Distribution of the Imperiled Meek’s Crayfish (Orconectes meeki meeki (Faxon)) in the White River Drainage of Missouri, USA: Associations with Multi-scale Environmental Variables

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Abstract. — Meek’s crayfish, Orconectes meeki meeki (Faxon), exists only in the White River drainage of Missouri and Arkansas, USA, and is known from only three tributaries to Table Rock Reservoir in one Missouri county. “Critically imperiled” and among the rarest crayfishes in Missouri, its distribution has never been assessed. Study objectives were to estimate the Missouri distribution of O. m. meeki, and identify any associations between crayfish and multi-scale environmental variables. We used a probabilistic method and stratified (by stream order) random design to survey 71 of 223 stream segments in the drainage during 2002 – 2004. The crayfish was detected at six sites, at a rate of 0.08 (+ 0.04, 90% confidence interval). Most locations for O. m. meeki were isolated from each other by the reservoir. Meek’s crayfish typically used cobble/pebble substrate as refuge. It was found at segments with lower elevation, lower substrate embeddedness, lower macrophyte densities, and larger substrate than segments where it was not detected. The crayfish was associated with smaller drainage areas and lower stream connectivity, and all O. m. meeki collection sites had a common dominant geology. Whereas Meek’s crayfish is stable in Arkansas, it remains rare enough to warrant concern about its status in Missouri. [Keywords. — conservation status; distribution; habitat; Orconectes meeki meeki].

INTRODUCTION

Meek’s crayfish, Orconectes meeki meeki (Faxon), is known from only the upper White River drainage in Missouri and Arkansas, USA, and is among Missouri’s rarest crayfish. A previous statewide crayfish survey included 49 sites on 26 perennial streams in the Missouri portion of this drainage and yielded Meek’s crayfish from only three localities in Stone County (Figure 1; Pflieger 1996), and never from the North Fork White River basin. Specimens from a possible fourth locality (collected (Figure 1; Pflieger 1996), and never from the North Fork White River basin. Specimens from a possible fourth locality (collected (Figure 1; Pflieger 1996), and never from the North Fork White River basin. Specimens from a possible fourth locality (collected (Figure 1; Pflieger 1996), and never from the North Fork White River basin. Specimens from a possible fourth locality (collected (Figure 1; Pflieger 1996), and never from the North Fork White River basin. Specimens from a possible fourth locality (collected (Figure 1; Pflieger 1996), and never from the North Fork White River basin. Specimens from a possible fourth locality (collected (Figure 1; Pflieger 1996), and never from the North Fork White River basin. Specimens from a possible fourth locality (Schuster 2006, personal communication). Orconectes m. meeki is “critically imperiled” in Missouri (Missouri Natural Heritage Program 2007) but astacologists assigned it the global status of “currently stable” (Taylor et al. 2007).

The construction of Table Rock Reservoir in 1958 geographically fragmented the known Missouri locations for this crayfish, and similar situations have been cause for concern with other rare stream organisms (e.g., Williams’ crayfish Orconectes williamsi Fitzpatrick; Westhoff et al. 2006). Additionally, recent observations indicate that several streams in this drainage suffer from shifting substrate and deposited fine sediments, presumably resulting from recent or current land use practices (Bayless and Vitello 2002; Jacobson 2004). This crayfish has been inadequately studied since first described by Faxon (1898). To assess its conservation status in Missouri it is necessary to complete a comprehensive survey of its distribution.

Surveys to assess distributions and conservation status of stream invertebrates of concern (e.g., crayfishes, mussels) are increasingly common in North America. Historically, these surveys incorporated relatively few design measures, especially in the sample site selection process, to minimize sampling bias and facilitate repeatability. Recent freshwater mussel surveys have improved designs with standardized sampling protocol and random selection of sampling sites (Smith et al. 2001; Warren et al. 2004), but such measures are rare in crayfish surveys.

No quantitative data exist relating O. m. meeki to its habitat or environmental variables that may influence its distribution or abundance. Pflieger (1996) indicated that in Missouri this crayfish occurred in “small clear creeks having stable substrates consisting of bedrock, rubble, and coarse gravel.” Biologists sampling in Arkansas reported finding this crayfish under large stones in riffles (juveniles under smaller stones; Fitzpatrick 1966), buried under rocks in rapid water or stagnant pools (Williams 1954) or buried under rocks and logs along stream margins or drying areas (Bouchard and Robison 1980). Knowledge of a species’ habitat is essential to conservation and management, and multi-scale approaches to habitat investigations are increasingly
desirable (Kotliar and Wiens 1990; Maddock 1999). The stream-reach scale has been particularly useful for assessing medium- and long-term effects of anthropogenic activities (Frissell et al. 1986). Previous crayfish distribution studies have incorporated measurements of potentially important environmental variables (Daniels 1980; Ratcliffe and DeVries 2004; Westhoff et al. 2006). Data relating presence of *O. m. meeki* to specific environmental variables at multiple spatial scales should prove useful to future conservation efforts.

Our primary objective was to estimate the distribution of *O. m. meeki* in streams of the upper White River drainage of Missouri, using a stratified random probabilistic survey method that facilitated repeatability, and our ability to make inferences about unsampled portions of the drainage. We focused our efforts by excluding the North Fork White River basin. We also attempted to determine associations between occurrence of this crayfish and selected microhabitat-, reach-, and watershed-scale environmental variables.

**MATERIALS AND METHODS**

**Study Area**

In Missouri, the White River drainage (exclusive of the North Fork White River basin) encompasses a 10-county area in the Ozarks (Figure 1). This drainage consists of > 945 km of perennial and many more kilometers of intermittent streams. Streams flow through a mostly rural landscape with forest dominating the southern portion, and agricultural land dominating the northern (James River sub-basin) portion of the drainage, although urbanization is increasing rapidly. Streams are typically located in narrow, steep-sided valleys, and are characterized by high gradients and well-defined riffles and pools (Kiner and Vitello 2000; Bayless and Vitello 2002).

**Distribution Survey**

United States Geological Survey (USGS) topographic maps (1:24K scale) were used to catalog all 152 named streams in the Missouri portion of the drainage. Streams were then divided into segments by stream order (as detailed in Westhoff et al. 2006) resulting in a total of 223 perennial sampling units that we termed “stream segments”, each containing only one stream order. As a stream joins another stream of similar order and transitions to a higher stream order, it becomes a new stream segment. The pool of 223 stream segments was our sampling population, and included 144 first-order, 60 second-order, 14 third-order, four fourth-order, and one fifth-order stream segments.

We used a stratified random probabilistic survey design with proportional allocation (Lohr 1999) to sample for *O. m. meeki* during April – August of 2002 – 2004. This design allowed us to determine the distribution of *O. m. meeki*, and estimate mean proportions (hereafter termed detection rates) with 90% confidence intervals for stream segments harboring this crayfish for the
entire drainage area, and for each of three strata (stream order: first, second, and third or greater). This approach also facilitates biologists’ ability to make 1) inferences about unsampled portions of the drainage, and 2) statistical comparisons with future resurveys. We randomly selected 71 of the 223 stream segments to sample, and another 55 as an over-sample list for situations where we could not access the stream or it was not flowing (although all stream segments were identified by maps as perennial, we discovered upon arrival that many were dry). In such situations we selected the next alternate stream segment from the over-sample list. We used 51 over-sample stream segments because we were unable to gain access to 16 segments and another 35 were dry. The 122 total visited stream segments were composed of 90 first-, 27 second-, and four third-order or greater segments.

Upon arriving at a selected stream segment we marked upstream and downstream ends of a sampling reach within it using a Garmin V Global Positioning System (GPS). Sampling reach length was established to approximate 20 times the bankfull width (Rosgen 1996) to ensure that we incorporated all major habitat types, which tend to repeat at multiples of bankfull width. Reach-scale approximated the definition proposed by Frissell et al. (1986), but was slightly larger for some streams.

Sampling employed an “incremental seining” approach (Winston 2004), using a 1 m² seine with 3 mm Delta mesh, and only occasional use of a larger seine (same mesh size) in large pools, to intensively sample all available habitats for either 20 seine hauls or for at least 2 h. The 1 m² seine was selected primarily because many of the sampled stream reaches were less than 2 or 3 m in width. Seine hauls in moderate- to fast-flowing water were stationary and substrate was kicked in an area of about 1 – 3 m; in slow-flowing water, two workers dragged the seine upstream for 1 – 10 m. Our intent was to ensure collection of all crayfish species present. The incremental approach facilitates future efforts to repeat our sampling and thus evaluate any faunal changes. At most sampled segments, we recorded sampling time for each seine haul, as a general indication of effort, but not for quantification. We also estimated four microhabitat (as defined by Frissell et al. 1986) variables as described by Westhoff et al. (2006): dominant substrate, cover features, apparent water velocity, and depth (Table 1). All seining data were archived in the Missouri Department of Conservation “MDCMeta” database archival system.

Crayfish data were recorded separately for each seine haul. Captured crayfish were identified to species. All *O. m. meeki* were identified to sex and reproductive form (for males). All crayfish were returned to the stream unharmed, except for a small sub-sample that was preserved for population genetics analysis (Fetzner and DiStefano 2008).

The three previously reported localities for *O. m. meeki* in Missouri (Pflieger 1996) were revisited during (Little Indian Creek) or following (Stone County Creek, Indian Creek) this
survey to confirm the presence of the species. Crayfish sampling was conducted with seines and handnets for at least 2 h at these three historical locations.

Environmental Variable Associations

We compiled a list of 58 reach- and eight watershed-scale environmental variables that we hypothesized had the most potential to influence distribution and abundance of *O. m. meeki* (for complete list see Westhoff et al. 2005). This list contained both quantifiable, continuous variables (e.g., mean depth, mean bankfull width, wetted width to depth ratio, depth of deposited fine sediment [“embeddedness”], reach gradient, drainage area) and categorical, descriptive variables (e.g., stream order, link magnitude, confluence difference, dominant substrate). Through pilot sampling and exploratory data analysis (detailed in Westhoff et al. 2006) we reduced the list to 18 variables (six on watershed-scale, 12 on reach-scale).

Following crayfish sampling in each segment, we recorded data for reach-scale environmental variables onsite or in the laboratory. Total macrophyte area was determined by estimating the area (m$^2$) of every macrophyte patch in the sampling reach and totaling the measurements for a cumulative reach value. Bankfull width, bankfull depth, and wetted width were measured at one longitudinally random point in each of three riffles and three pools (six total locations for each variable; Westhoff et al. 2005). Wetted width transects were established at each of those three riffle and three pool locations. At three points across each transect (25%, 50%, and 75% of wetted width) we measured water depth, and estimated embeddedness and dominant substrate type according to procedures developed by Kaufmann et al. (1999). On top of the wetted width transect, we established a bankfull width transect, and measured bankfull depth at four points (20%, 40%, 60%, and 80% of bankfull width; to approximate the cross-section channel shape along that transect). Reach gradient and elevation (one value per stream segment) were calculated using Geographic Information Systems (GIS)/ArcView software (version 9.0).

In the laboratory, we used GIS/ArcView software or topographic maps to collect data for eight watershed-scale variables including stream order (including only perennial streams; Orth 1983), link magnitude at stream mouth (a metric similar to stream order, except that the numeric value of link magnitude steadily increases as streams meet, regardless of their size; Osborne and Wiley 1992), and confluence difference (assigns a numeric value to the size difference between a receiving stream and its tributary at their confluence; Mattingly and Galat 2002). We obtained information about the remaining variables such as underlying geological features from a database constructed by Missouri Resource Assessment Partnership staff (Sowa 2004, personal communication). We noted those stream segments that were fragmented by reservoirs.

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### Table 1. Microhabitat-scale variable values at seine haul locations where *Orconectes m. meeki* (OM) was captured, from six stream segments harboring OM in White River drainage of Missouri, USA. Total seine hauls = 186; 162 seine hauls containing OM = 87% of total.

<table>
<thead>
<tr>
<th>Microhabitat variable</th>
<th>Seine hauls containing OM</th>
<th>Total seine hauls in microhabitat</th>
<th>Percent of seine hauls with OM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth &lt; 25 cm</td>
<td>37</td>
<td>44</td>
<td>84%</td>
</tr>
<tr>
<td>Depth 25 – 50 cm</td>
<td>13</td>
<td>13</td>
<td>100%</td>
</tr>
<tr>
<td>Depth &gt; 50 cm</td>
<td>3</td>
<td>4</td>
<td>75%</td>
</tr>
<tr>
<td>Low current velocity</td>
<td>14</td>
<td>16</td>
<td>88%</td>
</tr>
<tr>
<td>Moderate current velocity</td>
<td>14</td>
<td>15</td>
<td>93%</td>
</tr>
<tr>
<td>High current velocity</td>
<td>25</td>
<td>30</td>
<td>83%</td>
</tr>
<tr>
<td>DS$^a$ bedrock</td>
<td>1</td>
<td>5</td>
<td>20%</td>
</tr>
<tr>
<td>DS$^a$ boulder</td>
<td>3</td>
<td>5</td>
<td>60%</td>
</tr>
<tr>
<td>DS$^a$ cobble</td>
<td>21</td>
<td>21</td>
<td>100%</td>
</tr>
<tr>
<td>DS$^a$ pebble</td>
<td>23</td>
<td>24</td>
<td>96%</td>
</tr>
<tr>
<td>DS$^a$ gravel</td>
<td>3</td>
<td>4</td>
<td>75%</td>
</tr>
<tr>
<td>DS$^a$ sand</td>
<td>0</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>DS$^a$ silt</td>
<td>0</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>DS$^a$ detritus</td>
<td>2</td>
<td>2</td>
<td>100%</td>
</tr>
<tr>
<td>Emergent vegetation patch</td>
<td>1</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>Woody debris</td>
<td>1</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>Root mass</td>
<td>1</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>Undercut bank</td>
<td>0</td>
<td>0</td>
<td>–</td>
</tr>
</tbody>
</table>

$^a$ DS = Dominant substrate, according to classifications by Bovee and Milhous (1978). A substrate size class must compose at least 30% of the sampled area to be dominant (i.e., more than one substrate size class could be recorded as dominant for a given seine haul).
Table 2. Six stream segments where *Orconectes m. meeki* was detected during survey (2002-04) of the White River drainage of Missouri. Accompanying data for each stream segment include 11-Digit Hydrologic Unit Code (HUCs), UTMs coordinates (NAD 1983 Zone 15 North) for the upstream end of the sampling site, and crayfish species associates collected (*Orconectes neglectus* = NE, *Orconectes ozarkae* = OZ, *Orconectes virilis* = VI, *Orconectes williamsi* = WI, unidentified young-of-year = UK).

<table>
<thead>
<tr>
<th>Stream segment, stream order</th>
<th>Date sampled</th>
<th>HUC</th>
<th>X-UTM coordinate</th>
<th>Y-UTM coordinate</th>
<th>Location access</th>
<th>Species associates(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aunts Creek, South, 1(^a)</td>
<td>07/08/03</td>
<td>11010002070</td>
<td>461797</td>
<td>4059882</td>
<td>Near creek mouth at Table Rock Reservoir (by boat)</td>
<td>NE, OZ, VI, UK</td>
</tr>
<tr>
<td>Little Indian Creek, 1(^a)</td>
<td>08/07/02</td>
<td>11010001140</td>
<td>459946</td>
<td>4042256</td>
<td>5.6 km NW of Blue Eye, Hwy 86 to Dogwood Canyon</td>
<td>NE, OZ, VI, WI</td>
</tr>
<tr>
<td>Little Indian Creek(^b), 2(^nd)</td>
<td>08/07/02</td>
<td>11010001140</td>
<td>459241</td>
<td>4042219</td>
<td>6.3 km NW of Blue Eye, Hwy 86 at Dogwood Canyon</td>
<td>NE, OZ, VI, WI</td>
</tr>
<tr>
<td>Rock Creek, 1(^a)</td>
<td>07/16/03</td>
<td>11010001080</td>
<td>437254</td>
<td>4050845</td>
<td>8.0 km W of Shell Knob, FR 2225</td>
<td>NE, WI, UK</td>
</tr>
<tr>
<td>Rockhouse Creek, 1(^a)</td>
<td>06/08/04</td>
<td>11010002060</td>
<td>436140</td>
<td>4062113</td>
<td>SW of Hailey, along Barry CR 1200</td>
<td>None</td>
</tr>
<tr>
<td>Wooley Creek, 1(^a)</td>
<td>06/03/04</td>
<td>11010002070</td>
<td>449449</td>
<td>4062113</td>
<td>Near creek mouth at Table Rock Reservoir (accessed by boat)</td>
<td>None</td>
</tr>
</tbody>
</table>

\(^a\) Meek’s crayfish was the only species present at Rockhouse (n = 185 specimens collected) and Wooly (n = 191) creeks, dominated the community at Rock (n = > 200) and Aunts (n = 65) creeks, and was somewhat uncommon at both segments of Little Indian Creek (1\(^a\) order segment n = 12, 2\(^nd\) order segment n = 5).

\(^b\) Little Indian Creek, second-order segment, was one of three Meek’s crayfish sites previously reported by Pflieger (1996).

Statistical Analyses

Randomly selected stream segments were classified as sampled, not sampled because the stream was dry, or not sampled due to lack of access. Sampled segments, as well as those that were initially selected but not sampled, were plotted in GIS/ ArcView (Figure 2) to facilitate examination for obvious spatial patterns in survey results. Survey rates of detection for *O. m. meeki* were based on a domain analysis (Lohr 1999) using the SAS macro SMSUB (Sample Means Subpopulations; SAS Institute, Inc. 2005). The population size of each stratum was \(N_1 = 144\) for first-order segments, \(N_2 = 60\) for second-order segments, and \(N_3 = 19\) for third-order or greater segments. Because segments from the over-sample list were used, the sampling weights \(N_i/n_i\), where \(n_i\) refers to the number of segments visited in stratum \(h\), were calculated for the first-, second-, and third-order or greater stream segments as \(144/71, 60/17,\) and \(19/5\), respectively.

Microhabitat-scale data collected in association with each incremental seine haul were summarized and tabulated for qualitative comparisons among the stream segments where *O. m. meeki* was detected.

We calculated mean estimates and 90% confidence intervals for 18 reach- and watershed-scale environmental variables, and comparisons were made between the two domains or subgroups (segments where *O. m. meeki* was and was not detected) using estimation of domain procedures (Cochran 1977; Lohr 1999). We used the SAS macro SMSUB (SAS Institute, Inc. 2005) to derive the overall mean for each domain and tested for differences using the \(t\)-test produced by SMSUB using linear contrasts. We chose not to analyze stream-order specific contrasts (Westhoff et al. 2006) because we collected Meek’s crayfish at only one second-order segment and at no third-order or greater segments. No corrections were made to adjust for potential experiment-wise error for multiple tests. Due to the exploratory, broad-based nature of this survey, it was important that we strike a balance between potential for Type I and Type II error and not exclude any environmental variables that were potentially important to this species’ distribution (Angermeier 1995). We selected an alpha level of 0.10 to determine significance in our analyses, to address potentially low statistical power, and to avoid Type II error that can be associated with such large scale studies, and the small sample sizes that are common when studying rare organisms (Peterman 1990; Angermeier 1995).

RESULTS

Distribution Survey

We detected *O. m. meeki* in 6 of 71 sampled stream segments, an overall detection rate of 0.08 (± 0.04, 90% confidence interval) (Figure 2, Table 2). The detection rates for the 46 first-, and 19 second-order stream segments were 0.11 (± 0.06) and 0.05 (± 0.08), respectively, with no significant difference between them. No Meek’s crayfish were detected in the six third-order or greater segments we sampled. We failed to collect *O. m. meeki* at two locations where the species was recorded by Pflieger (1996).

Stream segments where we detected *O. m. meeki* were confined to the southwestern portion of the drainage, surrounding Table Rock Reservoir, in Stone and Barry counties (Figure 2). The crayfish was detected in four of the 16 USGS 11-digit hydrologic units composing the Missouri portion of the drainage. Several
Table 3. Environmental variables for which estimation of domain analyses indicated a significant difference (alpha = 0.10) between six stream segments where Orconectes m. meeki (OM) was detected and 65 segments where it was not detected:

<table>
<thead>
<tr>
<th>Environmental variable</th>
<th>Scale</th>
<th>Mean (± 90% confidence interval) at sites with OM</th>
<th>Mean (± 90% confidence interval) at sites without OM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage area (km²)</td>
<td>Watershed</td>
<td>35 ± 9</td>
<td>152 ± 80</td>
<td>0.0176</td>
</tr>
<tr>
<td>Total Connectivity (longitudinal m)</td>
<td>Watershed</td>
<td>25,260 ± 17,779</td>
<td>377,901 ± 39,840</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Mean elevation (m above sea level)</td>
<td>Reach</td>
<td>298 ± 6</td>
<td>310 ± 9</td>
<td>0.0707</td>
</tr>
<tr>
<td>Mean embeddedness of pools (%)</td>
<td>Reach</td>
<td>18 ± 4</td>
<td>23 ± 3</td>
<td>0.0691</td>
</tr>
<tr>
<td>Mean embeddedness of riffles (%)</td>
<td>Reach</td>
<td>13 ± 3</td>
<td>20 ± 2</td>
<td>0.0015</td>
</tr>
<tr>
<td>Median dominant substrate size in pools (diameter, mm)</td>
<td>Reach</td>
<td>97 ± 29</td>
<td>43 ± 7</td>
<td>0.0028</td>
</tr>
<tr>
<td>Median dominant substrate size in riffles (diameter, mm)</td>
<td>Reach</td>
<td>97 ± 29</td>
<td>66 ± 9</td>
<td>0.0878</td>
</tr>
<tr>
<td>Macrophyte area (m²)</td>
<td>Reach</td>
<td>16 ± 10</td>
<td>83 ± 41</td>
<td>0.0086</td>
</tr>
<tr>
<td>Mean bankfull width : bankfull depth of pools (m:m)</td>
<td>Reach</td>
<td>16.4 ± 3.0</td>
<td>21.0 ± 1.1</td>
<td>0.0170</td>
</tr>
<tr>
<td>Mean bankfull width : bankfull depth of riffles (m:m)</td>
<td>Reach</td>
<td>19.4 ± 4.8</td>
<td>26.0 ± 1.6</td>
<td>0.0289</td>
</tr>
<tr>
<td>Mean wetted width : wetted depth of pools (m:m)</td>
<td>Reach</td>
<td>59.6 ± 9.4</td>
<td>46.8 ± 5.5</td>
<td>0.0549</td>
</tr>
</tbody>
</table>

* Analysis of the watershed-scale variable “Dominant Geology” indicated (P < 0.0001) that all six segments harboring OM occurred in Canadian Limestone/Dolomite, although that was the underlying formation for 74% of the 71 sampled segments.

hydrologic units in the northern and eastern part of the drainage were thoroughly sampled without detection of O. m. meeki, suggesting that the crayfish might not occur in those areas.

Meek’s crayfish dominated the crayfish community in four segments where we detected it, but was uncommon in the other two segments. It was associated with four other species of crayfish (Table 2).

Incremental Seining Microhabitat Associations

A total of 186 seine hauls were obtained at the six stream segments where we detected O. m. meeki. Qualitative comparisons suggested that only one microhabitat-scale variable (dominant substrate) had a positive association with this crayfish at these segments (Table 1). Nearly 100% of the 45 seine hauls conducted over cobble- and pebble-dominated substrates contained Meek’s crayfish. This crayfish was frequently collected at all sampled depths and current velocities.

Environmental Variable Associations

Mean values for three watershed-scale environmental variables exhibited significant differences (P < 0.10) between survey stream segments where we did and did not detect O. m. meeki (Table 3). “Drainage area”, a watershed-scale variable whose numeric value increases from headwaters to stream mouth, was negatively related to presence of Meek’s crayfish. “Total connectivity” represents the cumulative longitudinal distance of unimpounded streams connected to a sampled segment, and was also negatively related to presence of O. m. meeki. Analysis of the variable “Dominant Geology” indicated that all six segments harboring Meek’s crayfish had a similar underlying geology.

Nine reach-scale variables were significantly associated with presence of O. m. meeki, although several of these variables were similar to each other (Table 3). Mean embeddedness of both riffles and pools measured accumulation of fine sediments on stream substrates (Kaufmann et al. 1999), and was negatively associated with Meek’s crayfish. Two other variables concerned with substrate indicated a positive relationship between the crayfish and larger substrate particle sizes (cobble). We observed significant associations between O. m. meeki and the three ratio variables intended to provide a measure of stream channel cross-sectional morphology (mean bankfull width to mean bankfull depth of pools, mean bankfull width to mean bankfull depth of riffles, and mean wetted width to wetted depth of pools). In two cases, presence of O. m. meeki was associated with smaller ratios representing stream channels that were narrower and deeper than channels where the crayfish was not detected; whereas the third variable showed a positive relation between larger ratios and the crayfish.

**DISCUSSION**

**Distribution**

Our study doubled the known Missouri distribution of O. m. meeki from the previous three locations (Figure 1; Pflieger 1996). We detected Meek’s crayfish at 6 stream segments on five streams in Stone and Barry counties, and four of these streams (five segments) were previously unreported locations for this crayfish.
(Figure 2; Pfieger 1996). However, we were unable to find this crayfish at two previously reported locations in Indian Creek, or Stone County Creek which was largely dry during our visit.

The stratified random survey of 71 of a possible 223 stream segments detected *O. m. meeki* at 8% of sampled segments, and our probabilistic approach (Lohr 1999) allowed us to conclude that this crayfish might occur in some more of the unsampled 152 segments in the Missouri portion of the drainage. However, the geographical distribution of sites where we found Meek’s crayfish suggests that any future efforts to locate this species should concentrate sampling in the southern portion of the drainage (Figure 2).

Our study confirmed previous reports suggesting that *O. m. meeki* was associated with small streams (primarily first-order), and burrowed under coarse rock substrate (Fitzpatrick 1966; Pfieger 1996). We also confirmed some use of drying streams as reported by Bouchard and Robison (1980), and the use of at least one stream that dried completely (DiStefano et al. in press). This suggests that this crayfish might occur in some of the many intermittent streams in this drainage, and that future surveys for this species should include such streams.

Our survey’s *O. m. meeki* locations were connected to only a small length of perennial stream habitat (average of 25 km) before being impounded by Table Rock Reservoir (Figure 2; “total connectivity”, Table 3). These data indicate that the known population (and historic locations) of Meek’s crayfish could be termed fragmented, causing concern for long term conservation of the species in Missouri. Population genetics analysis suggests a shared ancestry among crayfish from some of these locations, but that overall dispersal rates and genetic exchange among most localities are low (Fetzner & DiStefano 2008). The reservoir has impounded many kilometers of these streams and altered flows and channel morphology (Jacobson et al. 2001; Herbert & Gelwick 2003), and possibly further restricted crayfish movements. It is unknown whether *O. m. meeki* is tolerant of impounded lentic habitats. However, impoundment has certainly increased access to these crayfish for large centrarchid fish predators that favor crayfish as prey in Ozarks streams (Rabeni 1992; DiStefano 2005). This scenario may present substantial future challenges for natural resource managers and conservation biologists with regard to recolonization of sites that suffer declines, and genetic exchange among isolated sites (MacArthur 1972; Herbert & Gelwick 2003).

**Multi-scale Environmental Associations**

*Orconectes m. meeki* was associated with large rocky substrates, but no other microhabitat-scale associations (depth, current velocities) were apparent (Table 1). Habitat partitioning has been observed among crayfishes in Ozark stream communities (Rabeni 1985; DiStefano et al. 2003), and our observations suggested that Meek’s crayfish was more of a habitat generalist than some of its species associates, such as *O. williamsi*, which was generally associated with higher current velocities and shallow depths, and *Orconectes neglectus* (Faxon), which was often observed in slower velocity pools (Westhoff et al. 2006).

Associations with reach- and watershed-scale environmental variables provided insight about *O. m. meeki*’s habitat preferences, but not without discrepancies (Table 3). This crayfish was associated with streams draining small watersheds underlain by Canadian Limestone/Dolomite geology, but not necessarily at the highest elevations. Mean bankfull width to mean bankfull depth ratios for both riffles and pools at segments harboring *O. m. meeki* suggested crayfish associations with stream channel morphologies that were narrower and deeper, relative to wider, shallower channels where this species was not detected; yet, mean wetted width to mean wetted depth ratios of pools appeared to contradict this finding. It will be important to clarify this relationship between Meek’s crayfish and channel morphology because increased channel widths and decreased depths of pools and riffles due to channel instability and aggradation of sediments is a commonly observed phenomenon in Ozarks streams, often associated with land use disturbances such as land clearing and gravel mining (Lagasse et al. 1980; Lisle 1982; Jacobson and Primm 1997; Brown et al. 1998).

Four reach-scale variables related to stream substrates (mean embeddedness of pools and riffles, median dominant substrate size in pools and riffles; Table 3) indicated that stream segments harboring *O. m. meeki* were associated with cobble substrates (> 64 mm diameter), with reduced loads of fine sediments around them relative to segments not harboring this crayfish. This may be related to *O. m. meeki*’s noted burrowing behavior (Williams 1954; Bouchard and Robison 1980) and use of interstices for shelter, as larger substrates will create more interstitial spacing, but fine sediments fill in or clog those interstices (Lenat et al. 1981; Minshall 1984). Fifty sand and gravel mines adjacent to streams were recently active in the southern two-thirds of the Missouri portion of this drainage (Bayless and Vitello 2002) with an undetermined number in the northern portion. Mining-induced changes in sediment supply, channel form, and streambed degradation (Lagasse et al. 1980; Brown et al. 1998) degrade physical habitat for many stream species (Newport and Moyer 1974; Waters 1995), and could affect distribution of *O. m. meeki*.

*Orconectes m. meeki* was likely absent from stream segments containing high densities of macrophytes, primarily water willow (*Justicia* sp.), relative to segments with low densities of emergent vegetation (Table 3). This negative association with water willow was previously demonstrated for *O. williamsi* by Westhoff et al. (2006). One possible cause might be divergent habitat preferences of this macrophyte and *O. m. meeki*. We recorded the highest densities of water willow in larger streams where the forest canopy was relatively open, but Meek’s crayfish was clearly associated with smaller streams. Also, these results were probably influenced by very high water willow densities (1285 m2) at one fourth-order stream segment (James River) where *O. m. meeki* was not detected (Westhoff et al. 2006).

*Orconectes m. meeki* was collected syntopically with four other crayfish species in the drainage; *O. neglectus*, at four stream segments; *O. williamsi*, *Orconectes ozarkae* Williams, and *Orconectes virilis* (Hagen), at three segments each. The use of species associates has been examined as one means, in conjunction with abiotic approaches, to identify potential habitat for imperiled stream species (Pfieger 1978). However, we do not believe the presence of *O. neglectus* as the most common syntopic species of *O. m. meeki* is indicative of suitable habitat for the latter species, but
rather, is simply due to the former species’ dominance throughout the drainage (Westhoff et al. 2006). Alternatively, evidence from the state of Arkansas suggests that presence of O. williamsi might serve as an indication of suitable habitat for O. m. meeki as the former species co-occurred at 87% of sites occupied by the latter species (Wagner et al. 2007).

Conservation and Management Implications

Limited natural range, as we have documented for O. m. meeki in Missouri, is cited as an important factor associated with imperilment of stream crayfishes (Taylor et al. 2007), but physical habitat degradation or alteration, and chemical pollution pose additional threats. Historical and active lead mines (78 historical mines) and extensive gravel mining (see above) in the upper White River drainage, and land use disturbance associated with rapidly increasing urbanization in formerly rural portions of the drainage (Bayless and Vitello 2002; Center on Urban and Metropolitan Policy 2002), potentially affect chemical and physical stream habitats and their associated crayfish (Johnson and Eaton 1980; Jacobson and Primm 1997; Allert et al. 2008). Fragmentation of the Missouri O. m. meeki population by Table Rock Reservoir is a cause for concern with regard to recolonization of sites that may suffer declines or simply with regard to genetic exchange (Fetzner and DiStefano 2008). Our failure to detect Meek’s crayfish at two of the three Missouri historical known locations may be reason for increased concern. This underscores the importance of comprehensive distribution studies and continued monitoring for rare or imperiled crayfishes such as O. m. meeki to assess changing conservation status or evaluate trends. Our survey’s incorporation of analyses to detect crayfish species-environmental variable associations should facilitate conservation efforts by providing biologists with the ability to predict locations of additional sites harboring these species or locations that may be suitable for reintroduction efforts (Furse and Wild 2002).

Our survey indicated that O. m. meeki is very rare in the Missouri portion of the White River drainage, but recent observations indicate that it is more common in the neighboring state of Arkansas (Wagner 2008, personal communication). Therefore, we concur with the currently assigned conservation status ranks of “critically imperiled” in Missouri (Missouri Natural Heritage Program 2007), but “apparently secure” (Missouri Natural Heritage Program 2007) or “currently stable” (Taylor et al. 2007) globally.

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