Relationship between Habitat Quality and Occurrence of the Threatened Black Redhorse (*Moxostoma duquesnei*) in Lake Erie Tributaries

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Recovery planning for the nationally threatened black redhorse (*Moxostoma duquesnei*) is limited by a lack of knowledge regarding species ecology, population size and factors that affect distribution and abundance. Generalized additive models (GAM) were used to evaluate the influence of habitat quality on the distribution of the black redhorse in the Grand River (Ontario) and 11 western Lake Erie tributaries (Ohio). Black redhorse were captured at 26% of Grand River sites and 6% of western Lake Erie tributary sites. In western Lake Erie tributaries, black redhorse were more likely to be found at sites of intermediate upstream drainage area (a surrogate for watercourse size) and less likely to be found at sites with poor substrate, pool, cover and channel conditions. In the Grand River, occurrence was negatively associated with higher gradients and small and large upstream drainage areas. Habitat quality was found to be associated with the distribution of golden redhorse (*M. erythrunum*) but not the other two co-occurring redhorse species. Site occupancy was negatively associated with poor substrate and pool conditions. Results from this study indicate that, in areas of black redhorse occurrence, river reaches with clean, coarse bed material, well-developed riffles and pools, and stable channels require specific protection. Repatriation efforts in formerly occupied watercourses will likely require restoration of the condition of these habitats.

Key words: fishes, species at risk, rivers, recovery planning, general additive models

Introduction

Redhorse (*Moxostoma* spp.) are relatively large, laterally compressed and superficially similar suckers that are typically found in large streams and rivers (Jenkins and Burkhead 1993; Scott and Crossman 1998). Six redhorse species are found in Ontario, of which two are designated at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC): black redhorse (*M. duquesnei*) (Threatened) and river redhorse (*M. carinatum*) (Special Concern) (COSEWIC 2005a). These two species and the greater redhorse (*M. valenciennesi*) are also imperiled in several neighbouring jurisdictions in the United States (NatureServe 2005). In Canada, black redhorse have been collected from only seven watersheds in southwestern Ontario. Most of these watersheds have been adversely affected by agricultural land use practices. Of these seven watercourses, it is only relatively widespread in the Grand River and Thames River. Threats to remaining black redhorse populations include high turbidity levels and siltation rates, high nutrient levels, altered flow regimes, barriers to movement and physical habitat degradation (COSEWIC 2005b; Portt et al. 2006). In Catfish Creek, where black redhorse is presumed extirpated, habitat quality has been degraded by phosphorus, ammonia and nitrate concentrations that greatly exceed provincial water quality objectives, and very high suspended sediment concentrations (Nelson 2006).

Listing of black redhorse under Schedule 1 of the Canadian *Species at Risk Act* (SARA) will require the development of a recovery strategy and associated action plans. It will also require defining critical habitat and, where applicable, residence habitat (Rosenfeld and Hatfield 2006). However, recovery planning for black redhorse is limited by a lack of knowledge regarding species ecology, population size and factors that affect distribution and abundance. In contrast to sportfishes, the distribution and habitat requirements of most Canadian non-game fishes are poorly documented (Minns 2001).

Parker (1989) hypothesized that the distribution of black redhorse in Canada is limited by the availability of suitable habitat. However, limited research has been undertaken to identify specific habitat variables associated with the presence of black redhorse. Using data from two regions of the Lake Erie basin (Grand River watershed, Ontario, and 11 Ohio tributaries of western Lake Erie), generalized additive models (GAM) were used to assess the influence of habitat quality on black redhorse occurrence. Trautman (1981) considered black redhorse to be less tolerant of elevated levels of turbidity and siltation than other redhorse species in its range. To evaluate whether black redhorse are less tolerant of degraded habitats, the influence of habitat quality

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was also assessed for three co-occurring redhorse species: golden redhorse (*M. erythrurum*), greater redhorse and shorthead redhorse (*M. macrolepidotum*).

**Materials and Methods**

**Data Collection**

The Grand River watershed (43°21'N, 80°18'W) is the largest in southern Ontario, with an area of over 6500 km². More than half of the 158 species of freshwater fishes known to occur in Ontario are present in this watershed (Mandrak and Crossman 1992). Agriculture (79%) and woodlands (17%) are the dominant landcover types, although urban development across the watershed is increasing. Stresses to fish species at risk in the Grand River include impairment of water quality and quantity, barriers to fish movement, baitfish harvesting, drain maintenance activities, incremental habitat loss, channelization and stream bank hardening, and invasive species (Portt et al. 2006).

During spring (May to June) and late summer-early fall (late August to early October) of 2002 to 2004, 151 sites across the Grand River watershed were sampled. Sites were distributed across a range of surficial geologies (i.e., glaciolacustrine deposits, till plains, moraines), watercourse sizes (1 to 239 m wide) and land uses (urban or settled areas and agricultural areas). Depending on watercourse size, sites were sampled with either a single backpack electrofisher, two backpack electrofishing crews working in tandem, or a 5-KW pulsed DC boat-mounted electrofisher with a single boom anode and single netter. For sites sampled with a backpack electrofisher, site length was set at 10 times channel width, with a minimum length of 40 m (Stanfield 2005). Boat electrofishing effort was standardized at 2000 seconds. Capture probabilities for redhorse using electrofishing gear are unknown. However, past gear type comparisons indicate that the likelihood of capturing redhorse with electrofishing equipment is much higher than with a seine net (Holm and Boehm 1997; Patton et al. 1998). As well, boat electrofishing surveys of Illinois (Retzer and Kowalik 2002) and Ohio (Yoder and Beaumier 1986; Sanders 1992) rivers have been effective at capturing rare redhorse species.

Habitat condition at each site was characterized using the Qualitative Habitat Evaluation Index (QHEI), a visual habitat index comprised of seven principal metrics (Rankin 1989, Table 1). QHEI was applied because it has been shown to generate scores strongly correlated with fisheries assessment data (Rankin 1989; Frimpong et al. 2005; Santucci et al. 2005), it is not as time intensive as other habitat survey methods, and could be applied to both wadeable and non-wadeable sites sampled. The field form and a detailed description of the QHEI method can be accessed from: http://www.epa.state.oh.us/dsw/bioassess/ohstrat.html.

For consistency with the Ohio dataset, upstream drainage area was used in the analysis as a surrogate for watercourse size. In the Grand River watershed, upstream drainage area was highly correlated with field channel width measurements (Pearson correlation coefficient, $r = 0.9; p < 0.001$). Instead of QHEI scores for gradient, channel gradient (m/km) at each site was estimated from topographic maps (1:50,000 scale). Upstream drainage area was calculated using the Ontario Flow Assessment Tool (Version 1.0) (Chang et al. 2002).

Redhorse species presence/absence and QHEI data were also available for 1295 sites sampled in 11 Ohio watersheds (Ashtabula River, Black River, Conneaut Creek, Chagrin River, Cuyahoga River, Grand River, Maumee River, Rocky River, Sandusky River, Portage River and Vermilion River) of the western Lake Erie basin. These watersheds represent a range of habitat con-

<table>
<thead>
<tr>
<th>Habitat metric (range of scores)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate (0–20)</td>
<td>Based on type and quality of bed material present. Sites with high scores are characterized by a greater number of particle sizes, the presence of coarse bed material (e.g., gravel and cobble) and low levels of embeddness and silt deposition.</td>
</tr>
<tr>
<td>Cover (0–20)</td>
<td>Based on amount and diversity of cover present. Sites with high scores have large amounts and a variety of available cover types for fishes.</td>
</tr>
<tr>
<td>Channel (0–20)</td>
<td>Based on the development and stability of channel habitat. Sites with high scores have stable banks, sinuous channels and well-developed riffle and pool habitats.</td>
</tr>
<tr>
<td>Riparian (0–10)</td>
<td>Based on the amount and quality of the riparian buffer. Sites with high scores have wide, forested riparian buffers and little bank erosion.</td>
</tr>
<tr>
<td>Pool/current (0–12)</td>
<td>Based on quality of pool habitat and flow characteristics. Sites with high scores have deep, large pools and a diversity of water velocities.</td>
</tr>
<tr>
<td>Riffle/run (0–8)</td>
<td>Based on quality of riffle and run habitats. Sites with high scores have deep riffle and run habitats and unembedded coarse bed material.</td>
</tr>
</tbody>
</table>
ditions (very poor to excellent) (Ohio EPA 1998) and sizes of watershed (313 to 17,115 km²) (Schiefer 2002). Agriculture dominates the land use across much of this area, although some watersheds (e.g., Cuyahoga River) are also highly industrialized or developed for residential use (Schiefer 2002). Leading causes of impairment to aquatic life in Ohio watercourses include habitat alteration, organic enrichment, siltation, metal contamination, flow alteration and nutrient loading (Ohio EPA 1998).

Data were collected as part of Ohio Environmental Protection Agency surveys to evaluate and monitor Ohio Water Quality Standards designations and changes in biological, chemical or physical indicators. Fish communities were sampled in a standardized manner with either boat- or backpack electrofishers, depending on whether sampling sites were wadeable (Ohio EPA 1987). Sampling data were collected over a 19-year period (1984–2003).

## Distribution Modelling

At spatial scales beyond those of most experiments, empirical models provide one of the few options to evaluate how environmental factors influence species occurrence (Manel et al. 2001). GAMs were used to infer the relative influence of habitat condition on the probability of site occurrence by individual redhorse species. GAMs are similar to logistic regression, but relax the assumption that relationships between the dependent variable and predictor variables are linear. The relationship is described by estimating a nonparametric smooth function (Knapp and Preisler 1999). Relaxation of the linearity assumption is attractive as a number of shapes for individual relationships are plausible and unlikely to be known before analysis. GAMs are also well suited for examining species patterns across landscapes, as spatial coordinates can be incorporated into models. Species distribution and habitat data are often spatially autocorrelated (Hinch et al. 1994), which can create problems for statistical tests that assume independence of error terms (Legendre and Legendre 1998). To address the influence of spatial autocorrelation, geographic coordinates (Universal Transverse Mercator, UTM) were included as predictor variables (Preisler et al. 1997).

For each redhorse species, the specific relationship used for \( \Theta_i \) (i.e., logit line) was:

\[
\Theta_i = s_1(\text{UTM-E}) + s_2(\text{UTM-N}) + s_3(\text{drainage area}) + s_4(\text{gradient}) + s_5(\text{riffle/run}) + s_6(\text{pool/current}) + s_7(\text{riparian}) + s_8(\text{channel}) + s_9(\text{cover}) + s_{10}(\text{substrate})
\]  

(1)

In equation 1, \( s_k \) represents the nonparametric smooth function that characterizes the effect of each independent variable on the probability of response. Regression calculations were done using S-Plus (Mathsoft 2002) and nonparametric functions were estimated using a spline smoothing function.

In multiple regression analysis, multi-collinearity between predictor variables may confound individual effects. Therefore, Pearson correlation coefficients (\( r \)) were calculated for all pairwise combinations of predictor variables. Correlation coefficients ranged between \(-0.6\) and \(0.6\), below the recommended cutoff of \( |r| \geq 0.85 \) (Berry and Felman 1985). The best combination of independent variables was determined by evaluating the change in deviance resulting from dropping each variable from the model in the presence of all other variables. The significance of each variable on the probability of occurrence was tested with analysis of deviance and likelihood ratio tests (based on the binomial distribution) (Guisan et al. 2002). Due to the effect large sample sizes can have on the statistical significance of predictor variables in regression analysis (despite weak associations), western Lake Erie tributary predictor variables were only considered to have significant effects when \( p < 0.01 \) (Knapp 2005). Relative importance of significant variables was determined by calculating Akaike Information Criteria (AIC) (Burnham and Anderson 1998; Guisan et al. 2002). Larger AIC values indicate a greater relative importance.

For each species, response curves describing the contribution of the significant predictor variables to the probability of occurrence were developed. Response curves are based on partial residuals standardized to have an average value of 0. The vertical axis of the plots represents the variable contribution of each predator to the response. Influential variables exhibit a high range of values and values above and below zero indicate positive or negative association with the dependent variable, respectively (Granadeiro et al. 2004). A variance ratio test (Schluter 1984; Taylor 1996) was used to determine if the occurrences of redhorse species covaried among sites sampled. Values that deviate from 1 indicate that species tend to covary positively (greater than 1) or negatively (less than 1). To determine statistical significance of covariance, a statistic, \( W \), was calculated and compared to the chi-square distribution.

## Results

Six redhorse species were collected from the two study areas: black redhorse, golden redhorse, greater redhorse, river redhorse, shorthead redhorse and silver redhorse (\( M. amissurum \)). Individual redhorse species were captured from 3 to 31% of the Grand River sites sampled and 1 to 23% of the western Lake Erie tributary sites. Golden redhorse was the most widespread species while river redhorse was the least frequently caught. Due to the low number of occurrences, GAMs were not developed for river redhorse and silver redhorse. Across both areas, there was significant positive covariation of redhorse species occurrence across sites sampled (Grand River: VR = 3.01, \( W = 449, p < 0.001 \); western Lake Erie tributaries:
VR = 2.36, W = 351, p < 0.001). Redhorse species richness at sampling sites was positively correlated to drainage area (Grand River: r = 0.67, p < 0.0001; western Lake Erie tributaries: r = 0.27, p < 0.0001).

**Black Redhorse**

Black redhorse were captured at 26% of Grand River sites and 6% of western Lake Erie tributary sites. In the Grand River, the GAM indicates that geographic location, drainage area and gradient were important in predicting site occupancy (Table 2). Site occupancy was negatively associated with higher gradients and small and large upstream drainage areas (Fig. 1). In western Lake Erie tributaries, the GAM indicates that geographic location, drainage area, pool, channel, cover and substrate were important in predicting site occupancy (Table 3). Site occupancy was negatively associated with small and large upstream drainage areas and low channel (<12), cover (<10), pool (<7) and substrate (<10) scores (Fig. 2).

**Golden Redhorse**

Golden redhorse were captured at 30% of Grand River sites and 23% of western Lake Erie tributary sites. In the Grand River, the GAM indicates that geographic location and substrate were important in predicting site occupancy (Table 2). Site occupancy was negatively associated with low substrate (<10) scores (Fig. 3). In western Lake Erie tributaries, the GAM indicates that geographic location and drainage area were important in predicting site occupancy (Table 3). Site occupancy was negatively associated with low pool (<6) scores (Fig. 3).

**Greater Redhorse**

Greater redhorse were detected at 32% of Grand River sites and 4% of western Lake Erie tributary sites. In the Grand River, the GAM indicates that geographic location, gradient and drainage area were important in predicting site occupancy (Table 2). Occurrence was positively associated with drainage area and negatively associated with higher channel gradient (Fig. 4). In western Lake Erie tributaries, the GAM indicates that geographic location and drainage area were important in predicting site occupancy (Table 3). Based on the hump-shaped response curve, greater redhorse were less likely to be captured from sites with small and very large upstream drainage areas (Fig. 4).

**Shorthead Redhorse**

Shorthead redhorse were captured at 21% of Grand River sites and 7% of western Lake Erie tributary sites. In the Grand River, only geographic location was important in predicting site occupancy (Table 2). In western Lake Erie tributaries, the GAM indicates that geographic location and drainage area were important in predicting site occupancy (Table 3). Based on the hump-shaped response curve, shorthead redhorse were more likely to be captured from sites with small and large drainage areas (Fig. 3).

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**TABLE 2.** Results of generalized additive models developed for Grand River redhorse

<table>
<thead>
<tr>
<th>Species</th>
<th>Black redhorse</th>
<th>Golden redhorse</th>
<th>Greater redhorse</th>
<th>Shorthead redhorse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null deviance</td>
<td>174.59</td>
<td>185.65</td>
<td>188.83</td>
<td>155.98</td>
</tr>
<tr>
<td>df (null model)</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Model deviance</td>
<td>27.43</td>
<td>72.83</td>
<td>57.97</td>
<td>23.35</td>
</tr>
<tr>
<td>df (full model)</td>
<td>111.11</td>
<td>110.96</td>
<td>111.25</td>
<td>111.07</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Deviance increase</th>
<th>AIC</th>
<th>Deviance increase</th>
<th>AIC</th>
<th>Deviance increase</th>
<th>AIC</th>
<th>Deviance increase</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTM-E</td>
<td>8.8 (6.3)</td>
<td>106</td>
<td>8.9 (8.6)</td>
<td>152</td>
<td>12.7 (15.0)**</td>
<td>140</td>
<td>10.7 (8.8)*</td>
<td>104</td>
</tr>
<tr>
<td>UTM-N</td>
<td>11.0 (8.1)*</td>
<td>108</td>
<td>10.6 (10.3)*</td>
<td>154</td>
<td>11.3 (9.5)*</td>
<td>138</td>
<td>24.2 (22.3)**</td>
<td>118</td>
</tr>
<tr>
<td>Drainage area</td>
<td>21.0 (16.6)**</td>
<td>118</td>
<td>8.8 (8.5)</td>
<td>151</td>
<td>11.6 (9.7)*</td>
<td>139</td>
<td>9.0 (7.3)</td>
<td>102</td>
</tr>
<tr>
<td>Gradient</td>
<td>14.4 (10.9)**</td>
<td>112</td>
<td>6.5 (6.1)</td>
<td>149</td>
<td>17.1 (15.0)**</td>
<td>146</td>
<td>6.7 (5.3)</td>
<td>100</td>
</tr>
<tr>
<td>Riffle/run</td>
<td>1.8 (1.2)</td>
<td>99</td>
<td>3.4 (3.1)</td>
<td>146</td>
<td>3.9 (3.1)</td>
<td>131</td>
<td>0.9 (0.7)</td>
<td>94</td>
</tr>
<tr>
<td>Pool/current</td>
<td>4.8 (3.3)</td>
<td>102</td>
<td>3.5 (3.2)</td>
<td>146</td>
<td>6.0 (4.8)</td>
<td>134</td>
<td>0.5 (0.4)</td>
<td>94</td>
</tr>
<tr>
<td>Riparian</td>
<td>7.6 (5.5)</td>
<td>105</td>
<td>2.4 (2.1)</td>
<td>145</td>
<td>2.8 (2.1)</td>
<td>130</td>
<td>9.2 (7.4)</td>
<td>94</td>
</tr>
<tr>
<td>Channel</td>
<td>4.3 (3.0)</td>
<td>101</td>
<td>6.3 (5.9)</td>
<td>149</td>
<td>8.3 (6.7)</td>
<td>135</td>
<td>6.3 (5.0)</td>
<td>99</td>
</tr>
<tr>
<td>Cover</td>
<td>0.3 (0.2)</td>
<td>97</td>
<td>0.8 (0.7)</td>
<td>143</td>
<td>9.4 (7.8)</td>
<td>137</td>
<td>5.5 (4.4)</td>
<td>98</td>
</tr>
<tr>
<td>Substrate</td>
<td>6.2 (4.4)</td>
<td>103</td>
<td>10.0 (9.7)**</td>
<td>153</td>
<td>5.7 (4.6)</td>
<td>133</td>
<td>4.3 (3.3)</td>
<td>97</td>
</tr>
</tbody>
</table>

*Significant model variables highlighted in bold. Significance levels are: * = (p < 0.05) and ** = (p < 0.01).

*Increase in deviance resulting from dropping selected variable from the model. Percent increase (in parentheses) was calculated as [deviance increase/null deviance - model deviance].

AIC calculated as (deviance of full model less one covariate) + 2[(df of null model) - (df of full model less one covariate)].
location and drainage area were important in predicting site occupancy (Table 3). Based on the hump-shaped response curve, shorthead redhorse were less likely to be captured from sites with small and very large upstream drainage areas (Fig. 5).

**Discussion**

Habitat condition has been shown to influence fish species composition, abundance and productivity within river segments (Harper and Everard 1998). In mid-western rivers of North America, poor habitat quality is considered to be a major threat to black redhorse and other catostomid species (Cooke et al. 2005). The influence of habitat (substrate, pool, channel and cover habitat scores) on black redhorse distribution was evident in western Lake Erie tributaries. The importance of well-developed pools and coarse river bed materials with low levels of fines is consistent with descriptions of juvenile and adult black redhorse collection sites (Bowman 1970; Kott et al. 1979; Clarke 2004) and spawning habitats (Bowman 1970; Kwak and Skelly 1992).

**TABLE 3.** Results of generalized additive models developed for redhorse species in western Lake Erie tributaries

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Black redhorse</th>
<th>Golden redhorse</th>
<th>Greater redhorse</th>
<th>Shorthead redhorse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null deviance</td>
<td>616.6</td>
<td>1329.2</td>
<td>397.4</td>
<td>648.4</td>
</tr>
<tr>
<td>df (null model)</td>
<td>1294</td>
<td>1294</td>
<td>1294</td>
<td>1294</td>
</tr>
<tr>
<td>Model deviance</td>
<td>211.5</td>
<td>629.8</td>
<td>131.2</td>
<td>272.4</td>
</tr>
<tr>
<td>df (full model)</td>
<td>1258.4</td>
<td>1252.5</td>
<td>1253.2</td>
<td>1252.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Deviance increase</th>
<th>AIC</th>
<th>Deviance increase</th>
<th>AIC</th>
<th>Deviance increase</th>
<th>AIC</th>
<th>Deviance increase</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTM-E</td>
<td>80.9 (24.9)**</td>
<td>362.7</td>
<td>245.6 (47.5)**</td>
<td>949.8</td>
<td>28.7 (12.1)**</td>
<td>234.8</td>
<td>58.0 (18.3)**</td>
</tr>
<tr>
<td>UTM-N</td>
<td>28.2 (7.5)**</td>
<td>310.5</td>
<td>35.7 (4.9)**</td>
<td>739.9</td>
<td>4.8 (1.9)</td>
<td>210.0</td>
<td>31.0 (9.0)**</td>
</tr>
<tr>
<td>Drainage area</td>
<td>72.0 (21.6)**</td>
<td>354.6</td>
<td>102.8 (15.6)**</td>
<td>803.4</td>
<td>48.3 (22.2)**</td>
<td>249.6</td>
<td>107.8 (40.2)**</td>
</tr>
<tr>
<td>Gradient</td>
<td>1.4 (0.3)</td>
<td>283.4</td>
<td>1.8 (0.2)</td>
<td>707.0</td>
<td>6.9 (2.7)</td>
<td>211.9</td>
<td>1.8 (0.5)</td>
</tr>
<tr>
<td>Riffle/run</td>
<td>2.96 (0.7)</td>
<td>284.4</td>
<td>3.1 (0.4)</td>
<td>707.9</td>
<td>6.4 (2.4)</td>
<td>350.4</td>
<td>2.3 (0.6)</td>
</tr>
<tr>
<td>Pool/current</td>
<td>21.9 (5.7)**</td>
<td>304.5</td>
<td>32.6 (4.5)**</td>
<td>737.4</td>
<td>11.3 (4.4)*</td>
<td>353.1</td>
<td>5.0 (1.3)</td>
</tr>
<tr>
<td>Riparian</td>
<td>6.5 (1.6)</td>
<td>288.5</td>
<td>7.8 (1.0)</td>
<td>712.7</td>
<td>8.2 (3.2)</td>
<td>360.8</td>
<td>12.7 (3.5)*</td>
</tr>
<tr>
<td>Channel</td>
<td>6.7 (1.7)**</td>
<td>288.9</td>
<td>4.2 (0.5)</td>
<td>709.0</td>
<td>4.9 (1.9)</td>
<td>349.4</td>
<td>1.4 (0.4)</td>
</tr>
<tr>
<td>Cover</td>
<td>9.2 (2.3)**</td>
<td>291.2</td>
<td>0.8 (0.1)</td>
<td>705.6</td>
<td>5.7 (2.2)</td>
<td>350.0</td>
<td>2.0 (0.5)</td>
</tr>
<tr>
<td>Substrate</td>
<td>14.5 (3.7)**</td>
<td>297.4</td>
<td>6.9 (0.9)</td>
<td>703.7</td>
<td>10.8 (4.2)*</td>
<td>352.0</td>
<td>4.1 (1.1)</td>
</tr>
</tbody>
</table>

*aSignificant model variables highlighted in bold. Significance levels are: * = (p < 0.05) and ** = (p < 0.01).

*bIncrease in deviance resulting from dropping selected variable from the model. Percent increase (in parentheses) was calculated as [deviance increase/null deviance - model deviance].

*cAIC calculated as (deviance of full model less one covariate) + 2[(df of null model) - (df of full model less one covariate)].
In contrast, there was no habitat-related effect on black redhorse distribution in the Grand River. The lack of a habitat effect may be explained by differences in the distribution of QHEI habitat scores between the two datasets (Fig. 6). Compared to western Lake Erie tributaries, there were: (i) few high (>9) pool scores; (ii) few low (<5) and high (>17) substrate scores; (iii) few low channel scores; and (iv) few high cover scores measured at Grand River sites. The influence of subjectivity associated with different individuals assessing habitat in the two regions is an unknown but a potential confounding factor. The distribution of black redhorse in the Grand River may also be the result of other factors not addressed by this study. Harding et al. (1998) found that historic land-use and riparian conditions were better predictors of current benthic invertebrate and fish diversity in southern Appalachian Mountain watersheds than current conditions. Fifty years ago, domestic sewage and industrial discharges into the Grand River was so severe that some reaches were devoid of game fish (Ontario Department of Planning and Development 1953). Therefore, the current range of black redhorse in the Grand River may reflect past pollution events. As well, the Grand River watershed has been fragmented by 136 public and private dams. In the United States, conversion of riverine habitat to reservoirs, poor tailwater habitat, and the blockage of migratory routes have been implicated in the decline of redhorse species (Bowman 1970; Jenkins and Burkhead 1993; Quinn and Kwak 2003). A concurrent study is underway investigating the impacts of dams on black redhorse distribution and population genetic structure.

Although considered more tolerant of poor habitat conditions than black redhorse (Goodchild 1990; Thomas et al. 2005), the golden redhorse was less likely to be found at sites with poor substrate (Grand River only) and poor pool habitat (western Lake Erie tributaries only) quality. As compared to other channel bed material, Nelson and Franzin (2000) found golden redhorse along the Assini-

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**Fig. 2.** Shape of nonparametric functions and 95% confidence intervals for the significant predictors of black redhorse in western Lake Erie tributaries.

**Fig. 3.** Shape of nonparametric functions and 95% confidence intervals for the significant predictors of golden redhorse in the western Lake Erie tributaries (pool and drainage area) and Grand River (substrate only).
boine River, Manitoba, to be strongly associated with areas of gravel-cobble and cobble-boulder. In Ohio, Trautman (1981) described golden redhorse to be most abundant in moderately clear, unpolluted streams with large permanent pools and well-defined rocky-riffles. Trautman and Gartman (1974) considered the extirpation (or at least substantial reduction in abundance) of golden redhorse from Gordon Creek, Ohio, to have resulted from the loss of well-defined riffle habitat after channelization. Accordingly, its distribution and relative abundance in Ohio rivers have also increased since improvements to habitat and water quality have been made (Yoder et al. 2005).

Habitat conditions measured in this study did not influence the distribution of greater redhorse and shorthead redhorse in either the Grand River or western Lake Erie tributaries. This is somewhat surprising as greater redhorse and shorthead redhorse are considered intolerant to pollution (Yoder and Beaumier 1986; Van Hassel et al. 1988) and sensitive to increased levels of turbidity and siltation (Becker 1983), and both species have been shown to respond positively to water quality improvements (Van Hassel et al. 1988; Yoder et al. 2005). Individual redhorse life-stages have been reported to utilize physically different habitats (Aadland et al. 1991). Therefore, the ability of species presence-absence data to identify habitat associations may be limited as pooling of capture data for different life stages increases the variation in habitat scores at sites where the species is present. Models based on presence-absence data rather than abundance can also present functionally different relationships between organisms and environmental variables (Barry and Welsh 2002). Therefore, the definition of redhorse habitat requires further investigation of the relationships between habitat and individual life stages, and between habitat and population-limiting factors.

By influencing habitat volume and heterogeneity, watercourse size and gradient can account for much of the variation in riverine fish distribution (Quist et al. 2004; Brunger-Lipsey et al. 2005). For all redhorse species, drainage area (surrogate for watercourse size) was an important predictor of occurrence. In the Grand River, black redhorse were only captured from sites greater than 22 m wide; golden redhorse and shorthead redhorse from sites greater than 9 m wide; and greater redhorse from sites greater than 7 m wide. The relationship between black redhorse occurrence and watercourse size is consistent with Bowman (1970) who reported black redhorse to be more abundant in medium- and large-sized Ozark Highland streams than small ones, and Jenkins (1970) who reported black redhorse to be typically absent from streams less than 3 m wide. Similarly, Becker (1983) described greater redhorse to occur in medium- to large-sized rivers with adults occasionally occurring in streams as narrow as 5 to 9 m wide. Watercourse size has also been found to be an important determinant of golden redhorse, shorthead redhorse and silver redhorse distribution in Illinois (Larimore and Smith 1963) and Wisconsin (Newall and Magnuson 1999). Curry and Spacie (1984) suggested that watercourse size thresholds associated with catostomid distributions reflect the minimum amount of required spawning habitat. As many redhorse species are pool-dwelling species (Larimore and Smith 1963), small streams may simply not provide suitably sized pools for adults of these large-bodied fishes.

Habitat loss and degradation is considered the predominant threat factor affecting freshwater fish species at risk in Canada (Dextrase and Mandrak 2006). Accordingly, the recovery of species at risk is strongly focused on

![Fig. 4. Shape of nonparametric functions and 95% confidence intervals for the significant predictors of greater redhorse in the Grand River (drainage area and gradient) and western Lake Erie tributaries (right graph: drainage area).](http://iwaponline.com/wqrj/article-pdf/41/4/341/230380/wqrjc0410341.pdf)

![Fig. 5. Shape of nonparametric functions and 95% confidence intervals for the significant predictors of shorthead redhorse in western Lake Erie tributaries.](http://iwaponline.com/wqrj/article-pdf/41/4/341/230380/wqrjc0410341.pdf)
identifying and protecting habitats important to population survival (e.g., critical habitat) and recovery. Results from this study indicate that river reaches with clean coarse bed material (gravel and cobble), well-developed riffles and pools, and stable channels are more likely to support populations of black redhorse. Therefore, these habitats require specific protection. Black redhorse populations in Illinois and Ohio rivers have responded positively to improvements in water quality and habitat (Retzer 2005; Yoder et al. 2005). Recovery plans for Canadian populations should target similar improvements.

In watercourses where black redhorse have been extirpated, repatriation will first require that habitat quality is improved. Data from western Lake Erie tributaries indicate that the QHEI could support a number of identified black redhorse recovery actions such as the: (i) long-term monitoring of the condition of black redhorse habitat; (ii) targeted sampling of watercourses suspected to support black redhorse; (iii) documentation of critical habitat; (iv) evaluation of the success of habitat stewardship initiatives; and (v) evaluation of habitat suitability in extirpated reaches before repatriation efforts are initiated. QHEI could also be applied to collect baseline data supporting environmental impact assessments of projects in areas of black redhorse occurrence. A standardized and more quantitative approach for describing stream habitat has been developed for wadeable riverine habitats in Ontario: the Ontario Stream Assessment Protocol (OSAP) (Stanfield 2005). However, OSAP is limited to wadeable habitats and therefore unable to characterize the riverine habitats where black redhorse are found in southwestern Ontario. As well, species-habitat associations have also not been tested for Moxostoma using OSAP data. Nonetheless, future research on species-habitat associations using more quantitative field measurements (e.g., pebble count) would help to refine descriptions of black redhorse habitat requirements and thresholds of impact from activities affecting black redhorse habitat.

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