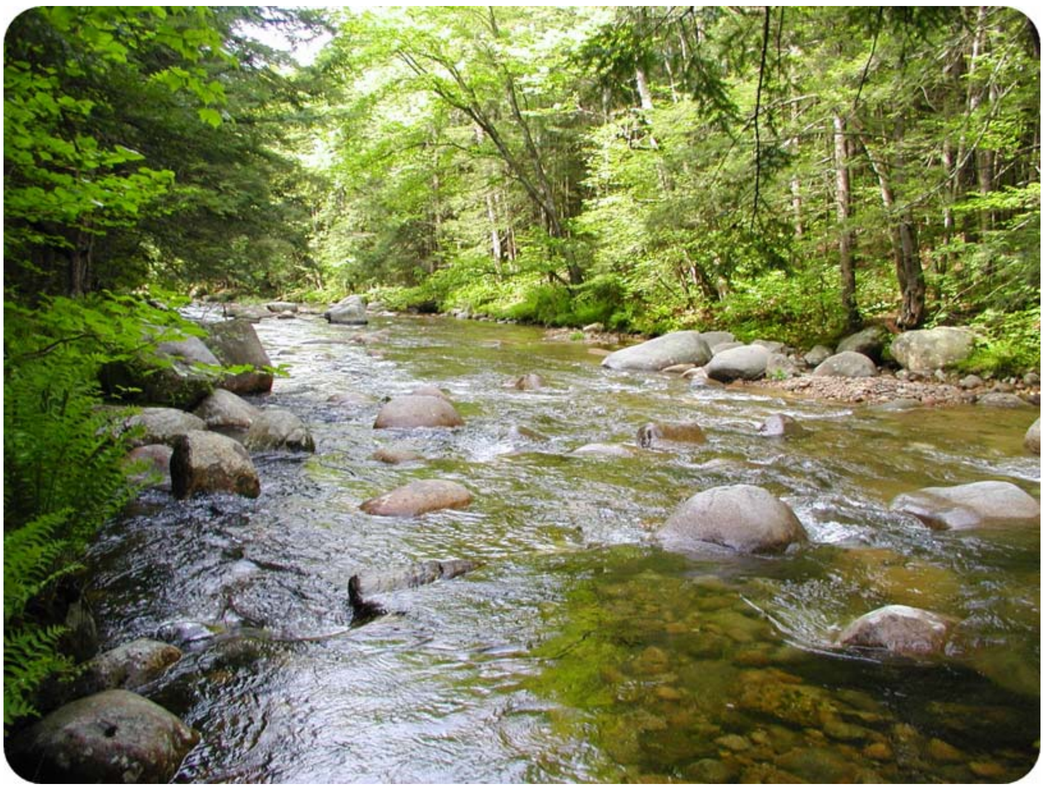
Predicated Coldwater Fish Indicator Species Presence in New Hampshire Wadeable Streams



NEW HAMPSHIRE DEPARTMENT OF Environmental Services

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Predicted Cold Water Fish Indicator Species Presence in New Hampshire Wadeable Streams

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1. Introduction

New Hampshire surface water quality regulations (Env Ws-1703.07) require the implementation of stricter dissolved oxygen criteria for naturally reproducing coldwater fish communities during certain periods of the year (see "c" below). Specifically, the criteria state that:

> (a) Class A waters shall have a dissolved oxygen content of at least 75% saturation, based on a daily average, and an instantaneous minimum of at least 6 mg/l at any place or time except as naturally occurs.
>
> (b) Except as naturally occurs, or in waters identified in RSA 485-A:8, III, or subject to (c) below, class B waters shall have a dissolved oxygen content of at least 75% of saturation, based on a daily average, and an instantaneous minimum dissolved oxygen concentration of at least 5 mg/l.
>
> (c) For the period from October 1st to May 14th, in areas identified by the fish and game department as cold water fish spawning areas of species whose early life stages are not directly exposed to the water, the 7 day mean dissolved oxygen concentration shall be at least 9.5 mg/l and the instantaneous minimum dissolved oxygen concentration shall be at least 8 mg/l. This period shall be extended to June 30 for a particular waterbody if the fish and game department determines it is necessary to protect spring spawners and late hatches of fall spawners.

These criteria are, in turn, utilized by the Department of Environmental Services to complete water quality assessments of its rivers, streams, lakes, and impoundments in preparation of 305(b)/303(d) water quality reports as required by the Environmental Protection Agency. To date, DES has applied the coldwater fish spawning area dissolved oxygen criteria only to specific stream segments known to contain naturally reproducing populations of salmonid species as determined from field sampling completed by the New Hampshire Fish and Game Department. While this "on-the-ground" approach assures the correct application of stricter water quality criteria (see "c" above) to specific localized areas, it is severely limiting on a statewide basis. As a result, in its 2004 water quality assessment report, of the 3,189 stream assessment units identified by DES, only 24 (less than 1 percent) were designated as coldwater fish spawning areas. A more inclusive statewide approach is limited by the exclusion of non-salmonid coldwater fish species from consideration and the necessity for field sampling to confirm the presence or absence of naturally reproducing (resident) coldwater fish species.

In response to the limited application of the stricter dissolved oxygen criterion, the DES biomonitoring unit utilized its statewide fish assemblage data in an attempt to develop a model that accurately predicts where instream conditions are favorable for the support of coldwater fish species. The underlying assumption for the development of the predictive model was that the distribution of fish species is controlled largely by the physical and chemical features of the environment in which they exist. Natural variation in factors such as the stream temperature, riparian cover, drainage area, stream gradient, latitude, and substrate composition are all considered to be important variables that, in the absence of substantial human influences, determine the spatial distribution of fish species and overall composition of fish communities. Candidate predictive variables were chosen based on their permanence (i.e., rate of change or lack thereof) and collectability. A variable's permanence is important because it limits the effect of human influences on fish communities and minimizes the amount of natural variation at a specific location. For example, a variable that describes a stream reach such as latitude is uninfluenced by anthropogenic activities and does not change over time. In contrast, substrate composition in the same stream reach could be drastically changed by either human activities or natural flooding processes. Variables that had a high level of permanence were included for consideration in model development.

If successful, the model could then be used to predict the presence or absence of coldwater fish species in wadeable streams based on environmental variables. Once the likelihood of coldwater fish species presence is established, decisions can be made on the application of suitable dissolved oxygen criteria. The assumption is if coldwater fish species can be predicted to naturally occur with reasonable accuracy, then its reproductive capacity (i.e., potential for spawning success) must be protected in order to allow the species to persist.

Since it is critically important to appropriately apply water quality standards the objectives of this analysis were: 1) to determine if a model could be built that accurately predicts where coldwater fish species occur or do not occur in New Hampshire; 2) if so, to decide what environmental variables are important in determining the presence or absence of coldwater fish species; 3) to determine the model's predicative success and 4) to assess the practicality of applying the model's results statewide for the purposes of implementing dissolved oxygen criteria.

2. METHODS

2.1 Dataset

Fish data used in model development were collected from first to fourth order streams throughout the state of New Hampshire from 1997 through 2006. Fish collections were completed using backpack electrofishing equipment primarily during the months of June, July, and August, and included species identification and enumeration followed by release back into the stream. Fish sampling events at individual stations generally included a single pass 150 meter stream reach with a total shocking time between 13 – 25 minutes.

From an original dataset of over 200 stations, 163 stations were included in the analysis. The final dataset eliminated sites known to have significant human disturbances based on objective criteria, thus predictions based the resultant model were meant to represent the expected current distribution of coldwater fish species in New Hampshire wadeable streams in the absence of human impact. The 163 stations were randomly broken into calibration (n = 115) and validation (n = 48) datasets. The calibration dataset was used during model development while the validation dataset was used to test the model's performance. For each station, fish data was reviewed and all known records of "stocked" fish were removed. The presence of stocked fish is not indicative of long term survival via natural reproduction, but rather a fisheries management decision (Halliwell et. al. 1999). Species were considered as indicators and subsequent inclusion into the model's development only if they met the following criteria: 1) strict coldwater "specialists"; 2) had greater than 30 occurrences across all sites; 3) were known to have a statewide distribution; 4) are native to the state. The result of these restrictions limited indicator species to resident (naturally reproducing) brook trout (*Salvelinus fontinalis*) and slimy sculpin (*Cottus cognatus*). A site was considered to be supportive of coldwater fish species if it had one or both of these species. Sites that had neither species were not considered to be supportive of the conditions necessary for the persistence of coldwater fish species.

2.2 Data analysis

The presence of a coldwater fish indicator species was tested against a suite of environmental variables that were considered to be relatively stable and easy to collect. The continuous variables included latitude, longitude, elevation, drainage area, and stream gradient (as reported in the USGS Sparrow Model, Moore et al. 2004). Discrete (categorical) variables included major river basin, and bioregion (as defined by the Ecological Drainage Units proposed by The Nature Conservancy, Olivero 2003). All variables were regularly documented for biological stream surveys completed by the DES biomonitoring unit using geographic information systems and were considered as potentially important in determining if stream conditions were favorable for the presence of coldwater fish species. Individual tests for differences in continuous environmental variables associated with coldwater fish indicator species presence or absence were completed using the Mann-Whitney U-test. Chi-square contingency tables were completed to elucidate if indicator species presence was associated with categorical variables (Zar 1984).

To determine if any of the continuous variables were interrelated a correlation matrix was constructed. Person correlation coefficients less than 0.7 were considered to be an appropriate threshold in determining variable independence. Correlation coefficients greater than 0.7 were used to identify redundant variables.

Predictive model development was completed using logistic regression to determine if the likelihood of brook trout or slimy sculpin presence could be predicted by the consideration of one to several environmental variables. The use of logistic regression allows for the production of estimated probabilities of occurrence for binomial data (present / absent) where the computed probability represents the predicted chance of occurrence (present). In this application, the dependent variable is indicator fish species with the observed occurrence of brook trout or slimy sculpin as "present" and the lack of indicator fish species presence as "absent". The theoretical model is presented as

$$P(\text{present}) = \frac{1}{1 + \exp -(\alpha + \beta_1 X_1 + .. \beta_i X_i)}$$

Where P(present) is the estimated probability of coldwater fish indicator species occurrence; α is a constant, β_i is the variable-specific regression coefficient, and X_i is the value of the respective independent variable(s). The logistic model produces probabilities of occurrence limited between zero and one and is well suited for indicator variables with non-normal or binary distributions (Hosmer and Lemeshow, 1989). The SPSS software package was used for model development and a likelihood ratio test at the 0.05 level of probability was used to indicate if a variable's inclusion in the model was significant.

Model development followed a standardized process utilizing a stepwise procedure to identify the model(s) that accounted for the greatest variation and had the best predicative abilities. Next, "block"-type variable loading was completed to reaffirm results from the stepwise procedure and produce residual plots to identify outlier points. Once outlier points were identified, field data were re-examined and a final subjective decision was made regarding site removal from further model development. In all, six sites were found to be unrepresentative of the dataset and removed from further analysis. Primary reasons for site removal included significant human impact, inappropriate sample location (i.e., low gradient, sandy bottomed reach sampled in a medium to high gradient stream largely dominated by a cobble bottom), and inefficient fish sampling (i.e., few individuals capture due to high flow conditions). After outlier sites were removed, the best predictive model was re-run to obtain final model results.

Logistic models built on continuous variables were compared to those built on categorical variables. The percentage of correct predictions was used to determine if a suite of continuous variables was more useful in predicting the presence or absence of coldwater fish indicator species than individual categorical variables. Categorical variables, such as bioregions (i.e., ecounits) or river drainage basins are often considered as potentially important "large-scale" landscape-level units useful for classifying biological communities (Omernick 1987; Fausch et al. 1990). However, empirical data from aquatic communities have shown mixed results in the correspondence to landscape-level categories, leading to the belief that a robust suite of continuous environmental variables may be more useful predictors (Hawkins and Vinson 2000; Van Sickle and Hughes 2000).

Final model selection was based on statistical significance, the percentage of correct predictions for sites with and without resident brook trout or slimy sculpin, and relative importance of individual variables. The validation dataset was used to confirm results obtained from the calibration dataset and make final adjustments to the probability of occurrence threshold (i.e., cutoff for presence / absence) utilizing comparisons of type I and type II error rates.

After model development and validation, analyses were completed using t-tests to determine if instantaneous measurements of dissolved oxygen, water temperature, specific conductance, and pH collected coincident with fish samples varied significantly between both predicted and observed occurrences of coldwater fish indicator species.

3. Results

3.1 Coldwater fish indicator species associations with environmental variables

The observed presence of a coldwater fish indicator species from the calibration dataset was associated with sites that had significantly ($p<0.001$ for all) greater latitudes, higher elevations, smaller drainage areas, and steeper gradients than sites without a coldwater fish indicator species (Figure 1; Table 1). Longitude did not differ significantly ($p>0.05$) between sites with and without a coldwater fish indicator species. The indicator species were present at 66 (57.4 percent) of the 115 the sites included in the calibration dataset.

Figure 1. Distribution of continuous environmental variables for sites where coldwater fish indicator species were observed present (CW) and absent (NCW) in the calibration dataset. Circles (○) indicate outlier points (1.5-3x interquartile range); stars (★) indicate extreme points (>3x interquartile range).

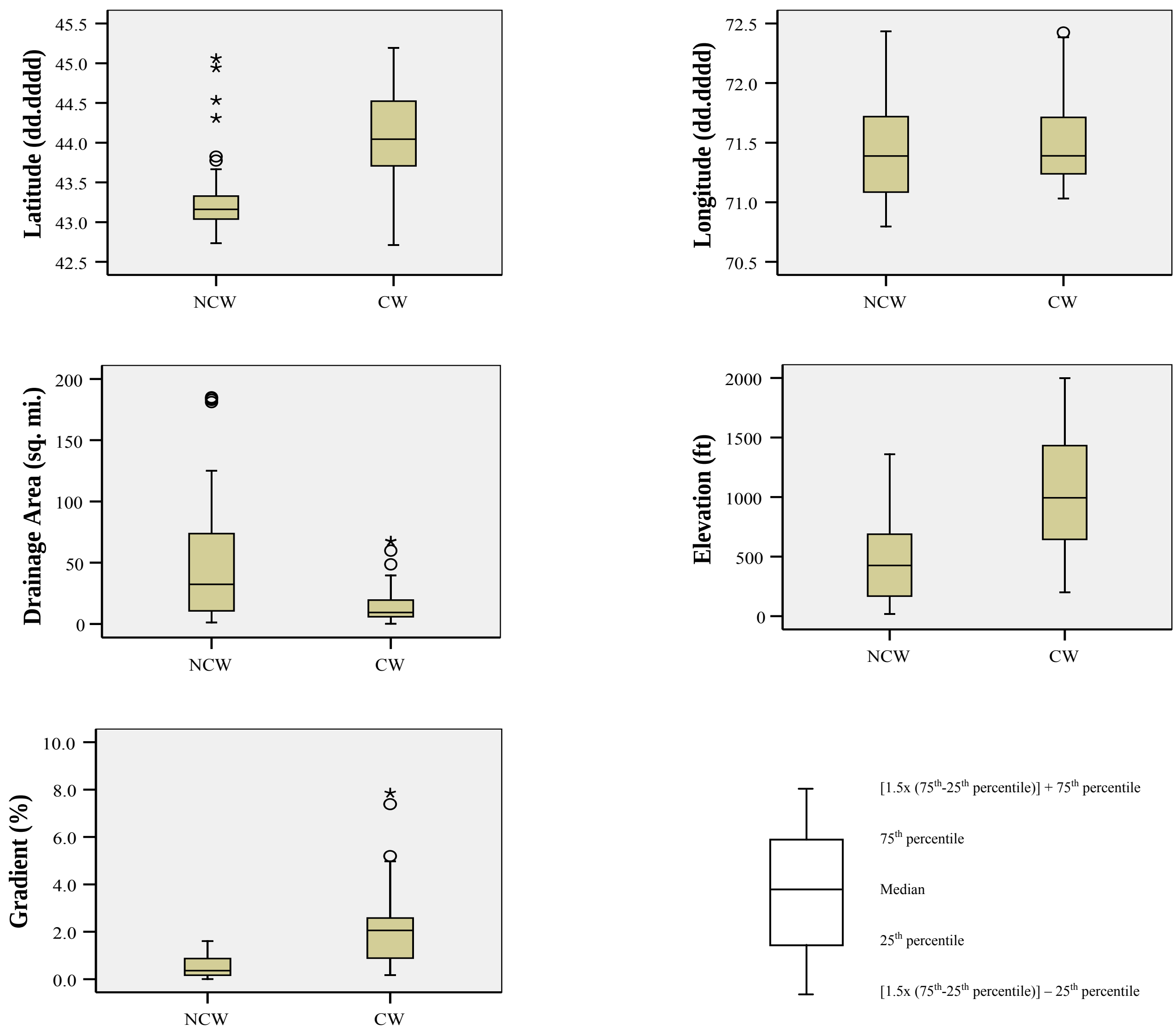


Table 1. Continuous environmental variable mean, minimum, and maximum values for sites where coldwater fish indicator species were observed present (present) and absent (absent) in the calibration dataset.

	Absent (n=49)			Present (n=66)			
	Mean	Min	Max	Mean	Min	Max	Mann-Whitney p-value
Latitude (dd.dddd)	43.295	42.7333	45.0599	44.0991	42.7106	45.1941	<0.001
Longitude (dd.dddd)	-71.4574	-72.4329	-70.7964	-71.4955	-72.4245	-71.0322	0.396
Elevation (ft)	462.5	18.2	1359.6	1045.5	200.9	1998.7	<0.001
Drainage Area (mi^{2})	60.4	1.19	391.9	15.2	0.2	67.55	<0.001
Gradient (%)	0.552	0.003	1.598	2.311	0.17	14.289	<0.001

The distribution of data for the validation dataset compared favorably with the calibration dataset (Figure 2) and both had similar ranges (Table 2). Coldwater fish indicator species were observed at 29 (60.4 percent) of 48 sites included in the validation dataset.

Figure 2. Distribution of continuous environmental data for calibration (n=66) and validation (n=49) datasets.

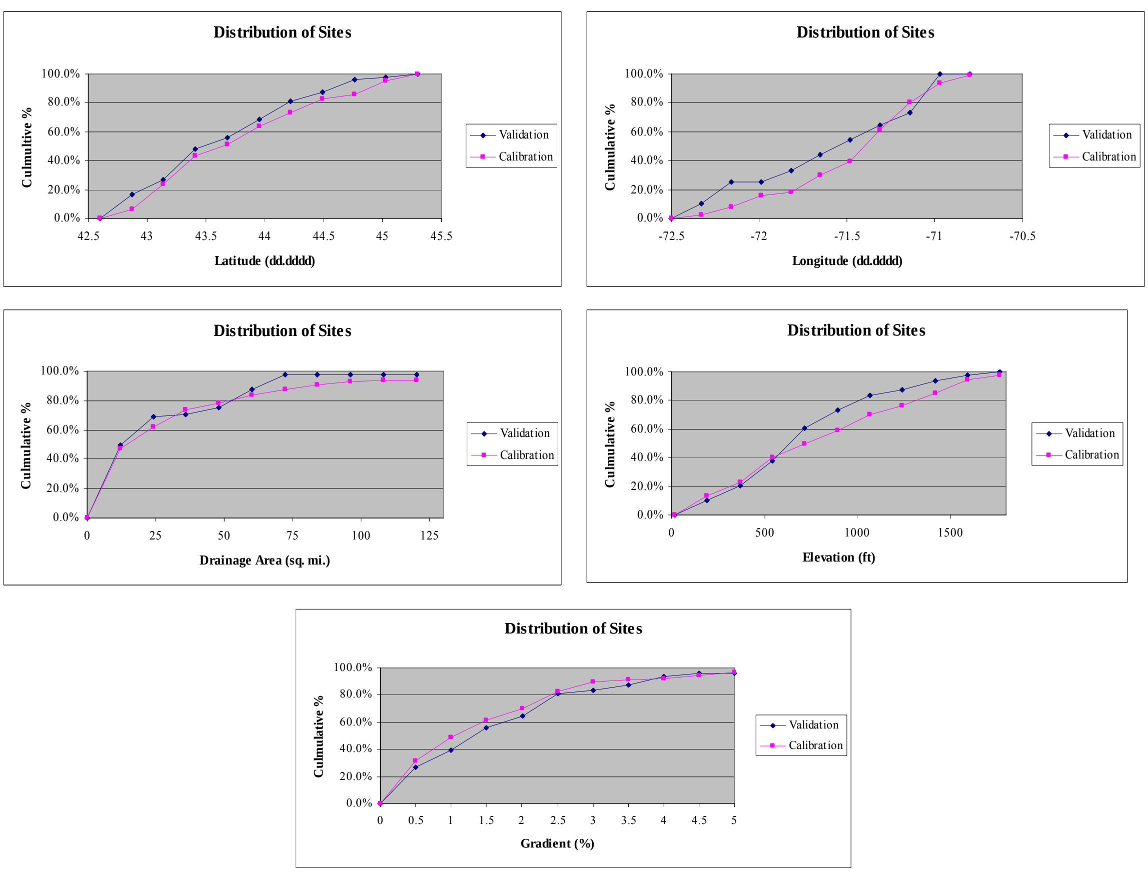


Table 2. Mean, minimum, maximum, and range for continuous environmental data associated with sites included in the calibration and validation datasets.

	Mean	Min	Max	Range
CALIBRATION (n=115)				
Latitude (dd.dddd)	43.7564	42.7106	45.1941	2.4835
Longitude (dd.dddd)	-71.4793	-72.4329	-70.7964	1.6365
Elevation (ft)	797.1	18.2	1998.7	1980.5
Drainage Area (mi^2)	34.4	0.2	391.9	391.7
Gradient (%)	1.561	0.003	14.289	14.286
VALIDATION (n=48)				
Latitude (dd.dddd)	43.6057	42.7313	45.0924	2.3611
Longitude (dd.dddd)	-71.6134	-72.4281	-71.0007	1.4274
Elevation (ft)	701.9	75.4	1702.5	1627.1
Drainage Area (mi^2)	24.6	1.4	153.1	151.6
Gradient (%)	1.809	0.005	12.928	12.923

The categorical variables bioregion and basin also proved useful in describing the presence or absence of indicator species (chi-square test, $p<0.005$ for both; Table 3). In general, the categorical data indicated that coldwater fish indicator species were

Table 3. Observed and expected frequencies of indicator species presence (present) and absence (absent) for categorical variables [(A) bioregion, (B) river basin] in the calibration dataset.

A.

		Bioregion*				
		1	2	3	4	totals
Absent	obs	2	3	8	36	49
	exp	2.98	11.08	7.24	27.70	
Present	obs	5	23	9	29	66
	exp	4.02	14.92	9.76	37.30	
	totals	7	26	17	65	115
						Chi-square= 15.30

B.

		Basin**					
		1	2	3	4	5	totals
Absent	obs	0	2	11	19	17	49
	exp	5.54	2.98	18.32	13.63	8.52	
Present	obs	13	5	32	13	3	66
	exp	7.46	4.02	24.68	18.37	11.48	
	totals	13	7	43	32	20	115
							Chi-square= 33.69

* Bioregion 1 = Androscoggin EDU, Bioregion 2 = Upper Connecticut EDU, Bioregion 3 = Lower Connecticut EDU, Bioregion 4 = Merrimack-Coastal EDU

** Basin 1 = Saco, Basin 2 = Androscoggin, Basin 3 = Connecticut, Basin 4 = Merrimack, Basin 5 = Piscataqua observed more frequently than expected in the northern bioregions (1, 2) and northern/western river basins (1, 2, 3) and absent more frequently than expected in southern bioregions (4, 5) and southern/eastern river basins (4, 5). Taken together, tests of continuous and categorical variables associations with brook trout and slimy sculpin showed that seven of eight variables were significant indicators of coldwater fish indicator species presence or absence in wadeable streams.

Next, a correlation matrix was completed to explore relationships between independent continuous variables (Table 4). Correlations (Pearson) between all variables ranged from -0.30 to 0.81. Latitude and elevation had the highest correlation coefficient (0.81) indicating sample site elevation increased with increasing northern latitudes (Figure 3). The strong relationship in the calibration dataset between latitude and elevation was subsequently considered in final model development. Correlation coefficients between all remaining variable combinations were less than 0.40. With the exception of latitude and elevation, the lack of redundancy in continuous variables indicated further exploration of their combined resultant effects on indicator species occurrence was warranted. That is to say, unrelated independent variables were considered in the logistic model development phase. For exploration purposes only, the initial model development phase also included the simultaneous consideration of latitude and elevation for comparative purposes.

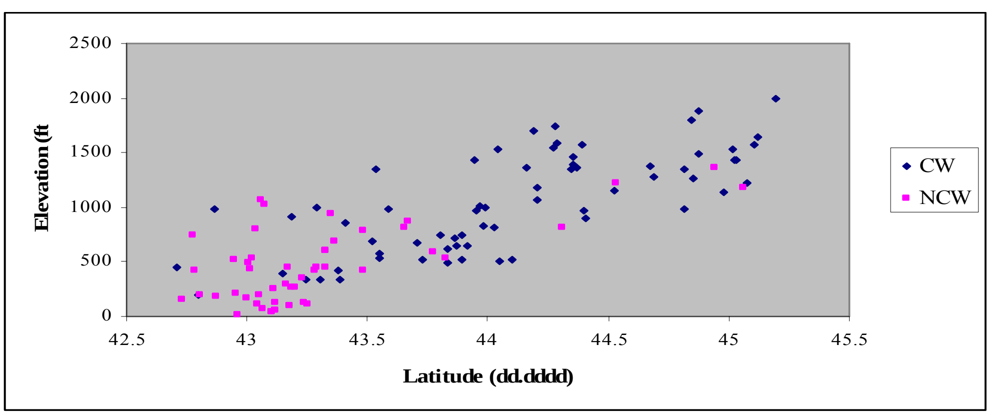
Table 4. Pearson correlation coefficients for continuous environmental variables.

Pearson Correlation Coefficients					
	Elevation	Drainage Area	Longitude	Latitude	Gradient
Elevation	1.000	-0.296**	0.111	0.809**	0.382**
Drainage Area		1.000	0.110	-0.253**	-0.293**
Longitude			1.000	-0.207*	0.046
Latitude				1.000	0.330**
Gradient					1.000

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Figure 3. Relationship of latitude and elevation for sites with observed coldwater fish indicator species presence (CW) and absence (NCW) from the calibration dataset. Pearson correlation coefficient 0.81, $p<0.01$.



3.2 Continuous variable model development and selection

The combined influence of four (latitude, longitude, size, elevation) continuous environmental variables was tested against the observed presence of coldwater fish indicator species using logistic regression. A total of five candidate predictive models were identified with each model proving useful as a predictor of indicator species presence (Table 5; $p<0.001$). Of the five models, four included drainage area and elevation, three included latitude, and two included longitude. Likelihood ratio tests indicated that the iterative addition of select continuous environmental variables significantly ($p<0.05$ for all) improved overall model fit (Table 5; reduction in likelihood ratio from models 1 - 4).

Table 5. Logistic regression models and comparative statistics developed for predicting the occurrence of coldwater fish indicator species in New Hampshire wadeable streams using continuous environmental variables (△-2 log likelihood = likelihood ratio).

Model #	Continuous Variable(s)	Entry Method	Model Chi-Square	df	Sig.	-2 log likelihood	△ -2 log likelihood
1	Elevation	Stepwise	45.477	1	<.001	111.424	-------
2	Elevation, Drainage Area	Stepwise	66.791	2	<.001	90.111	21.313***
3	Elevation, Drainage Area, Latitude	Stepwise	73.088	3	<.001	83.814	6.297**
4	Elevation, Drainage Area, Latitude, Longitude	Stepwise	77.282	4	<.001	79.619	4.195*
5	Latitude, Longitude, Drainage Area	Stepwise	77.139	3	<.001	79.763	-0.144
Final	Latitude, Longitude, Drainage Area#	Block	99.094	3	<.001	47.941	-------

*** Model sig. different from previous @ p<0.001
** Model sig. different from previous @ p<0.025
* Model sig. different from previous @ p<0.05
# Outlier points removed from model

Model five included latitude, longitude, and drainage area and compared favorably with model 4 [insignificant change ($p>0.05$) in likelihood ratio], yet with fewer variables. A model that included either elevation or latitude (not both) was expected given their strong correlation. The fit of the model five was improved by the elimination of outlier points resulting in a higher model chi-square value and reduced likelihood ratio as reflected in the final continuous variable model (Table 5).

Statistical results from individual models built on continuous environmental variables were compared to model-specific classification tables based on the predictive accuracy of each model. Predictive accuracy was defined as the percentage of sites predicted as having indicator species present or absent compared to the respective observations. For predicted indicator species presence or absence the accuracy of the model was determined using a 50 percent probability threshold. That is, individual sites were predicted to contain the indicator species if the predicted probability of occurrence was ≥ 0.50 (50 percent). If the probability of occurrence was <0.50, then a site was predicted not to contain the indicator species. Overall, the predictive accuracy of the models based on the calibration dataset ranged from 75.7 to 89.9 percent and increased as overall model complexity increased (Table 6). All models were slightly more accurate at predicting the presence of the indicator species compared to their absence. The final continuous variable model was 92.3 percent and 86.4 percent accurate at predicting the respective presence and absence of indicator species (Table 6).

Table 6. Observed and predicted occurrences of coldwater fish indicator species from calibration data for continuous environmental variable logistic regression models and respective predication accuracies [probability of occurrence threshold = 50%; present = p(present) ≥ 0.50; absent = p(present) < 0.50].

	Observed↓	Predicted→	Absent	Present	Percent Correct
Model 1	Absent		36	13	73.5
	Present		15	51	77.3
	Overall				75.7
Model 2	Absent		37	12	75.5
	Present		8	58	87.9
	Overall				82.6
Model 3	Absent		39	10	79.6
	Present		9	57	86.4
	Overall				83.5
Model 4	Absent		38	11	77.6
	Present		7	59	89.4
	Overall				84.3
Model 5	Absent		38	11	77.6
	Present		7	59	89.4
	Overall				84.3
Final	Absent		38	6	86.4
	Present		5	60	92.3
	Overall				89.9

A comparison of odds ratios from individual variables in the final continuous model indicated that latitude had an overwhelming effect on the occurrence of Brook trout or slimy sculpin (Table 7). Odds ratios define the importance of an independent variable's affect on the model's outcome (Hosmer and Lemeshow 1989). Odds ratios greater than one are indicative of a variable's increasing likelihood on positive model outcome (i.e., chances of occurring), while odds ratios less than one indicate a decreasing likelihood of positive model outcome. Odds ratios near or equal to one indicate a variable's independence on model outcome. For the final continuous variable model, latitude had an odds ratio of 175.8 indicating that there was an approximately 175x greater chance of encountering either of the indicator species for every one degree increase in latitude. When considering longitude, brook trout or slimy sculpin were 22x more likely to be found for every one degree westward change in longitude. Finally, resident indicator fish species were approximately 0.40x less likely to occur for every 10 square mile increase in drainage area.

Table 7. Final logistic regression coldwater fish indicator species predictive model coefficients (B), standard errors (S.E.), Wald statistics (Wald, degrees freedom (df), level of significance (Sig.), and odds ratios [Exp(B)] for continuous environmental variables.

Variable	B	S.E.	Wald	df	Sig.	Exp(B)
Latitude (dd.dddd)	5.170	1.145	20.383	1	<.001	175.840
Longitude (dd.dddd)	3.091	1.182	6.834	1	0.009	22.004
Drainage Area (sq. mi.)*	-0.933	0.313	8.896	1	0.003	0.393
Constant	-443.661	116.726	14.447	1	<.001	0.000

* Drainage area (sq. mi.) must be divided by 10

Stream gradient was omitted from model development as estimates were from distinct localized (<500ft) stream reaches and did not represent continuous river segments. River segments often contain varying degrees of gradational severity that alternate over the stream course. The results from individual variable testing correctly indicated that gradient was an important factor in determining the occurrence of indicator species within distinct sample units. However, the data were more reflective of the associated physical habitat availability in that specific area and cannot be translated across lengthy river segments. In contrast, variables included in model development represent the primary factors that control the presence or absence of the indicator species across a broader spatial scale and reflect the continuous nature of natural stream courses.

3.3 Categorical variable model development and testing

Separate predictive models were also developed using logistic regression for the categorical variables river basin and bioregion. As noted above, both variables were found to be important explaining the presence or absence of resident fish indicator species. Logistic model development further confirmed these findings as resultant models for basin and bioregion were significantly ($p \leq 0.001$ for both) better at predicting the presence or absence of brook trout or slimy sculpin than predictions made by chance (Table 8).

Table 8. Logistic regression models and comparative statistics developed for predicting the occurrence of coldwater fish indicator species in New Hampshire wadeable streams using discrete landscape variables.

Model	Discrete Variable	Entry Method	Model Chi-Square	df	Sig.	-2 log likelihood
Bsn	Basin	Block	39.945	4	<0.001	117.416
Brgn	Bioregion	Block	17.067	3	0.001	139.834

For the model developed using basin,an overall predicative accuracy of 74.8 percent was observed with presence and absence predictions differing by less than 2.5 percent (Table 9). The model developed based on bioregion was less accurate with an only 63.5 percent of sites being correctly classified. The bioregional model performed especially poor in predicting the presence of the indicator species with only 56.1 percent of sites correctly classified. When compared to the predictive accuracy for the final model using continuous environmental variables (89.9 percent - calibration dataset), models built basin or bioregion were less accurate (74.8 percent - basin; 63.5 percent - bioregion). Thus, further testing and validation of the discrete variable models was not completed.

Table 9. Observed and predicted occurrences of coldwater fish indicator species from calibration data for categorical variable logistic regression models and respective predication accuracies [probability of occurrence threshold = 50%; present = p(present) $\geq$ 0.50; absent = p(present) < 0.50].

	Observed↓	Predicted→	Absent	Present	Percent Correct
Bsn	Absent		36	13	73.5
	Present		16	50	75.8
	Overall				74.8
Brgn	Absent		36	13	73.5
	Present		29	37	56.1
	Overall				63.5

The results indicate that while landscape variables were helpful in explaining general patterns in the collective geographic distribution of brook trout and slimy sculpin statewide, individual environmental variables were better overall predictors of their presence for stream segments within distinct intrastate geographic areas (i.e., watersheds).

3.4 Final model validation, adjustment, and application

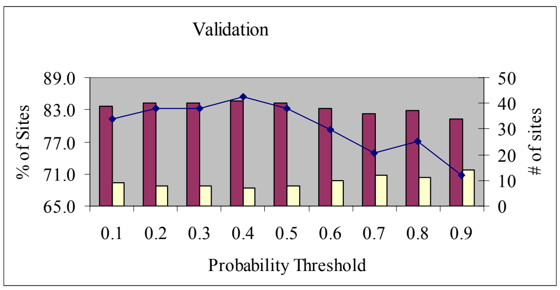
The final continuous variable model was applied to the validation dataset with 50 percent probability of occurrence threshold and resulted in an overall predictive accuracy of 83.3 percent (Table 10) compared to 89.9 percent for the calibration dataset (Table 6). Similar to the calibration dataset, the model more accurately predicted sites where coldwater fish indicator species were present (89.7 percent) compared to sites where they were absent (73.7 percent). In order to further explore the model's performance, probability of occurrence thresholds were subsequently adjusted through an

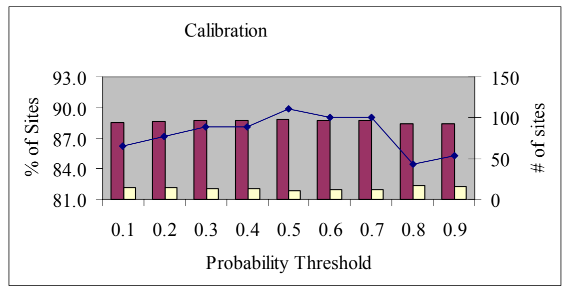
Table 10. Observed and predicted occurrences of coldwater fish indicator species from validation data for the final continuous environmental variable logistic regression model and respective predication accuracies [probability of occurrence threshold = 50%; present = p(present) $\geq$ 0.50; absent = p(present) < 0.50].

	Observed↓	Predicted→	Absent	Present	Percent Correct
Final	Absent		14	5	73.7
	Present		3	26	89.7
	Overall				83.3

incremental range from 0.10 (10 percent) to 0.90 (90 percent). By manipulating the probability of occurrence thresholds it was possible to determine the model's accuracy at various levels of leniency. A lenient model would designate stream segments as containing coldwater fish indicator species at a low probability of occurrence. Conversely, a model lacking leniency, or strict model, would require a high probability of occurrence prior to predicting a site to contain either of the indicator species. Incremental threshold adjustments were also completed on the calibration dataset for comparison purposes. For the validation dataset the percentage of correct predictions was maximized at a 40 percent probability of occurrence threshold (85.5 percent correct predictions) compared to 50 percent for the calibration dataset (89.9 percent correct predictions) (Figure 4). In addition, two x two contingency tables were constructed for

Figure 4. Number (# of sites, bars) of correct (red) and incorrect (yellow) site predictions and overall percentage of correct (% correct, line) predictions for validation and calibration data using the final continuous environmental variable logistic regression model across incremental probability of occurrence thresholds.





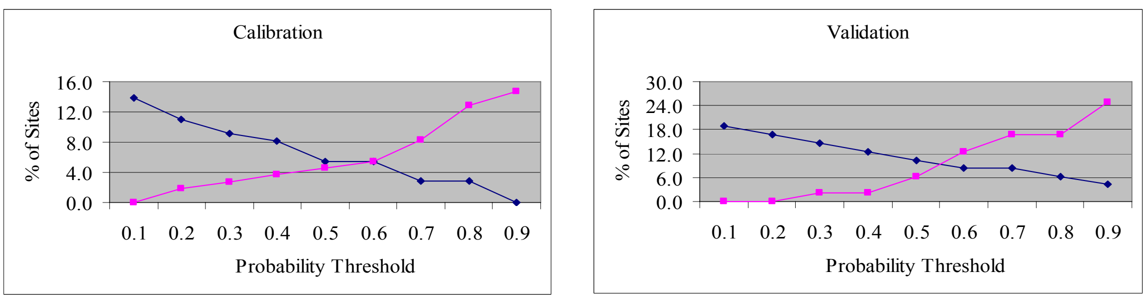
each probability threshold and indicated that the predictions were significantly ($p<0.001$ for all) better than those made by chance at all probability of occurrence thresholds (Table 11).

Table 11. Contingency table results for incremental probability thresholds for the validation dataset (Chi-square critical value with 1 df at $\alpha_{0.05} = 3.841$).

Probability Threshold	Chi-Square	P-value
0.1	28.87	<0.001
0.2	34.00	<0.001
0.3	32.76	<0.001
0.4	38.28	<0.001
0.5	32.56	<0.001
0.6	24.78	<0.001
0.7	17.96	<0.001
0.8	22.77	<0.001
0.9	15.91	<0.001

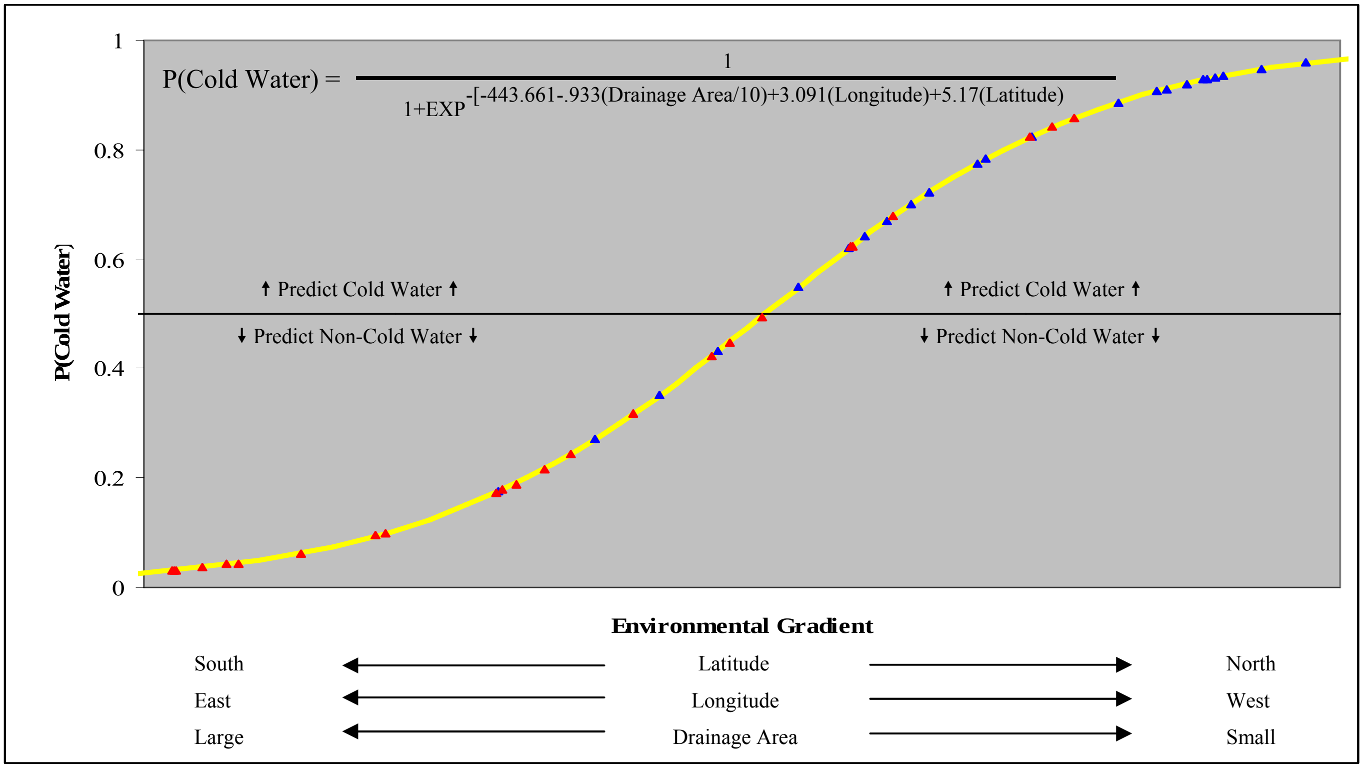
A final threshold probability of occurrence was selected based on the examination of type I and type II error rates for the calibration and validation dataset. Type I errors were those sites where coldwater fish indicator species were not observed but were predicted to occur by the model. Type II errors were those sites where the indicator species were observed but not predicted to occur. Type I and type II error rates intersected at the 50 percent probability of occurrence threshold for the calibration dataset resulting in the misclassification of 5.5 percent of the sites (Figure 5). For the validation dataset type I and type II error rates intersected near the 55 percent probability of occurrence threshold resulting in a misclassification of approximately 10 percent of the sites (Figure 5). Low probability of occurrence thresholds were associated with relatively high type I error rates (13.8 percent - calibration; 18.8 percent validation at 10 percent probability of occurrence). In other words, utilizing low probability of occurrence thresholds frequently predicted the presence of the indicator species at sites were they were not observed. Conversely, high probability of occurrence thresholds were associated with high type II error rates (14.7 percent - calibration; 25 percent validation at 90 percent probability of occurrence). Thus, using high probability of occurrence thresholds frequently failed to predict a positive occurrence at sites where the indicator species were actually observed. A final probability of occurrence threshold of 50 percent was chosen based on the close agreement of the intersection points of type I and type II error rates from the calibration and validation dataset and the relatively high predicative accuracies (89.9 percent - calibration; 83.3 percent validation).

Figure 5. Type I (blue line) and Type II (pink line) error rates at incremental probability thresholds for the final continuous environmental variable logistic regression model using the validation and calibration datasets.



In practice, the examination of type I and type II error rates across the range of probability thresholds are important in understanding the linkage to the coldwater fish species dissolved oxygen criterion. A type I error would result in the improper application of coldwater fish species dissolved oxygen criterion to stream segments where they fail to naturally occur (i.e., more stringent criteria applied than required). In contrast, a Type II error would result in not applying the coldwater fish species dissolved oxygen criterion to stream segments where they naturally occur (i.e., less stringent standards applied than required). The critical importance of the proper implementation of water quality criteria justifies the selection of the 50 percent probability of occurrence threshold. The resultant threshold equally distributes the types of incorrect predictions made by the model. At this threshold the coldwater fish species dissolved oxygen criterion would only be applied if there was a ≥ 50 percent chance a site was predicted by the model to contain coldwater fish indicator species. In practice, the chosen threshold represents the implementation of a criterion that is neither over- or under-protective of resident coldwater fish species. The logistic regression equation and resulting line that describes the probability of occurrence for brook trout and slimy sculpin is presented in figure 6.

Figure 6. Probability of coldwater fish indicator species occurrence predictions based on the final continuous environmental variable logistic regression equation based on latitude, longitude, and drainage area. Red triangles (▲) are observed non-occurrences of coldwater fish indicator species (n=44). Blue triangles (▲) are observed occurrences of coldwater fish indicator species (n=65). Horizontal black line delineates 50% probability of occurrence threshold.



The balanced approach was selected with the understanding that the coldwater fish species dissolved oxygen criterion could be applied to additional streams or stream segments with less than a predicted 50 percent probability of occurrence based on field sampling results and professional experience. Conversely, the coldwater fish species dissolved oxygen criterion could be removed from streams or stream segments where evidence proves that coldwater fish species did not naturally occur. The reversal of model predictions is cautioned against as anthropogenic impacts may alter natural stream community species composition. In cases where the removal of the coldwater fish species dissolved oxygen criterion is under consideration, strong historical and comparative evidence should be produced that supports the claim that conditions in the stream or stream segment were not favorable for the occurrence of coldwater species.

The predictive model is intended to serve as a "first-cut" statewide determination of the occurrence of coldwater fish indicator species and not wholly representative of all the factors controlling the distribution of fish assemblages across New Hampshire. The known presence or absence of coldwater fish species in certain areas of New Hampshire that are not predicted by this model are recognized, but assumed to be in the minority. However, the model appears to provide an efficient and accurate mechanism for the statewide implementation of differential dissolved oxygen criteria based on presence and absence of the two most widely recognized fish species indicative of coldwater stream environments.

The resulting 50 percent probability of occurrence threshold lines separating coldwater fish indicator species presence and absence depict a northwest to southeast gradient dependent on drainage area (Map 1a). In general, the indicator species were expected to occur in stream segments farther south and east for small drainages as compared to stream segments with large drainages. Specifically, the presence of Brook trout or slimy sculpin in streams with drainage areas between five and 30 square miles are expected to extend from the extreme southern corner of the state's western boundary to approximately the mid-point of the eastern state boundary. In contrast, the expected presence of coldwater fish indicator species in streams with larger drainages (70-100 square miles) are restricted to northern sections of the state with the boundary line extending from the approximate mid-point of the western state boundary to the upper quarter of the eastern state boundary. A similar northwest to southeast probability of occurrence gradient was predicted when drainage area was held constant with streams from northwestern sections of the state being more likely to contain coldwater fish species than areas from the southeast (Map 1b). For example, given a stream with a $30mi^2$ drainage area, the indicator species had a higher likelihood of occurring in the northwestern two-thirds (probability of occurrence >70 percent) of the state than the southeastern third (<30 percent probability of occurrence) of the state. Maps 2 (calibration) and 3 (validation) demonstrate major probability of occurrence categories for coldwater fish indicator species based on model predictions compared at actual fish sample locations and instances of correct and incorrect predictions. The results demonstrate that most sites are correctly classified (>89 percent -calibration; >83 percent -validation) and would result in the application of the correct dissolved oxygen criteria.

3.5 Model limitations

The application of the model is limited to streams with drainage areas less than 100 square miles as only nine sites (6 percent) used to create the model drained larger areas. Similarly, because of limited data and uncertainty associated with the model, it is recommended that streams with less than a five square mile drainage and southeast of the 50 percent probability of occurrence threshold line be field verified before the determination of coldwater fish species presence or absence (Map 1a). The data used to create the model only included a total of five sites (three percent) with drainage areas less than five square miles and that were beyond the limits (south and east) of the associated threshold line. Of these five sites, only two were observed to contain naturally existing populations of Brook trout or slimy sculpin. These limited results suggest that coldwater fish species may naturally occur throughout New Hampshire in streams with small (less than five square miles) drainage areas. It is believed that sites were coldwater fish species naturally occur outside the model's predictions are strongly influenced by groundwater contributions to overall streamflow resulting in cooler water temperatures. As more data become available it may be advantageous to incorporate a groundwater variable into future efforts to improve the model.

Additionally, while stream gradient was not included in the final model, it nevertheless was shown to be important in explaining the presence or absence of coldwater fish indicator species. Specifically, when the calibration and validation datasets were combined, 51 out of 75 (68 percent) of sites with gradients less the 1 percent did not contain either brook trout or slimy sculpin. However, regardless of model predictions, the presence of the indicator species in low gradient (less than one percent) stream segments are apparently limited throughout New Hampshire mostly likely by the absence of suitable physical habitat. Even so, where conditions are favorable for their occurrence and with the exception of manmade or natural barriers, the movement of coldwater fish species is almost certainly continuous through low gradient stream sections. Thus, it is recommended that the coldwater fish species dissolved oxygen criterion be implemented based on model predictions without consideration for stream gradient as coldwater fish species will use low gradient stream sections as corridors or temporary holdover stops between areas of more suitable physical habitat conditions.

Finally, although obvious, it is important to note that the presence or absence coldwater fish species is ultimately driven by stream water temperature and in turn dissolved oxygen concentration (Halliwell 1989). Thus, while proximate factors such as the lack of physical habitat may limit coldwater fish species occurrence even in the presence of optimal water temperatures, coldwater fish species will rarely, if ever, occur where water temperatures are unsuitable regardless of physical habitat conditions. Given undisturbed stream conditions (i.e., no unnatural habitat disturbances), the primary factors controlling water temperature in New Hampshire are latitude and elevation. The data used herein indicate a close relationship between these two factors with higher elevation sites generally occurring at higher latitudes. Specifically, brook trout and slimy sculpin were most often found at sites north of 43.5 degrees latitude and in excess of 500 feet in elevation (Figure 3). However, the data also indicate where these species were found south of 43.5 degrees latitude, 45 percent (nine of 20 sites total) of the sites were at higher elevations (greater than 500ft). Moreover, when drainage area is taken into account, eight of 15 sites (53 percent) with drainage areas less than 15 square miles, south of 43.5 degrees latitude, and above 500 feet in elevation from the calibration and validation datasets combined had naturally occurring populations of either brook trout or slimy sculpin. The results indicate that in certain instances the cooler climate experienced at higher elevations can offset the affect of southern latitudinal warming and create instream thermal regimes favorable to support coldwater fish species. As a result, for stream segments where the elevational affect on instream water temperature are substantial, a re-designation of stream segments may be required based on field sampling results.

3.6 Indicator species occurrence and field measurements

After model development was completed, observed and predicted indicator species presence and absence were compared with instantaneous field measurements for specific conductance, pH, dissolved oxygen, and temperature. For both observed and predicted data, all four environmental variables tested were significantly different between observed and predicted occurrences of Brook trout and slimy sculpin (Table 12). Mean stream water temperatures at sites where indicator species were observed or were predicted to occur were approximately 3 degrees Celsius lower than at sites where observations or predictions were to the contrary. On average, specific conductance was more than twice as high at sites without the indicator species versus sites observed or predicted to contain brook trout or slimy sculpin. Coldwater fish indicator sites also tended to have a higher pH than non-coldwater fish indicator species sites. For dissolved oxygen, sites without brook trout or slimy sculpin had lower dissolved oxygen averages than sites where they were observed or predicted to occur. The significant difference in mean dissolved oxygen concentrations between cold and non-coldwater fish indicator species sites is important as it provides a partial justification for the application of the respective differential standards outlined in Env Ws-1703.07. Further, mean dissolved oxygen concentrations for sites where brook trout or slimy sculpin were observed or predicted to occur were above the spawning period threshold (9.5 mg/L) detailed in Env Ws-1703.07. It is important to note, however, that most, if not all of the dissolved oxygen measurements were taken (summer – fall) outside periods of coldwater fish species spawning and egg incubation periods (late fall - late spring). Thus, given the lower water temperatures in winter as compared with summer and the ability of cold water to hold greater concentrations of dissolved oxygen than warm water, it is likely that dissolved oxygen measurements taken during periods of coldwater fish reproductive activity would be higher than were observed.

Table 12. Mean, range, t-test results between observed and predicted occurrences of coldwater fish indicator species for specific conductance, pH, dissolved oxygen, and water temperature.

		Observed		**Predicted**	
		Present (n=95)	Absent (n=68)	Present (n=186)	Absent (n=186)
Specific Conductance (µmhos)	Mean	58.6	112.4	57.9	121.0
	Range	16-256	31-407	17-256	34-407
	t-test*	5.86, 161, <0.0001		6.99, 161, <0.0001	
pH	Mean	6.74	6.55	6.77	6.47
	Range	5.15-8.81	5.47-7.82	5.32-8.81	5.15-8.33
	t-test*	2.29, 161, 0.023		3.54, 161, 0.0005	
Dissolved Oxygen (mg/L)	Mean	9.67	8.58	9.56	8.62
	Range	4.08-11.29	3.22-11.09	5.80-11.29	3.22-11.09
	t-test*	6.66, 161, <0.0001		5.40, 161, <0.0001	
Water Temperature (°C)	Mean	16.1	19.4	16.3	19.5
	Range	9.3-23.9	13.1-24.6	9.3-23.9	13.1-24.6
	t-test*	8.50, 161, <0.0001		7.94, 161, <0.0001	

* t-test results: t statistic, df, p-value

4. Summary and Recommendations

The determination of the coarse environmental conditions favorable for the support and successful reproduction of coldwater fish species in New Hampshire wadeable streams was based on presence or absence of either resident brook trout or slimy sculpin populations. Both species were considered good indicators as they are strictly associated with cold water, were commonly encountered in fish samples (greater than 30 occurrences), and have a statewide distribution. When considered individually elevation, gradient, drainage area, and latitude were all important in explaining the presence or absence of coldwater fish indicator species. The results indicated that brook trout and slimy sclupin were associated with streams at higher elevations, higher gradients, more northerly latitudes, and smaller drainage areas than streams where these species were absent. Longitude, by itself, was not significantly associated with the presence of indicator species. For landscape-level categorical variables, river basin and bioregion also proved useful in explaining the occurrence of coldwater fish indicator species. Brook trout and slimy sculpin were more commonly observed in northern and western river basins and bioregions. Overall, the results confirm commonly known factors that explain the observed distributional patterns of the indicator species and resident coldwater fish species in general in New Hampshire rivers and streams. However, they do not provide a mechanism useful for predicting where coldwater fish species are expected to occur.

Subsequently a coldwater fish species likelihood of occurrence predictive tool was constructed using fish data from 163 sampling stations collected from 1997 through 2006 using binary logistic regression. The model was constructed using minimally impacted wadeable streams and thus provides a mechanism for predicting the current presence or absence of the indicator species in the absence of significant levels of human perturbation. Model predictions may not coincide with field observations where local anthropogenic impacts have altered the stream conditions (i.e., temperature, dissolved oxygen) necessary to support the indicator species.

The best model was based solely on continuous environmental variables and found to be successful at predicting indicator species presence with an accuracy of between 83 (validation dataset) – 90 percent (calibration dataset). Important variables included in the model were latitude, longitude, and drainage area. Of these variables, latitude proved to be the most important in explaining the presence or absence of the indicator species in wadeable stream segments. Latitude is a coarse and complex environmental variable that influences several interrelated variables. In the northern hemisphere, as one moves north, an obvious and inverse response in stream temperature is expected. Also, as noted in the correlation matrix and specific to New Hampshire, higher latitudes and elevations are also positively correlated ($r = 0.81$). In both situations, the cooler water temperatures associated with more northerly latitudes and higher elevations create an environment more favorable for the existence of coldwater fish species. Thus, the overwhelming importance of latitude in the model was not unexpected. Similarly, the observed occurrence of the indicator species was biased towards western regions of the state. While not important without taking latitude into consideration, the inclusion of longitude into the final predictive model was important in explaining the observed natural decline in frequency of brook trout and slimy sculpin in wadeable streams statewide from northwest to southeast. Finally, the inclusion of drainage area into the final model was important for explaining where indicator species occurred within finer scale geographic regions. For example, within a given area of the state, the indicator species were expected to occur more commonly in small (less than 15 square miles) compared to large drainages (greater than 75 square miles). Taken collectively, based on model predictions, coldwater fish species are most likely to occur in streams with small drainages from areas in northwestern New Hampshire.

Model validation included an adjustment of probability of occurrence thresholds to maximize prediction accuracy and investigate error rates. Using validation data, prediction accuracies were maximized at the 40 percent probability of occurrence threshold (85.4 percent correct predictions). A slight, but minimal, reduction of the model's predictive accuracy was observed at the 50 percent probability of occurrence threshold (83.3 percent). At the same probability threshold, the prediction accuracy for the calibration data was maximized at 89.9 percent. At the 50 percent probability of occurrence threshold Type I and II error rates were 10.4 and 6.3 percent, respectively, for the validation data. Calibration data had a 5.5 percent Type I error rate and 4.6 percent Type II error rate. The results indicate that between six and 10 out of 100 stream segments that do not contain the indicator species would be misclassified as suitable for their occurrence by the model (Type I errors). Conversely, between five and six out of 100 stream segments that contain the indicator species would be misclassified as unsuitable for their occurrence by the model (Type II errors). At the proposed threshold, a stream segment would be expected to contain a coldwater fish species if its geographic position and drainage area resulted in probability of occurrence greater than or equal to 50 percent. The selection of the 50 percent probability of occurrence threshold was an attempt to equally distribute classification errors across stream segments with minimal environmental disturbance where the indicator species were expected to be present or absent.

The decision to balance incorrect predictions of indicator species presence or absence represents an unbiased management decision. At the recommended 50 percent probability of occurrence threshold, the coldwater fish spawning dissolved oxygen criterion would be applied to all streams predicted to have coldwater fish indicator species. At this threshold the improper implementation of dissolved oxygen criteria is expected to occur at low frequencies and approximately equal among stream segments with and without predicted occurrences of brook trout or slimy sculpin. The use of a lower probability of occurrence threshold would result in a higher frequency of expected coldwater fish species occurrence and be more protective of streams by assessing them against a higher dissolved oxygen criterion. However, the use of a low probability of occurrence threshold would also result in a higher risk of applying the coldwater fish species dissolved oxygen criterion to stream segments without naturally occurring coldwater fish species. In contrast, a high probability of occurrence threshold would be less protective of streams that are expected to support coldwater fish species by assessing them against lower dissolved oxygen criterion. If the predictive model is implemented as a tool for determining where differential dissolved oxygen criteria are applied, water quality and fishery managers should work cooperatively to decide on a final probability of occurrence threshold.

The model is limited in application to streams segments with upstream drainage areas from five – 100 square miles based on the data that was used for its construction. Limited observations from southeastern streams with drainages less than 5mi^2 indicate that there is potential for environmental conditions that favor the occurrence of naturally reproducing brook trout or slimy sculpin populations. In contrast, while the data is limited it also indicates that occurrence of the brook trout or slimy sculpin is highly unlikely in streams with drainages 100 square miles, except for streams in extreme northern sections of New Hampshire. However, in certain instances groundwater influx may significantly cool instream water temperatures creating conditions favorable for the support of coldwater fish species regardless of a stream's drainage area or geographic position. In addition, for stream segments with small drainages (less than 15 square miles) at elevations in excess of 500 feet and south of 43.75 degrees latitude, the results indicate that brook trout or slimy sculpin may occur statewide and that model predictions may require adjustment. Finally, it is strongly recommended that field data and professional experience be utilized when necessary to override model predictions and ensure the implementation of the appropriate dissolved oxygen criteria.

While the model appears to provide an acceptable level of accuracy for the prediction of coldwater fish indicator species statewide and subsequent proper dissolved oxygen criteria application, it is not entirely inclusive of all potentially important environmental variables. Several accessory environmental variables could well be important predictors of indicator species likelihood of occurrence. Factors such as substrate size or type, ground water influx (as noted above), riparian cover amount and type, and bedrock geology could all improve the model's accuracy. However, these variables could be time consuming to collect, limited in availability, or weak predictors. Future work might investigate how these variables could be included in future model refinement. There may also be data points included in the model's development where naturally occurring populations of the indicator species have been extirpated due to recent (less than 50 years) or historic (greater 50 years) anthropogenic influences. Such influences (i.e., acid deposition, global climate change) are difficult, if not, impossible to account for. As a result the model represents one developed on the best available information and current distribution of the indicator species yet cannot be considered to be exclusive of all past or prevailing anthropogenic influences.

Ultimately, the logistic regression model based on latitude, longitude, and drainage area appears to be an accurate predictor of the presence of brook trout or slimy sculpin in New Hampshire wadeable streams and has practical application for implementation of the coldwater fish species dissolved oxygen criterion for streams draining drainages between five – 100 square miles. If implemented as suggested, stream segments from nearly 80 percent of New Hampshire could be designated as either expecting to contain or not contain coldwater fish species. While the primary objective of the study was successful in determining where differential dissolved oxygen criteria should be implemented, the model could be applied for other purposes such as the establishment of instream temperature criteria, fish assemblage index development, or environmental permitting. Future efforts should focus on further model refinement and verification through the inclusion of additional data.

5. References

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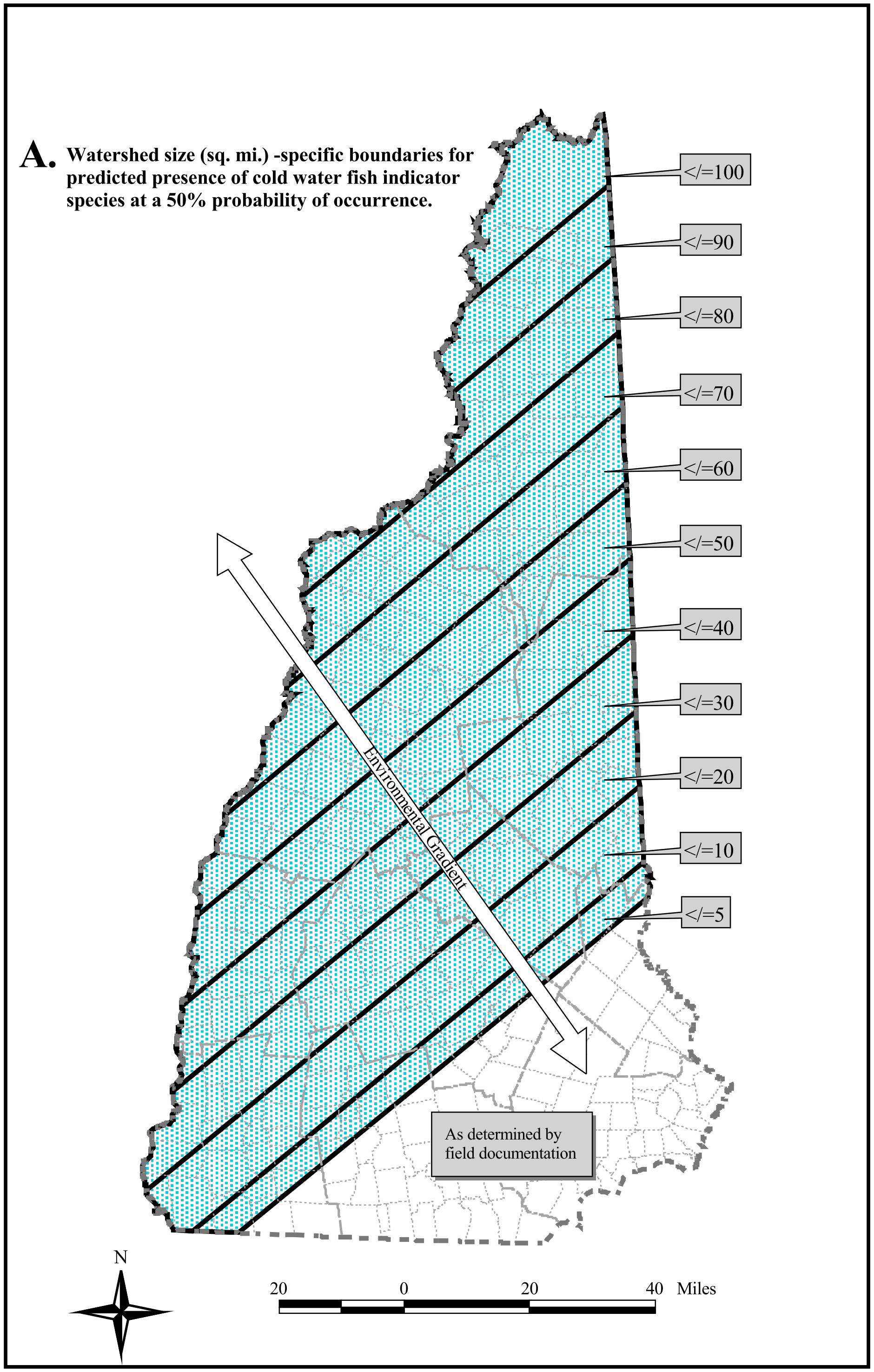
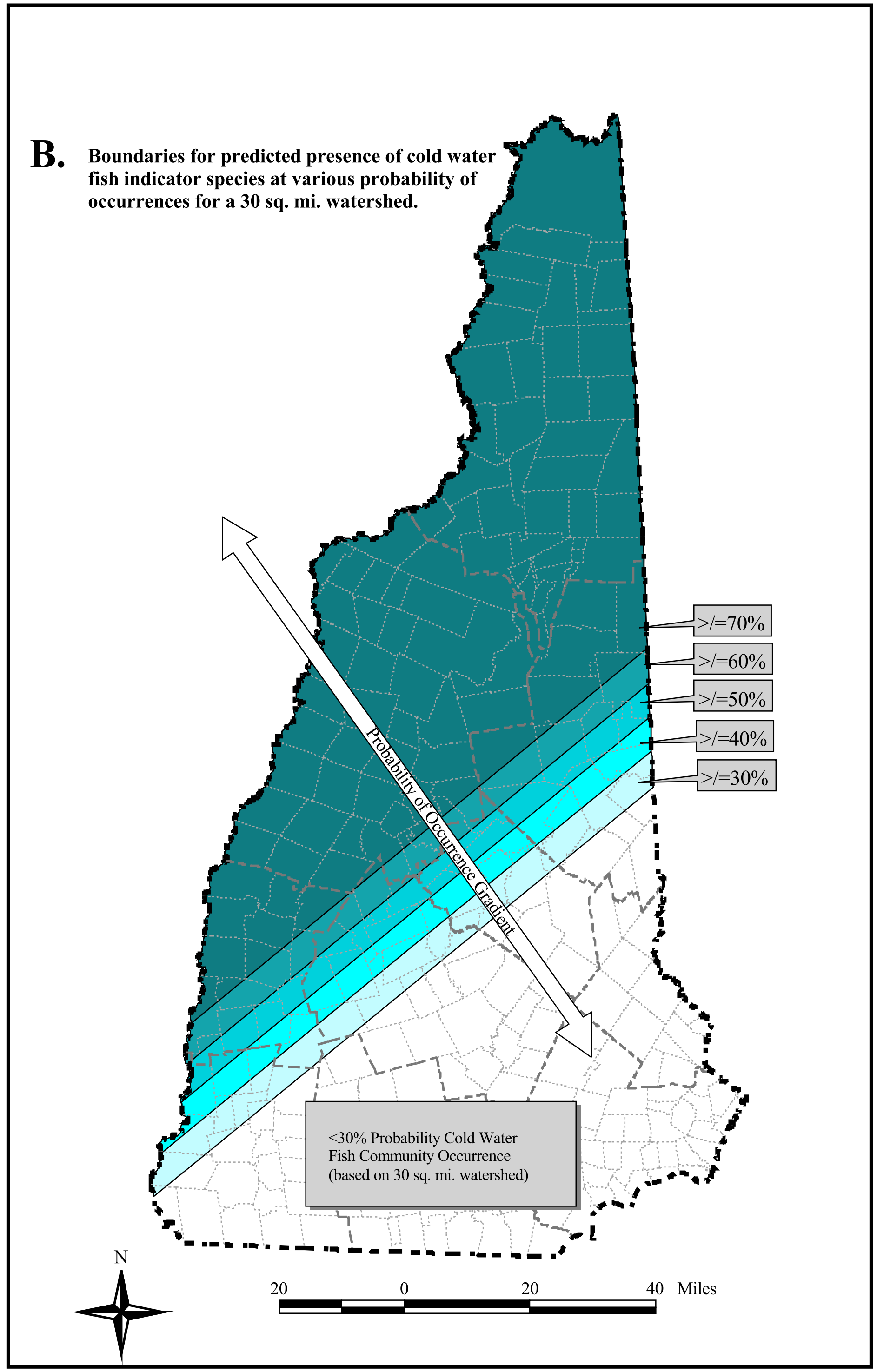
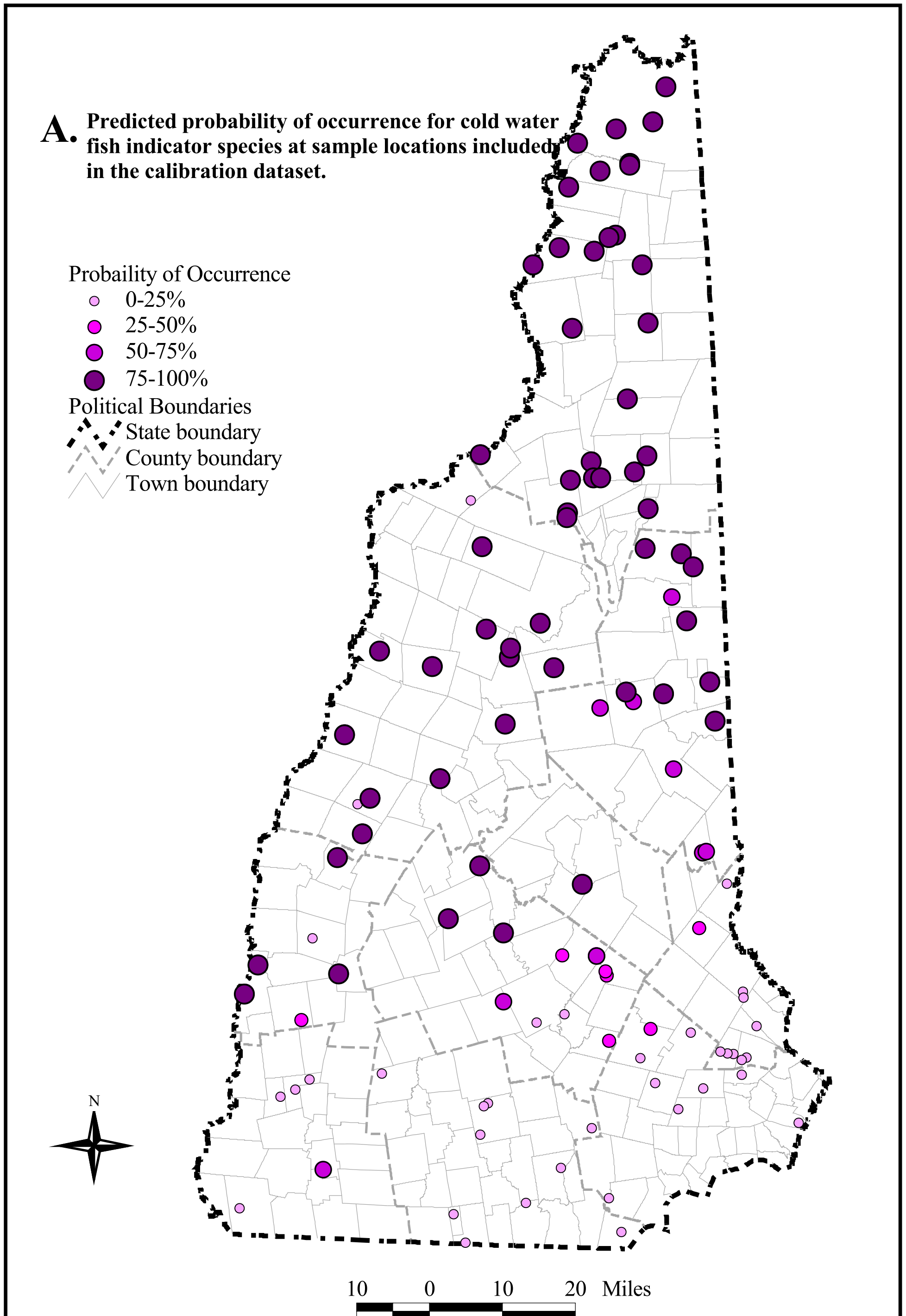
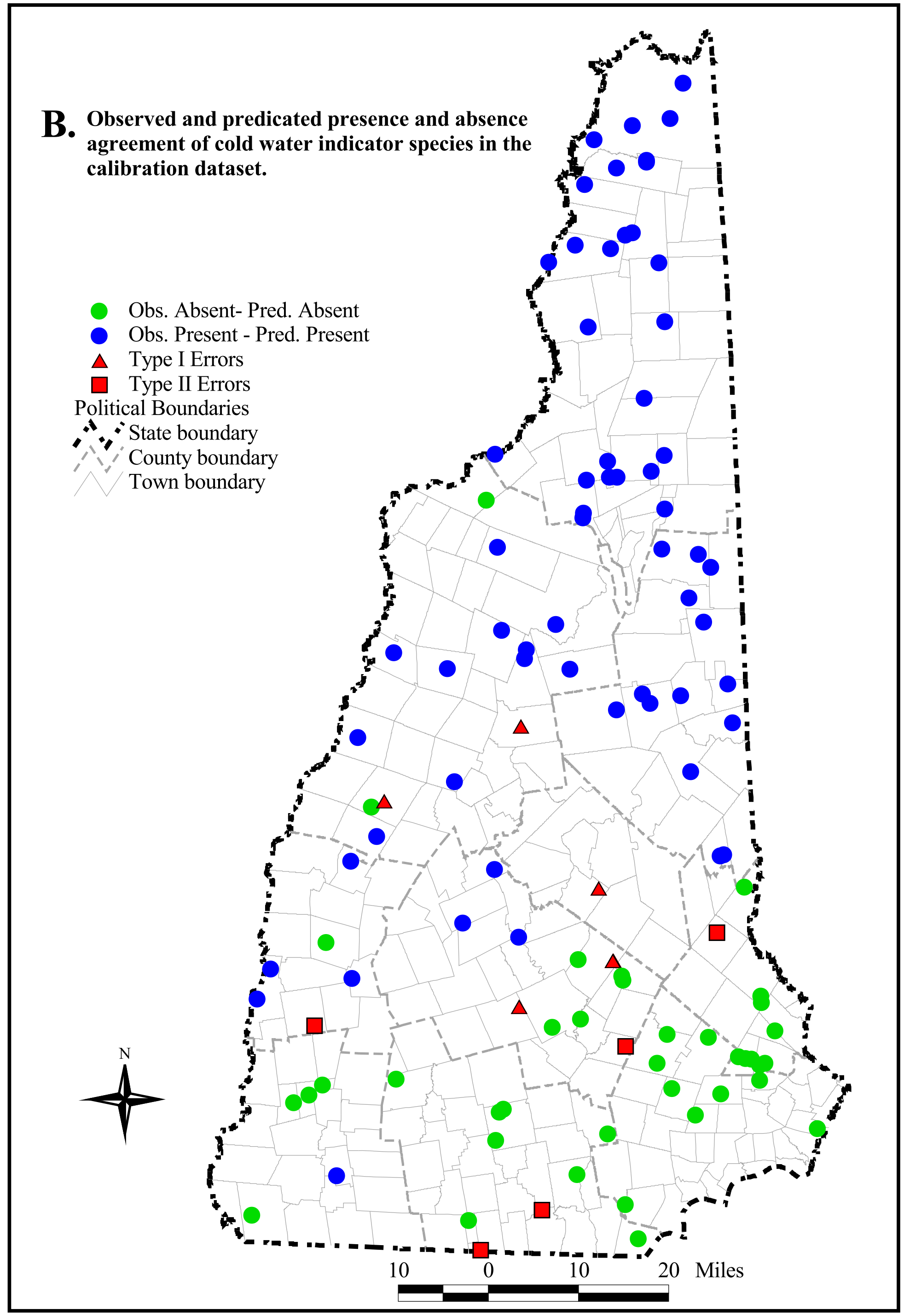
Map 1. Proposed boundaries for predicted occurrence of cold water fish indicator species in New Hampshire wadeable streams. A. - watershed size; B. - Probability of occurrence



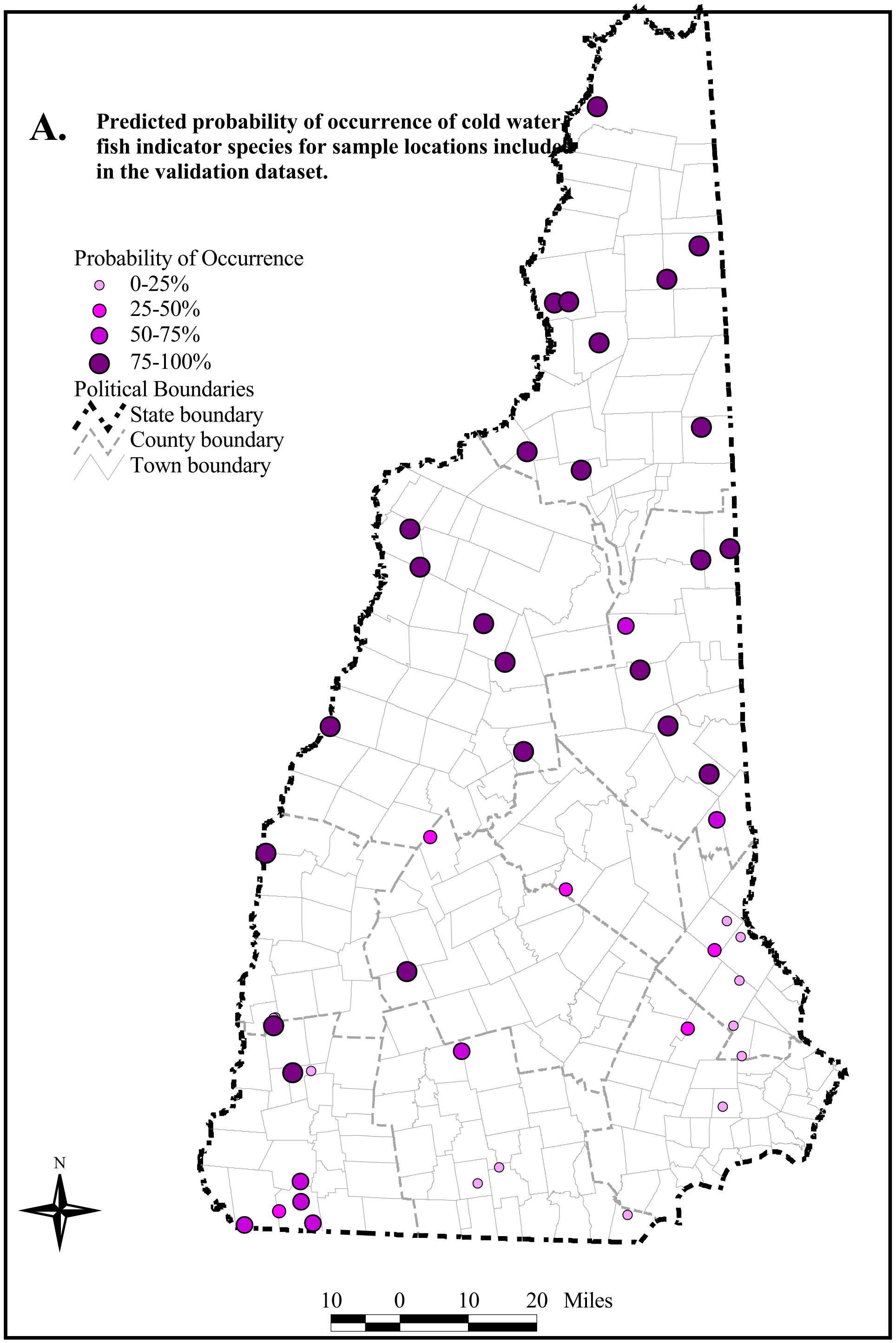


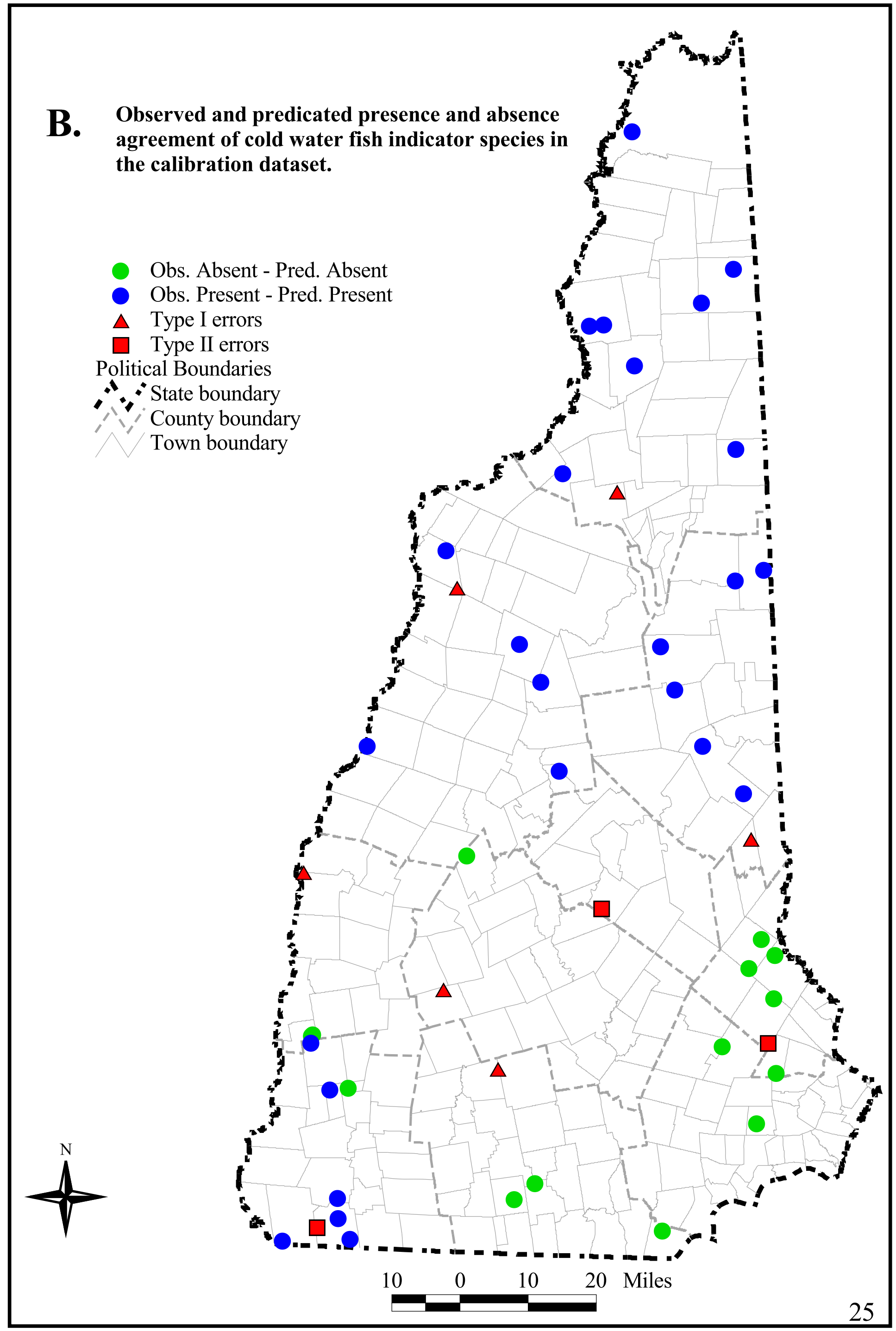
Map 2. Sample locations included in the calibration dataset and corresponding model predictions. A. - Major probability of occurrence categories; B. - Observed and predicted agreement





Map 3. Sample locations included in the validation dataset and corresponding model predictions. A. - Major probability of occurrence categories; B. - Observed and predicted agreement





7. APPENDICIES

Appendix A. Site identifiers, stream name, town, and dataset designation for logistic regression model development.

Appendix B. Continuous and categorical variables.

Appendix C. Observed presence, probability of occurrence, and predicted presence of cold water fish indicator species at fish sample locations.

Appendix A. Site identifiers, stream name, town, and dataset designation for logistic regression model development.

Site_ID	Stream Name	Town	Dataset (Calibration = 1; Validation = 0)
00M-15	Witches Brook	Amherst	1
00M-23	Beaver Brook	Derry	1
00M-48	Baboosic Brook	Merrimack	1
00M-6	Cohas Brook	Manchester	1
00M-7	Shaker Brook	Loudon	1
00M-8	Sanborn Brook	Loudon	1
00P-30	Exeter River	Fremont	1
00P-32	Bellamy River	Madbury	1
00P-46	Little River	Hampton	1
00S-36	Artist Brook	North Conway	1
01A-21	Moose River	Gorham	1
01A-22	Peabody River	Martins Location	1
01C-20	Lafayette Brook	Franconia	1
01M-01	Owl Brook	Holderness	0
01M-02	Beebee River	Campton	1
01M-03	Baker River	Warren	1
01M-05	Jackman Brook	Woodstock	0
01M-07	Moosilauke River	Woodstock	1
01M-08	Soucook River	Pembroke	1
01M-16	Weed Brook	Moultonboro	1
01M-17	Cockermouth River	Groton	1
01S-13	Saco River-East Branch	Bartlett	1
01S-14	Slippery Brook	Chatham	1
01S-15	Burnt Knoll Brook	Chatham	0
01S-23	Ellis River	Sargents Purchase	1
03M-TREND01	Sanborn Brook	CHICHESTER	1
03M-TREND02	Sanborn Brook	CHICHESTER	1
03M-TREND03	Sanborn Brook	LOUDON	1
03p-01	Hartford Brook	DEERFIELD	1
03p-02	Lamprey River	DEERFIELD	1
04c-01	Blow-Me-Down Brook	Cornish	0
04c-03	Tully Brook	Richmond	0
04c-05	Clay Brook	Charlestown	1
04c-07	Pauchaug Brook	Winchester	0
04c-11	Ammonoosuc River	Carroll	1
04c-13	Mohawk River	Colebrook	1
04c-15	Cone Brook	Columbia	1
05a-15	Dead Diamond River	Second College Grant	1
05c-05	Wild Ammonoosuc River	Bath	0
05c-07	Pettyboro Brook	Bath	0
05m-17	Hancock Br. E. Br. Pemigewasset	Lincoln	1
05m-19	Walker Brook	Mason	1
05m-21	M. Br. Piscataquog	New Boston	1
05p-03	Bean River	Nottingham	0

Appendix A. continued			
Site_ID	**Stream Name**	**Town**	**Dataset** (Calibration = 1; Validation = 0)
06c-13	Little Sugar River	Charlestown	1
06c-15	Cushman Brook	Dalton	1
06m-01	Mad River	Waterville Valle	1
06m-11	West Branch Warner River	Bradford	0
06p-07	Oyster River	Barrington	0
97C-152	Blood Brook	GOSHEN	1
97C-153	Skinner Brook	GRANTHAM	1
97C-155	Sugar River	NEWPORT	1
97C-156	Bicknell Brook	ENFIELD	1
97C-157	Rice Brook	RICHMOND	0
97C-160	Martin Brook	SWANZEY	0
97C-162	Ashuelot Brook	WINCHESTER	1
97C-164	Cold River	LANGDON	0
97C-165	Mascoma River	CANAAN	1
97C-166	Ashuelot River	GILSUM	1
97C-167	Ashuelot River	SURRY	1
97C-168	Eastman Brook	PIERMONT	1
97C-169	Ashuelot River	GILSUM	1
97M-159	Smith River	DANBURY	0
98A-13	Clear Stream	MILLSFIELD	1
98A-20	Moose Brook	ERROL	0
98A-21	Sterns Brook	MILAN	1
98C-1	Indian Stream	PITTSBURG	0
98C-10	Simms Stream	COLUMBIA	1
98C-11	East Branch Simms Stream	COLUMBIA	1
98C-12	Mohawk River	COLEBROOK	1
98C-14	Stratford Bog Brook	STRATFORD	0
98C-15	Nash Stream	STRATFORD	1
98C-16	Mill Brook	STARK	0
98C-18	Upper Ammonoosuc River	BERLIN	1
98C-2	Indian Stream	PITTSBURG	1
98C-23	Stag Hollow Brook	JEFFERSON	1
98C-24	Israel River	RANDOLPH	1
98C-25	South Branch Israel River	JEFFERSON	1
98C-26	Cherry Mill Brook	JEFFERSON	1
98C-3	Bishops Brook	STEWARTSTOWN	1
98C-39	Deception Brook	CARROLL	1
98C-4	Perry Stream	PITTSBURG	1
98C-5	Scott Brook	PITTSBURG	1
98C-6	Connecticut River	PITTSBURG	1
98C-7	Dead Water Stream	CLARKSVILLE	1
98C-8	Middle Branch Cedar Stream	CLARKSVILLE	1
98C-9	Bog Brook	CLARKSVILLE	1
98C-90	East Branch Stratford Bog Brook	STRATFORD	0
98P-32	Lamprey River	EPPING	1
98P-48	Mad River	FARMINGTON	1
98P-50	Cocheco River	FARMINGTON	0
98P-51	Cocheco River	ROCHESTER	0

Appendix A. continued			
Site_ID	**Stream Name**	**Town**	**Dataset** (Calibration = 1; Validation = 0)
98P-52	Cocheco River	ROCHESTER	1
98P-53	Isinglass River	ROCHESTER	1
98P-54	Isinglass River	BARRINGTON	0
98P-69	Lamprey River	RAYMOND	1
98P-71	Piscassic River	NEWMARKET	1
98P-72	Little River	LEE	1
98P-73	North River	NOTTINGHAM	1
98P-79	Churchill Brook	BROOKFIELD	1
98S-43	Swift River	TAMWORTH	1
98S-44	Paugus Brook	TAMWORTH	1
98S-46	Whiteface River	SANDWICH	1
98S-55	Bearcamp River	TAMWORTH	1
98S-57	Deer River	MADISON	1
98S-58	Snow Brook	EATON	1
98S-60	Lovell River	OSSIPEE	0
98S-64	Cold Brook	FREEDOM	1
98S-65	Beech River	OSSIPEE	1
99C-26	Shaker Brook	MARLBOROUGH	1
99C-38	Cold River	ACWORTH	1
99C-4	Mirey Brook	RICHMOND	0
99C-52	Warren Brook	ALSTEAD	0
99C-59	Dart Brook	GILSUM	0
99C-60	Ashuelot River	GILSUM	0
99M-17	Beaver Brook	PELHAM	1
99M-27	Middle Branch Piscataquog	NEW BOSTON	1
99M-28	Dudley Brook	DEERING	0
99M-3	North Branch	ANTRIM	1
99M-30	Souhegan River	WILTON	0
99M-32	South Branch Piscataquog River	NEW BOSTON	1
99M-44	Bear Brook	ALLENSTOWN	1
99M-47	Tioga River	BELMONT	1
99M-5	Stirrup Iron Brook	BOSCAWEN	1
99M-6	Needle Shop Brook	HILL	1
99M-8	Bradley Brook	ANDOVER	1
99P-15	Exeter River	BRENTWOOD	0
99P-19	Pike Brook	BROOKFIELD	0
NH HEX 10.02	Bog Brook	WHITEFIELD	0
NH HEX 11.01	Bumpus Brook	RANDOLPH	1
NH HEX 12.02	Peabody Brook	SHELBURNE	0
NH HEX 14.02	Ammonoosuc River	LITTLETON	1
NH HEX 15.01	Appleby Brook	CARROLL	0
NH HEX 16.02	East Branch Saco River	JACKSON	1
NH HEX 18.01	Eastman Brook	THORNTON	1
NH HEX 19.01	Swift River	ALBANY	0
NH HEX 2.05	Indian Stream	PITTSBURG	1
NH HEX 20.01	Langdon Brook	CHATHAM	0
NH HEX 21.05	Grant Brook	LYME	1
NH HEX 22.05	Hubbard Brook	THORNTON	0

Appendix A. continued			
Site_ID	**Stream Name**	**Town**	**Dataset** (Calibration = 1; Validation = 0)
NH HEX 23.01	Johnson Brook	THORNTON	1
NH HEX 24.02	Paugus Brook	TAMWORTH	0
NH HEX 26.05	Hewes Brook	LYME	0
NH HEX 27.04	Mascoma River	CANAAN	1
NH HEX 30.02	Poland Brook	OSSIPEE	0
NH HEX 34.03	Tioga River	BELMONT	0
NH HEX 35.01	Churchill Brook	BROOKFIELD	1
NH HEX 36.01	Branch River	MILTON	1
NH HEX 38.05	Trask Brook	SUNAPEE	1
NH HEX 39.01	Dolf Brook	HOPKINTON	1
NH HEX 41.04	Berry Brook	FARMINGTON	0
NH HEX 43.03	Cold River	LANGDON	0
NH HEX 46.02	Turkey River	CONCORD	1
NH HEX 53.01	Purgatory Brook	LYNDEBOROUGH	0
NH HEX 59.03	Souhegan River	GREENVILLE	1
NH HEX 6.01 (RD)	Unnamed Brook	ERROL	0
NH HEX 61.04	Beaver Brook	PELHAM	0
NH HEX 9.05	Newell Brook	DUMMER	1
sp03p-101	Lamprey River	LEE	0
sp03p-102	Lamprey River	LEE	1
sp03p-103	Lamprey River	LEE	1
sp03p-104	Lamprey River	DURHAM	1
sp03p-105	Lamprey River	DURHAM	1

Appendix B. Continuous and categorical variables.

Site_ID	Stream Name	Elevation (ft)	Watershed Area (mi^2)	Longitude (dd.dddd)	Latitude (dd.dddd)	Gradient (%)	Basin	Bioregion
00M-15	Witches Brook	201	4.7	71.5953	42.7956	0.29	Merrimack	coastal_merrimack
00M-23	Beaver Brook	193	41.5	71.3533	42.8063	0.20	Merrimack	coastal_merrimack
00M-48	Baboosic Brook	177	49.0	71.4926	42.8709	0.39	Merrimack	coastal_merrimack
00M-6	Cohas Brook	209	15.0	71.4034	42.9568	0.00	Merrimack	coastal_merrimack
00M-7	Shaker Brook	451	14.3	71.4878	43.3279	1.24	Merrimack	coastal_merrimack
00M-8	Sanborn Brook	604	5.3	71.3873	43.3267	1.11	Merrimack	coastal_merrimack
00P-30	Exeter River	169	1.2	71.1489	42.9962	0.12	Piscataqua	coastal_merrimack
00P-32	Bellamy River	93	23.5	70.9167	43.1743	0.25	Piscataqua	coastal_merrimack
00P-46	Little River	18	6.2	70.7964	42.9645	0.05	Piscataqua	coastal_merrimack
00S-36	Artist Brook	512	2.2	71.1156	44.0465	7.86	Saco	coastal_merrimack
01A-21	Moose River	962	5.9	71.2302	44.4007	3.03	Androscoggin	androscoggin
01A-22	Peabody River	1582	5.9	71.2279	44.2876	3.84	Androscoggin	androscoggin
01C-20	Lafayette Brook	1072	6.5	71.7245	44.2071	4.07	Connecticut	Upper CT
01M-01	Owl Brook	631	7.2	71.6292	43.7322	1.36	Merrimack	coastal_merrimack
01M-02	Beebee River	538	29.3	71.6563	43.8251	1.49	Merrimack	coastal_merrimack
01M-03	Baker River	963	19.5	71.8723	43.9484	2.36	Merrimack	coastal_merrimack
01M-05	Jackman Brook	1340	5.2	71.7467	44.0026	2.32	Merrimack	coastal_merrimack
01M-07	Moosilauke River	815	17.1	71.7119	44.0292	2.25	Merrimack	coastal_merrimack
01M-08	Soucook River	263	86.0	71.481	43.201	0.19	Merrimack	coastal_merrimack
01M-16	Weed Brook	593	5.5	71.3874	43.775	0.54	Merrimack	coastal_merrimack
01M-17	Cockermouth River	670	13.3	71.8499	43.7074	2.57	Merrimack	coastal_merrimack
01S-13	Saco River-East Branch	520	39.6	71.1591	44.0979	1.86	Saco	coastal_merrimack
01S-14	Slippery Brook	1369	8.3	71.0939	44.1622	4.03	Saco	coastal_merrimack
01S-15	Burnt Knoll Brook	1023	3.0	71.1096	44.1358	2.50	Saco	coastal_merrimack
01S-23	Ellis River	1180	13.6	71.2378	44.202	4.11	Saco	coastal_merrimack
03M-TREND01	Sanborn Brook	450	10.1	71.3605	43.2927	1.11	Merrimack	coastal_merrimack
03M-TREND02	Sanborn Brook	424	10.7	71.3583	43.2845	1.11	Merrimack	coastal_merrimack
03M-TREND03	Sanborn Brook	599	5.3	71.3878	43.3266	1.11	Merrimack	coastal_merrimack
03p-01	Hartford Brook	255	9.8	71.2596	43.107	0.35	Piscataqua	coastal_merrimack
03p-02	Lamprey River	452	4.9	71.2298	43.1688	0.82	Piscataqua	coastal_merrimack
04c-01	Blow-Me-Down Brook	423	25.0	72.3765	43.5159	0.90	Connecticut	Lower CT
04c-03	Tully Brook	938	5.3	72.2322	42.7365	2.43	Connecticut	Lower CT
04c-05	Clay Brook	330	4.4	72.4245	43.2424	2.40	Connecticut	Lower CT
04c-07	Pauchaug Brook	337	5.1	72.4281	42.7313	2.37	Connecticut	Lower CT
04c-11	Ammonoosuc River	1549	37.0	71.4712	44.269	0.17	Connecticut	Upper CT
04c-13	Mohawk River	1494	8.4	71.3428	44.8712	2.21	Connecticut	Upper CT
04c-15	Cone Brook	989	7.3	71.572	44.8132	7.39	Connecticut	Upper Ct
05a-15	Dead Diamond River	1360	26.3	71.0853	44.9426	0.11	Androscoggin	Androscoggin
05c-05	Wild Ammonoosuc River	848	48.3	71.9318	44.1218	1.48	Connecticut	Upper CT
05c-07	Pettyboro Brook	638	13.2	71.9628	44.2012	1.32	Connecticut	Upper CT
05m-17	Hancock Br. E. Br. Pemigewasset	1532	11.9	71.5516	44.0419	2.62	Merrimack	coastal_merrimack
05m-19	Walker Brook	445	6.1	71.7726	42.7106	2.27	Merrimack	coastal_merrimack
05m-21	M. Br. Piscataquog	496	15.8	71.7181	43.0035	0.97	Merrimack	coastal_merrimack
05p-03	Bean River	276	4.1	71.157	43.146	0.64	Piscataqua	coastal_merrimack
06c-13	Little Sugar River	343	29.3	72.3853	43.3057	2.09	Connecticut	Lower_CT
06c-15	Cushman Brook	894	8.3	71.731	44.4046	2.58	Connecticut	Upper_CT
06m-01	Mad River	1435	24.7	71.5108	43.9467	1.54	Merrimack	coastal_merrimack
06m-11	West Branch Warner River	670	10.9	71.9674	43.2678	1.29	Merrimack	coastal_merrimack
06p-07	Oyster River	165	2.2	71.0227	43.1529	0.94	Piscataqua	coastal_merrimack
97C-152	Blood Brook	996	6.1	72.1473	43.287	2.45	Connecticut	Lower CT
97C-153	Skinner Brook	1354	4.8	72.1531	43.5373	2.38	Connecticut	Lower CT
97C-155	Sugar River	688	218.5	72.2248	43.3634	0.81	Connecticut	Lower CT

Appendix B. continued								
Site_ID	**Stream Name**	**Elevation (ft)**	**Watershed Area (mi^2)**	**Longitude (dd.dddd)**	**Latitude (dd.dddd)**	**Gradient (%)**	**Basin**	**Bioregion**
97C-156	Bicknell Brook	986	9.2	72.0784	43.5892	1.82	Connecticut	Lower CT
97C-157	Rice Brook	660	4.5	72.2681	42.7801	1.27	Connecticut	Lower CT
97C-160	Martin Brook	494	8.6	72.2698	42.8231	0.49	Connecticut	Lower CT
97C-162	Ashuelot Brook	423	391.9	72.4329	42.7817	0.66	Connecticut	Lower CT
97C-164	Cold River	617	59.3	72.3456	43.1695	1.11	Connecticut	Lower CT
97C-165	Mascoma River	812	81.0	72.0934	43.652	0.20	Connecticut	Lower CT
97C-166	Ashuelot River	802	71.9	72.2712	43.0387	1.44	Connecticut	Lower CT
97C-167	Ashuelot River	528	95.3	72.3145	43.022	0.35	Connecticut	Lower CT
97C-168	Eastman Brook	829	14.8	72.0309	43.9817	1.72	Connecticut	Lower CT
97C-169	Ashuelot River	1062	64.1	72.2309	43.0601	1.48	Connecticut	Lower CT
97M-159	Smith River	823	40.2	71.9004	43.5517	0.12	Merrimack	coastal_merrimack
98A-13	Clear Stream	1348	19.7	71.2418	44.8119	0.85	Androscoggin	androscoggin
98A-20	Moose Brook	1550	3.6	71.2043	44.7277	3.60	Androscoggin	androscoggin
98A-21	Sterns Brook	1225	34.7	71.1263	44.5331	0.64	Androscoggin	androscoggin
98C-1	Indian Stream	1307	63.5	71.4097	45.0924	0.36	Connecticut	Upper CT
98C-10	Simms Stream	1266	28.0	71.4933	44.8494	1.30	Connecticut	Upper CT
98C-11	East Branch Simms Stream	1799	2.3	71.3866	44.8419	2.15	Connecticut	Upper CT
98C-12	Mohawk River	1881	1.4	71.3218	44.8754	4.79	Connecticut	Upper CT
98C-14	Stratford Bog Brook	1011	16.9	71.5379	44.6783	2.84	Connecticut	Upper CT
98C-15	Nash Stream	1377	38.4	71.4539	44.6758	1.41	Connecticut	Upper CT
98C-16	Mill Brook	1063	15.5	71.4051	44.5946	3.54	Connecticut	Upper CT
98C-18	Upper Ammonoosuc River	1157	48.7	71.2879	44.5235	0.58	Connecticut	Upper CT
98C-2	Indian Stream	1229	67.4	71.4354	45.0744	0.36	Connecticut	Upper CT
98C-23	Stag Hollow Brook	1571	7.5	71.3976	44.3895	2.97	Connecticut	Upper CT
98C-24	Israel River	1457	8.2	71.3699	44.355	2.41	Connecticut	Upper CT
98C-25	South Branch Israel River	1387	10.5	71.3919	44.355	5.19	Connecticut	Upper CT
98C-26	Cherry Mill Brook	1349	0.2	71.461	44.3497	2.12	Connecticut	Upper CT
98C-3	Bishops Brook	1133	13.5	71.4637	44.9792	0.41	Connecticut	Upper CT
98C-39	Deception Brook	1739	4.2	71.4702	44.2789	2.54	Connecticut	Upper CT
98C-4	Perry Stream	1579	24.4	71.32	45.1043	0.41	Connecticut	Upper CT
98C-5	Scott Brook	1999	8.1	71.167	45.1941	0.47	Connecticut	Upper CT
98C-6	Connecticut River	1644	59.9	71.2071	45.119	0.53	Connecticut	Upper CT
98C-7	Dead Water Stream	1531	13.3	71.3674	45.0143	2.02	Connecticut	Upper CT
98C-8	Middle Branch Cedar Stream	1433	12.6	71.2778	45.0261	1.52	Connecticut	Upper CT
98C-9	Bog Brook	1435	8.8	71.2778	45.0298	2.17	Connecticut	Upper CT
98C-90	East Branch Stratford Bog Brook	1548	2.4	71.496	44.6817	4.36	Connecticut	Upper CT
98P-32	Lamprey River	108	106.6	71.075	43.0413	0.20	Piscataqua	coastal_merrimack
98P-48	Mad River	343	10.5	71.0841	43.3852	1.38	Piscataqua	coastal_merrimack
98P-50	Cocheco River	251	48.3	71.0408	43.3729	0.22	Piscataqua	coastal_merrimack
98P-51	Cocheco River	229	58.1	71.0014	43.3393	0.11	Piscataqua	coastal_merrimack
98P-52	Cocheco River	119	84.7	70.9571	43.2482	0.18	Piscataqua	coastal_merrimack
98P-53	Isinglass River	122	73.8	70.9547	43.2347	0.13	Piscataqua	coastal_merrimack
98P-54	Isinglass River	189	66.4	71.0057	43.2473	0.19	Piscataqua	coastal_merrimack
98P-69	Lamprey River	191	52.4	71.2164	43.0531	0.04	Piscataqua	coastal_merrimack
98P-71	Piscassic River	68	19.4	70.9623	43.0693	0.24	Piscataqua	coastal_merrimack
98P-72	Little River	129	20.0	71.0239	43.1192	0.71	Piscataqua	coastal_merrimack
98P-73	North River	296	8.7	71.1103	43.1612	0.71	Piscataqua	coastal_merrimack
98P-79	Churchill Brook	578	4.9	71.0714	43.5472	1.62	Piscataqua	coastal_merrimack
98S-43	Swift River	645	28.1	71.2748	43.8733	1.29	Saco	coastal_merrimack
98S-44	Paugus Brook	743	25.3	71.2968	43.8934	1.29	Saco	coastal_merrimack
98S-46	Whiteface River	717	29.5	71.3746	43.86	0.42	Saco	coastal_merrimack
98S-55	Bearcamp River	491	67.6	71.2836	43.8313	0.57	Saco	coastal_merrimack
98S-57	Deer River	515	4.3	71.1855	43.8894	0.88	Saco	coastal_merrimack
98S-58	Snow Brook	644	3.9	71.0466	43.9144	1.80	Saco	coastal_merrimack
98S-60	Lovell River	655	14.0	71.2083	43.785	1.47	Saco	coastal_merrimack

Appendix B. continued								
Site_ID	**Stream Name**	**Elevation (ft)**	**Watershed Area (mi^2)**	**Longitude (dd.dddd)**	**Latitude (dd.dddd)**	**Gradient (%)**	**Basin**	**Bioregion**
98S-64	Cold Brook	621	4.8	71.0322	43.8305	1.90	Saco	coastal_merrimack
98S-65	Beech River	520	15.0	71.1565	43.7271	0.58	Saco	coastal_merrimack
99C-26	Shaker Brook	983	9.6	72.1881	42.8669	0.81	Connecticut	Lower CT
99C-38	Cold River	915	34.7	72.2557	43.1876	0.47	Connecticut	Lower CT
99C-4	Mirey Brook	591	13.8	72.3297	42.7606	0.09	Connecticut	Lower CT
99C-52	Warren Brook	510	12.5	72.3519	43.1528	3.83	Connecticut	Lower CT
99C-59	Dart Brook	793	6.1	72.295	43.0531	2.37	Connecticut	Lower CT
99C-60	Ashuelot River	1070	65.6	72.2417	43.0575	2.27	Connecticut	Lower CT
99M-17	Beaver Brook	154	73.0	71.3164	42.7333	0.01	Merrimack	coastal_merrimack
99M-27	Middle Branch Piscataquog	442	17.5	71.7061	43.0103	0.97	Merrimack	coastal_merrimack
99M-28	Dudley Brook	831	8.7	71.8083	43.0997	1.69	Merrimack	coastal_merrimack
99M-3	North Branch	1030	51.1	72.0186	43.0731	0.87	Merrimack	coastal_merrimack
99M-30	Souhegan River	490	63.8	71.7606	42.8211	0.75	Merrimack	coastal_merrimack
99M-32	South Branch Piscataquog River	519	41.6	71.7283	42.9431	0.35	Merrimack	coastal_merrimack
99M-44	Bear Brook	388	9.9	71.3511	43.1441	0.59	Merrimack	coastal_merrimack
99M-47	Tioga River	783	4.1	71.4282	43.4806	1.19	Merrimack	coastal_merrimack
99M-5	Stirrup Iron Brook	417	5.9	71.661	43.3759	2.99	Merrimack	coastal_merrimack
99M-6	Needle Shop Brook	686	6.5	71.7317	43.52	1.94	Merrimack	coastal_merrimack
99M-8	Bradley Brook	853	2.2	71.8247	43.4067	2.32	Merrimack	coastal_merrimack
99P-15	Exeter River	96	62.4	71.0578	42.981	0.20	Piscataqua	coastal_merrimack
99P-19	Pike Brook	601	3.8	71.0687	43.5864	0.09	Piscataqua	coastal_merrimack
NH HEX 10.02	Bog Brook	953	12.4	71.6181	44.3651	0.69	Connecticut	Upper CT
NH HEX 11.01	Bumpus Brook	1359	1.5	71.2681	44.367	14.29	Androscoggin	androscoggin
NH HEX 12.02	Peabody Brook	792	1.9	71.1051	44.4155	12.93	Androscoggin	androscoggin
NH HEX 14.02	Ammonoosuc River	820	125.0	71.7594	44.3071	0.77	Connecticut	Upper CT
NH HEX 15.01	Appleby Brook	1703	2.2	71.459	44.3266	6.16	Connecticut	Upper CT
NH HEX 16.02	East Branch Saco River	1701	9.9	71.1299	44.1905	3.22	Saco	coastal_merrimack
NH HEX 18.01	Eastman Brook	992	11.5	71.6395	43.9892	1.43	Merrimack	coastal_merrimack
NH HEX 19.01	Swift River	1230	45.8	71.33	43.9973	0.01	Saco	coastal_merrimack
NH HEX 2.05	Indian Stream	1175	69.9	71.4391	45.0599	0.36	Connecticut	Upper CT
NH HEX 20.01	Langdon Brook	670	4.2	71.0246	44.1583	3.43	Saco	coastal_merrimack
NH HEX 21.05	Grant Brook	743	11.9	72.1339	43.801	2.54	Connecticut	Lower CT
NH HEX 22.05	Hubbard Brook	584	13.3	71.6827	43.92	3.08	Merrimack	coastal_merrimack
NH HEX 23.01	Johnson Brook	1010	5.2	71.644	43.969	4.98	Merrimack	coastal_merrimack
NH HEX 24.02	Paugus Brook	795	11.5	71.2894	43.9044	1.90	Saco	coastal_merrimack
NH HEX 26.05	Hewes Brook	459	10.6	72.1956	43.7851	2.27	Connecticut	Lower CT
NH HEX 27.04	Mascoma River	872	32.4	72.0574	43.6657	0.51	Connecticut	Lower CT
NH HEX 30.02	Poland Brook	535	3.8	71.0901	43.6839	1.59	Saco	coastal_merrimack
NH HEX 34.03	Tioga River	492	23.4	71.507	43.4413	0.15	Merrimack	coastal_merrimack
NH HEX 35.01	Churchill Brook	533	7.0	71.0613	43.5499	0.50	Piscataqua	coastal_merrimack
NH HEX 36.01	Branch River	426	53.5	71.0015	43.481	0.15	Piscataqua	coastal_merrimack
NH HEX 38.05	Trask Brook	945	4.3	72.1232	43.3476	0.45	Connecticut	Lower CT
NH HEX 39.01	Dolf Brook	356	6.3	71.6617	43.2283	0.19	Merrimack	coastal_merrimack
NH HEX 41.04	Berry Brook	439	6.4	71.078	43.3118	0.75	Piscataqua	coastal_merrimack
NH HEX 43.03	Cold River	603	59.9	72.3501	43.1679	1.11	Connecticut	Lower CT
NH HEX 46.02	Turkey River	274	32.3	71.5639	43.1844	0.15	Merrimack	coastal_merrimack
NH HEX 53.01	Purgatory Brook	267	12.0	71.6993	42.8554	1.73	Merrimack	coastal_merrimack
NH HEX 59.03	Souhegan River	747	30.6	71.8061	42.7721	1.60	Connecticut	Lower CT
NH HEX 6.01 (RD)	Unnamed Brook	1291	1.4	71.1089	44.7986	2.44	Androscoggin	androscoggin
NH HEX 61.04	Beaver Brook	140	52.5	71.3324	42.7541	0.01	Merrimack	coastal_merrimack
NH HEX 9.05	Newell Brook	1273	6.7	71.2253	44.6862	2.61	Androscoggin	androscoggin
sp03p-101	Lamprey River	75	153.1	71.0007	43.0878	0.10	Piscataqua	coastal_merrimack
sp03p-102	Lamprey River	62	181.2	71.0032	43.1155	0.01	Piscataqua	coastal_merrimack
sp03p-103	Lamprey River	58	183.0	70.9858	43.1144	0.16	Piscataqua	coastal_merrimack

Appendix B. continued								
Site_ID	**Stream Name**	**Elevation (ft)**	**Watershed Area (mi^2)**	**Longitude (dd.dddd)**	**Latitude (dd.dddd)**	**Gradient (%)**	**Basin**	**Bioregion**
sp03p-104	Lamprey River	44	184.3	70.9618	43.1018	0.16	Piscataqua	coastal_merrimack
sp03p-105	Lamprey River	39	185.0	70.9483	43.1054	0.16	Piscataqua	coastal_merrimack

Appendix C. Observed presence, probability of occurrence, and predicted presence of cold water fish indicator species at fish sample locations.

Site_ID	Stream Name	Town	Observed (1=present; 0=absent)	Probability of occurrence	Predicted (1=present; 2=absent)
00M-15	Witches Brook	Amherst	1	0.176	0
00M-23	Beaver Brook	Derry	0	0.003	0
00M-48	Baboosic Brook	Merrimack	0	0.004	0
00M-6	Cohas Brook	Manchester	0	0.094	0
00M-7	Shaker Brook	Loudon	0	0.494	0
00M-8	Sanborn Brook	Loudon	0	0.624	1
00P-30	Exeter River	Fremont	0	0.174	0
00P-32	Bellamy River	Madbury	0	0.031	0
00P-46	Little River	Hampton	0	0.036	0
00S-36	Artist Brook	North Conway	1	0.975	1
01A-21	Moose River	Gorham	1	0.996	1
01A-22	Peabody River	Martins Location	1	0.993	1
01C-20	Lafayette Brook	Franconia	1	0.997	1
01M-01	Owl Brook	Holderness	1	0.960	1
01M-02	Beebee River	Campton	0	0.842	1
01M-03	Baker River	Warren	1	0.980	1
01M-05	Jackman Brook	Woodstock	1	0.994	1
01M-07	Moosilauke River	Woodstock	1	0.983	1
01M-08	Soucook River	Pembroke	0	0.001	0
01M-16	Weed Brook	Moultonboro	0	0.943	1
01M-17	Cockermouth River	Groton	1	0.959	1
01S-13	Saco River-East Branch	Bartlett	1	0.642	1
01S-14	Slippery Brook	Chatham	1	0.974	1
01S-15	Burnt Knoll Brook	Chatham	1	0.983	1
01S-23	Ellis River	Sargents Purchase	1	0.978	1
03M-TREND01	Sanborn Brook	CHICHESTER	0	0.448	0
03M-TREND02	Sanborn Brook	CHICHESTER	0	0.424	0
03M-TREND03	Sanborn Brook	LOUDON	0	0.624	1
03p-01	Hartford Brook	DEERFIELD	0	0.190	0
03p-02	Lamprey River	DEERFIELD	0	0.318	0
04c-01	Blow-Me-Down Brook	Cornish	0	0.937	1
04c-03	Tully Brook	Richmond	1	0.516	1
04c-05	Clay Brook	Charlestown	1	0.966	1
04c-07	Pauchaug Brook	Winchester	1	0.658	1
04c-11	Ammonoosuc River	Carroll	1	0.935	1
04c-13	Mohawk River	Colebrook	1	1.000	1
04c-15	Cone Brook	Columbia	1	1.000	1
05a-15	Dead Diamond River	Second College Grant	0	0.997	1
05c-05	Wild Ammonoosuc River	Bath	0	0.908	1
05c-07	Pettyboro Brook	Bath	1	0.998	1
05m-17	Hancock Br. E. Br. Pemigewasset	Lincoln	1	0.984	1
05m-19	Walker Brook	Mason	1	0.173	0
05m-21	M. Br. Piscataquog	New Boston	0	0.245	0
05p-03	Bean River	Nottingham	0	0.263	0
06c-13	Little Sugar River	Charlestown	1	0.775	1
06c-15	Cushman Brook	Dalton	1	0.999	1
06m-01	Mad River	Waterville Valle	1	0.907	1

Appendix C. continued					
Site_ID	**Stream Name**	**Town**	**Observed (1=present; 0=absent)**	**Probability of occurrence**	**Predicted (1=present; 2=absent)**
06m-11	West Branch Warner River	Bradford	0	0.813	1
06p-07	Oyster River	Barrington	1	0.225	0
97C-152	Blood Brook	GOSHEN	1	0.929	1
97C-153	Skinner Brook	GRANTHAM	1	0.982	1
97C-155	Sugar River	NEWPORT	0	0.000	0
97C-156	Bicknell Brook	ENFIELD	1	0.974	1
97C-157	Rice Brook	RICHMOND	1	0.616	1
97C-160	Martin Brook	SWANZEY	1	0.579	1
97C-162	Ashuelot Brook	WINCHESTER	0	0.000	0
97C-164	Cold River	LANGDON	0	0.085	0
97C-165	Mascoma River	CANAAN	0	0.063	0
97C-166	Ashuelot River	GILSUM	0	0.011	0
97C-167	Ashuelot River	SURRY	0	0.001	0
97C-168	Eastman Brook	PIERMONT	1	0.993	1
97C-169	Ashuelot River	GILSUM	0	0.023	0
97M-159	Smith River	DANBURY	0	0.498	0
98A-13	Clear Stream	MILLSFIELD	1	0.998	1
98A-20	Moose Brook	ERROL	1	0.999	1
98A-21	Sterns Brook	MILAN	0	0.961	1
98C-1	Indian Stream	PITTSBURG	1	0.986	1
98C-10	Simms Stream	COLUMBIA	1	0.999	1
98C-11	East Branch Simms Stream	COLUMBIA	1	1.000	1
98C-12	Mohawk River	COLEBROOK	1	1.000	1
98C-14	Stratford Bog Brook	STRATFORD	1	0.999	1
98C-15	Nash Stream	STRATFORD	1	0.990	1
98C-16	Mill Brook	STARK	1	0.998	1
98C-18	Upper Ammonoosuc River	BERLIN	1	0.912	1
98C-2	Indian Stream	PITTSBURG	1	0.980	1
98C-23	Stag Hollow Brook	JEFFERSON	1	0.997	1
98C-24	Israel River	RANDOLPH	1	0.996	1
98C-25	South Branch Israel River	JEFFERSON	1	0.995	1
98C-26	Cherry Mill Brook	JEFFERSON	1	0.998	1
98C-3	Bishops Brook	STEWARTSTOWN	1	1.000	1
98C-39	Deception Brook	CARROLL	1	0.997	1
98C-4	Perry Stream	PITTSBURG	1	1.000	1
98C-5	Scott Brook	PITTSBURG	1	1.000	1
98C-6	Connecticut River	PITTSBURG	1	0.984	1
98C-7	Dead Water Stream	CLARKSVILLE	1	1.000	1
98C-8	Middle Branch Cedar Stream	CLARKSVILLE	1	1.000	1
98C-9	Bog Brook	CLARKSVILLE	1	1.000	1
98C-90	East Branch Stratford Bog Brook	STRATFORD	1	1.000	1
98P-32	Lamprey River	EPPING	0	0.000	0
98P-48	Mad River	FARMINGTON	1	0.351	0
98P-50	Cocheco River	FARMINGTON	0	0.013	0
98P-51	Cocheco River	ROCHESTER	0	0.004	0
98P-52	Cocheco River	ROCHESTER	0	0.000	0
98P-53	Isinglass River	ROCHESTER	0	0.000	0
98P-54	Isinglass River	BARRINGTON	0	0.001	0
98P-69	Lamprey River	RAYMOND	0	0.003	0
98P-71	Piscassic River	NEWMARKET	0	0.031	0
98P-72	Little River	LEE	0	0.045	0
98P-73	North River	NOTTINGHAM	0	0.178	0
98P-79	Churchill Brook	BROOKFIELD	1	0.670	1
98S-43	Swift River	TAMWORTH	1	0.701	1

Appendix C. continued					
Site_ID	**Stream Name**	**Town**	**Observed (1=present; 0=absent)**	**Probability of occurrence**	**Predicted (1=present; 2=absent)**
98S-44	Paugus Brook	TAMWORTH	1	0.784	1
98S-46	Whiteface River	SANDWICH	1	0.723	1
98S-55	Bearcamp River	TAMWORTH	1	0.047	0
98S-57	Deer River	MADISON	1	0.947	1
98S-58	Snow Brook	EATON	1	0.932	1
98S-60	Lovell River	OSSIPEE	1	0.819	1
98S-64	Cold Brook	FREEDOM	1	0.887	1
98S-65	Beech River	OSSIPEE	1	0.722	1
99C-26	Shaker Brook	MARLBOROUGH	1	0.550	1
99C-38	Cold River	ACWORTH	1	0.432	0
99C-4	Mirey Brook	RICHMOND	1	0.425	0
99C-52	Warren Brook	ALSTEAD	1	0.871	1
99C-59	Dart Brook	GILSUM	1	0.861	1
99C-60	Ashuelot River	GILSUM	0	0.020	0
99M-17	Beaver Brook	PELHAM	0	0.000	0
99M-27	Middle Branch Piscataquog	NEW BOSTON	0	0.216	0
99M-28	Dudley Brook	DEERING	0	0.577	1
99M-3	North Branch	ANTRIM	0	0.042	0
99M-30	Souhegan River	WILTON	0	0.002	0
99M-32	South Branch Piscataquog River	NEW BOSTON	0	0.022	0
99M-44	Bear Brook	ALLENSTOWN	1	0.272	0
99M-47	Tioga River	BELMONT	0	0.823	1
99M-5	Stirrup Iron Brook	BOSCAWEN	1	0.825	1
99M-6	Needle Shop Brook	HILL	1	0.921	1
99M-8	Bradley Brook	ANDOVER	1	0.928	1
99P-15	Exeter River	BRENTWOOD	0	0.000	0
99P-19	Pike Brook	BROOKFIELD	0	0.732	1
NH HEX 10.02	Bog Brook	WHITEFIELD	1	0.997	1
NH HEX 11.01	Bumpus Brook	RANDOLPH	1	0.997	1
NH HEX 12.02	Peabody Brook	SHELBURNE	1	0.996	1
NH HEX 14.02	Ammonoosuc River	LITTLETON	0	0.012	0
NH HEX 15.01	Appleby Brook	CARROLL	1	0.998	1
NH HEX 16.02	East Branch Saco River	JACKSON	1	0.977	1
NH HEX 18.01	Eastman Brook	THORNTON	1	0.984	1
NH HEX 19.01	Swift River	ALBANY	1	0.503	1
NH HEX 2.05	Indian Stream	PITTSBURG	0	0.973	1
NH HEX 20.01	Langdon Brook	CHATHAM	1	0.978	1
NH HEX 21.05	Grant Brook	LYME	1	0.991	1
NH HEX 22.05	Hubbard Brook	THORNTON	1	0.977	1
NH HEX 23.01	Johnson Brook	THORNTON	1	0.990	1
NH HEX 24.02	Paugus Brook	TAMWORTH	1	0.931	1
NH HEX 26.05	Hewes Brook	LYME	1	0.992	1
NH HEX 27.04	Mascoma River	CANAAN	0	0.858	1
NH HEX 30.02	Poland Brook	OSSIPEE	1	0.828	1
NH HEX 34.03	Tioga River	BELMONT	1	0.444	0
NH HEX 35.01	Churchill Brook	BROOKFIELD	1	0.621	1
NH HEX 36.01	Branch River	MILTON	0	0.012	0
NH HEX 38.05	Trask Brook	SUNAPEE	0	0.952	1
NH HEX 39.01	Dolf Brook	HOPKINTON	0	0.678	1
NH HEX 41.04	Berry Brook	FARMINGTON	0	0.347	0
NH HEX 43.03	Cold River	LANGDON	0	0.080	0
NH HEX 46.02	Turkey River	CONCORD	0	0.099	0
NH HEX 53.01	Purgatory Brook	LYNDEBOROUGH	0	0.169	0
NH HEX 59.03	Souhegan River	GREENVILLE	0	0.031	0

Appendix C. continued					
Site_ID	**Stream Name**	**Town**	**Observed (1=present; 0=absent)**	**Probability of occurrence**	**Predicted (1=present; 2=absent)**
NH HEX 6.01 (RD)	Unnamed Brook	ERROL	1	1.000	1
NH HEX 61.04	Beaver Brook	PELHAM	0	0.001	0
NH HEX 9.05	Newell Brook	DUMMER	1	0.999	1
sp03p-101	Lamprey River	LEE	0	1.495E-07	0
sp03p-102	Lamprey River	LEE	0	1.267E-08	0
sp03p-103	Lamprey River	LEE	0	1.004E-08	0
sp03p-104	Lamprey River	DURHAM	0	7.723E-09	0
sp03p-105	Lamprey River	DURHAM	0	7.064E-09	0