Appendix 6

Habitat Suitability Criteria

Introduction

This appendix describes the details of determining habitat suitability criteria for selected fish and macro-invertebrate species for the Lamprey River protected instream flow project. These criteria were used to evaluate the habitat quality within the areas and across the range of flow conditions mapped during this project. Habitat suitability criteria were established based on empirical data (for adult resident fish during summer) as well as literature reviews (spawning life stage). For each species, criteria were identified for specifying not-suitable, suitable, and suitable-optimal habitat. Habitat models were created for each of the selected indicator fish species (e.g., common shiner, fallfish, American eel, common white sucker, longnose dace, redbreast sunfish, and Atlantic salmon). Additional models were also created for selected benthic macro-invertebrate taxa (e.g., ephemeroptera, plecoptera, trichoptera, odonata) and anadromous fish species (e.g., American shad, alewife, and blueback herring).

Empirical Data Based Model

The empirical set of criteria for the rearing and growth (R&G) bioperiod was developed from habitat use data collected in earlier studies. A Microsoft Access database was developed that included all the fish samples collected by the Rushing Rivers Institute and or the Northeast Instream Habitat Program on rivers located in the Northeast. It includes observations from the 18 rivers presented in the Table 1.

Table 1 - The data sources used for calculation of logistic regression models.

PrjID	Name	# Grids	Description	Species used
1	Upper Souhegan Fish Data	91	Fish data for the Upper Souhegan River including species caught, individual lengths, grid habitat data, and fishing HMU's habitat data	Longnose dace White sucker Fallfish Atlantic salmon
2	Upper W.B. Swift Fish Data	100	Fish data for the Upper section of the West Branch of the Swift River, New Salem/Shutesbury, Massachusetts. Including species, grid and HMU habitat attributes and hydraulic measurements data.	Not used in model
3	Lower Souhegan Fish Data	33	Lower Souhegan River Fish, grid, and fishing HMU data for Site 7 grids; Snorkeling survey for Sites 6, 8, 9, 10, and 11 include fish species with HMU data from nearest-flow mapping.	Common shiner Longnose dace White sucker Fallfish
4	Lower W.B. Swift River Fish Data	100	Fish Data for the Lower West Branch Swift River, New Salem, Massachusetts. Electrofishing grids; data includes species, grid and HMU habitat data, and hydraulic measurements.	Atlantic salmon
5	Fort River Fish Data 2006	81	Fish Data collected from the Fort River, Amherst in July of 2006. Fish were collected from the two case study sites of	Common shiner Longnose dace White sucker

PrjID	Name	# Grids	Description	Species used
			the MesoHABSIM 2006 Summer Course. Data includes species, grid and HMU habitat data, and hydraulic measurements.	Fallfish
6	Pomperaug River	90	Fish Data collected from the mainstem of the Pomperaug River, CT. Data includes fish species, lengths, grid and HMU habitat data and hydraulic measurements.	Redbreast sunfish Common shiner Longnose dace White sucker Fallfish
7	Nonnewaug River	60	Fish data collected during the Summer of 2004 on the Nonnewaug River (Upper Pomperaug Watershed), CT. Data includes fish species, lengths, HMU and grid habitat data and hydraulic measurements.	Longnose dace White sucker
8	Weekeepeemee River Fish Data	47	Fish data collected in the Summer of 2004 on the Weekeepeemee River, CT. Data includes species, lengths, grid and HMU habitat data, and hydraulic measurements.	Longnose dace White sucker
9	Lower Eightmile River Mainstem	97	Fishing survey data collected from the Lower Eightmile River, Mainstem, Connecticut, in July of 2004. Data includes species caught, grid and HMU habitat data, and hydro data.	Redbreast sunfish Common shiner White sucker Fallfish American eel Atlantic salmon
10	Fenton River 2003	508	Fish data collected on the Fenton River, Connecticut, 2003.	Common shiner White sucker Fallfish
11	East Branch Eightmile River Fish Data	117	Fishing survey data collected from the mainstem of the East Branch Eightmile River, Connecticut, in July and August of 2004.	Redbreast sunfish Common shiner Longnose dace White sucker American eel Atlantic salmon
12	Upper Mainstem Eightmile Fish Survey Data 2004	72	Fishing survey data collected from the Upper Mainstem Eightmile River, Connecticut, in July and August of 2004.	Common shiner, Longnose dace, Fallfish, American eel, Atlantic salmon
13	Stony Clove Creek Fishing Survey Data 2002	269	Fishing survey data from the Stony Clove Creek, NY (mainstem) collected in July of 2002.	Longnose dace White sucker
14	Round Out Fishing Survey Data	106	Fishing survey data from Round Out, NY collected in July of 2002.	Not used in model
15	Stewart Brook Fishing Survey Data 2002	16	Fishing survey data from Stewart Brook, NY collected in August of 2002.	Common shiner Longnose dace White sucker
16	Spring Brook Fishing Survey	24	Fishing survey data from Spring Brook, NY collected in August of 2002.	Longnose dace

PrjID	Name	# Grids	Description	Species used
	Data 2002			
17	Trout Brook Fishing Survey Data 2002	24	Fishing survey data from Trout Brook, NY collected in August of 2002.	Not used in model
18	Willowemoc Creek Fishing Survey Data 2002	16	Fishing survey data from Willowemoc Creek, NY collected in August of 2002.	Not used in model
19	Lamprey River BMI Collection Data 2006 & 2007	56	Designated River Instream Flow Study within Site 2 (Grids 1-42) and Site 4 (Grids 43-56).	EPT taxa Odonates
20	Upper Souhegan River BMI Survey Data 2004	112	BMI Data Collected on the Upper Souhegan River in 2004 as part of the Souhegan River Instream Flow Study.	EPT taxa Odonates
21	Lower Souhegan River BMI Survey Data 2005	93	BMI collection data from the Lower Souhegan River collected during the Souhegan River Instream Flow Study.	EPT taxa Odonates

For each fish species (individuals one year of age and older), habitat data obtained from rivers where the species has been observed in abundance higher than 5% of a total observations of these species were included in the analysis. A multivariate statistical model (logistic regression) was used 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 along with the number of individuals and species captured.

To calculate the response functions for the species above, each grid that was sampled during the survey was described 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. A logistic regression model was used to identify the characteristics of habitat used versus habitat unused by each fish species. The model uses Akaike Information Criterion (Sakamoto et al. 1986) to determine which parameters should be included in the following regression formula:

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

where:

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

From the output of the logistic regression function, three important types of information were obtained: the environmental attributes that significantly correspond with species' presence and abundance, the regression coefficients b-values and their associated standard errors. The b-values indicate the strength and direction (+ or -) of the association between each habitat attribute and fish presence. The standard errors are the standard deviation of the sampling distribution associated with the estimation method. The term *standard error* is derived from the fact that, as long as the estimator is unbiased, the standard deviation of the error (the difference between the estimate and the true value) is the same as the standard deviation of the estimates themselves; this is true since the standard deviation of the difference between the random variable and its expected value is equal to the standard deviation of a random variable itself. Because the selection of right attributes may have critical influence on modeling results, to increase model certainty we applied very rigorous procedure for this purpose.

In the first step, 20% of the randomly selected data were separated to be used for model validation. These data have the same proportion of occupied grids as the whole data set. The regression formula is developed with the remaining 80% of the data.

Subsequently, for each mesohabitat mapped during the biological survey, the probability of fish presence was calculated 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

In a subsequent step, the predictive strength of the model was determined as well as identified thresholds between predictions for suitable and not suitable habitat by comparing probabilities of fish presence with actual observations. A Relative Operating Characteristic (ROC) curve was created for presence predictions (Metz 1986). The curve examines the discrimination performance of the model over a range of threshold levels by plotting the proportion of grids correctly predicted to be occupied (sensitivity or true positive rate), versus 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 and 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 unoccupied areas. In the following assessment, the habitats with a probability of presence greater than Pt were classified as suitable.

To validate model strength, the computed formula was applied to the validation data (20%) and compared to the number of the fish observations with predictions of suitable habitat. The proportion of correct predictions is recorded as a success rate.

This procedure is repeated 20 times and each time a new set of randomly selected data is set aside for validation purposes. After 20 runs the model generates a list of parameters that were selected in at least two runs and conducts one more run using only these parameters as input attributes. The success rate of this last model is reported together with the average of success rates from previous runs. If these numbers are relatively close and the average is not much higher then the current success rate, the result is considered satisfactory and the model is considered final.

To distinguish suitable habitat, binary dependent variables were used to indicate presence and absence. In a second model, the focus was on high and low abundances. The fish data were separated into 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 white suckers, more than three fish indicated high abundance. For fallfish, common shiner, longnose dace, and redbreast sunfish, more than two individuals were needed. For Atlantic salmon and American eel, the presence of more than one individual indicated high abundance. There was no abundance model for macro invertebrates. While all the available data were used for the presence and abundance models, only the data from grids in which fish were caught were used.

The probability of presence and of high abundance was calculated for every species. The observed presence and abundance at each grid was associated with the probability for the HMU where the grid was located. 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, b-values and their associated standard errors 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 (SD = 11). Substrate in these areas was generally small, ranging from sand to mesolithal. 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 Habitat Suitability Criteria

Due to the lack of empirical habitat suitability data for the spawning life-stages of the resident indicator fish species and anadromous fish species, a literature review (see references) was conducted to determine a set of habitat criteria and parameters defining suitable spawning habitat for each of the selected species. Using this information, a literature-based spawning habitat suitability model was developed based on four habitat attributes (e.g., depth, velocity, choriotop (i.e., substrate type and size), and HMU type) and ranges of acceptable values for each of those attributes. With regard to acceptable ranges of values for each of the four habitat attributes, the spawning habitat requirements of common shiner, fallfish, American eel, common white sucker, longnose dace, redbreast sunfish, Atlantic salmon, American shad, alewife, and blueback herring, were determined. The resulting spawning habitat suitability models were then capable of classifying each of the individual HMUs from all of the mapped flow conditions as “not suitable”, “suitable”, or “suitable-optimal”, based on the measured depth, velocity, and choriotop values and HMU-type classification of each mapped unit.

To determine suitability for a discrete HMU, the HMU’s depth, velocity, and choriotop distributions and HMU-type were compared to the ranges specified within the literature. With regard to HMU type, a discrete HMU was considered acceptable if its type is often associated with the other attributes required for spawning by a particular species. For example, a sand-bottom backwater was not considered to be an acceptable HMU for spawning by a species that uses fast-water gravelly areas nor was a gravel-bottom riffle considered suitable for species requiring slack-water sandy conditions for spawning. However, these HMU types *were* considered acceptable for species that do require these respective habitat types for spawning. With regard to hydraulic measurements (7 for depth, 7 for velocity and 7 choriotop descriptions) an HMU was considered to have acceptable ranges for the target fauna if at least three of the seven (or > 0.30) measured/mapped values for each habitat attribute (e.g., depth, velocity, choriotop) within the HMU were within the range of suitable values determined for each species.

For an HMU to be considered “suitable”, all three of the hydraulic measurements (depth, velocity and choriotop) must be present within acceptable ranges for at least 30% of the measured values for each attribute. Generally, it is assumed that all three of the selected attributes (e.g., depth, velocity, choriotop) *and* HMU type need to occur within acceptable ranges for a discrete HMU to be considered “suitable-optimal” spawning habitat (i.e., an HMU must be deemed “suitable” in order to qualify as “suitable-optimal”).

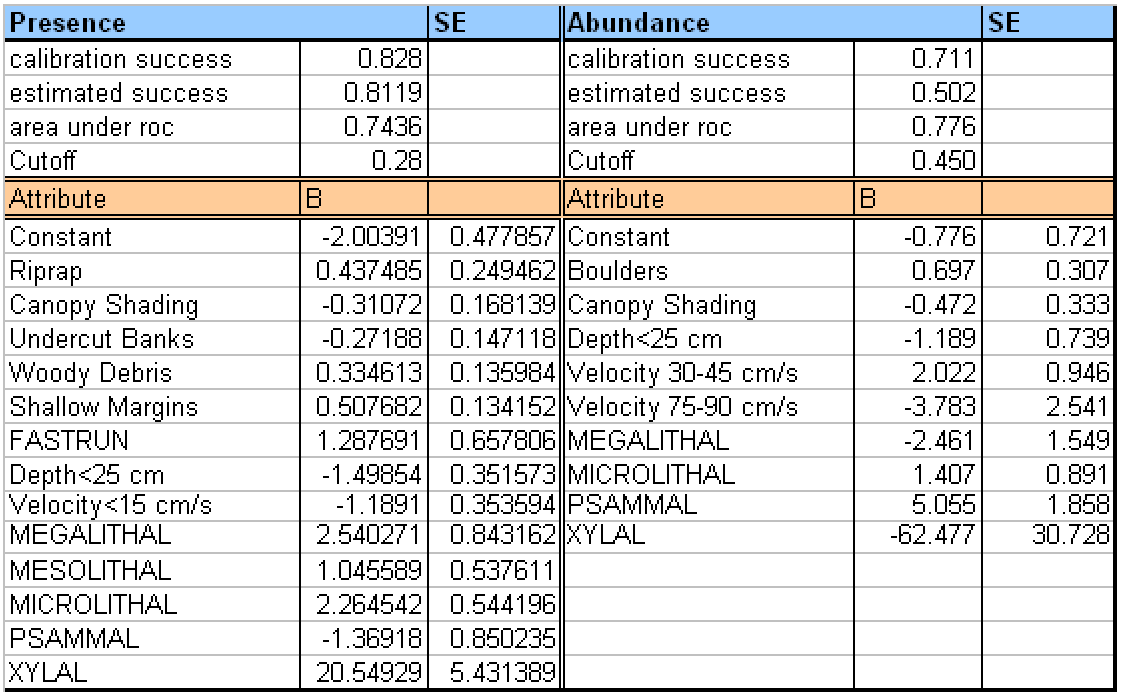
However, adjustments were made to the model for individual species whose spawning requirements deviated from the parameters of the model. For instance, in the case of American shad it was determined that spawning habitat suitability for this species was critically dependent upon depth and water velocity conditions for suitable spawning habitat (i.e., if suitable hydraulic conditions were met this species was not dependent upon choriotop characteristics for spawning habitat suitability). Hence, acceptable values of only two attributes, depth and velocity, were required for an HMU to be considered “suitable” for shad spawning. Because of the species strong dependence upon these two factors, HMUs were considered “suitable” having met only these two criteria and “suitable-optimal” if they met only three or more of the four criteria. Backwater mesohabitats were considered “unsuitable” for all species requiring flowing water for spawning. By applying this model to the previously mapped mesohabitats, spawning suitability maps could be created for all of the selected indicator and anadromous fish species.

Results

The results of the habitat suitability criteria analyses are presented in the following series of tables:

Table 2 represents attributes of both models for common shiner established from 1,014 grids from all rivers including 148 grids where common shiner was captured and 71 grids with high abundance of this species. The presence model consists of a high number of habitat attributes that significantly correspond with observed fish. They describe swiftly flowing, but shallow HMUs such as fastrun accompanied by shallow margins and woody debris. The model also indicates more affinity to coarser substrate and woody deposits. Not many common shiners were found in shallow and slow areas with shading and undercut banks. The abundance model describes similar swift habitats, but with boulders as well as finer gravel and sandy substrate.

Table 2 - Physical attributes correlating with presence and high abundance of common shiner.

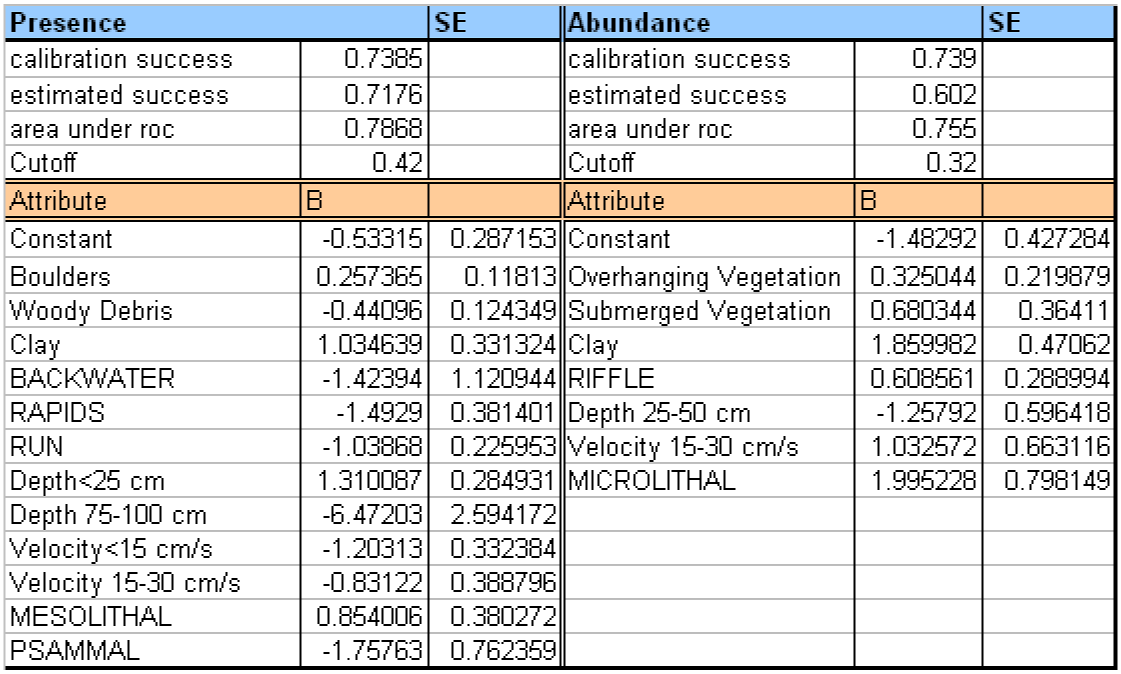


Presence		SE	Abundance		SE
calibration success	0.828		calibration success	0.711	
estimated success	0.8119		estimated success	0.502	
area under roc	0.7436		area under roc	0.776	
Cutoff	0.28		Cutoff	0.450	
Attribute	B		Attribute	B	
Constant	-2.00391	0.477857	Constant	-0.776	0.721
Riprap	0.437485	0.249462	Boulders	0.697	0.307
Canopy Shading	-0.31072	0.168139	Canopy Shading	-0.472	0.333
Undercut Banks	-0.27188	0.147118	Depth<25 cm	-1.189	0.739
Woody Debris	0.334613	0.135984	Velocity 30-45 cm/s	2.022	0.946
Shallow Margins	0.507682	0.134152	Velocity 75-90 cm/s	-3.783	2.541
FASTRUN	1.287691	0.657806	MEGALITHAL	-2.461	1.549
Depth<25 cm	-1.49854	0.351573	MICROLITHAL	1.407	0.891
Velocity<15 cm/s	-1.1891	0.353594	PSAMMAL	5.055	1.858
MEGALITHAL	2.540271	0.843162	XYLAL	-62.477	30.728
MESOLITHAL	1.045589	0.537611			
MICROLITHAL	2.264542	0.544196			
PSAMMAL	-1.36918	0.850235			
XYLAL	20.54929	5.431389			

Note: The area under ROC curve is a measure of discrimination capacity of the model (0-1). Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of the logistic regression model. SE refers to standard error.

Table 3 represents the attributes of both models for longnose dace established from 900 grids, including 300 grids where longnose dace were captured and 100 grids with high abundance of this species. The presence model consists of a number of habitat attributes that describe fast flowing shallow HMUs with large gravel and boulders as cover. The abundance model describes riffle habitats, low velocities, fine substrates and both overhanging and submerged vegetation cover.

Table 3 - Physical attributes correlating with presence and high abundance of longnose dace.

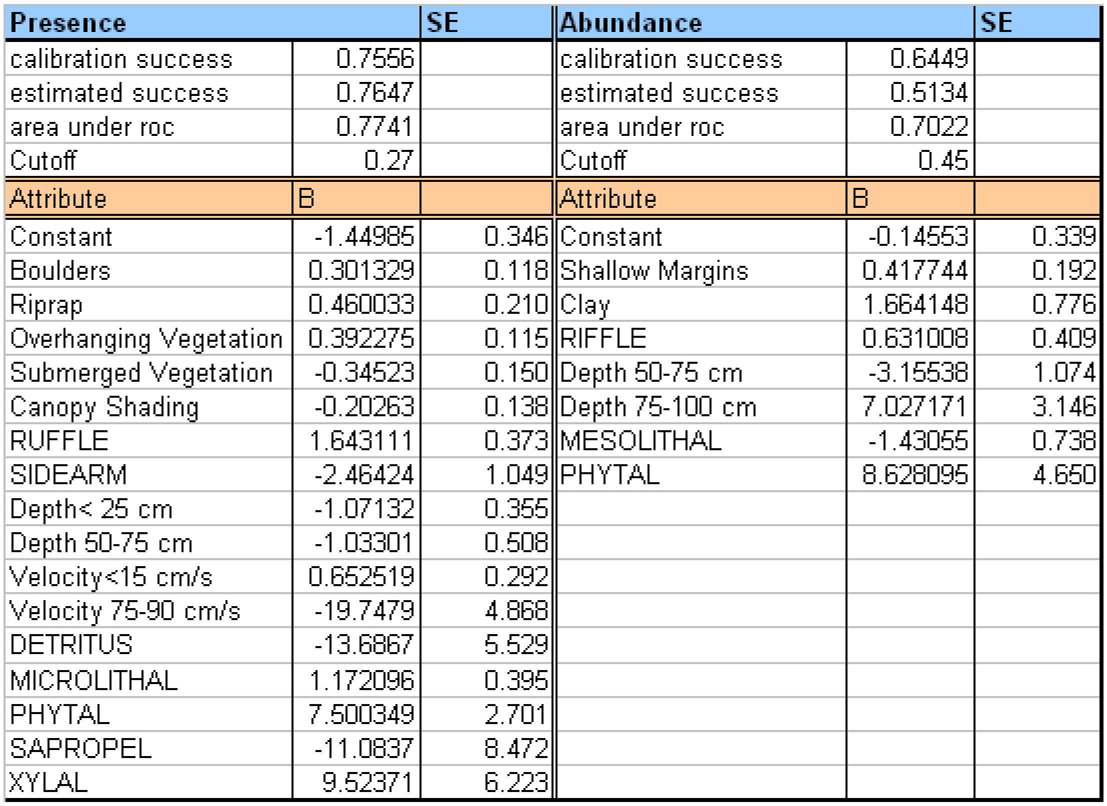


Presence		**SE**	**Abundance**		**SE**
calibration success	0.7385		calibration success	0.739	
estimated success	0.7176		estimated success	0.602	
area under roc	0.7868		area under roc	0.755	
Cutoff	0.42		Cutoff	0.32	
Attribute	B		Attribute	B	
Constant	-0.53315	0.287153	Constant	-1.48292	0.427284
Boulders	0.257365	0.11813	Overhanging Vegetation	0.325044	0.219879
Woody Debris	-0.44096	0.124349	Submerged Vegetation	0.680344	0.36411
Clay	1.034639	0.331324	Clay	1.859982	0.47062
BACKWATER	-1.42394	1.120944	RIFFLE	0.608561	0.288994
RAPIDS	-1.4929	0.381401	Depth 25-50 cm	-1.25792	0.596418
RUN	-1.03868	0.225953	Velocity 15-30 cm/s	1.032572	0.663116
Depth<25 cm	1.310087	0.284931	MICROLITHAL	1.995228	0.798149
Depth 75-100 cm	-6.47203	2.594172			
Velocity<15 cm/s	-1.20313	0.332384			
Velocity 15-30 cm/s	-0.83122	0.388796			
MESOLITHAL	0.854006	0.380272			
PSAMMAL	-1.75763	0.762359			

Note: The area under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model. SE refers to standard error.

Table 4 represents attributes of both models for fallfish established from 998 grids, including 208 grids where fallfish were captured and 91 grids with high abundance of this species. The presence model consists of a number of habitat attributes that describe fast flowing ruffles, a range of substrates, riprap and overhanging vegetation. The abundance model describes a positive correlation with riffles, clay, moderate depths, vegetation dominant substrates and shallow margins.

Table 4 - Physical attributes correlating with presence and high abundance of fallfish.

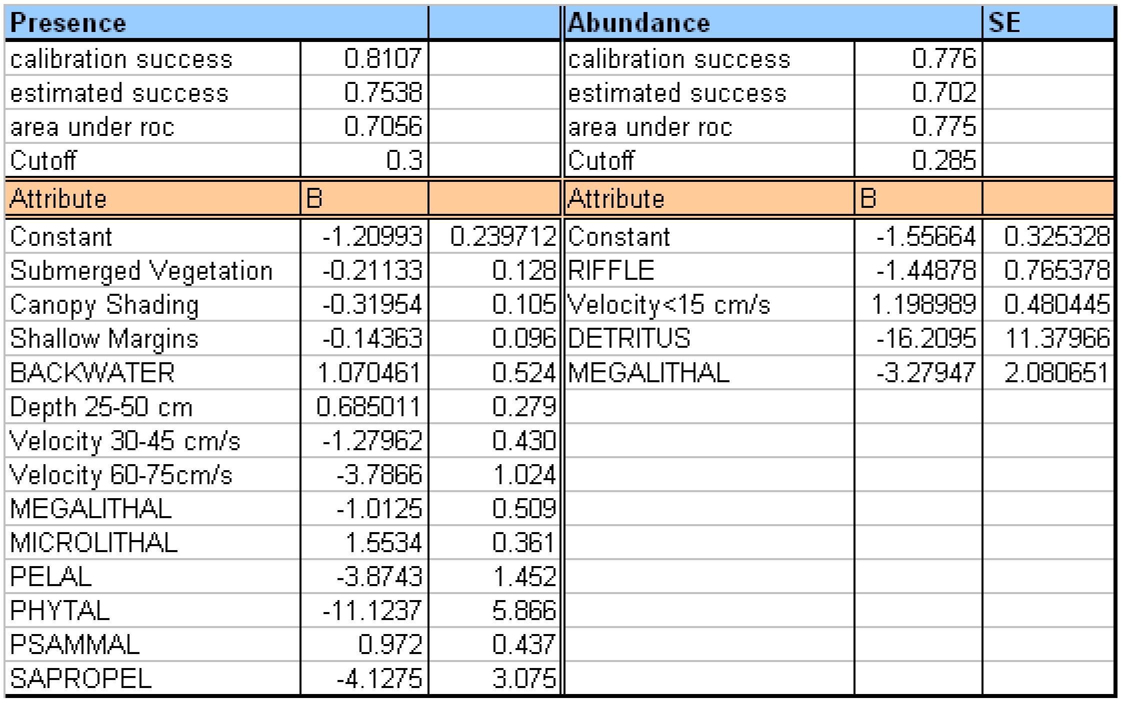


Presence		SE	Abundance		SE
calibration success	0.7556		calibration success	0.6449	
estimated success	0.7647		estimated success	0.5134	
area under roc	0.7741		area under roc	0.7022	
Cutoff	0.27		Cutoff	0.45	
Attribute	B		Attribute	B	
Constant	-1.44985	0.346	Constant	-0.14553	0.339
Boulders	0.301329	0.118	Shallow Margins	0.417744	0.192
Riprap	0.460033	0.210	Clay	1.664148	0.776
Overhanging Vegetation	0.392275	0.115	RIFFLE	0.631008	0.409
Submerged Vegetation	-0.34523	0.150	Depth 50-75 cm	-3.15538	1.074
Canopy Shading	-0.20263	0.138	Depth 75-100 cm	7.027171	3.146
RUFFLE	1.643111	0.373	MESOLITHAL	-1.43055	0.738
SIDEARM	-2.46424	1.049	PHYTAL	8.628095	4.650
Depth< 25 cm	-1.07132	0.355			
Depth 50-75 cm	-1.03301	0.508			
Velocity<15 cm/s	0.652519	0.292			
Velocity 75-90 cm/s	-19.7479	4.868			
DETRITUS	-13.6867	5.529			
MICROLITHAL	1.172096	0.395			
PHYTAL	7.500349	2.701			
SAPROPEL	-11.0837	8.472			
XYLAL	9.52371	6.223			

Note: The area under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model. SE refers to standard error.

Table 5 represents attributes of both models for white sucker established from 1,481 grids including 241 grids where white suckers were captured and 57 grids with high abundance of this species. The presence model indicates affinity to finer substrate, slower HMUs and moderate depths. The abundance model describes a preference for slow velocities.

Table 5 - Physical attributes correlating with presence and high abundance of white sucker.



Presence			**Abundance**		**SE**
calibration success	0.8107		calibration success	0.776	
estimated success	0.7538		estimated success	0.702	
area under roc	0.7056		area under roc	0.775	
Cutoff	0.3		Cutoff	0.285	
Attribute	B		Attribute	B	
Constant	-1.20993	0.239712	Constant	-1.55664	0.325328
Submerged Vegetation	-0.21133	0.128	RIFFLE	-1.44878	0.765378
Canopy Shading	-0.31954	0.105	Velocity<15 cm/s	1.198989	0.480445
Shallow Margins	-0.14363	0.096	DETRITUS	-16.2095	11.37966
BACKWATER	1.070461	0.524	MEGALITHAL	-3.27947	2.080651
Depth 25-50 cm	0.685011	0.279			
Velocity 30-45 cm/s	-1.27962	0.430			
Velocity 60-75cm/s	-3.7866	1.024			
MEGALITHAL	-1.0125	0.509			
MICROLITHAL	1.5534	0.361			
PELAL	-3.8743	1.452			
PHYTAL	-11.1237	5.866			
PSAMMAL	0.972	0.437			
SAPROPEL	-4.1275	3.075			

Note: The area under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model. SE refers to standard error.

Table 6 represents attributes of the presence model for redbreast sunfish established from 304 grids including 77 grids where common shiners were captured and 19 grids with a high abundance of this species. The presence model indicates affinity with deeper HMUs, submerged vegetation, woody debris and a range of substrates. The abundance model shows a positive correlation with coarse gravel with percentages of medium to fine gravel.

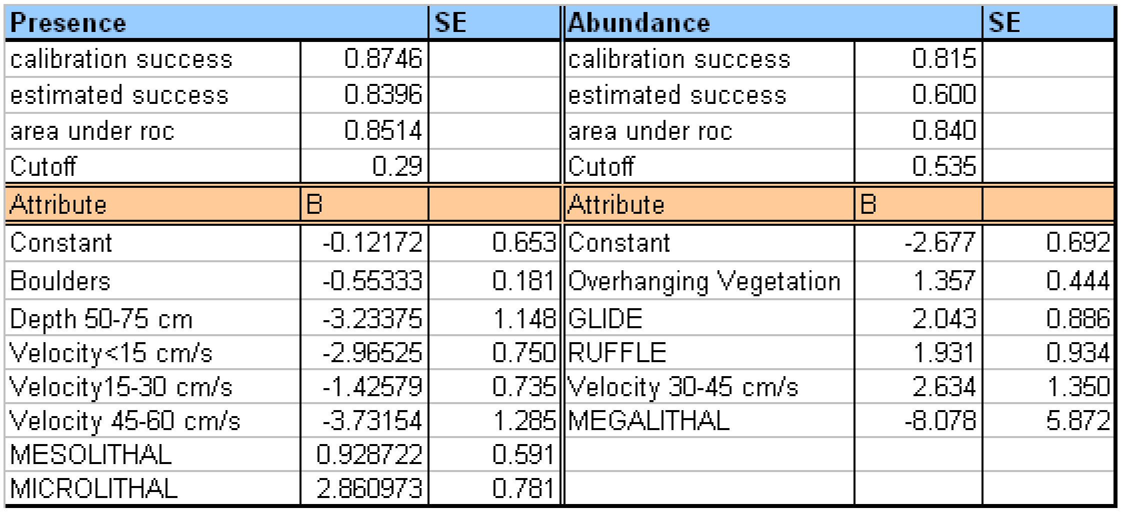
Table 6 - Physical attributes correlating with presence and high abundance of redbreast sunfish.

Presence		**SE**	**Abundance**		**SE**
calibration success	0.7874		calibration success	0.644	
estimated success	0.6847		estimated success	0.508	
area under roc	0.8028		area under roc	0.664	
Cutoff	0.375		Cutoff	0.325	
Attribute	B		Attribute	B	
Constant	-3.45768	0.584733	Constant	-1.13417	0.541064
Submerged Vegetation	0.708403	0.195875	MACROLITHAL	-3.31326	2.433419
Woody Debris	0.500645	0.188314	MICROLITHAL	1.752182	1.491726
POOL	2.305729	0.666977			
RUFFLE	1.693686	0.588576			
RUN	1.108258	0.393056			
Velocity 60-75 cm/s	-8.30376	5.176568			
DETRITUS	-16.4452	7.139448			
MEGALITHAL	2.547214	0.984116			
MESOLITHAL	1.84357	0.917442			
PELAL	3.564471	1.857144			
PSAMMAL	-1.58377	0.917273			

Note: The area under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model. SE refers to standard error.

Table 7 represents attributes of both models for Atlantic salmon established from 477 grids including 81 grids where Atlantic salmon were captured and 24 grids with high abundance of this species. The presence model shows the preference for a substrate that consists of cobbles with medium to fine gravel. The abundance model shows correlation with a number of habitat HMU attributes that describe moderate velocity ruffles and glides with overhanging vegetation.

Table 7 - Physical attributes correlating with presence and high abundance of Atlantic salmon.

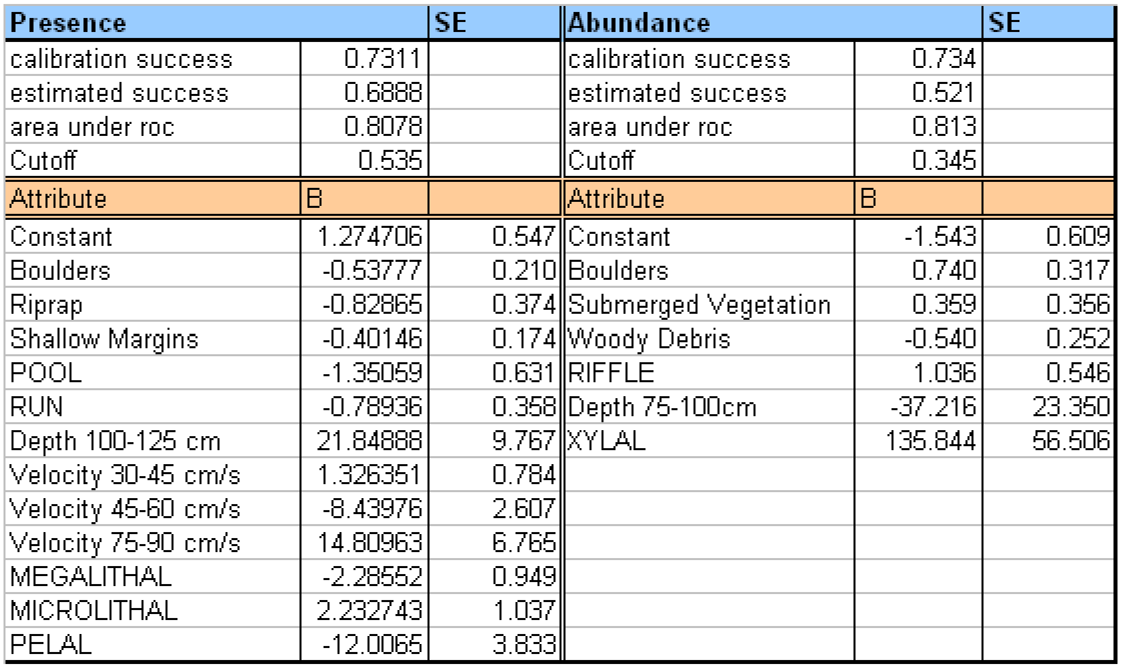


Presence		SE	Abundance		SE
calibration success	0.8746		calibration success	0.815	
estimated success	0.8396		estimated success	0.600	
area under roc	0.8514		area under roc	0.840	
Cutoff	0.29		Cutoff	0.535	
Attribute	B		Attribute	B	
Constant	-0.12172	0.653	Constant	-2.677	0.692
Boulders	-0.55333	0.181	Overhanging Vegetation	1.357	0.444
Depth 50-75 cm	-3.23375	1.148	GLIDE	2.043	0.886
Velocity<15 cm/s	-2.96525	0.750	RUFFLE	1.931	0.934
Velocity15-30 cm/s	-1.42579	0.735	Velocity 30-45 cm/s	2.634	1.350
Velocity 45-60 cm/s	-3.73154	1.285	MEGALITHAL	-8.078	5.872
MESOLITHAL	0.928722	0.591			
MICROLITHAL	2.860973	0.781			

Note: The area under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model. SE refers to standard error.

Table 8 represents attributes of both models for American eel established from 377 grids, including 108 grids where American eels were captured and 36 grids with a high abundance of this species. The presence model indicates an affinity with deeper and variable-velocity habitats with coarse gravel. The abundance model shows a correlation with riffle habitats and boulder cover and the existence of wood substrates.

Table 8 - Physical attributes correlating with presence and high abundance of American eel.



Presence		SE	Abundance		SE
calibration success	0.7311		calibration success	0.734	
estimated success	0.6888		estimated success	0.521	
area under roc	0.8078		area under roc	0.813	
Cutoff	0.535		Cutoff	0.345	
Attribute	B		Attribute	B	
Constant	1.274706	0.547	Constant	-1.543	0.609
Boulders	-0.53777	0.210	Boulders	0.740	0.317
Riprap	-0.82865	0.374	Submerged Vegetation	0.359	0.356
Shallow Margins	-0.40146	0.174	Woody Debris	-0.540	0.252
POOL	-1.35059	0.631	RIFFLE	1.036	0.546
RUN	-0.78936	0.358	Depth 75-100cm	-37.216	23.350
Depth 100-125 cm	21.84888	9.767	XYLAL	135.844	56.506
Velocity 30-45 cm/s	1.326351	0.784			
Velocity 45-60 cm/s	-8.43976	2.607			
Velocity 75-90 cm/s	14.80963	6.765			
MEGALITHAL	-2.28552	0.949			
MICROLITHAL	2.232743	1.037			
PELAL	-12.0065	3.833			

Note: The area under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model. SE refers to standard error.

For macro-invertebrates, only presence models were developed, as data on high and low abundance were not available. Table 9 represents attributes for family Ephemeroptera established from 266 quadrates including 146 quadrates where these animals were found. The model consists of a number of habitat attributes that describe deeper and moderate velocity rapids, riffles, glides and sidearms.

Table 9 - Physical attributes correlating with presence and high abundance of ephemeropterans.

Presence		**SE**
Calibration	0.751	
Estimated Success	0.701	
Area under ROC	0.8547	
Cutoff	0.54	
Attribute	B	
Constant	-0.123721	0.284562
GLIDE	1.485773	0.639667
RAPIDS	2.764193	0.614154
RIFFLE	3.459786	0.691803
SIDEARM	1.513393	0.801861
Depth 75-100 cm	-5.793782	1.770467
Depth>125 cm	3.106786	1.028438
Velocity 15-30 cm/s	1.904018	0.684961
MACROLITHAL	-3.974174	0.670433

Note: The area under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model. SE refers to standard error.

Table 10 represents attributes for family Plecoptera established from 266 quadrates sampled including 88 quadrates where these animals were found. The presence model indicates affinity to habitats with fast flowing water, cobbles substrates and overhanging vegetation.

Table 10 - Physical attributes correlating with presence and high abundance of plecopterans.

Presence		**SE**
Calibration	0.7816	
Estimated Success	0.7	
Area under ROC	0.8388	
Cutoff	0.395	
Attribute	B	
Constant	0.1743	0.541
Overhanging Vegetation	-0.6206	0.279
Canopy Shading	0.7626	0.259
RAPIDS	1.0262	0.528
RIFFLE	2.5884	0.778
Depth 75-100 cm	-4.3899	3.126
Velocity <15 cm/s	-2.956	0.662
Velocity 30-45 cm/s	-7.5367	2.065
MESOLITHAL	1.7867	0.757
MICROLITHAL	-1.9958	0.729

Note: The area under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model. SE refers to standard error.

Table 11 represents attributes for family Trichoptera established from 266 quadrates sampled including 181 quadrates where these animals were found. The model indicates affinity to shallow habitats and substrates consisting of cobbles.

Table 11 - Physical attributes correlating with presence and high abundance of trichopterans.

Presence		**SE**
Calibration	0.7011	
Estimated Success	0.6588	
Area under ROC	0.7589	
Cutoff	0.67	
Attribute	B	
Constant	0.2226	0.215
BACKWATER	-1.6865	0.625
SIDEARM	-1.3965	0.644
DEPTH<25 cm	3.6023	0.821
MESOLITHAL	1.5417	0.655
MICROLITHAL	-1.4871	0.593

Note: The area under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model. SE refers to standard error.

Table 12 represents attributes for family Odonata established from 266 quadrates sampled including 71 quadrates where these animals were found. The model indicates affinity to glide habitats and undercut banks.

Table 12 - Physical attributes correlating with presence and high abundance of odonates.

Presence		SE
Calibration	0.7663	
Estimated Success	0.6431	
Area under ROC	0.7102	
Cutoff	0.44	
Attribute	B	
Constant	-0.8288	0.189
Undercut Banks	1.1165	0.787
GLIDE	1.7451	0.519
Velocity 45-60 cm/s	-3.6847	1.643
Velocity 60-75 cm/s	-3.2659	1.667

Note: The area under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model. SE refers to standard error.

Spawning habitat

The literature survey of the spawning requirements of selected resident indicator and anadromous fish species allowed for the identification of the habitat attributes and conditions (ranges of values) necessary to determine “not suitable”, “suitable”, and “suitable-optimal” spawning habitat for these species. The seasonal timing, specific water temperature range, and strategies of spawning were also specified for each species but were not used as inputs in the spawning habitat suitability model. Table 13 presents the spawning habitat characteristics established for each of the selected species based on the literature survey.

Table 13 - Spawning habitat suitability criteria* for the resident indicator and anadromous fish species of the Lamprey Designated River.

Resident Indicator Fish Species	Seasonal Period	Water Temp.	Optimal Meso-Habitat	Water Depth	Current Velocity	Choriotop (Substrate)	Comments
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
Fallfish	Late April through Early June	15.0-19.0°C	Glides, Pools, Runs	<=99 cm	<20 cm/s	Akal, Micro	Gravel nests built by male; nest building may initiate spawning behavior in females
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
Redbreast Sunfish	May-August	20.0-25.0°C	Runs, Pools, Glides	25-150 cm	<30cm/s	Psammal; Akal	Cover is critical (boulders, woody debris); MG-Riverine
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

Anadromous Fish Species	**Seasonal Period**	**Water Temp.**	**Meso-Habitat**	**Water Depth**	**Current Velocity**	**Choriotop (Substrate)**	**Comments**
Alewife	May – July (as late as August possible)	10.5-16.0°C 15.0-20.0°C		15-300 cm	Slow 0-14cm/s	Akal, Detrital, Micro, Pelal, Psammal	Submerged vegetation
American Shad	May through Mid-June	Range: 8-26°C Peak: 14-21.0°C	Run, Glide, Pool, Fast Run	51-125 cm+	16-104 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)
Blueback Herring	May – July (as late as August possible)	14.0-26.0°C 20.0-24.0°C		51-125 cm+	Swift 16-104cm/s	Akal, Micro, Meso	

*Spawning habitat suitability criteria references included at the end of this appendix.

Discussion

The models presented here all have a satisfying capacity to discriminate between occupied and unoccupied habitats, which is indicated by high areas under ROC curves. The models also correspond well 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. In some of the models individual attributes received very high coefficient value (eg. xylal substrate for white sucker with -529). This is most likely due to the fact that only few samples with these attributes were available and the result is more due to coincident than showing real pattern. A sensitivity analysis of the model was conducted by excluding these attributes and resulting models proved to be insignificantly different. As a result, the original models were used without any exclusion. The only exception was the model for redbreast sunfish which indicated high affinity of this species with rapids, based on 2 out of 304 observations that happened to be in rapid HMU. This result was unreasonable and the model has been recalculated without including presence of rapids as an independent variable.

Because fish models are developed for individual species and on a very large database, they may be more reliable than those for invertebrates. On the other hand, lower mobility of invertebrate fauna reduces the impact of coincidence on the observations. The family of odonates occupies wide range of habitats and therefore the model presented here need to be view with caution. However, only a few species in our samples were found to have similar habitat use.

The literature based spawning model presented here has the capacity to discriminate between and identify “not suitable”, “suitable”, and “suitable-optimal” habitat units. It is a more conservative and robust version of similar literature-based models previously used to identify the level of suitability of habitats for spawning on the Quinebaug River and Souhegan River (NHDES 2008). The current model requires that at least three out of the seven measured values for an attribute be met in order for the attribute to be considered as having met the criteria. It also requires that all three habitat attributes (depth, velocity, and choriotop) exist in acceptable proportions within an HMU for that unit to be considered as suitable. Previous models required either lower proportions of measured values for the consideration of individual attributes as suitable or did not require that all three of the habitat attributes be present in acceptable proportions together within a unit for the unit to be considered suitable.

The changes made to this model seem to have strengthened it by requiring a greater portion of measured values to meet the criteria developed for each species in order to be considered suitable or optimal. This provides assurance that a more substantial area of the habitat possesses the defined attributes than in the previous models. Although these changes may cause decreases in the amount of “suitable” and “suitable-optimal” spawning habitat throughout the river due to its more conservative standards, confidence in the accuracy of its ability to identify actual suitable conditions within the mapped habitat units is increased. Overall, this model provides the ability to identify suitable spawning habitat for the selected species at various flows when applied to habitat mappings of the river conducted under multiple flow conditions.

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