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Modified Habitat Suitability Index Model for Brown Trout in Southeastern Wyoming

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Abstract.—The habitat suitability index (HSI) model for brown trout *Salmo trutta* in stream systems, developed by the U.S. Fish and Wildlife Service, was tested with data from 30 reaches on nine streams in southeastern Wyoming. The HSI was not significantly correlated ($P > 0.05$) with brown trout standing stock. We analyzed 14 individual suitability index variables from the HSI model plus 25 other habitat variables for their relation to standing stock. Two HSI model variables and seven of the additional variables had significant correlations with brown trout standing stock. When these nine variables were used in multiple regression analysis, the best model ($R^2 = 0.52$) for predicting standing stock (S, kg/hectare) of brown trout included measures of cover and flow regime: $S = 1.71MTCR + 114.3V_{14} - 0.60$; $MTCR$ is a measure of cover availability and V_{14} is the average annual base flow expressed as a percent of average annual daily flow. An index of fishing pressure was also developed and found to significantly influence brown trout standing stock.

A habitat suitability index (HSI) model for brown trout *Salmo trutta* was developed by the Western Energy and Land Use Team of the U.S. Fish and Wildlife Service to be used in their habitat evaluation procedure (Raleigh et al. 1984). The model involved suitability index (SI) graphs for 18 habitat variables believed to govern the carrying capacity of brown trout in riverine systems. Habitat suitability index models have been developed for several fish species but few have been tested with field data (Terrell 1984). The objective of our study was to test the HSI model developed by Raleigh et al. (1984) and modify the model to develop predictive capabilities for southeastern Wyoming streams.

Two models had been developed previously with specific application to trout stream habitat assessment in southeastern Wyoming. Binns and Eiserman (1979) developed the habitat quality index (HQI) for Wyoming trout streams. The HQI incorporated six instream habitat variables and three water regime variables that were rated and combined in a multiple regression model to predict trout standing stock (kg/hectare). The trout cover rating (TCR) of the Wyoming Water Resources Research Institute, which included measures of overhead bank cover, instream rubble and boulder cover, and deep-water habitat, was published by Wesche (1980). The resultant rating was significantly correlated with brown trout standing stock.

Methods

Data collected at 30 sites on nine streams in southeastern Wyoming were used. Fish populations were dominated by naturally reproducing brown trout. Detailed descriptions of the study streams and sampling procedures were given by Wesche (1973, 1974, 1980), Wesche et al. (1977), and Eifert and Wesche (1982). Table 1 presents a summary of physical characteristics for these study streams. We estimated fish populations by electrofishing with battery-powered backpack gear, using the removal method of DeLury (1947), except in the Encampment River, where sodium cyanide was used at three sites.

Analyzed variables included 13 of the 18 variables incorporated into the published brown trout HSI model of Raleigh et al. (1984) (Table 2). Suitability index ratings were derived from the SI graphs of Raleigh et al. (1984). Data on average maximum water temperature during embryo development (V_2), average velocity over spawning areas during spawning and embryo development (V_5), average size of substrate in spawning areas, (V_7), and annual maximum and minimum pH (V_{13})

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TABLE 1.—Range of physical characteristics for nine study streams in southeastern Wyoming.

Stream	Number of reaches sampled	County (status)[a]	Elevation (m)	Length of reaches (m)	Mean width of reaches (m)	Average discharge (m^3/s)	Gradient (%)
Douglas Creek	7	Albany (NV)	2,499–2,835	76–253	4.8–12.2	0.9–2.2	0.5–1.3
Hog Park Creek	5	Carbon (NF)	2,513–2,533	93–189	6.2–7.9	0.8–1.3[b]	0.4–1.8
South Fork of Hog Park Creek	2	Carbon (NF)	2,522–2,524	145–157	4.2–4.6	0.5[b]	0.8–1.1
Lake Creek	2	Albany (NF)	2,597–2,603	106–123	3.8–5.2	0.3[b]	0.6–1.1
Encampment River	3	Carbon (NF)	2,490–2,493	84–141	9.5–16.0	4.5[b]	1.1–1.8
Laramie River	4	Albany (P)	2,249–2,341	120–134	9.6–17.7	4.5	0.1–0.4
Little Laramie River	2	Albany (P)	2,309–2,311	73–94	10.3–11.3	2.9	0.3
Deer Creek	2	Converse (P)	1,615–1,981	183–198	11.5–13.7	1.2	0.3–0.4
Horse Creek	3	Laramie (P)	2,015–2,144	91	2.4–3.4	0.1	0.7–2.0

[a] NF = national forest; P = private.
[b] Estimated by comparison of drainage basin characteristics with those of adjacent gaged watersheds.

were not available. Because the brown trout populations were reproducing naturally and water quality was nearly pristine at the study sites, we assumed that the HSI model performance would not be affected if these four variables were given optimal SI ratings of 1.0. Average percent rooted vegetation (V_{12}) was not included because of its similarity to average percent vegetation (V_{11}).

We recalibrated the SI graphs from our data by using the maximum performance method of Li et al. (1984). The HSI model was run with the recalibrated curves and compared with results obtained by using the published SI graphs.

An additional 25 habitat variables were assessed for their correlation with brown trout standing stock (Table 3). Included is a rated cross-sectional velocity variable based on fish abundance and cross-sectional velocity data from the nine study streams:

TABLE 2.—Suitability index variables for the brown trout riverine model (Raleigh et al. 1984) and sources of data. Asterisks (*) denote variables used in model testing.

Variable		Data source
V_1*	Average maximum water temperature (°C)	Field measurements, 1973–1976
V_2	Average maximum water temperature during embryo development	Not available
V_3*	Average dissolved O_2 (mg/L)	Field measurements, 1973–1976
V_4*	Average thalweg depth (m)	Cross-sectional transects
V_5	Average velocity over spawning areas	Not available
V_6*	Percent cover during the late growing season low-water periods	Cross-sectional transects: percent instream cover in water ≥15 cm deep
V_7	Average diameter of substrate components in spawning areas	Not available
V_8*	Percent of substrate components 10–40 cm in diameter	Cross-sectional transects
V_9*	Dominant substrate type	Cross-sectional transects and photography
V_{10}*	Percent pools	Cross-sectional transects: percent water ≥30 cm deep
V_{11}*	Average percent vegetation	Photography
V_{12}	Average percent rooted vegetation	Not included: similar to V_{11}
V_{13}	Maximum pH	Not available
V_{14}*	Average annual base flow as a percent of average annual daily flow	Gaging stations: for ungaged streams, data were developed on the basis of gaged streams of similar elevation and characteristics; used either late-summer or winter low-flow values (whichever was lowest)
V_{15}*	Pool class rating	Photography
V_{16}*	Percent fines	Cross-sectional transects and substrate records
V_{17}*	Percent of stream area shaded	Photography
V_{18}*	Nitrate-nitrogen (mg/L)	Wyoming Water Research Center and Wyoming Game and Fish Department records

TABLE 3.—Additional habitat variables analyzed for relationships with brown trout standing stock in southeastern Wyoming. References describing computation of the variables are included. Variables with parenthetic symbols were significantly correlated with standing stock.

Variable	References
Average stream width	Platts et al. (1983)
Coefficient of variation of stream width	Hermansen and Kreg (1984)
Average depth	Platts et al. (1983)
Coefficient of variation of stream depth (*CVDEP*)	Hermansen and Kreg (1984)
Width depth ratio	Platts et al. (1983)
Cross-sectional velocity	Platts et al. (1983)
Rated cross-sectional velocity (*RCSVEL*)	This paper
Coefficient of variation of cross-sectional velocity	Hermansen and Kreg (1984)
Time-of-travel velocity	Binns and Eiserman (1979)
Gradient	Platts et al. (1983)
Sinuosity	Platts et al. (1983)
Rubble substrate (*RUB*)	Wesche (1980)
Rubble substrate at depth ≥15 cm	Wesche (1980)
Deep-water habitat >45 cm	Wesche (1980)
Overhead bank cover	Wesche (1980)
Rubble–boulder cover	Wesche (1980)
Trout cover rating for small streams	Wesche (1980)
Trout cover rating for large streams (*TCRL*)	Wesche (1980)
Modified trout cover rating (*MTCR*)	This paper
Rating of late-summer stream flow (*LSSF*)	Binns and Eiserman (1979)
Rating of average stream flow variation (*ASV*)	Binns and Eiserman (1979)
Mean stream flow variation	Binns and Eiserman (1979)
Average annual summer base flow as a proportion of average discharge	Raleigh et al. (1984)
Average annual winter base flow as a proportion of average discharge	Raleigh et al. (1984)
Aquatic vegetation	Binns and Eiserman (1979)

1 = <0.10 m/s or ≥0.45 m/s;
2 = ≥0.10 m/s and <0.20 m/s or >0.30 m/s and <0.45 m/s;
3 = ≥0.20 m/s and ≤0.30 m/s.

Late-summer and winter low-streamflow data and average annual daily flow were obtained from gaging stations near the study sites. The lowest low-flow value was used to compute an average annual base flow as a percentage of average daily flow (V_{14}).

A simple linear regression was used to determine the correlation between each independent variable and brown trout standing stock estimates (kg/hectare). The independent variables that were significantly correlated ($P \leq 0.05$) with brown trout

TABLE 4.—Linear regression equations for habitat variables significantly correlated ($P \leq 0.05$) with brown trout standing stock in southeastern Wyoming streams. Variables are defined in Tables 2 and 3.

Standing stock (kg/hectare)	*N*	r^2
$2.2 + 168.8V_{14}$	30	0.36
$12.9 + 113.8TCRL$	24	0.29
$1.8 + 158.4V_{17}$	30	0.24
$-22.1 + 38.68RCSVEL$	26	0.23
$-6.4 + 1.853CVDEP$	28	0.22
$-0.6 + 42.38ASV$	30	0.19
$47.2 + 1.701MTCR$	28	0.18
$114.9 - 1.009RUB$	28	0.15
$-23.4 + 36.96LSSF$	30	0.14

standing stock were used in multiple linear regressions for model development. Both the Statistical Package for Social Sciences and the Biomedical Data Analysis Programs were used (Nie et al. 1975; Dixon et al. 1981).

To assess the influence of angler harvest on brown trout standing stock, we divided our sample of 30 study sites into three classes based on anticipated fishing pressure: 1 = reaches on private land (low fishing pressure); 2 = reaches on national forest land more than 800 m from a public road (moderate pressure); 3 = reaches on national forest land within 800 m of a public road (high pressure). A simple linear regression was then used to determine the relationship between pressure and standing stock.

Results

The HSI model prediction was not significantly correlated with brown trout standing stock. The HSI component for water quality [$C_{OQ} = (V_1 \times V_3 \times V_{13} \times V_{14})^{1/4}$] was significantly related ($R^2 = 0.18$) but its predictive ability was low. When we recalibrated the SI graphs using our data, the performance of the HSI model was not improved.

Two of the SI graphs published by Raleigh et al. (1984) yielded ratings with significant positive correlations with brown trout standing stock (Table 4). These involved measures of flow regime (V_{14}) and shade (V_{17}). Seven other habitat variables also had significant correlations: the coefficient of variation of depth (*CVDEP*), the rated cross-sectional velocity (*RCSVEL*), the proportion of rubble substrate (*RUB*), the trout cover rating for large streams (*TCRL*), a modification of *TCRL* (*MTCR*), a rating of late-summer stream flow (*LSSF*), and a rating of average stream flow variation (*ASV*) (Table 4). These nine variables

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were used in a multiple regression analysis to develop an alternate stream habitat model.

The best multiple regression model ($R^2 = 0.52$; $P = 0.003$) included two variables to predict the standing stock (S, kg/hectare) of brown trout:

$$S = 0.71MTCR + 114.3V_{14} - 0.60.$$

Models with additional variables did not improve the predictability of trout standing stock.

The modified brown trout cover rating ($MTCR$) for a stream reach was based on two habitat components, overhead bank cover and water 45 cm or more in depth:

$$MTCR = OBC + WAT45;$$

OBC is the linear distance of overhead bank cover divided by the thalweg length, and $WAT45$ is the area of water 45 cm or more deep divided by surface area.

Undercut banks, logs, snags, and brush piles provided overhead bank cover when the water depth under the overhang was at least 15 cm deep and the overhang was at least 9 cm wide. Detailed field methods for measuring OBC and $WAT45$ were described by Wesche (1980). Average annual base flow as a percentage of average annual daily flow (V_{14}) was computed according to Raleigh et al. (1984), and the suitability index curve is reproduced in Figure 1.

When regressed against standing stock, our simple rating of fishing pressure was a significant predictor ($r^2 = 0.16$) of brown trout standing stock among the southeastern Wyoming sites. This variable was not used in the multiple regression model development, however, due to the qualitative nature of our rankings.

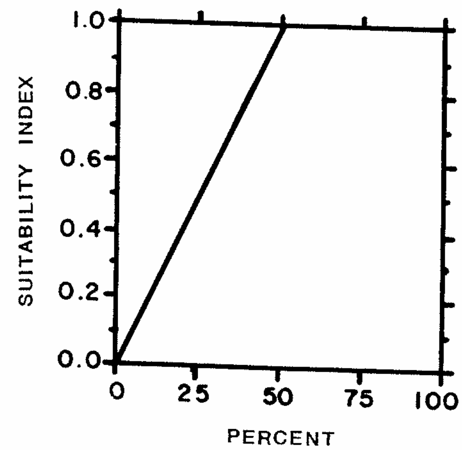

FIGURE 1.—Suitability index graph for the average annual base flow regime (V_{14}) during the late-summer and winter low-flow period as a percentage of the average annual daily flow (Raleigh et al. 1984).

Discussion

Our brown trout stream habitat model is a hybrid containing variables previously included in the trout cover rating (Wesche 1980) and the HSI model (Raleigh et al. 1984). The two variables in our model are measures of critical habitat features that influence brown trout abundance in Rocky Mountain streams. The $MTCR$ quantifies overhead bank cover and deep-water cover in the stream reach, and provides insight into the channel morphometry and stream-bank characteristics. Annual flow variation is described by V_{14} with emphasis on base flow.

Our $MTCR$ variable was a significant predictor ($r^2 = 0.18$) of trout standing stock. The importance of this type of cover to brown trout is stressed by its inclusion in the three habitat evaluation models from which our variables were derived (Binns and Eiserman 1979; Wesche 1980; Raleigh et al. 1984), as well as in several other studies (Boussu 1954; Lewis 1969; DeVore and White 1978).

Wesche et al. (1985) found the overhead bank cover component to be a significant predictor of trout standing stock in streams of southeastern Wyoming dominated by brown trout. Their data set included many of the stream reaches used in our analysis. The OBC variable was not a significant predictor by itself in our analysis but, in combination with other variables in an index of habitat quality ($MTCR$ or $TCRL$), it contributed to the prediction of brown trout standing stock. Also, the study by Wesche et al. (1985) used total trout standing stock as the dependent variable, whereas our study considered only the brown trout standing stock.

Average annual base flow as a percentage of average annual daily flow (V_{14}) was the most significant single predictor of brown trout standing stock ($r^2 = 0.36$) among our variables. Increasing concern for maintaining suitable instream flow levels lends credence for inclusion of V_{14} in our model (Stalnaker and Arnette 1976; Wesche and Rechard 1980). Numerous investigators have described habitat losses that can occur as base flow levels are reduced (Wesche 1973, 1974; Tennant 1976). Burton and Wesche (1974) studied the duration of various base flow levels in a variety of brown trout streams and found that the streams with the higher base flows present for the longest duration during the summer supported significantly greater brown trout standing stocks. Both

Binns and Eiserman (1979) and Raleigh et al. (1984) considered base flow important enough to be included in their habitat models.

Application of Model

We recommend that a two-stage approach be used for assessing brown trout habitat quality in riverine systems. The first stage is to assess water quality variables that may limit brown trout survival, such as dissolved oxygen, pH, temperature, and heavy-metal concentrations. These variables can be evaluated according to guidelines established by the U.S. Environmental Protection Agency and state water quality agencies.

The second stage of the assessment process is to measure the physical habitat and determine its quality. Our model was developed with physical and biological data from southeastern Wyoming streams, but we believe that the variables involved (cover and base flow regime) are of universal importance to brown trout and that the model should be applicable to other regions for comparative assessment of habitat quality. If absolute estimates of brown trout standing stock are required in other regions, new model coefficients may have to be developed.

Habitat models such as the one we have presented can be useful tools for fisheries managers to inventory and evaluate physical stream habitat. Based upon the two variables included in our model, we feel it would best be applied in management situations where flow regimes may be altered and the brown trout carrying capacity of a stream may be physically changed. A major influence of water development can be on the base flow regime. Whether such development will result from storage, diversion, or land use practices such as timber harvest, the model presented could be used to predict change in brown trout standing stock in response to various degrees of potential base flow augmentation or depletion. Likewise, as cover has also been identified as an important habitat feature regulating standing stock, our model could be used to assess the potential benefits of various habitat restoration and other stream and land management strategies. The influence of fishing pressure must be considered when one interprets model predictions. Our results indicted that much of the variation in standing stock unaccounted for by habitat features may be due to angler harvest.

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