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RELATIONSHIPS BETWEEN MULTI-SCALE ENVIRONMENTAL AND LAND-USE FACTORS AND SUMMER DEMOGRAPHICS OF THE NORTHERN CLEARWATER CRAYFISH, *ORCONECTES PROPINQUUS* (DECAPODA: CAMBARIDAE)

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ABSTRACT. Crayfish are structurally important in streams as a main component in the food chain and as decomposers of organic material. They exhibit wide sensitivities to environmental disturbance and serve as response indicators of habitat degradation and anthropogenic effects. Thirty stream reaches in central Indiana were sampled to determine relationships between relative abundance, size, age, sex, and habitat associations of the Northern Clearwater Crayfish, *Orconectes propinquus*. Females were significantly more abundant than males ($P = 0.08303$). The frequency of crayfish in gravel substrate was significantly higher than that of cobble substrate ($P < 0.0001$). The size of crayfish in cobble substrate were significantly larger ($P < 0.001$) than individuals found in gravel substrates, while females were significantly larger ($P = 0.013$) than males in gravel substrates. Watershed variables were not significantly related to crayfish abundance. The only reach scale variable that proved to be significant ($P = 0.084$) was a boulder substrate score. Microhabitat variables showed a significant increase between catch-per-unit-effort (CPUE) and cobble ($P = 0.083$) and gravel ($P = 0.099$) substrates.

Keywords: watershed-scale, reach-scale, microhabitat, age, cumulative frequency distribution

INTRODUCTION

Tertiary burrowing crayfish play a vital role in the structure and function of stream ecosystems (Momot 1995; Butler et al. 2003). Tertiary burrowing crayfish are decapods that live the majority of life in open bodies of water and depend on weakly constructed burrows during drought conditions for survival (Hobbs 1981). They are structurally important in a stream as ecosystem engineers and are a key component of the food chain (Taylor et al. 1996; Creed & Reed 2004). Fish, turtles, salamanders, birds, and mammals all utilize crayfish as a primary source of food (Bovbjerg 1952; Rabeni 1992). Crayfish can be a keystone species in many stream ecosystems by affecting species throughout many trophic levels in aquatic food webs (Parkyn et al. 1997; Flinders & Magoulick 2005). Crayfish are also decomposers of organic material within a stream and contribute to overall stream health and energy transformation between trophic levels (Butler et al. 2003; Montemarano et al 2007; Stewart et al 2010). Crayfish are sensitive indicators of habitat degradation and respond to anthropogenic effects in streams. Species composition and relative abundance reflects anthropogenic response to water quality, habitat, land use change, and stressors (Butler et al. 2003; Simon & Morris 2009).

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The Northern Clearwater Crayfish, *O. propinquus* (Girard 1852) is a tertiary burrowing crayfish (Hobbs Jr. 1989). The species is common in areas of North America ranging from southern Ontario and Quebec, as far south as southern Illinois, Indiana, Ohio, Pennsylvania, and New York, and as far west as Iowa and Minnesota (Hobbs Jr. 1989; Crocker & Barr 1968). The species is most common in Midwestern United States headwater streams (Simon 2001). *O. propinquus* is found in both stream and lake ecosystems (Page 1985; Hobbs III 1988). The species' habitat is typically rocky riffle habitat in streams (Crocker & Barr 1968; Page 1985; Taylor & Schuster 2004; Momot 1966), but they prefer coarse habitat that can provide cover from predators. They function as omnivores and feed on plant material and various invertebrate larvae in streams (Page 1985).

Watershed and reach-scale land use can influence chemical and physical factors associated with a stream (Allan 2004). On a reach-scale, the channel morphology can be largely influenced by bank material, riparian vegetation, and the slope at which water and other inputs enter the stream (Allan 2004; Wang et al. 1997). The resulting channel morphology and substrate can determine the types of species that will likely inhabit that particular reach. Watershed-scale land uses are known to have negative impacts on stream ecosystems (Burskey & Simon 2010). For example, agricultural practices increase sediment inputs and nutrients into streams and may negatively affect water quality, habitat, and biological assemblages (Allan 2004; Nerbonne & Vondracek 2001). Excessive sediment loads in streams can negatively affect macroinvertebrates, such as crayfish, by reducing food sources and filling in interstitial pore spaces in preferred habitats (Nerbonne & Vondracek 2001). Urban land use has also been found to reduce stream habitat quality by the addition of chemical contaminants (Wang et al. 1997). Alternatively, many types of land use can improve stream quality. Forest land use has been found to correlate with high quality habitat and also for bank stability and instream cover (Wang et al. 1997)

Factors known to influence crayfish distribution at the stream reach-scale include presence of predators, amount and stability of instream cover, age and body size, food sources, and competition among other crayfish (Stewart et al. 2010; Rabeni 1985). Larger crayfish are best able to defend themselves (Stein 1977) and are more capable of obtaining preferred cover through competition (Stewart et al. 2010).

The four primary objectives of this study were to: (1) determine overall CPUE patterns with watershed-, reach-, and microhabitat-scale associations for *O. propinquus* based on gender and habitat; (2) determine variation in size among *O. propinquus* based on gender and habitat associations; (3) examine the age range that exist in headwater streams based on gender and habitat associations; and (4) determine those factors that affect the CPUE of *O. propinquus* at watershed-, reach-, and micro-habitat-scales.

METHODS

Study area.—The study area was within the Interior Plateau Level III ecoregion of Indiana (Woods et al. 2011). This ecoregion is characterized by rolling and heavily dissected, rugged terrain (Woods et al. 2011). The underlying soil is composed of sandstone, siltstone, shale, and limestone (Woods et al. 2011). The ecoregion consists of high hills and knobs, and low and narrow valleys. The streams of this region are medium to high gradient (Woods et al. 2011).

A total of 30 sites were sampled in the counties of Brown, Monroe, Morgan and Lawrence in south central Indiana (Figure 1). Sites are located in the East Fork White River watershed, which is dominated by karst topography and limestone quarries (Rapid Watershed Assessment 2011). Land use is mainly agricultural cropping and livestock pasturing, but includes several forest types. Forested areas were the most common land use buffering the focus streams, composing 57% of the total land use.

Study design.—Site selection was chosen based on a random probability study design. Sites were classified by Strahler stream order (Strahler 1957) and selected without replacement from the universe of wadeable first through third order streams in the four county areas (Stevens & Olsen 2004). These sites were previously sampled as part of the U.S. Environmental Protection Agency (USEPA) Regional Monitoring and Assessment Program (REMAP) in the Eastern Corn Belt Plain study. Stream site conditions ranged from the highest quality streams in south central Indiana to those of lower quality due to poor land management practices (Simon & Dufour 1998).

The following research questions and *a priori* hypotheses were tested to evaluate the association between habitat, relative abundance, and CPUE of Northern Clearwater Crayfish based on gender, age, and landscape scale factors.

Questions regarding relative abundance included whether there is an equal distribution of males and females based on gender ratios, and whether male to female gender ratios are equal in cobble and gravel substrates. We evaluated the percentage of cobble and gravel substrates at each site using a qualitative habitat proce-

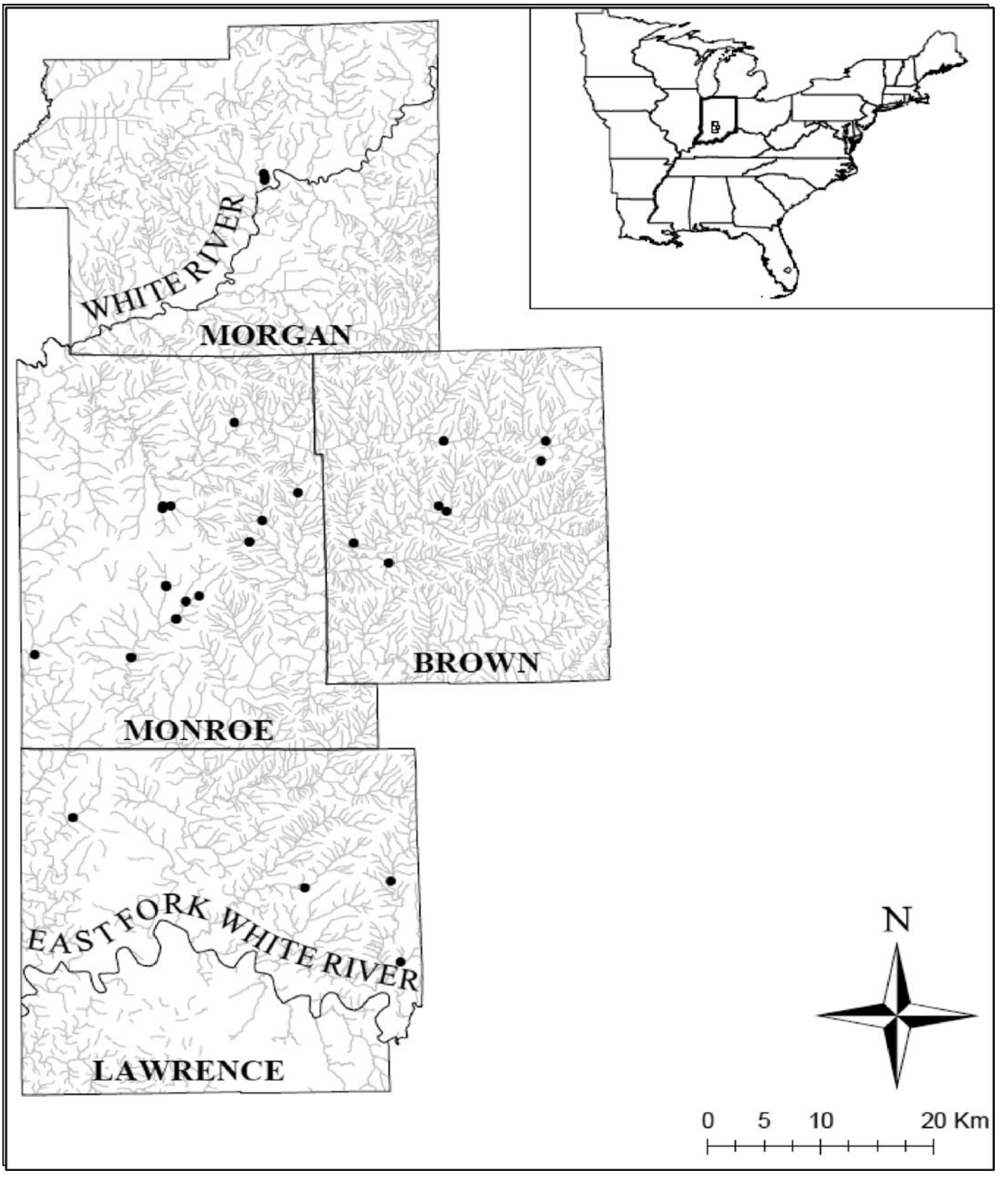

Figure 1.—Study sites (black dots) sampled during an investigation of *O. propinquus* habitat associations in southcentral Indiana, USA, headwater streams.

dure (Rankin 1989). Within similar relative abundance categories, we evaluated whether there would be a greater CPUE of *O. propinquus* in cobble substrate compared to gravel substrates

We explored two size-related questions, including whether *O. propinquus* is larger in size in large coarse substrates compared to smaller coarse substrates, and whether males are larger than females.

Scale and habitat associated questions were placed into three categories, including watershed-, reach-, and microhabitat-scales. For the watershed-scale associations, we evaluated whether the CPUE of crayfish changes with land use, whereas for reach scale we evaluated whether increasing reach scale habitat heterogeneity led to greater CPUE. For microhabitat scale associations we explored whether the CPUE increases with increasing size of substrate. Finally, age was evaluated to determine if ontogenetic differences existed in age class use of large-coarse compared to moderate-coarse substrates.

Field sampling.—The stream reach length sampled was 15 times the wetted width (Simon 2004). The study stream reaches ranged from a minimum distance of 50 meters (m) to a maximum distance of 250 m. Sampling proceeded in an upstream manner beginning at the downstream end of the stream reach, thereby reducing disturbance to upstream crayfish.

The sampling events occurred between June 17 and July 18, 2010, and generally followed the method used by Simon (2004). A one-man minnow seine (1 m $\times$ 1 m) with 3.1 mm standard mesh netting was used to collect crayfish by kick-seining a 1 m^2 area of substrate directly upstream of the seine (Mather & Stein 1993). Crayfish were sampled from twenty 1 m^2 plots of habitat randomly distributed in the stream reach, which represent the coarse substrate habitat portions of each stream reach (Barbour et al. 1999). The CPUE is defined by the number of crayfish collected within a m^2. Captured individuals of *O. propinquus* and all other crayfish species were counted, sexed, and released after the completion of the sampling event.

A total of twenty 1 m^2 seine samples were completed at each site; ten samples each were randomly located in both gravel-dominated and cobble-dominated substrates. Substrate size was classified following USEPA physical habitat procedures (Kaufmann et al. 1999), and seine sample locations were classified as either cobble or gravel based on the dominate substrate ($>$ 50%).

Stream width measurements at each site included wetted and bankfull widths (Kaufmann et al. 1999). The wetted width is the perpendicular measurement from shoreline to shoreline. Bankfull width measures the lateral extent of water that fills the channel to the top of each bank during periods of high flow.

Laboratory methods.—Individual *O. propinquus* that were too small to sex or measure in the field were taken to the laboratory where carapace length (CL) and postorbital carapace length (POCL; Hobbs Jr. 1981) and sex were recorded (Figure 2). Crayfish specimens were deposited in the Astacology collection at the Aquatic Research Center of the Indiana Biological Survey, Bloomington, Indiana.

Watershed-scale variables.—ArcMap 10.0 was used to overlay the watershed boundary with stream hydrology and 2006 land cover site information. The stream and land cover data were obtained from IndianaMap.org (Indiana map 2011). The stream layer included the 2008 National Hydrology Dataset (NHD) and was derived at 1:100,000 scale. The land cover layer included the 2006 USGS 30-meter resolution National Land Cover Data (NLCD). The percentage of each land use type was determined from the land use layer for each individual watershed.

Watershed-scale variables included 15 land cover types (Watershed Delineation Model 2013), which represent the number of acres contained within the area upstream of the most downstream margin of the sampled reach (listed in Table 5) and three additional variables (i.e., latitude, longitude, drainage area). The watershed boundaries and land cover types were delineated using the Watershed Delineation Model (2013), which utilizes the digital elevation associated with specific latitudes and longitudes. The drainage area for each of the 30 sites sampled were obtained from US Geological Survey sources (Hoggatt 1975).

Reach-scale variables.—Reach-scale variables were derived from qualitative habitat measures defined in the Qualitative Habitat Evaluation Index (QHEI; Rankin 1989). The habitat variables include a variety of habitat qualities within the wetted stream width and the riparian area of the stream. The qualitative habitat variables include the following categories: substrate types, instream cover, channel morphology, riparian quality/bank erosion, pool/glide and riffle/run quality, and local stream gradient. Each qualitative habitat category is ranked by a series of categories representing varying states of stream habitat condition. The total reach habitat score is the sum of each of the category scores, which provides a cumulative score for the entire stream reach. Each qualitative categorical score and the total reach habitat score was regressed against crayfish relative abundance to determine any significant relationships between the habitat category and crayfish relative abundance.

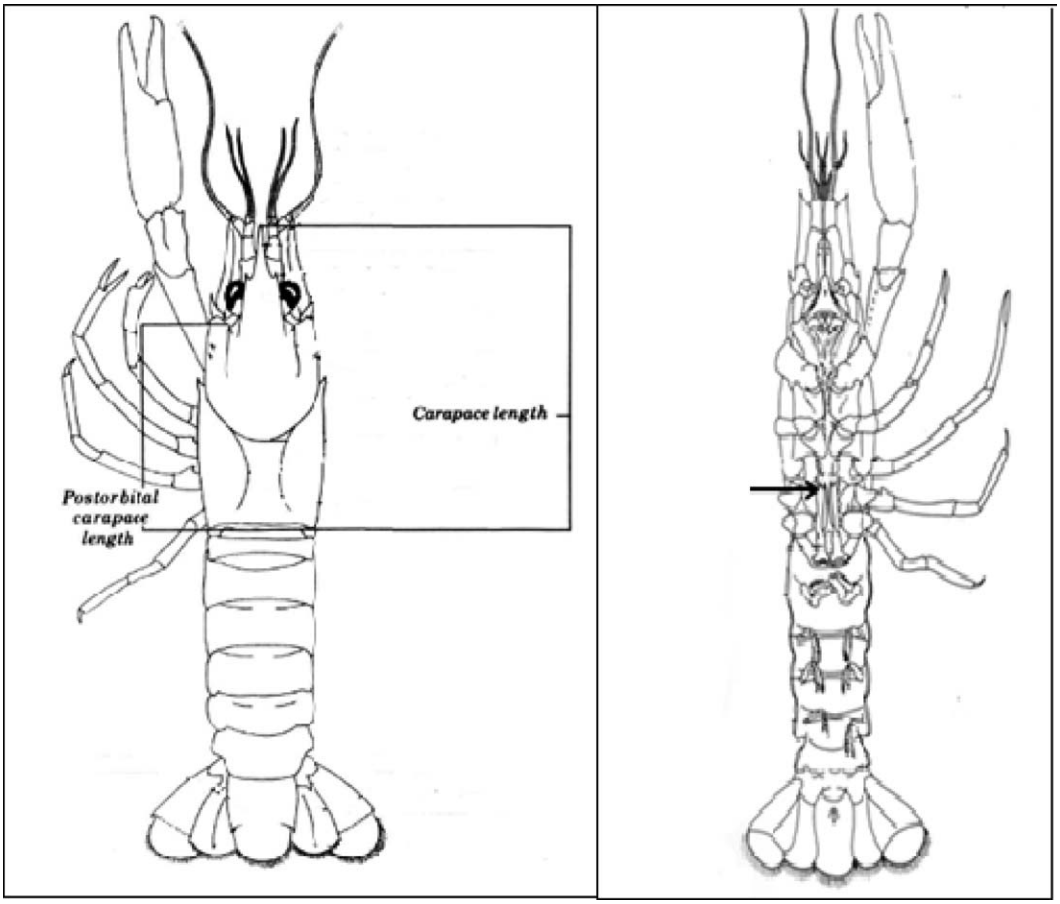

Figure 2.—Dorsal and ventral view of crayfish showing various measurements. a) CL and POCL are shown, and b) ventral view of male crayfish showing the location of sexual reproductive organs (adapted from Page 1985).

Individual substrate particle size categories for each stream reach were compared to crayfish CPUE to determine if any significant relationships existed. The substrate types observed included boulder, cobble, gravel, sand, bedrock, detritus/muck, and artificial. Each specific substrate size class was determined for each reach site and was used for the comparison based on the percent of the sample area occupied by each substrate type.

Several other physical reach-scale factors were evaluated including the total percentage of pool, run, and riffle habitat, and the wetted and bankfull width measurements for each reach. Each variable was compared to the CPUE of crayfish at each site.

Microhabitat-scale variables.—Two microhabitat-scale variables examined include the two primary coarse substrate types (cobble-dominated substrate and gravel-dominated substrate). At each site 10 random m^2 samples in each of the two substrate types were sampled using a kick seine method to collect individual crayfish. A CPUE was calculated based on the 10 seine samples in each substrate size class and compared to evaluate associations between gender, size, and CPUE with each of the microhabitat substrate types.

Statistical methods.—A variety of statistical methods were used to analyze each category of questions that were examined (Sokal & Rolf 1995). Basic statistics using Statistica (StatSoft Inc. 2012) were used for all analyses. Each statistical analysis conducted used a significance value of $\alpha = 0.10$ for field evaluation and a Tukey HSD post-hoc test. Analysis of

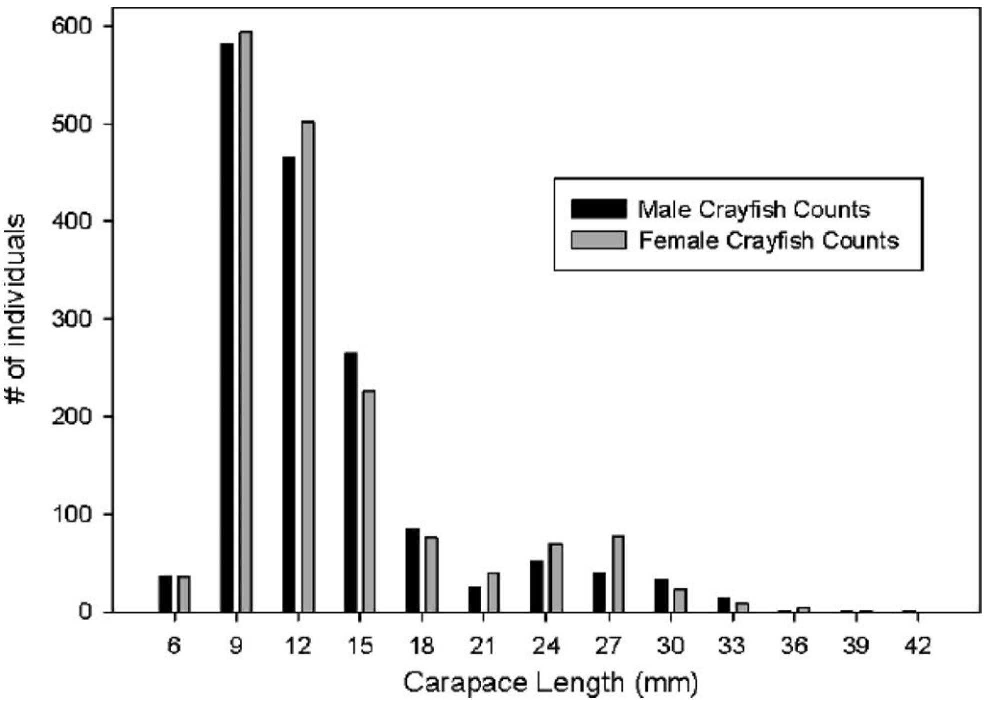

Figure 3.—Length frequency distribution showing the number of *O. propinquus* by sex.

biological community effects at landscape scales commonly utilize an $\alpha = 0.10$ since sample sizes are small (n=30) and the landscale units are often at large units (Burskey & Simon 2010; Stewart et al. 2010). Differences between relative abundance and CPUE of male and female *O. propinquus* among cobble and gravel habitats were determined using a Z-test. Differences between populations in crayfish length were assessed using a one-way Analysis of Variance (ANOVA). A length-frequency distribution was developed to evaluate differences in age structure. A simple univariate linear regression was used to analyze each category of the habitat-scale factor questions. The regressions compared a specific watershed, reach, or microhabitat variable with the CPUE of crayfish at each site.

RESULTS

Relative abundance and CPUE.—A total of 2,648 *O. propinquus* were collected from 29 of the 30 sites that were sampled during this study. *O. propinquus* individual CPUE effort ranged from 0 to 19.1 individuals/ m^2 at each stream reach. The number of males compared to females was consistent by site with males comprising 990 individuals and females 1,048 individuals (Figure 3). The sex ratio was 1:1.05 males to females. A total of 610 juveniles (range: 4.4 mm to 9.8 mm CL) were captured. The crayfish were classified as juvenile if the individuals were too small to determine the sex. In crayfish early development the primordial gonads of both genders have an androgenic gland, which develops further in males while disappearing in females. The number of crayfish captured in cobble-dominated substrates was 989, while 1,049 were collected from gravel-dominated substrates (Figure 4).

The predicted outcome was an equal CPUE of males and females for all sites, and an equal CPUE of males and females in both cobble- and gravel-dominated substrates. Females were significantly more abundant than males in the stream reaches (Z-statistic = -1.733, P = 0.083). For the comparison of crayfish occupying cobble-dominated compared to gravel-dominated substrate, the CPUE was significantly ($P < 0.001$) different in gravel-dominated substrates (Table 1).

Length frequency distribution and age range.—The mean CL for all of the crayfish collected was 12.7 mm. *O. propinquus* ranged in CL from

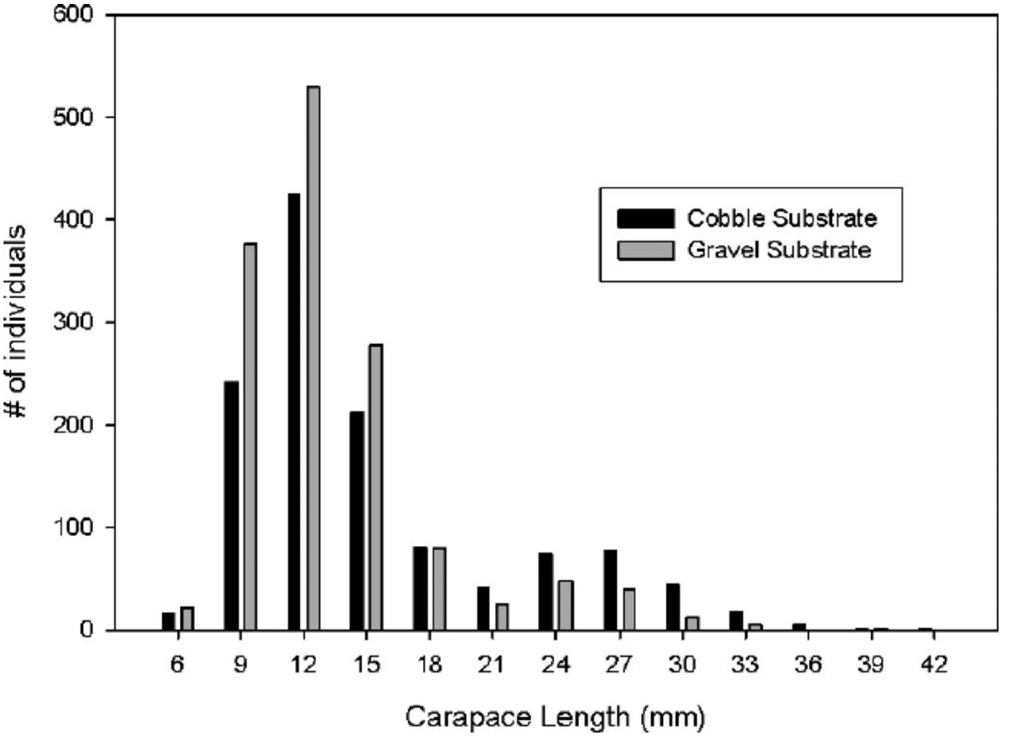

Figure 4.—Length frequency distribution of *O. propinquus* partitioned by substrate size class (cobble-dominated, gravel-dominated) in which they were collected. Large substrates include boulder and cobble, while small substrates include large and fine gravel.

4.4 mm to 39.8 mm. Mean CL was significantly larger for crayfish found in cobble-dominated substrates ($P < 0.001$) compared to gravel-dominated substrates (Figure 4). Females collected in gravel-dominated substrates had significantly larger CLs than males ($P = 0.013$; Table 2).

Three age classes were observed in this study (Table 3). Both male and female *O. propinquus* individuals attained similar size at each age. Age 0 individuals were 3–18 mm CL; age 1 individuals were 18–33 mm CL; and age 2 individuals were 33–42 mm CL. The length-frequency distribution showed the greatest number of individuals occurred at age 0 (cobble = 973, gravel = 1285; and males = 1433, females = 1434). The number of individuals decreased with increasing age group. Only eight individuals were found in the 2-year age group, and no individuals reached age 3 (Tables 3 and 4). Large individuals (>18 mm CL) had a greater occurrence in cobble substrates compared to smaller individuals (3–18 mm CL), which were more common with gravel substrates (Table 4).

Habitat scale factors.—None of the 18 watershed-scale variables showed a significant relationship with *O. propinquus* CPUE (Table 5).

Table 1.—Z-test statistical values for CPUE (individuals/m^2) comparisons between *O. propinquus* gender and substrate size (α=0.10).

Relative Abundance	Z	P -two-tail
Male vs. Female: all sites	−1.733	0.083
Male vs. Female Cobble	<.001	0.999
Male vs. Female Gravel	<.001	0.999
Cobble vs. Gravel	−4.340	<0.0001

Table 2.—F-test P-values (α=0.10) for *Orconectes propinquus* CPUE (individuals/m^2) comparisons between size, gender, and substrate type.

Carapace Length	F	P-value
Cobble vs. Gravel	70.643	< 0.001
Male vs Female: All Sites	0.547	0.460
Male Cobble vs. Female Cobble	0.601	0.438
Male Gravel vs. Female Gravel	6.140	0.013

Table 3.—Age class frequency distribution for male and female by age class. CL= carapace length.

Sex/Size class CL (mm)	N	Age
Male		
3–18	1433	0
18–33	164	1
33–42	3	2
Female		
3–18	1434	0
18–33	219	1
33–42	5	2

Only a single reach-scale variable, boulder substrate, was significantly correlated with crayfish CPUE (Table 6). An increasing amount of boulder habitat was associated with a decrease in crayfish relative abundance. Both microhabitat-scale factors, cobble- (P = 0.083) and gravel-dominated (P = 0.099) substrates, were positively associated with *O. propinquus* CPUE (Table 7).

DISCUSSION

The relative abundance of crayfish is dependent on available stream substrate types (Stewart et al. 2010; Burskey & Simon 2010; Rabeni 1985). The five lowest crayfish CPUE, i.e., 0, 2, 5, 10, and 15 individuals/m^2, occurred at sites with reduced reach-scale habitat. Guthrie Creek, Bean Blossom Creek, Griffey Creek, and two reaches at Sycamore Creek included variables that influenced the crayfish population. For example, Bean Blossom Creek (n = 2 individuals/m^2) was a stagnant stream with muck substrate, whereas Griffey Creek (n=5 individuals/m^2) was heavily impounded with an embedded substrate. These substrate factors are considered responsible for declining crayfish relative abundance due to reduced amounts of preferred substrate and instream cover.

Table 4.—Age class frequency distribution by size and coarse substrate type.

Substrate/Size class, CL (mm)	N	Age
Cobble		
3–18	973	0
18–33	254	1
33–42	7	2
Gravel		
3–18	1285	0
18–33	129	1
33–42	1	2

Table 5.—Simple linear regression (R^2, F-test, Significant F, and P-value, α=0.10) relationships between watershed-scale land use variables and *O.s propinquus* CPUE from headwater streams in south central Indiana.

Watershed Variables	R^2	*F*	P-value
Open water	0.0002	0.005	0.945
Developed open spaces	0.003	0.080	0.779
Developed low intensity residential	0.001	0.038	0.846
Developed medium intensity residential	< 0.0001	0.0009	0.976
Developed high intensity residential	0.0006	0.017	0.896
Deciduous forest	0.002	0.044	0.835
Evergreen forest	0.009	0.247	0.623
Mixed forest	0.042	1.213	0.280
Shrub/Scrub	0.021	0.607	0.443
Grasslands/Herbaceous	0.088	2.716	0.111
Pasture/Hay	0.002	0.047	0.830
Cultivated crop	0.072	2.113	0.157
Barren land	0.034	0.990	0.328
Woody wetland	0.005	0.153	0.699
Emergent herbaceous wetland	0.003	0.094	0.761
Latitude	0.050	1.461	0.236
Longitude	< 0.0001	0.0005	0.982
Drainage area	0.014	0.405	0.530

Rabeni's (1985) study, based on two *Orconectes* species, demonstrated that larger individual crayfish correlated with larger substrates particles. Crayfish substrate preference is typically associated with areas that offer the most overall cover and protection from predators (Stein & Magnuson 1976). Larger crayfish select larger substrates that provide the most cover. The larger substrates will provide more overall interstitial spaces, which provide more areal coverage for protection from predators (Stein & Magnuson 1976). CL was significantly correlated with large substrate sizes compared to small substrates; however, since the study area was not glaciated during the latest Wisconsin glaciation event the dominant particle size in the study area is cobble. Individual *O. propinquus* were associated with cobble substrates that exhibited the highest CPUE (Table 4), so that our study found that as substrate particle size increases so does the CPUE and size of individual crayfish.

Large individuals were associated with large substrate particle size and when mature adults

Table 6.—Simple linear regression (R^2, F-test, Significant F, and P-value, α=0.10) relationships between reach-scale variables and *O. propinquus* relative abundance from headwater streams in south central Indiana.

Reach-Scale Variable	R^2	*F*	P-value
Stream width			
Wetted Width (m)	0.0004	0.010	0.921
Active Width (m)	0.0018	0.050	0.825
Bank Full (m)	0.0300	0.866	0.360
Habitat			
Substrate	0.0150	0.426	0.519
Instream Cover	0.0043	0.122	0.729
Channel Morphology	0.0072	0.204	0.655
Bank Erosion and Riparian Zone	0.0480	1.412	0.245
Pool/ Current	0.0043	0.122	0.729
Riffle/Run	0.0213	0.608	0.442
Gradient	0.0016	0.046	0.831
QHEI Total Score	0.0006	0.017	0.897
Substrate			
Boulder	0.1026	3.202	0.084
Cobble	0.0544	1.611	0.214
Gravel	0.0222	0.637	0.431
Sand	0.0226	0.649	0.427
Bedrock	0.0026	0.074	0.787
Detritus/Muck	0.0698	2.102	0.158
Artificial	0.0287	0.828	0.371
Morphology			
% Pool	0.0374	1.090	0.305
% Run	0.0394	1.148	0.293
% Riffle	0.0003	0.008	0.930

were present, smaller individual crayfish typically were associated with small, gravel substrates (Stewart et al. 2010; Rabeni 1985). *O. propinquus* individuals were more abundant in gravel substrates than in cobble substrates; however, this was based on the association between CPUE and high number of age 0 individuals. Overall, Age 0 crayfish comprised the largest proportion of individual crayfish at all sites (n = 2258; 85.3%). A niche shift from small substrates to large substrate occurs at lengths greater than 18 mm CL. This niche shift demonstrates that individual crayfish select increasing substrate particle size proportional to increasing body size. Likewise, small age 1 individuals showed similar response as age 0 individuals with increasing CPUE in the less preferred gravel substrates.

Rabeni (1985) demonstrated that often the primary factor that determines crayfish dominance

Table 7.—Simple linear regression (R^2, F-test, Significant F, and P-value, α=0.10) relationships between microhabitat-scale substrate type and *O. propinquus* CPUE (number individuals/ m^2) from headwater streams in south central Indiana.

Microhabitat Variables	R^2	*F*	P-value
CPUE Cobble	0.103	3.232	0.083
CPUE Gravel	0.094	2.904	0.099

is size. Other studies have also shown that the dominance of many freshwater crayfish is based on size (Stewart et al. 2010; Pavey & Fielder 1996). The study area male to female sex ratio is 1:1.05. Male CPUE was expected to be greater than the CPUE for females, which was based on another assumption that males would be significantly larger than females. However, both of these expected outcomes did not prove to be true. Females were not larger than males in general; however, females were significantly larger than males in gravel substrates. This suggests that females could have a slight numerical advantage over males during the early stages of their lives or be forced into smaller substrate particle sizes due to dominance and territoriality. This would provide one explanation to females being significantly more abundant than males in the streams sampled. However, females would be exposed to increased predation pressure affecting female CPUE with increasing age class. Another possible explanation would be that females grow at a slightly slower pace than males, which could possibly skew the defined age classes. More research into the growth rates and size classes based on sex could better determine the causes.

Linear regression models showed little significance between scale variables tested at watershed- and reach-scales. This was a similar result observed by Burskey & Simon (2010) and Stewart et al. (2010). All study area watersheds comprised relatively small drainage area sizes (range: 9.1 to 49,166 acres). We selected headwater streams to isolate potential impacts and increase the percentage of catchment forested land use. Forested areas provided a large amount of coarse particulate organic matter (CPOM), which are positive factors for stream ecosystems (Englan & Rosemond 2004). Forests provide large amounts of organic material and detritus, which are very important for crayfish survival (Saffran & Barton 1993).

The high percentage of forested areas (mean: 57% for all sites) in these watersheds represent a least impacted condition for crayfish populations. A large amount of forested area is considered to be the most important factor for explaining low significance in watershed-scale analyses, since the forested landscape represented by our study area is larger than usual for most other watersheds. Forested landscapes represent the best case scenario and the high relative abundance attained in this study represents the maximum attainable condition.

Watershed land cover effects were not found to affect crayfish populations, whereas other studies linked various land use types to low crayfish abundance (Stewart et al. 2010; Simon & Morris 2009; Burskey & Simon 2010; Hrodey et al. 2009). Row-crop agriculture, urban, and developed areas have been shown to negatively impact aquatic habitats and fish and macroinvertebrate communities (Simon & Morris 2009); however, agricultural land use was not a predominant component in the study streams.

Reach scale stream variables scores showed increasing levels in the study area (cumulative habitat score range: 37.5 to 91.0, mean = 72.9). These relatively high reach scale habitat values show that streams represented relatively high overall ecological integrity. The only correlated variable with crayfish abundance included reach scale habitat substrate boulder proportion. Boulder presence showed a negative correlation with individual crayfish CPUE. This result seems contradictory; however, boulder substrate provide large interstitial spaces affording cover and habitat for predators. The univariate microhabitat-scale regression models showed a significant relationships between CPUE and both cobble and gravel substrates. This suggests that increasing amounts of coarse substrates correlates with increases in *O. propinquus* CPUE and may be differentially important for various life stages.

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