in each of three salinity regions. In the later years of the monitoring program, zooplankton monitoring was conducted semi-monthly during selected spring months.

Data Preparation

Each tributary was divided into three regions based on salinity: tidal fresh areas, low salinity (generally < 5 ppt), and moderate salinity (5-15 ppt). At each station and for each semi-monthly period, the average temperature and salinity was calculated as the mean value across all sampled depths. Average salinity, temperature, and secchi depth within each region were calculated across all stations within the region. This resulted in monthly regional average values in January and February, and semi-monthly regional average values for March-June in each tributary.

For each zooplankton sampling event, the average biomass (mg/m^3), consisting of cladocerans (typified by *Bosmina*) and copepods (typified by *Eurytemora affinis*, and *Acartia tonsa*), was calculated. Biomass values were calculated from zooplankton density (number/m^3) and species-specific conversion factors. The average microzooplankton biomass was calculated based on abundances of rotifers and copepod nauplii using biomass conversion factors. Use of the derived biomass estimates allow for the contribution of the mesozooplankton to be comparable to that of the microzooplankton, and to be easily comparable to calculated striped bass larval feeding requirements.

RESULTS

Potomac River

In the Potomac River, the correlation of the LSBHI with the catch per haul (CPH) beach seine values was highly significant (R=0.62, p<0.01; Figure 6). Because the year-class LSBHI values were a good fit to the juvenile abundance levels, the sub-index scores for the year-classes with the lowest LSBHI values (1987-1989, 1991, 1997) were examined further. The spawning sub-index scores were poor in 1987, 1991, and 1997 indicating unsuitable temperature and salinity values in those years for successful spawning in general, and for large females in particular. In 1988, none of the sub-indices were consistently low but they did not match up well with each other for the individual cohorts (e.g. when a high spawning sub-index occurred it was matched by a low early survival or zooplankton availability sub-index). Since the LSBHI score is limited by the lowest sub-index value, this resulted in a low overall LSBHI for 1988. Examination of the sub-index scores showed that in 1989 the LSBHI was affected by low rankings of both the spawning and early survival sub-indices, but the zooplankton availability index was high.

Patuxent River

The Patuxent River's LSBHI values also were significantly correlated (R=0.55, p=0.03) with the beach seine values (Figure 7). The LSBHI was extremely low in the Patuxent from 1986-1990, with much higher values recorded from 1991-2000. These findings correlated well with the juvenile index values which were also higher in the later years of the program. Low spawning sub-index scores for that river's regional semi-monthly cohorts were primarily responsible for the low LSBHI values for 1986, 1988, and 1990. Year-classes that may have been predicted to have some initial spawning success, but were indicated to be limited by poor matches with early survival and zooplankton sub-indices were those from 1987 and 1989. The highest ranking for both the LSBHI and striped bass juvenile index occurred in 1996 in the Patuxent River.

Choptank River

The LSBHI approach did not succeed in the Choptank, with no significant correlation (R=0.14, p=0.61) between the LSBHI values and the catch per haul data (Figure 8). Because of this poor fit, the relationship of the two indices was further examined.

Figure 8 indicates that the LSBHI and the juvenile index provided extremely inconsistent results in five years, namely 1987, 1988, 1989, 1992 and 1996. In 1989 and 1996 the LSBHI would have predicted poor conditions for recruitment but this was not the case, as evidenced by the high juvenile index ranks. In 1987, 1988 and 1992 just the reverse was true, the LSBHI predicted good conditions but the juvenile index was low. In 1989, none of the individual sub-indices were particularly low; however, they did not match up well for any particular cohort which resulted in a very low LSBHI ranking. The low LSBHI score in 1996 was comprised of an extremely low spawning sub-index for all cohorts, despite a very high score for the zooplankton availability sub-index. The indices appeared to track each other reasonably well between 1997-2000. Possible explanations for the lack of a good fit between the LSBHI and year class strength in the Choptank River are discussed in the next section.

DISCUSSION

The development of this index was precipitated by earlier attempts to develop a zooplankton food availability index and to correlate it with annual Maryland DNR striped bass juvenile index for selected Maryland tributaries of the Chesapeake Bay (summarized in Versar 2002). The food availability index calculations were based on the mean zooplankton density values (number/l) for the striped bass spawning period. In most years, zooplankton food availability was consistently at, or above minimum requirements in the Choptank, but this was not always the case in the Potomac where in several years zooplankton food availability was below the minimum requirement. The food availability index for the Patuxent indicated early years where values were at times below the minimum requirement, but since 1994 average annual zooplankton index values have been above the minimum food requirements. The correlation results between these values and the juvenile index for the Patuxent River were significant. However, the relationship in the Potomac and Choptank were not as strong, and it was hypothesized that other factors were also important. The LSBHI incorporated additional factors and this approach has resulted in an index that remains significant for the Patuxent, is much improved for the Potomac, and continues to be problematic for the Choptank River.

The poor fit between the annual LSBHI and the juvenile CPH values in the Choptank River may indicate that others factors are important in this tributary and may need to be considered. Freshwater flow has been documented to affect striped bass survival from egg to young of year (Kimmerer et al 2001, Rutherford et al. 1997)). Preliminary analyses of derived rank-based data from the Choptank suggest that one or more of the sub-indices and the juvenile index might be influenced by river flow rates. In this tributary, the quantity defined as the difference between the rank transformed LSBHI and the rank transformed juvenile abundance was significantly correlated with mean spring flow. Uphoff (1989) found significant relationships between post larval striped bass mortality rates and flow. If the relationship or relationships with flow can be quantified, then flow could be included in the LSBHI methods – possibly making it useful for the Choptank. This factor might also improve LSBHI correlation's with juvenile indices in the other tributaries, or it may only be used to score the Choptank. This leads to the possibility of adapting LSBHI to each tributary, maintaining the same general approach while recognizing differences among the rivers.

Uphoff (1989) found a positive relationship between larval mortality and rainfall and hypothesized that, in certain years, rainfall depressed pH values in the Choptank River to a level that resulted in lower post-larval survival. Lower pH has been shown to increase aluminum toxicity (Hall et al. 1985, Buckler et al. 1987), and Hall et al. (1988) indicated that copper and cadmium occurred in the low buffering capacity Choptank spawning areas at potentially harmful levels. Rutherford et al (1997) found no effect of pH on striped bass larval survival or recruitment in the Potomac River or Upper Bay and contrasted these regions to the poorly buffered rivers of the Chesapeake Bay's Eastern Shore, where low pH events were more common. A laboratory study (Houde et. al 1997) suggests that pH levels may have important effects on early striped bass growth and survival, and found that synergistic effects between pH, temperature, and prey level were at times as important as single factor effects. As was the case with flow, incorporating pH into the LSBHI may improve it's correlation with the juvenile index in the Choptank. Rutherford et al. (1997) however, indicated, that in 1989 the very high juvenile index value was associated with high rainfall and low pH, suggesting that chronic low pH levels by itself may not be harmful to striped bass larvae.

Another factor that is not considered in the LSBHI but may be important in determining year class strength is the size of the initial spawn (Olney et al. 1991, Uphoff 1997). In the Choptank River, Uphoff (1997) sampled striped bass eggs in several of the years for which LSBHI measurements were made. In 1989, a year when the LSBHI score was low, both the juvenile index and percent of net samples with striped bass eggs present (77%) were ranked very high. In 1987 and 1988 the LSBHI ranked relatively high, but both the juvenile indices and net samples with eggs present (56%, 44%, respectively) were relatively low. This would lend support to the importance of initial egg numbers and that the LSBHI, may be put into better context by the development of an additional index reflecting the size of the spawning stock. By maintaining a separate "Index of Parental Contribution" (IPC) it would be possible to correlate the LSBHI and the IPC with the juvenile indices in combination and separately – quantifying their relative importance.

The LSBHI, particularly if it were enhanced to consider additional variables could be useful for management decision-making. The index and its component sub-indices might be used to identify which tributaries may become better striped bass spawning and nursery habitat by incorporating more non-point controls or other management actions designed to affect water clarity and other habitat quality factors affected by run-off. Also, LSBHI values could be calculated under a variety of 'what if' scenarios, using input data developed to reflect a range of naturally occurring conditions, or implementation of various environmental management practices (e.g., BMP's)..

The current LSBHI was built using information from past analyses and modeling efforts, and the results were assessed using non-related environmental data and independent information from juvenile beach seine surveys. The LSBHI was not designed to replace current methods of assessing striped bass recruitment, but rather to take advantage of a long time-series of data covering fifteen year-classes of striped bass to assess the spawning and nursery habitat quality. It is a simple measure that can use the relatively low temporal resolution (with respect to the striped bass spawning period) data from the Bay Program, but it could be used with data of greater resolution should it become available. In addition to helping increase the understanding of habitat effects on striped bass recruitment, it can be used to help managers identify and then remediate environmental conditions. The existing LSBHI could be improved by incorporating additional factors (e.g., pH, flow) to better assess spawning and nursery habitat for striped bass and also by considering the importance of parental contribution. In addition, the general approach used to develop the LSBHI may also be applied to other species of ecological importance (e.g., forage fish) to the Chesapeake Bay.

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Figure 1. Overview of the calculation of a tributary's annual LSBHI value.

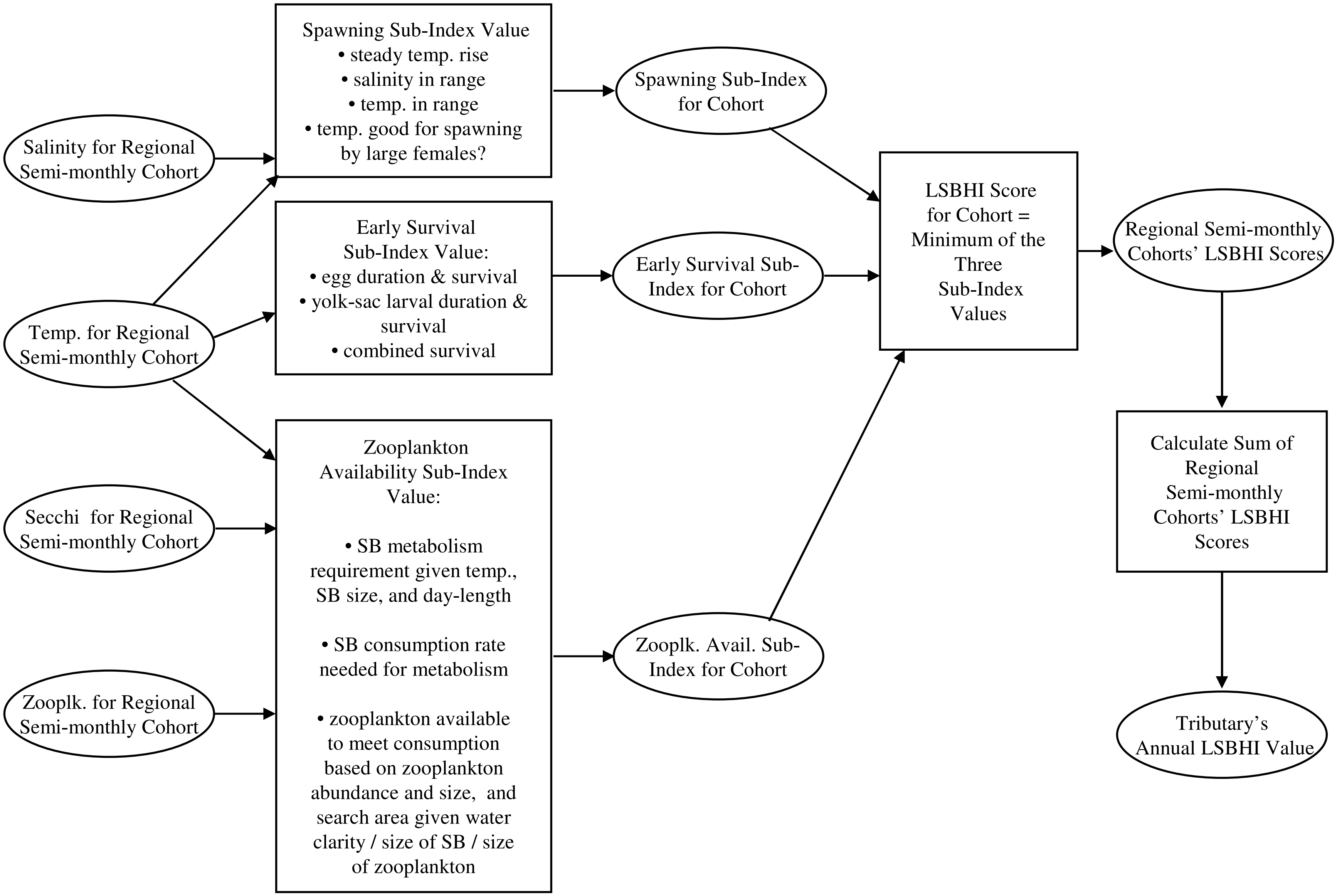


Figure 2. Calculation of spawning sub-index values for a regional semi-monthly cohort.

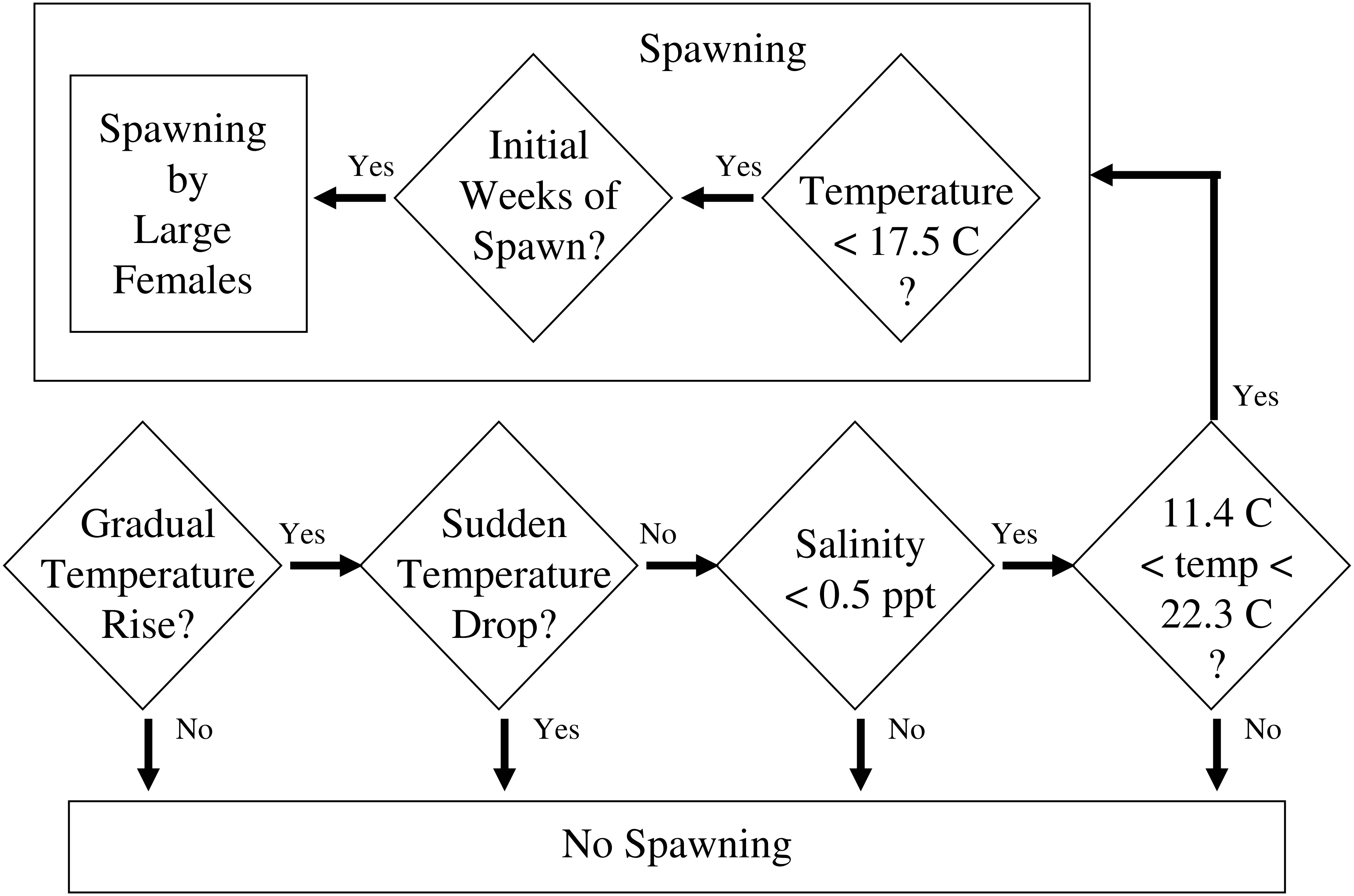


Figure 3. Plots of survival rate estimates as a function of temperature for a) eggs, b) yolk-sac larvae, c) combined.

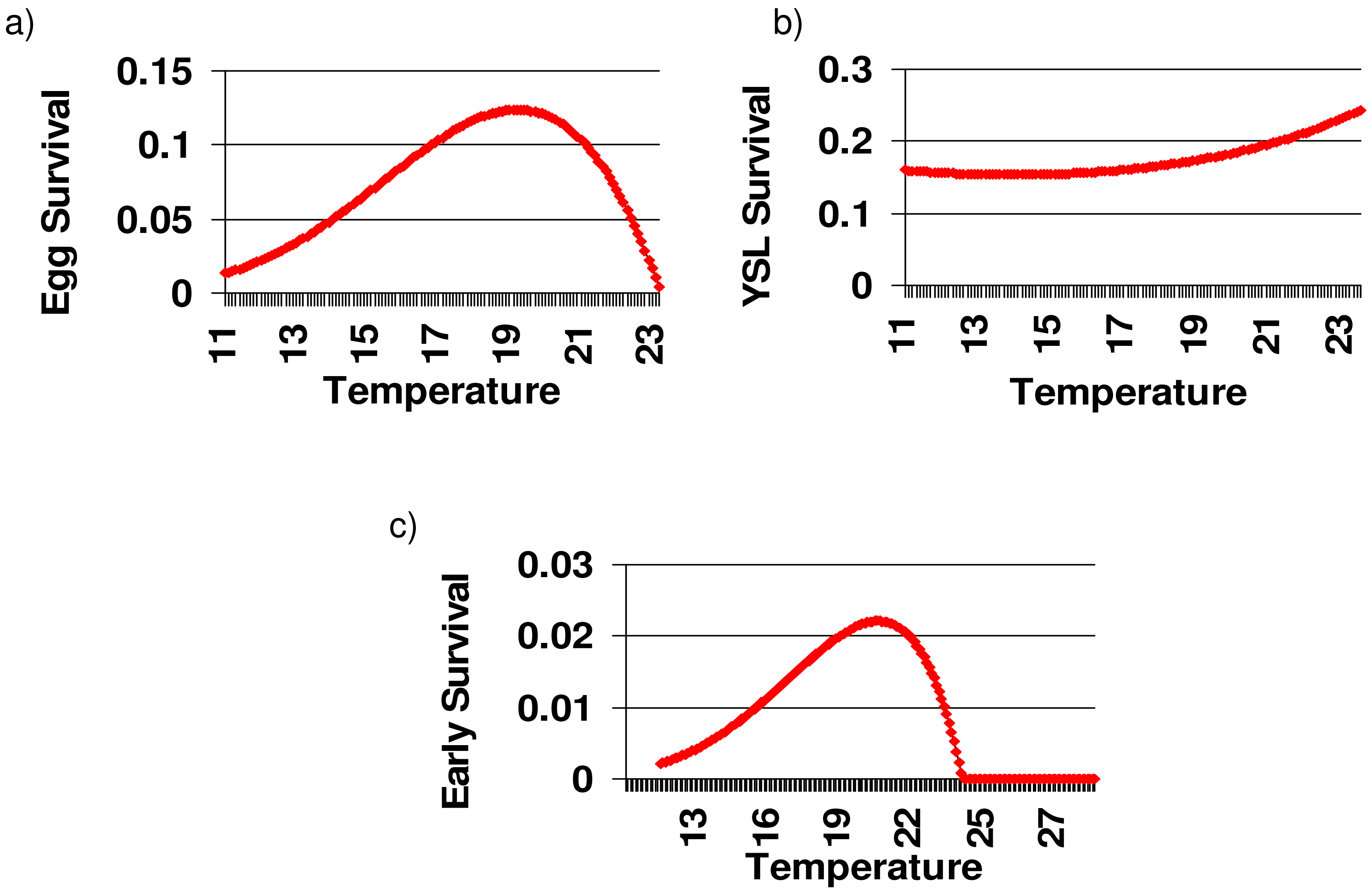


Figure 4. Volume of water searched by a feeding larval striped bass. Radius of the cylinder is a function of larval reaction distance (related to length of prey) and clarity of the water (estimated using secchi depth measurements). Length of the cylinder is a function of swimming speed (related to larval length) and hours of daylight.

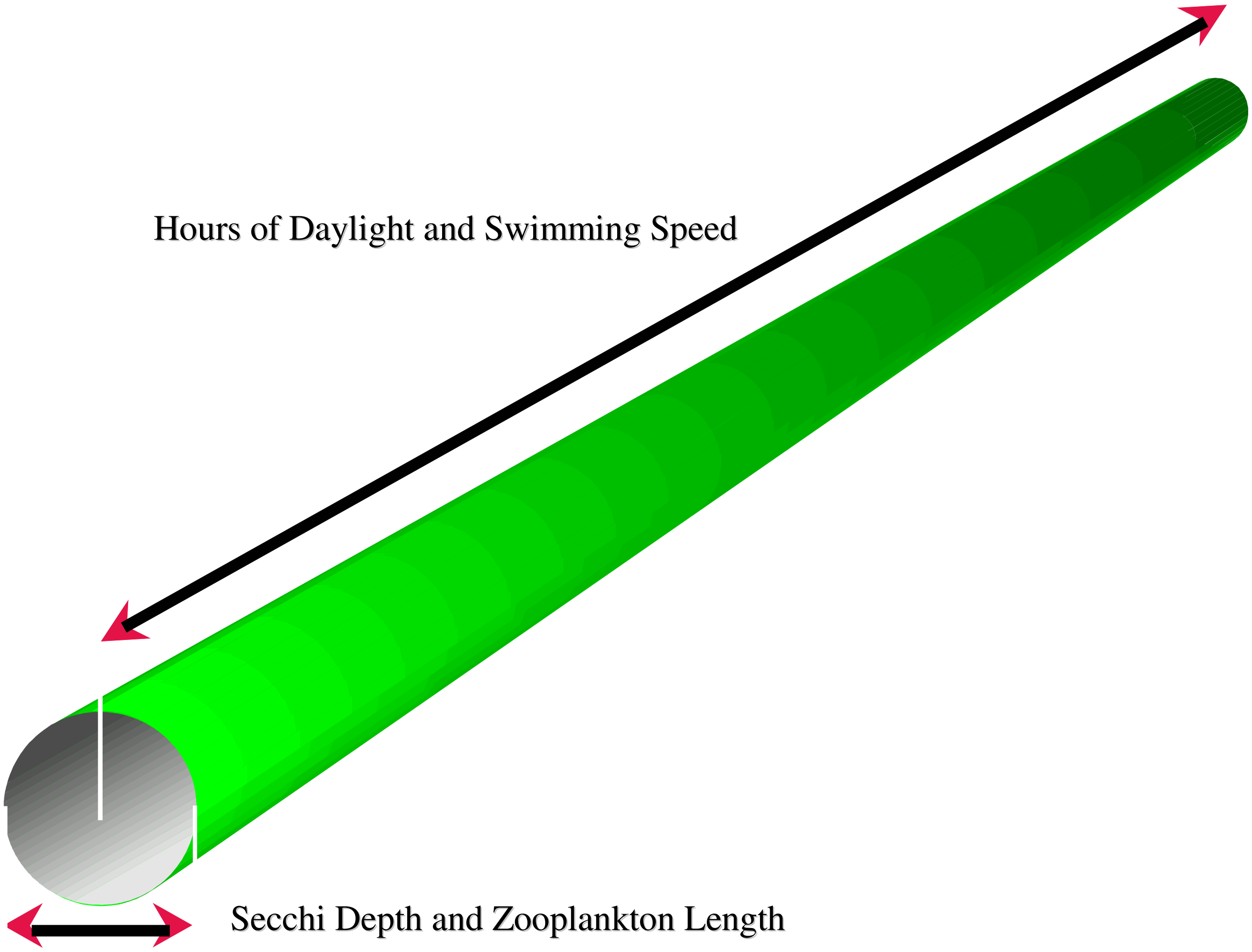


Figure 5. Functions underlying zooplankton availability sub-index: a) minimum and maximum daily ration of required zooplankton as a function of temperature, b) scoring of sub-index as a function of average zooplankton availability.

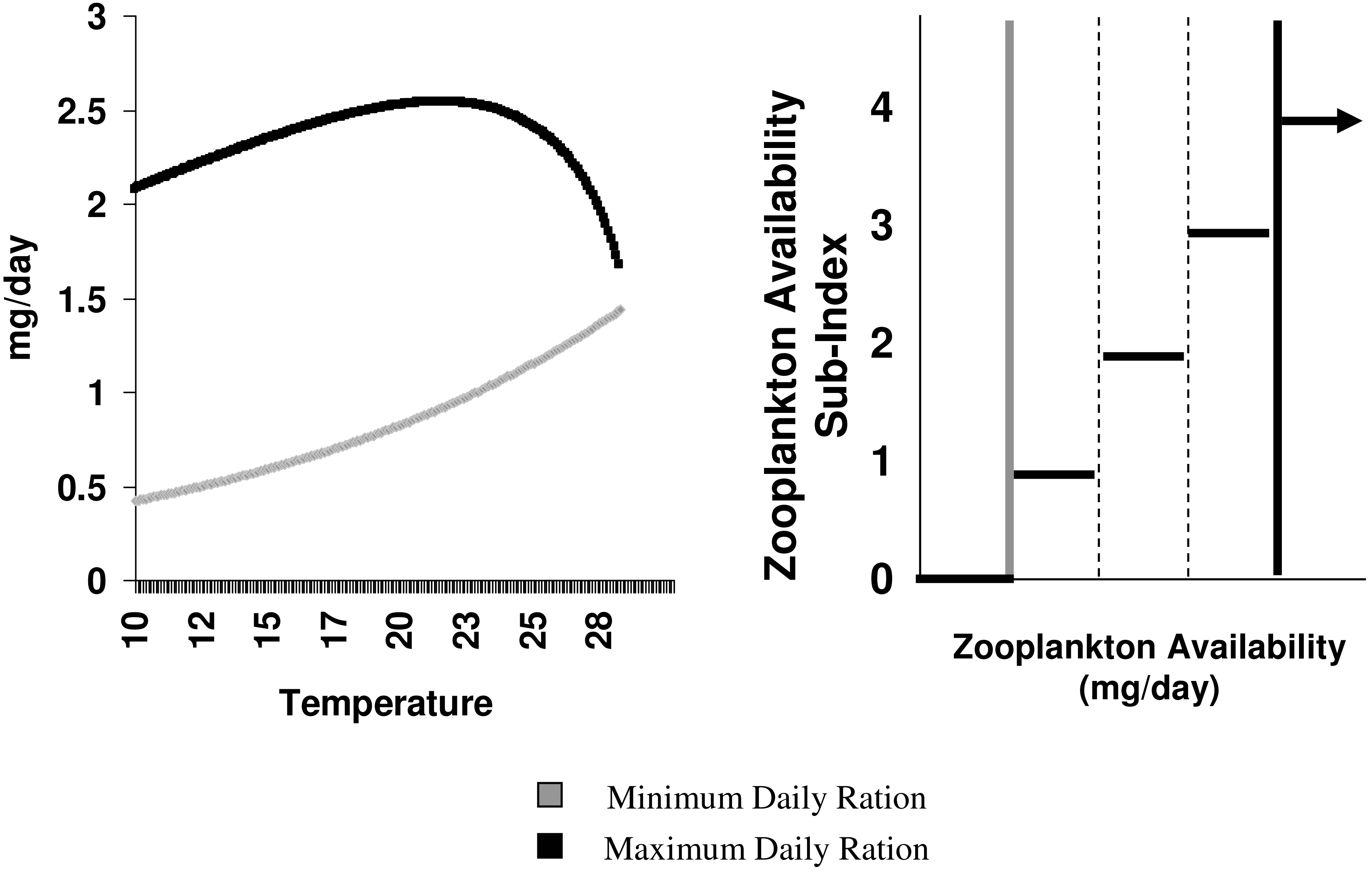


Figure 6. Spearman's rank correlation for the Potomac juvenile striped bass from the Maryland Beach Seine Survey with the LSBHI values calculated using the Chesapeake Bay Program monitoring data.

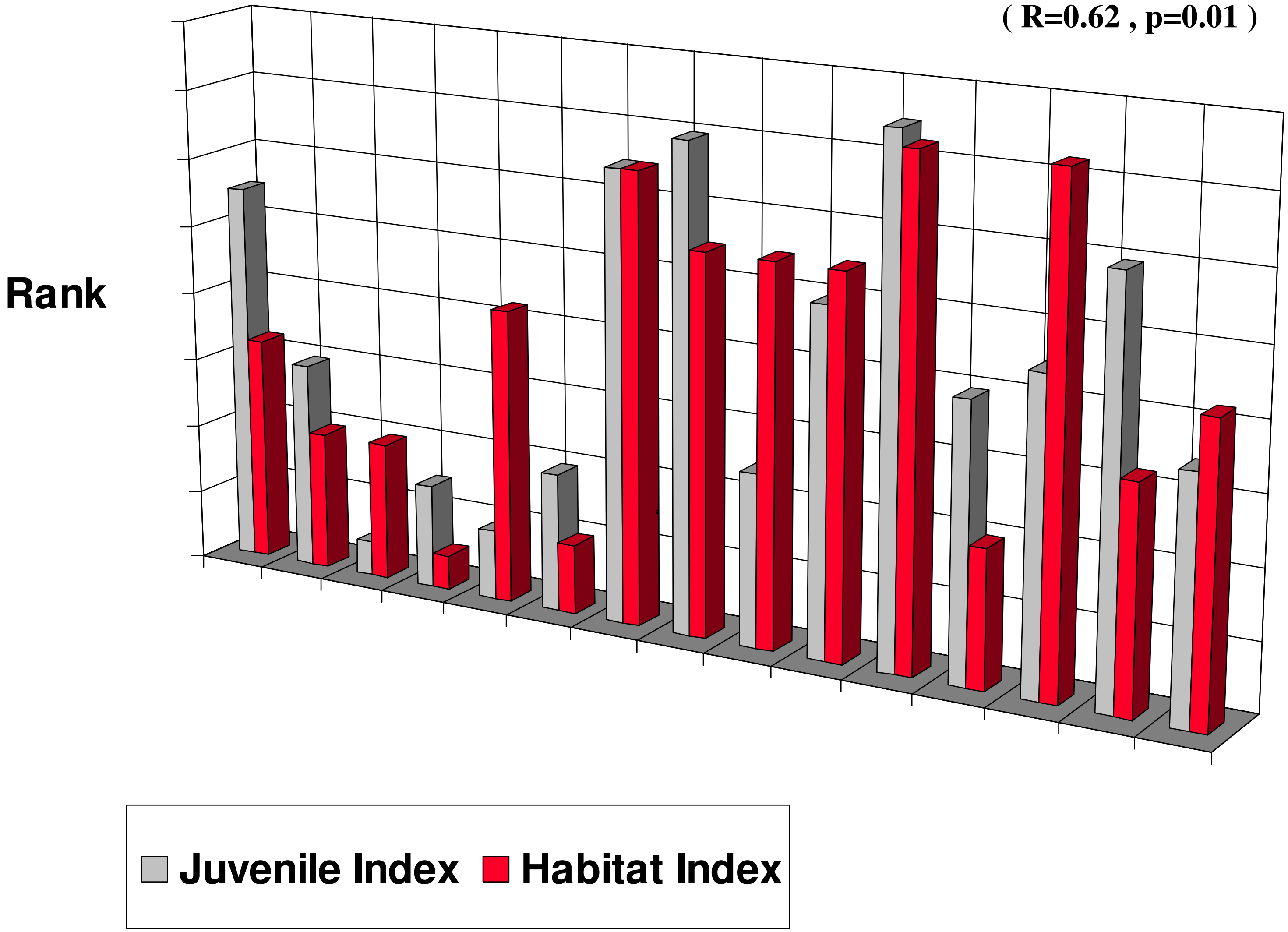
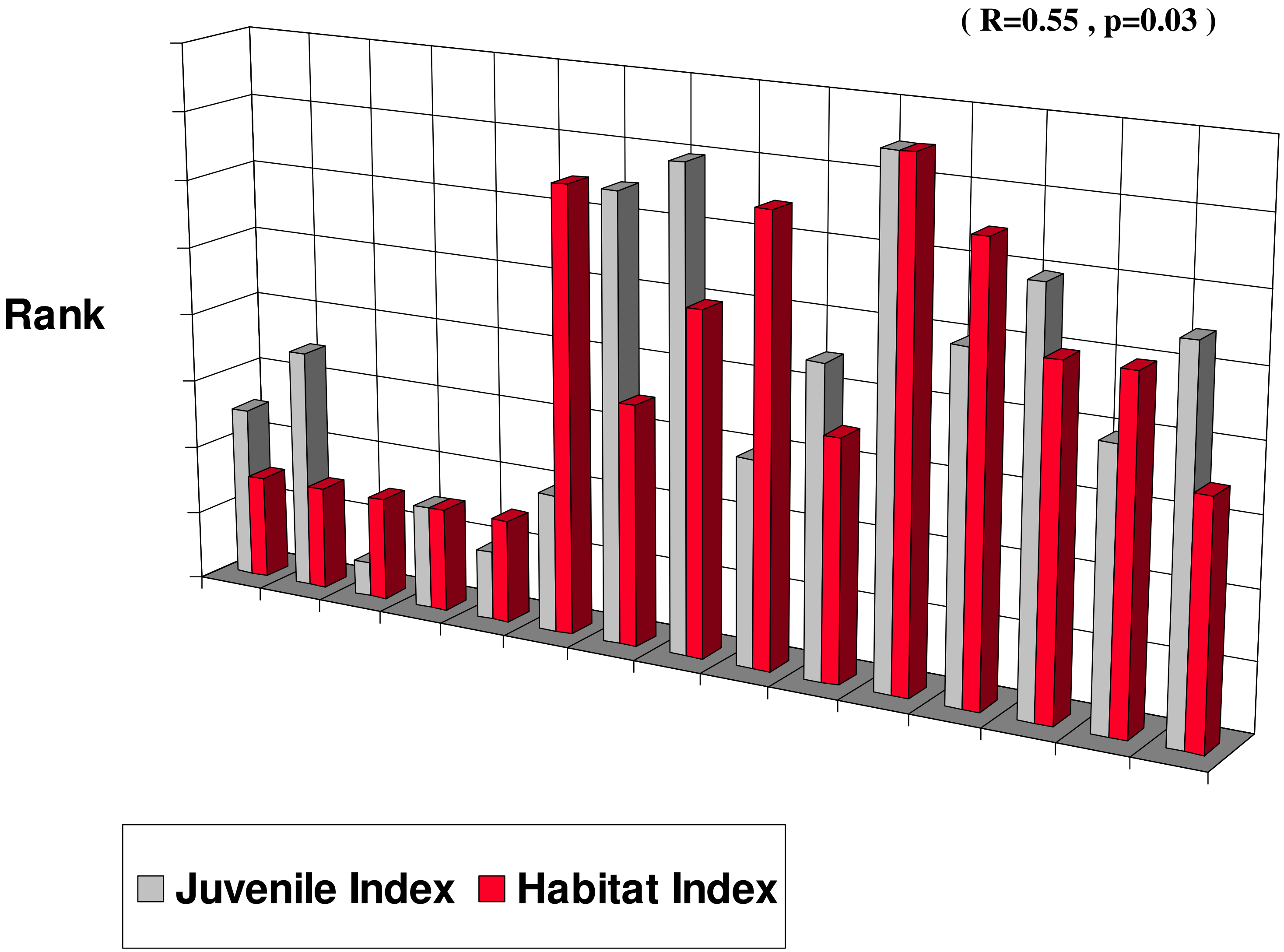


Figure 7. Spearman's rank correlation for the Patuxent juvenile striped bass from the Maryland Beach Seine Survey with the LSBHI values calculated using the Chesapeake Bay Program monitoring data.



(R=0.55 , p=0.03)

Figure 8. Spearman's rank correlation for the Choptank juvenile striped bass from the Maryland Beach Seine Survey with the LSBHI values calculated using the Chesapeake Bay Program monitoring data.