Appendix 3

Habitat Suitability Criteria

This appendix describes the details of determining habitat suitability criteria for the selected species. These criteria were used to evaluate the habitat quality in the areas mapped during this project. They were established based on empirical data (for adult resident fish in summer) as well as literature surveys (spawning life stage). For each species we identified criteria specifying not-suitable, suitable and optimal habitat. Habitat models were for longnose dace, blacknose dace, common shiner, white sucker, tessellated darter, Atlantic salmon, American eel, and brook trout.

Empirical data based model.

The empirical set of criteria for rearing and growth (R&G) season had been developed from habitat use data collected in earlier studies. For resident 1+ and older, longnose dace, blacknose dace, common shiner, white sucker, tessellated darter, Atlantic salmon, American eel, and brook trout we analyzed fish habitat data from several locations. These data were collected on the Eightmile River (345 grids) and Fenton River (506 grids) in Connecticut as well as 455 grids collected from Stony Clove (269), Roundout River (106), Trout Brook (24), Spring Brook (24), Stewart Brook (16) and Willowemoc (16) in New York. For each species we used only data from rivers where they occurred in significant numbers (more than 5 individuals captured). We used a multivariate statistical model (logistic regression) to compute the habitat selection criteria for adult resident fish species and Atlantic salmon. At each grid and quadrate the physical attributes of the HMU in which it was located were recorded together with the number of individuals and species captured.

To calculate the response functions for the species above, we described each grid that was sampled during the survey in terms of the same environmental characteristics used to develop the habitat database, as well as by the species presence and abundance. The environmental attributes were independent variables and the species were dependent variables in regression models describing habitat preference. We employed a stepwise forward logistic regression model (using SPSS) to identify the characteristics of habitat that is used versus habitat that is not used by each fish species. The model uses likelihood ratios to determine which parameters should be included in the following regression formula:

$$\mathbf{R=e^{-z}}$$

where:

- e = natural log base
- z = $b_1 \cdot x_1 + b_2 \cdot x_2 + \dots\dots + b_n \cdot x_n + a$
- $x_{1..n}$ = significant physical variables
- $b_{1..n}$ = regression coefficients
- a = constant

We established the b coefficients using an iterative process. The b coefficients represent how the attributes influence the dependent variable in the data set. This mathematical formula is based on proportions of occupied/non-occupied areas observed during the survey and do not capture all the possible circumstances or represent mechanisms of fish behavior. Furthermore, fish presence is due largely in part to a combination of environmental factors; interpreting the influence of individual parameters in the formula is therefore somewhat limited in applicability.

To distinguish suitable habitat, we used binary dependent variables indicating presence and absence and, in a second model, high and low abundances. The fish and invertebrate data was separated to low and high abundance classes. The cut off value was calculated from observed abundances per grid and was different for each species depending on their behavior (solitary vs. gregarious) and size. For blacknose dace and white sucker three or more fish indicated high abundance. For common shiner, longnose dace and tessellated darter two or more individuals were needed. For brook trout, the presence of more than one indicated high abundance. We used all the available data for the presence model, and for the abundance, we used only data from grids in which fish were caught. From the output of the logistic regression function, we obtained two important types of information: the environmental attributes that significantly correspond with species presence and abundance and the regression coefficients B-values. The B-values indicate the strength and direction (+ or -) of the association between each habitat attribute and fish presence and level of abundance.

In a subsequent step we determined the predictive strength of the model as well as identified thresholds between predictions for suitable and not suitable habitat by comparing probabilities of fish presence and high abundance for each grid and actual observations. The following procedure was used:

For each mesohabitat mapped during the biological survey, we calculated the probability of fish presence using computed regression equations and the following formula:

$$\mathbf{p = \frac{e^z}{(1+e^z)}}$$

Where:

- p = probability of presence/high abundance
- e = constant
- $z = b_1 \cdot x_1 + b_2 \cdot x_2 + \ldots\ldots + b_n \cdot x_n + a$
- $x_{1..n}$ = significant physical variables
- $b_{1..n}$ = regression coefficients
- a = constant

We calculated the probability of presence and of high abundance for every species. The observed presence and abundance at each grid was associated with the probability for the HMU where the grid was located. We created a relative operating characteristic (ROC) curve for presence and abundance predictions (Metz, 1978). The curve examines the discrimination performance of the model over a range of threshold levels, by plotting proportion of grids correctly predicted to be occupied (sensitivity or true positive rate), and the proportion of grids incorrectly predicted to be occupied (false positive rate). The area under the ROC curve defines the discrimination capacity of the model based on Mann-Whitney statistics (Pearce & Ferrier 2000). The inflection points on the ROC curve allow one to define the probability (Pt) that has the highest true positive rate and lowest false positive rate and therefore best separation of occupied and not occupied areas. Separate Pt values are selected for the presence and abundance models. In the following assessment the habitats with a probability of presence greater than Pt were classified as suitable. The suitable habitats with a probability of high abundance greater than selected Pt are deemed optimal. The areas under the curve and Pt values were selected and presented in the results section together with a list of significant parameters and B-values for both the presence and abundance models. The model was then applied to the data from the mapping survey to identify suitable and optimal habitat areas.

For the young-of-the-year (YOY) fish life stage habitat, which consists only of shallow margins, empirical criteria developed on the Quinebaug River were applied. Areas designated as shallow margins had an average depth of 12 cm (SD = 6 cm), and an average velocity of 15 $cm.s^{-1}$ (SD = 11). Substrate in these areas was generally small, ranging from sand to meso-lithal. Shallow margins are an attribute of a HMU and are mapped either as present or abundant. HMUs with abundant shallow margins were considered optimal.

Literature-based spawning habitat suitability criteria

Due to the lack of empirical data for resident adult fish spawning habitat suitability criteria, a literature-based spawning habitat model was developed to determine un-suitable, suitable, and optimal spawning habitat areas within the study area. Four criteria, water depth (cm), water velocity (cm/s), choriotop (substrate type and size), and hydromorpologic unit (HMU) type (e.g. riffle, pool, run) were determined to be the habitat attributes having the greatest influence on the suitability of spawning habitat for native fluvial fish species. An extensive literature review was conducted to define the spawning habitat requirements of the selected resident adult fish species and American shad with regard to these criteria. Acceptable parameters of these criteria were determined based on this research. These parameters were then entered into the literature-based Spawning Habitat Suitability Identification Model, an application within the MesoHABSIM software program, for each individual species. MesoHABSIM was then able to calculate suitability of each HMU within the study area based on the measured values for the selected criteria that were collected during the HMU survey mappings of the Pomperaug River watershed at various flows. The amount of suitable spawning habitat available to each species under varying flow conditions could then be calculated.

To determine suitability of an individual HMU, for a particular species, the selected parameters of each criterion (e.g. depth, velocity, choriotop, HMU type) were compared to the measured values for these criteria within each HMU. At least 30% of the measured values for each of the criterion (except HMU type) had to be met for that criterion to be considered suitable. If all three criterion existed in proportions greater than 30% within an individual HMU then that HMU was considered suitable. Depth, velocity, and choriotop were considered critical and all three criteria had to exist within acceptable parameters for greater than 30% of their measured values within an HMU for the HMU to be considered suitable for an individual fish species (based on that fish species selected acceptable parameters for each criterion). If an HMU was suitable for a particular species and was also classified as the same HMU type specified for optimal spawning conditions for that particular species, it was considered optimal. For example, if blacknose dace require riffle HMU types for optimal spawning conditions, all riffles that also met the suitability requirements of depth, velocity and choriotop, were considered optimal for blacknose dace. Any HMUs that did not meet the specified proportions (greater than 30%) of all three acceptable depth, velocity and choriotop criterion parameters were considered un-suitable.

In the case of American shad it was determined that this species was most dependent upon water depth and velocity conditions for suitable spawning habitat. The spawning habitat suitability of an HMU for this species was determined by depth and velocity alone. If more than 30% of the depth and velocity measurements within an HMU were within the acceptable parameters for this species, the HMU was considered suitable. An HMU was considered optimal for this species if, in addition to depth and velocity requirements being met, either choriotop or HMU type (or both) were determined to meet the required standards for this species.

By applying the results of this model to our delineated HMU field mappings of the Pomperaug River Watershed at various flows, spawning habitat suitability maps were created for Atlantic salmon, blacknose dace, brook trout, common shiner, longnose dace, tessellated darter, white sucker, and American shad. Un-suitable, suitable and optimal HMU areas were demarcated within these maps by the colors red, yellow, and green, respectively, for each species at each flow.

Results

Table 1 represents attributes of both models for blacknose dace established from 851 grids from all rivers including 386 grids where blacknose dace was captured and 225 grids with high abundance of this species. The presence model shows a negative correlation with submerged vegetation, canopy shading, large substrate, and higher velocities. The abundance model shows a correlation with lower velocities and glide HMUs, and a negative correlation with deep habitat areas.

Table 1: Physical attributes correlating with presence and high abundance of blacknose dace. The Area Under ROC curve is a measure of discrimination capacity of the model (0-1). Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. B represents regression coefficients of the logistic regression model.

blacknose dace			
Presence Model		**Abundance Model**	
Area under ROC curve	0.790	Area under ROC curve	0.658
Selected cut-off	0.4	Selected cut-off	0.58
Variables in the Equation	**B**	**Variables in the Equation**	**B**
Submerged_Vegitation	-0.671	GLIDE	0.934
Canopy_Shading	-0.569	D50_75	-2.188
CV75_90	-1.979	CV30_45	1.094
MEGALITHAL	-1.489		
AVG_FROUDE	0.981		
Constant	-0.605		

Table 2 represents attributes of both models for longnose dace established from 851 grids including 38 grids where longnose dace was captured and 8 grids with high abundance of this species. The data from the Fenton River was not used because this river is outside of the zoogeographic range of this species. The presence model consists of a number of habitat attributes that describe fast flowing shallow HMUs such as riffles and ruffles. The abundance model also shows an affinity to lower velocities.

Table 2: Physical attributes correlating with presence and high abundance of longnose dace. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

longnose dace			
Presence Model		**Abundance Model**	
Area under ROC curve	0.890	Area under ROC curve	0.693
Selected cut-off	0.015	Selected cut-off	0.78
Variables in the Equation	**B**	**Variables in the Equation**	**B**
RIFFLE	3.238	CV_15	3.080
RUFFLE	3.559		
D25_50	-1.934		
CV15_30	2.613		
CV75_90	3.774		
CV90_105	12.029		
Constant	-5.652		

Table 4 represents attributes of both models for white sucker established from 851 grids including 167 grids where white sucker was captured and 15 grids with high abundance of this species. The presence model indicates an affinity to depths between 25 and 50 cm, and a negative correlation with higher velocities. The abundance model describes a positive correlation with submerged vegetation.

Table 4: Physical attributes correlating with presence and high abundance of white sucker. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

white sucker			
Presence Model		**Abundance Model**	
Area under ROC curve	0.672	Area under ROC curve	0.620
Selected cut-off	0.16	Selected cut-off	0.15
Variables in the Equation	**B**	**Variables in the Equation**	**B**
D25_50	0.938	Submerged_Vegetation	0.597
CV60_75	-4.385	Constant	-2.612
Constant	-1.700		

Table 5 represents attributes of the presence model for common shiner established from 851 grids including 99 grids where common shiner was captured. The presence model indicates an affinity with shallow margins, woody debris, both gravel and larger substrates, and run HMUs. The model indicates a negative correlation with submerged vegetation and shallow water.

Table 5: Physical attributes correlating with presence and high abundance of common shiner. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

Common shiner	
Presence Model	
Area under ROC curve	0.704
Selected cut-off	0.10
Variables in the Equation	**B**
Submerged_Vegetation	-0.478
Woody_Debris	0.253
Shallow_Margins	0.297
RUN	0.516
D_25	-0.921
MEGALITHAL	2.018
MICROLITHAL	1.358
Constant	-2.758

Table 6 represents attributes of both models for brook trout established from 963 grids including 122 grids where brook trout was captured and 17 grids with high abundance of this species. The presence model consists of a number of habitat attributes that describe shaded areas with larger substrate. There is a negative correlation with riprap, moderate to fast flowing habitats, and gravel substrates. The abundance model shows correlation with riffles, woody debris, and deep, slower moving habitats. There is a negative correlation with moderate flowing habitats, and shallow depths.

Table 6: Physical attributes correlating with presence and high abundance of brook trout. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

brook trout			
Presence Model		**Abundance Model**	
Area under ROC curve	0.825	Area under ROC curve	0.759
Selected cut-off	0.09	Selected cut-off	0.52
Variables in the Equation	**B**	**Variables in the Equation**	**B**
Riprap	-0.742	Woody_Debris	2.308
Canopy_Shading	0.832	Riffle	3.100
CV45to_60	-2.573	D25_50	-4.131
CV60to_75	-4.475	D75to_100	10.074
MacroLithal	1.184	CV15_30	5.990
MicroLithal	-3.087	CV30to_45	-6.017
Constant	-1.794	Constant	-4.294

Table 7 represents attributes of both models for tessellated darter established from 851 grids including 191 grids where tessellated darter was captured and 74 grids with a high abundance of this species. The presence model consists of a number of habitat attributes that describe run HMUs with shallow margins. The model indicates a negative correlation with depths between 75 and 100 cm, and moderate flowing habitats. The abundance model shows a correlation with slower moving habitats.

Table 7: Physical attributes correlating with presence and high abundance of tessellated darter The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

tessellated darter			
Presence Model		**Abundance Model**	
Area under ROC curve	0.943	Area under ROC curve	0.658
Selected cut-off	0.15	Selected cut-off	0.36
Variables in the Equation	**B**	**Variables in the Equation**	**B**
Shallow_Margins	0.455	CV_15	1.013
RUN	0.402	Constant	-0.831
D75_100	-9.134		
CV45_60	-2.146		
Constant	-1.726		

Table 8 represents attributes of both models for American eel established from 345 grids including 116 grids where American eel was captured and 38 grids with a high abundance of this species. The presence model indicates a negative correlation with pool HMUs, and sandy substrates. The abundance model shows a correlation with boulder cover, and a negative correlation with sand.

Table 8: Physical attributes correlating with presence and high abundance of American eel. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

American eel			
Presence Model		**Abundance Model**	
Area under ROC curve	0.686	Area under ROC curve	0.668
Selected cut-off	0.38	Selected cut-off	0.31
Variables in the Equation	**B**	**Variables in the Equation**	**B**
POOL	-1.009	Boulders	0.598
PELAL	-5.777	PSAMMAL	-3.911
PSAMMAL	-2.362	Constant	-1.164

Table 9 represents attributes of both models for Atlantic salmon established from 345 grids including 34 grids where Atlantic salmon was. The presence model indicates affinity to riffle habitat with gravel and high Froude numbers (i.e. riffle habitat).

Table 9: Physical attributes correlating with presence and high abundance of Atlantic salmon. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

Atlantic salmon	
Presence Model	
Area under ROC curve	0.804
Selected cut-off	0.08
Variables in the Equation	**B**
RIFFLE	2.034
MICROLITHAL	2.712
AVG_FROUDE	3.345
Constant	-5.080

Spawning habitat criteria parameters

Our literature survey of the spawning requirements of resident adult and anadromous fish species allowed us to identify the habitat criteria and parameters necessary to determine un-suitable, suitable, and optimal spawning habitat for these species. The seasonal timing, specific water temperature range, and strategies of spawning were also identified for each species but were not used as inputs in our spawning habitat suitability model. The parameters of the criteria used to identify spawning habitat suitability for the resident adult fish of the Pomperaug River Watershed are described here individually for each species.

Blacknose dace spawn in the spring to early summer of the year over when water temperatures are between 15 and 22 degrees Celsius (°C). Optimal spawning conditions for this species consist of fast flowing, shallow riffles with fine gravel (akal) and gravel (microlithal) substrates. Although nests are not constructed, and no parental care is given to the eggs, blacknose dace are known to spawn over the stone nests built by fallfish (Trial et al. 1983, Hartel et al. 2002).

Brook trout spawning occurs in the fall when water temperatures are between 4 and 10°C. Optimal brook trout spawning habitat consist of shallow to moderately deep, flowing, riffles with gravel (microlithal) substrates. Redds are constructed by the female within areas of groundwater upwelling (Raleigh 1982, Witzel 1983). While riffles are the optimal spawning habitat type, given suitable parameters of the other criteria and a lack of riffle habitat brook trout will spawn in run, glide, and even pool habitats.

Common shiner spawning occurs in the spring to mid-summer seasons when water temperatures are between 15 and 21°C. Upstream spawning migrations, prompted by water temperature typically begin in May. Optimal common shiner spawning habitat consist of shallow flowing water, riffle habitats over sand (psammal) and gravel (akal, microlithal) substrates. Eggs are deposited into natural depressions in the gravel, small depressions excavated by the males, or over the nests of other nest-building minnows such as fallfish (Trial et al. 1983, Scarola, 1987, Hartel et al. 2002).

Longnose dace spawning occurs in the spring to early summer seasons when water temperatures are between 15 and 21°C. Optimal spawning habitat for longnose dace consists of fast moving, shallow water habitat of riffles, with gravel and cobble (mesolithal) substrates. Females are enticed to deposit their eggs between the crevices of rocks within a small (10" diameter) spawning territory guarded by the male of this species (Edwards et al. 1983, Scarola, 1987, Hartel et al, 2002).

Tessellated darter spawning occurs in the spring (May - early June) when water temperatures are between 12 and 20°C. Optimal spawning habitat for this species consists of shallow to moderately deep, flowing water of glide, pool, riffle and run habitats with a mixture of cobble (mesolithal), and sand (psammal) substrates. Females enter a crevice or cavity guarded by a male where they deposit their eggs on the underside of the substrate. Males guard and aerate the eggs with their pectoral fins (Hartel et al., 2002).

White sucker spawning occurs in the early spring following upstream migrations to suitable areas when water temperatures are between 13 and 20°C. Optimal white sucker spawning habitat consists of moderately shallow to shallow swift flowing waters of riffle habitats with gravel and cobble substrates. Eggs are broadcast over the substrate in flowing water and are carried downstream (Twomey et al. 1984, Scarola, 1987, Hartel et al 2002).

American shad, an anadromous species make their annual spawning migration from the sea into freshwater rivers during the spring of the year when water temperatures are between 10 and 13°C (Hartel et al. 2002). Optimal spawning conditions occur in moderate to deep-water runs, glides, and pools with swift to fast moving water when water temperatures are between 14 and 21°C (Stier, 1985). Spawning occurs at a broader range of water temperatures (8 - 26°C) but is most frequent during the optimal temperature range given (Stier, 1985).

Atlantic salmon spawn during the late autumn when water temperatures are between 4 and 10°C. At this time, adult Atlantic salmon that have spent the summer in coldwater pools of rivers or streams after making their spring upstream migration from the sea, move to suitable spawning areas in the upstream tributaries and portions of the river. Spawning habitat for this species consist of gravel (microlithal)-bedded riffles with swift flowing, moderate to moderately shallow depths (Armstrong et al. 2003). Eggs and milt are deposited just upstream of a gravel nest (redd) which is constructed by the female by turning on her side and vigorously beating her tail to loosen the gravel. The eggs are protected within the redd where they incubate over the winter before hatching out in the spring (Scarola 1987, Armstrong et al. 2003).

The criteria and parameters used to model spawning habitat suitability for these species are summarized in Table 12.

Table 12: Spawning habitat suitability criteria for selected resident and anadromous fish species of the Pomperaug River Watershed

Fish Species	Seasonal Period	Water Temperature	HMU Type	Depth	Velocity	Choriotop (substrate)	Comments
American Shad	May through Mid-June	Range: 8-26°C Optimal: 14-21.0°C	Run, Glide, Pool, Fast Run	50-125 cm+	15-105 cm/s	Psammal, Akal, Micro, Meso	Depth/velocity-Dependent
Atlantic Salmon	October through Early December	4.4-10.0°C	Riffle, Run, Glide, Ruffle, Rapid, Sidearm	25-74 cm	30-74 cm/s	Micro	Substrate-dependent (Gravel); Mean Froude # ~ 0.3 (Moir et al. 1998)
Blacknose Dace	Early June through Mid-July	15-22.0°C	Riffles (Ruffles)	<24 cm	20-44 cm/s	Akal, Micro	Small nest(depression) in gravel created from vigorous spawning movements
Brook Trout	October through November	4.5- 10.0°C	Riffle	7-64.5 cm	3-42 cm/s	Micro	Groundwater upwelling preferred; Cover (woody debris); redds constructed by females
Common Shiner	May through Mid-July	15.5-21.0°C	Riffles (Ruffles)	<20 cm	15-40 cm/s	Psammal, Akal, Micro	Spawns over nests of other minnows
Longnose Dace	May through Early July	15.5-21.0°C	Riffles (Ruffles), Rapids	<20 cm	45-59 cm/s	Micro, Meso, Macro	No nest; male guards eggs/territory
Tessellated Darter	May to Early June	12-20°C	Riffles, Ruffle, Glides, Runs, Pool	2-200 cm	15-45cm/s	Meso with psammal areas between	Males aerate and guard eggs with pectoral fins; spawn upside down on bottom of cover
White Sucker	Mid-April Through May	10.0-20.0°C	Riffles (Ruffles)	<50 cm	15-55 cm/s	Akal, Micro, Meso	Upstream spawning migrations

Discussion

The empirical-based models presented here all have a satisfying capacity to discriminate between occupied and not occupied habitats, which is indicated by high areas under ROC curves. However, the B-coefficients should not be interpreted as representing affinity of species with specific environmental attributes alone, but rather, as factors affecting the shape of the regression lines. The models include parameters that correspond with empirical expectations. For example, all fluvial specialists show clear affinity towards fast flowing, riffle habitats. The habitat for fluvial dependent species such as white sucker and common shiner is characterized by swift but deeper areas. Brook trout habitat is diverse but also clearly associated with fast flowing areas. Limited abundance of species such as common shiner and Atlantic salmon only allows for less precise models and the data was not sufficient to identify optimal habitats.

The literature-based spawning habitat model presented here is a more robust version of an earlier model used to identify suitable spawning habitats for individual fish species within the Quinebaug River. Including the current model as an application within the MesoHABSIM software program allows for the application of the model to different rivers and species without having to re-construct the models framework. In other words the overall portability and utility of the model have been enhanced. The basic template of the model allows the user to enter parameters for each criterion to define suitable spawning habitat for different fish species. The cut-off values for the proportion of measured values within an HMU used to determine the suitability of each habitat criterion can also be manually adjusted to make the model more or less conservative. Likewise, the model includes a function that allows the user to select which habitat criteria are critical to the suitability of habitat for each species and the matrix of those criteria required to define suitable or optimal spawning habitat. Overall this model has an excellent ability to identify the suitability of spawning habitats for the selected species at various flows when applied to habitat mappings of the river conducted under multiple flow conditions. It is important to realize that the model is applied at the mesohabitat-scale and that some suitable microhabitat spawning areas may exist within HMU defined as unsuitable by this model.

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