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# URBANIZATION IN A GREAT PLAINS RIVER: EFFECTS ON FISHES AND FOOD WEBS‡

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## ABSTRACT

Spatial variation of habitat and food web structure of the fish community was investigated at three reaches in the Kansas River, USA to determine if $\delta^{13}$C variability and $\delta^{15}$N values differ longitudinally and are related to urbanization and instream habitat. Fish and macroinvertebrates were collected at three river reaches in the Kansas River classified as the less urbanized reach (no urban in riparian zone; 40% grass islands and sand bars, braided channel), intermediate (14% riparian zone as urban; 22% grass islands and sand bars) and urbanized (59% of riparian zone as urban; 6% grass islands and sand bars, highly channelized) reaches in June 2006. The less urbanized reach had higher variability in $\delta^{13}$C than the intermediate and urbanized reaches, suggesting fish from these reaches utilized a variety of carbon sources. The $\delta^{15}$N also indicated that omnivorous and detritivorous fish species tended to consume prey at higher trophic levels in the less urbanized reach. Channelization and reduction of habitat related to urbanization may be linked to homogenization of instream habitat, which was related to river food webs. Published in 2009 by John Wiley & Sons, Ltd.

KEY WORDS: river food webs; stable isotopes; Kansas River; spatial variation; habitat heterogeneity

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## INTRODUCTION

Anthropogenic influences have had major effects on streams and rivers worldwide (Ward and Stanford, 1989). Although agriculture may have the broadest impact on riverine communities, localized urban effects can be more pronounced (Karr *et al*., 1985). Urbanization occupies only a small percentage of land along streams and rivers (10% or more of the catchment area in only 10 of the 150 large river basins in North America; Benke and Cushing, 2005), but strongly affects biota and habitat in streams and rivers (Allan, 2004). Urbanization causes river degradation due to the amount of impervious surface area (Paul and Meyer, 2001), which causes increased erosion, channel destabilization and widening, which leads to loss of habitat from channelization, excessive sedimentation, increases in temperature and reduction in large woody debris (Lenat and Crawford, 1994; Yoder *et al*., 1999; Wang and Kanehl, 2003) causing more homogeneous instream habitats. Fish and macroinvertebrate diversity and density tends to decrease with increased impervious surface cover and urban areas (Jones and Clark, 1987; Limburg and Schmidt, 1990; Wang *et al*., 1997). Also, Poulton *et al.* (2003) found that macroinvertebrate diversity and the per cent of large river fish specialists tended to decrease with increased urbanization in the channelized portions of the Missouri River. These alterations to the habitat and macroinvertebrate community also affect fishes. Yoder *et al.* (1999) found decreased abundance of invertivorous fish with increased urbanization and suggested this was due to an alteration in the aquatic food web. In the Illinois River Karr *et al.* (1985) found all feeding guilds had declining abundance of species (except for omnivores) and related this to habitat modifications due to urbanization. Also,

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growth of flathead catfish *Pylodictis olivaris* was slower in areas with less instream habitat diversity and increased urbanization, which suggests less food available or an increase in intraspecific competition in these areas (Paukert and Makinster, 2009).

Carbon stable isotope signature in fishes can be related to flow longitudinally (Finlay *et al*., 1999; Fry, 2002) and laterally (Gido *et al*., 2006) within rivers, and can be used to assess the diversity of resources available (Mercado-Silva *et al*., 2008). Finlay *et al.* (1999) determined that $\delta^{13}$C of algae and invertebrates varied with current velocity, and noted that isotopic distinction among habitats could be useful when determining the affects of different anthropogenic factors. Gido *et al.* (2006) determined $\delta^{13}$C values of fishes in secondary channels of the San Juan River, New Mexico and Utah were less variable than primary channels, suggesting fishes in secondary channels converge on the same resources, and habitat homogenization in the secondary channels may be related to the less variable $\delta^{13}$C values. Therefore, using $\delta^{13}$C values may be a useful tool to determine if fish and macroinvertebrates are affected by urbanization, which likely decrease riparian and instream habitat heterogeneity. Stable isotope $\delta^{15}$N values are used to determine trophic position (TP) of organisms and food sources. Trophic position is determined by the ratio of 15N/14N (expressed as $\delta^{15}$N) in fish tissue relative to that in basal food sources; $\delta^{15}$N is assumed to be greatest in fishes that consume high trophic level prey items with an enrichment of 3.4‰ per trophic level (Cabana and Rasmussen, 1996).

The objectives of this study were to determine if urbanization and instream habitat differs spatially within the Kansas River, and how these changes relate to trophic structure and fish food webs. We hypothesized that (1) reduction of instream habitat would be related to increased channelization due to urban land use, (2) TP of individual fish species would increase in areas with more instream habitat and (3) fish in areas of high habitat heterogeneity would have higher variability in $\delta^{13}$C values.

## METHODS

### *Study site*

The Kansas River begins near Junction City, Kansas at the confluence of the Smoky Hill and the Republican rivers and flows east 274 km where it joins the Missouri River. Bowersock Dam (a low-head dam at river kilometre, rkm, 83) is the only dam restricting the movement of fish on the main channel of the Kansas River (Eitzmann *et al*., 2007). The river is a shallow (typically $< 1.5$ m) sand bed river with many shallow side channels, and sandy islands usually overgrown with willows and grasses (Eitzmann and Paukert, in press) particularly in upriver reaches. Mean depth is typically $< 1.5$ m throughout the river most of the year (Paukert and Makinster, 2009).

Three reaches of the Kansas River were sampled for fishes, riparian and instream habitat and macroinvertebrates. The fish and macroinvertebrates were collected from 12th June to 29th June 2006, and the riparian and instream habitat was collected from images taken on 24 September 2006. The reaches were chosen as representative of reaches throughout the Kansas River and are classified as reach 1 (rkm [distance from the confluence of the Missouri River in Kansas City, Kansas] 230–236), reach 2 (rkm 120–126), and reach 3 (rkm 24–30).

### *Riparian and instream habitat*

One metre resolution aerial imagery was used to classify instream and riparian habitat in each reach (Paukert and Makinster, 2009). Transects were created perpendicular to the river channel at 0.8 km intervals within the three reaches, and riparian habitat (200 m on each side of the bankfull height) was measured along the transect. The length of the transect that was urban land (obvious roads, paved parking lots, sand pits and other man-made disturbances, Paukert and Makinster, 2009) was calculated for each transect using ArcGIS 9.0 (ESRI, Redlands, California, U.S.A.). Bankfull width (m) was calculated as distance between the two most pronounced banks along each transect (Paukert and Makinster, 2009). Within the bankfull width, the number of channels (areas containing flowing water), grass islands (grass and forested areas with a channel present on each side) and sand bars (sand areas between the bankfull mark and the channel) were recorded. The proportion of each instream habitat was calculated as the proportion of each transect within bankfull width in each habitat.

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*Field collections*

Multiple sampling gears were used in each reach to collect all fishes at each location. The gears used in collection included daytime boat electrofishing (7–11 A; 400–500 V; 40–60 pulses), gill nets (30.5 × 1.8 m deep, 4–7.62 m panels of 1.9, 3.8, 5.1 and 7.6 cm bar meshes), large hoop nets (1.1 m diameter, 3.8 cm bar mesh), small hoop nets (0.6 m diameter, 0.48 cm bar mesh), and a straight seine (4.5 × 1.2 m, 0.64 cm mesh). All species were collected from the randomly selected main channel and main channel border areas, and depth (m) was recorded at each site sampled.

Stomachs and dorsal muscle tissues were removed in the field from the large-bodied adult fish and placed on ice and transported to the laboratory. The smaller bodied adult fish were kept whole, placed in ice in the field and the dorsal muscle and stomachs were removed in the laboratory. Muscle and stomachs were taken from an average of 4 adult fish (range 1–6) of each species within each reach for stable isotope and stomach content analysis. Only adults were used to account for any possible diet shifts between age classes.

Macroinvertebrates were collected within each reach using macroinvertebrate nets and sieves to capture all available taxa. Macroinvertebrates were taken from the substrate and from woody debris in the main channel region. All aquatic macroinvertebrate taxa at each reach were collected and classified to family and by feeding guild (Merritt and Cummins, 1996). Tricoptera (Hydropsychidae), Ephemoptera (Baetidae), Diptera (Chironimidae) and Hemiptera (Corixidae) were classified as herbivores/detritivores, whereas Megaloptera (Corydalidae), Odonata (Coenagrionidae), and Plecoptera (Perlidae) were classified as predators. All macroinvertebrates were kept alive for 24 h to allow them to expel unwanted gut material (Jardine *et al*., 2005).

*Stable isotope analysis*

White dorsal muscle was used for stable isotope analysis because it best represents the isotopic signature of fish (Rounick and Hicks, 1985; Hesslein *et al*., 1993), has the lowest variability of $\delta^{13}$C and $\delta^{15}$N with respect to diet, and does not require the removal of inorganic carbonates (Pinnegar and Polunin, 1999). All samples of muscle and macroinvertebrates were dried at 60°C for 48 h prior to grinding into a fine powder. All fish and macroinvertebrate stable isotope analysis was conducted in the Stable Isotope Mass Spectrometry Laboratory (SISML) at Kansas State University or at North Carolina State University in the Analytical Services Lab - Stable Isotope Mass Spectrometry (ASL-SIMS) with a Thermo-Finnigan Delta Plus mass spectrometer with a CE 1110 elemental analyzer and Conflo II interface in continuous flow mode (CF-IRMS). Stable isotope ratios were calculated in standard notation:

$$\delta^{15}\mathrm{N} = [(^{15}\mathrm{N}/^{14}\mathrm{N}_{\mathrm{sample}}/^{15}\mathrm{N}/^{14}\mathrm{N}_{\mathrm{standard}}) - 1 \times 1000]$$

$$\delta^{13}\mathrm{C} = [(^{13}\mathrm{C}/^{12}\mathrm{C}_{\mathrm{sample}}/^{13}\mathrm{C}/^{12}\mathrm{C}_{\mathrm{standard}}) - 1 \times 1000]$$

Data are reported on a per thousand (‰) basis.

Although $\delta^{15}$N values of primary consumers may vary across site, Anderson and Cabana (2005) showed that trophic levels vary similarly across sites, and support the use of primary consumers as a baseline source for calculating TP. Therefore, TP was standardized similar to methods in Cabana and Rasmussen (1996) and Vander Zanden and Rassmussen (1999) by using a dominant primary consumer at each site as the baseline, assuming a 3.4‰ increase in $\delta^{15}$N with an increase of one trophic level (Minigawa and Wada, 1984; Post, 2002):

$$\mathrm{TP} = \left[\frac{(\delta^{15}\mathrm{N}_{\mathrm{fish}} - \delta^{15}\mathrm{N}_{\mathrm{primary\ consumer}})}{3.4}\right] + 2$$

Chironomids were chosen as our baseline primary consumer (TP = 2) because they were abundant in all three reaches and were similar to other primary consumers (i.e. ephemopterans; Gido and Franssen, 2007). The baseline $\delta^{15}$N value was therefore based on the chironomid samples taken in each reach. Isotope values were calculated for each individual fish, but macroinvertebrates were pooled by family and feeding guild (see above) to achieve the minimum mass needed for the analysis.

*Stomach content analysis*

Stomach contents were analyzed for all fishes to the lowest practical taxonomic level. Contents of the stomachs were allowed to dry at 60°C for 24 h, and each individual item was weighed to obtain a per cent diet by dry weight for each item for each individual fish. Data were summarized as mean per cent by dry weight of each diet item for each species at each reach. In addition, diet data were summarized by fish feeding guilds from Pflieger (1997; Table I).

TP was also calculated using the diet items found in each individual fish. In order to calculate TP, each diet item was identified as detritus and plant matter (TP = 1), macroinvertebrates (TP = 2), and fish (TP = 3). TP was then calculated using the equation in Vander Zanden *et al.* (1997):

$$\mathrm{TP}_{\mathrm{diet}} = \sum (V_i T_i) + 1$$

where $V_i$ is the per cent dry weight of the $i$th prey item and $T_i$ is the TP of the $i$th prey item.

*Data analysis*

An analysis of variance was used to determine if the mean proportion of urban land use in the riparian zone differed by reach. A multivariate analysis of variance (MANOVA) was used to test if mean proportion of instream habitat differed among reaches with measurements from each rkm as the replicates. If the MANOVA was significant an analysis of variance (ANOVA; Proc Mixed in SAS, SAS Institute Inc., Cary, North Carolina, U.S.A.) was used to test which habitat variables differed among reaches (Littel *et al*., 1996). An ANOVA was used to determine if mean depth differed among reaches. If there were differences, a least squares mean test was used to identify which sites differed. In the above analysis proportion data were arcsine square root transformed to better meet the assumptions of the ANOVA. Biplots of mean $\delta^{13}$C and $\delta^{15}$N values for each fish species and macroinvertebrate taxa were plotted to assess the trophic structure of fishes among the three reaches. Mean, range and standard deviation of the $\delta^{13}$C and $\delta^{15}$N values were calculated by the different trophic levels of macroinvertebrates and fishes among all reaches. An ANOVA or Kruskal Wallis test (if variances were not homogeneous—see below) was conducted to test if mean $\delta^{13}$C and $\delta^{15}$N values differed among reaches for each feeding guild to test where enrichment of 15N or 13C was highest. To test if variance in $\delta^{13}$C and $\delta^{15}$N differed across reaches for the different feeding guilds a Levene's test for homogeneity of variance was used. An ANOVA was also used to test if mean TP differed among reaches for the different feeding guilds collected in all reaches. Linear regression was used to test if stable isotope TP of all species from all sites and stomach content TP of all species were associated. A slope of one would indicate that TP for both methods was the same.

Table I. The species sampled from the Kansas River in summer 2006 and the feeding guild they represent based on literature (Pflieger, 1997; Thomas *et al*., 2005)

| Common name | Species | Species code | Feeding guild |
|---|---|---|---|
| Blue sucker | *Cycleptus elongatus* | Cycelo | Invertivorous |
| Bullhead minnow | *Pimephales vigilax* | Pimvig | Omnivorous |
| Channel catfish | *Ictalurus punctatus* | Ictpun | Omnivorous |
| Emerald shiner | *Notropis athernoides* | Notath | Detritivorous/Planktivorous |
| Flathead catfish | *Pylodictis olivaris* | Pyloli | Piscivorous |
| Freshwater drum | *Aplodinotus grunniens* | Aplgru | Invertivorous |
| Longnose gar | *Lepisosteus osseus* | Leposs | Piscivorous |
| Red shiner | *Cyprinella lutrensis* | Cyplut | Omnivorous |
| River carpsucker | *Carpiodes carpio* | Carcar | Detritivorous |
| Sand shiner | *Notropis stramineus* | Notstr | Omnivorous |
| Shovelnose sturgeon | *Scaphirhynchus platorynchus* | Scapla | Invertivorous |
| Smallmouth buffalo | *Ictiobus bubalus* | Ictbub | Omnivorous |

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## RESULTS

### *Riparian and instream habitat*

The proportion of urban land use in the riparian zone differed by reach ($F = 25.43$, DF = 2,26, $p < 0.0001$). Reach 1 had no urban land use in the riparian zone, whereas reach 2 had 14% (SE = 6) but reach 3 had 59% (SE = 9) in the riparian zone. Water depth at sampled sites differed among reaches ($F = 3.79$, DF = 2,157, $p = 0.025$), with shallower water in reach 1 (mean = 0.97 m) and 2 (mean = 1.03 m) compared to reach 3 (mean = 1.27 m). Instream habitat also differed among reaches (Wilks' $\lambda = 0.32$, DF = 8, 44, $p = 0.003$) as reach 1 typically was wider and had a higher proportion of bankfull width as grass islands (Figure 1). In contrast, reach 3 had tended to have fewer number of channels than reach 1, and therefore had a higher proportion of its bankfull width (0.94) as water (i.e. few braided channels or islands) compared to reach 1 (0.59 of its bankfull width as channel). Reach 2 was intermediate of reach 1 and 3 for its instream habitat (Figure 1). Therefore, reach 3 was deeper, had fewer islands and a high proportion its bankfull width as channel, and also had very high urban land use in its riparian zone and now will be referred to as an urban reach. Reach 1 was shallow, had no urban land use in its riparian zone, tended to be wider, and had a higher proportion of islands and will be referred to as the low urban reach. Reach 2 had intermediate urban land use and instream habitat compared to reach 1 and 3 and will be referred to as the intermediate reach.

### *Fish and macroinvertebrate collection*

A total of 157 individuals accounting for 12 species were used for stable isotope analysis. At least 3 individuals of each species were captured in each reach except for blue sucker (*Cycleptus elongatus*) in the intermediate reach (1 fish), emerald shiner (*Notropis atherinoides*) in the heterogeneous habitat reach (2 fish) and the homogeneous habitat reach (1 fish), and shovelnose sturgeon (*Scaphirhynchus platorynchus*) in the homogeneous habitat reach (2 fish). Woody debris contained many of the macroinvertebrate taxa (Chironimidae, Ephemeroptera, Hemiptera, Megaloptera, Odonata, Plecoptera and Trichoptera). Only plecopterans were not collected in all three reaches.

### *Macroinvertebrates*

The $\delta^{13}C$ values varied among reaches for each species. Macroinvertebrate $\delta^{13}C$ values ranged from −27.3 (Ephemeroptera) to −20.4 (Chironomids; Figure 2) in the low urbanized reach, from −25.0 (Megaloptera) to −23.2 (Hemiptera; Figure 2) in the intermediate reach, and from −25.8 (Trichoptera) to −24.2 (Plecoptera;

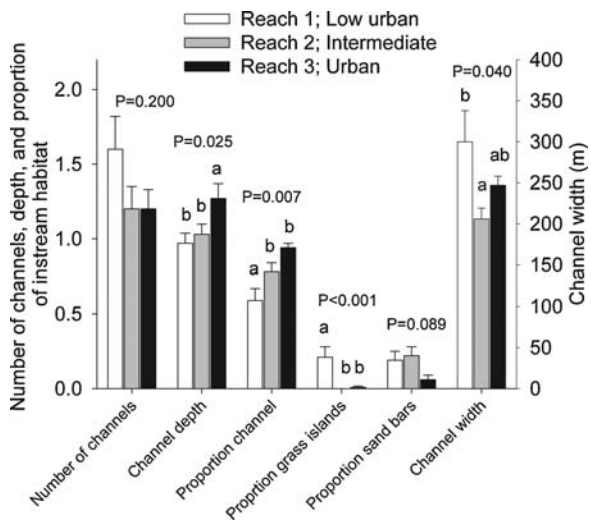


Figure 1. Mean proportion (± SE) of instream habitat from aerial imagery data from September 2006, and water depth from instream measurements in 2006. Identical lower case letters represent areas that were not significantly different among habitat types for each reach. White bars represent reach 1, grey bars represent reach 2, and black bars represent reach 3

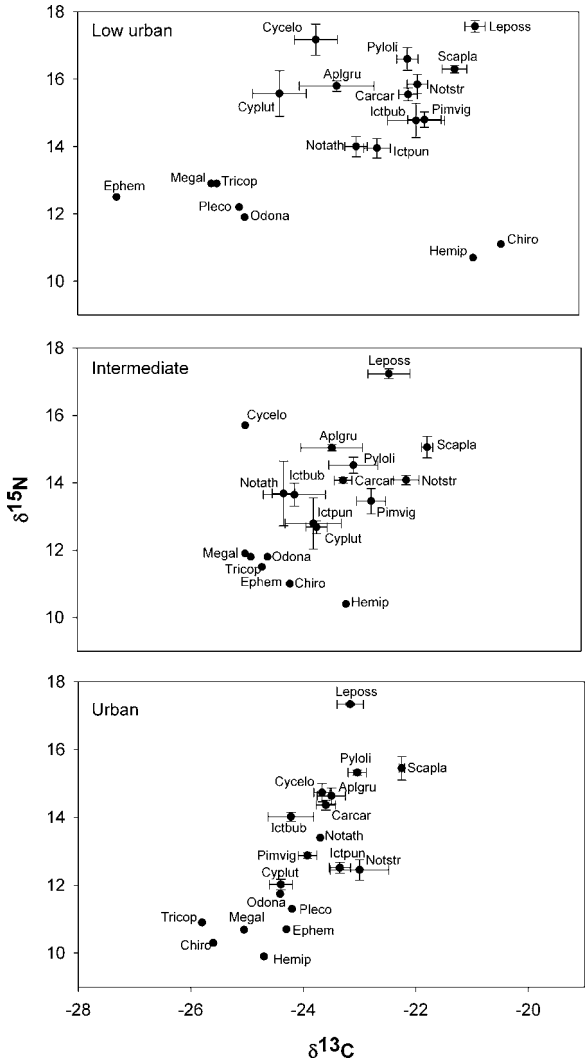


Figure 2. Mean (± SE) $\delta^{15}$N and $\delta^{13}$C of samples collected in the low urban reach (rkm 229–235), intermediate reach (rkm 120–126), and urbanized reach (rkm 24–30) from the Kansas River in summer 2006. Fish species codes are given in Table I. Macorinvertberate codes are Chiro (Chironimidae), Ephem (Ephemeroptera), Hemip (Hemiptera), Megal (Megaloptera), Odon (Odonata), Pleco (Plecoptera) and Trichop (Trichoptera)

Figure 2) in the urbanized reach. Mean $\delta^{13}$C values of herbivore/detritivore macroinvertebrates did not differ among reaches ($p = 0.318$), but was higher in the urbanized reach for predatory macroinvertebrates ($p = 0.016$; Table II). Variance was higher for herbivore/detritivore macroinvertebrates in the low urbanized reach ($p < 0.001$) and tended to be higher for predator invertebrates in this reach ($p = 0.078$). The range of $\delta^{13}$C in the low urbanized reach was 2 to 6 times higher for the intermediate and urbanized habitat reaches for both feeding groups of macroinvertebrates.

The mean $\delta^{15}$N values tended to be highest in low urbanized reach for predatory macroinvertebrates ($p = 0.078$) and herbivore/detritivore invertebrates ($p = 0.085$; Table II). The $\delta^{15}$N values were $> 12.0$ in the low urbanized reach for four of the seven macroinvertebrate taxa, and were $< 12.0$ for all taxa in the intermediate and urbanized reaches (Figure 2). Macroinvertebrate taxa in urbanized reach appeared to be the least enriched 15N with values $\leq 11.0$ for five of the seven taxa (Figure 2). In addition, variability of $\delta^{15}$N was higher in the low urbanized reach for herbivore/detritivore macroinvertebrates ($p = 0.021$) but not for predator macroinvertebrates ($p = 0.914$).

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Table II. The mean, range, and standard deviation (SD) of $\delta^{13}$C and $\delta^{15}$N for fish and invertebrate taxa collected in the low urban reach (rkm 229–235), intermediate (rkm 120–126), and highly urbanized reach (rkm 24–30) from the Kansas River in summer 2006. Species codes are given in Table I. *p*-values indicate if mean isotopic signature or variance differed among reaches for each taxa group for $\delta^{13}$C and $\delta^{15}$N

| | Low urban reach | | Intermediate reach | | Urban reach | | | |
|---|---|---|---|---|---|---|---|---|
| Carbon | Mean (Range) | SD | Mean (Range) | SD | Mean (Range) | SD | P for Means | P for Variance |
| Piscivore/insectivore | −22.05 (4.9) | 1.30 | −22.81 (4.7) | 1.20 | −23.22 (2.1) | 0.58 | 0.001 | 0.029 |
| Pyloli | −22.08 (1.1) | 0.43 | −23.07 (3.2) | 1.08 | −23.04 (0.8) | 0.36 | | |
| Leposs | −20.87 (1.2) | 0.46 | −22.43 (1.3) | 0.65 | −23.17 (0.8) | 0.35 | | |
| Scapla | −21.23 (1.3) | 0.54 | −21.75 (0.7) | 0.24 | −22.25 (0.1) | 0.07 | | |
| Cycelo | −23.73 (1.8) | 0.77 | −25.00 | — | −23.67 (0.5) | 0.25 | | |
| Aplgru | −23.35 (3.0) | 1.33 | −23.45 (3.5) | 1.35 | −23.5 (1.7) | 0.62 | | |
| Omnivore/detritivore | −22.46 (4.3) | 1.05 | −23.35 (4.7) | 1.0 | −23.75 (3.7) | 0.74 | <0.001 | 0.409 |
| Pimvig | −21.78 (1.3) | 0.60 | −22.75 (1.2) | 0.52 | −23.93 (0.7) | 0.33 | | |
| Ictpun | −22.63 (1.1) | 0.48 | −23.78 (3.5) | 1.23 | −23.35 (1.3) | 0.46 | | |
| Notath | −23.00 (0.4) | 0.28 | −24.35 (0.8) | 0.31 | −23.7 | — | | |
| Cyplut | −24.38 (1.9) | 0.96 | −23.73 (0.9) | 0.38 | −24.4 (1.1) | 0.38 | | |
| Carcar | −22.07 (1.0) | 0.41 | −23.25 (1.0) | 0.39 | −23.6 (1.0) | 0.37 | | |
| Notstr | −21.90 (0.8) | 0.37 | −22.13 (1.0) | 0.46 | −23.0 (1.9) | 1.04 | | |
| Ictbub | −21.93 (2.2) | 1.02 | −24.12 (3.1) | 1.24 | −24.22 (2.3) | 0.91 | | |
| Invertebrates | −24.26 (6.9) | 2.58 | −24.43 (1.8) | 0.67 | −24.87 (1.6) | 0.64 | | |
| Predator | −25.23 (0.6) | 0.32 | −24.80 (0.4) | 0.28 | −24.30 (0.2) | 0.10 | 0.016 | 0.078 |
| Herbivore/detritivore | −23.53 (6.9) | 3.41 | −24.25 (1.7) | 0.76 | −25.30 (1.1) | 0.50 | 0.318 | <0.001 |
| Nitrogen | | | | | | | | |
| Piscivore/insectivore | 16.72 (2.6) | 0.82 | 15.23 (4.0) | 1.00 | 15.34 (3.8) | 1.01 | <0.001 | 0.998 |
| Pyloli | 16.6 (1.8) | 0.76 | 14.52 (1.8) | 0.59 | 15.32 (0.4) | 0.16 | | |
| Leposs | 17.57 (1.1) | 0.41 | 17.23 (0.5) | 0.25 | 17.33 (0.1) | 0.07 | | |
| Scapla | 16.3 (0.6) | 0.27 | 15.05 (2.3) | 0.79 | 15.45 (0.7) | 0.49 | | |
| Cycelo | 17.18 (2.1) | 0.93 | 15.7 | — | 14.73 (0.8) | 0.46 | | |
| Aplgru | 15.8 (0.7) | 0.32 | 15.03 (0.5) | 0.23 | 14.63 (1.5) | 0.57 | | |
| Omnivore/detritivore | 15.04 (4.1) | 0.97 | 13.45 (5.2) | 1.06 | 13.06 (3.0) | 0.93 | <0.001 | 0.976 |
| Pimvig | 14.8 (1.0) | 0.45 | 13.45 (1.6) | 0.75 | 12.88 (0.4) | 0.17 | | |
| Ictpun | 13.95 (1.2) | 0.59 | 12.78 (5.2) | 1.85 | 12.52 (1.2) | 0.40 | | |
| Notath | 14.0 (0.6) | 0.42 | 13.68 (4.3) | 1.91 | 13.4 | – | | |
| Cyplut | 15.58 (2.9) | 1.35 | 12.68 (0.8) | 0.39 | 12.02 (0.8) | 0.36 | | |
| Carcar | 15.55 (1.2) | 0.46 | 14.07 (0.6) | 0.21 | 14.36 (0.8) | 0.32 | | |
| Notstr | 15.85 (1.4) | 0.57 | 14.08 (0.6) | 0.28 | 12.45 (1.3) | 0.61 | | |
| Ictbub | 14.78 (2.4) | 1.02 | 13.64 (2.0) | 0.76 | 14.02 (0.7) | 0.30 | | |
| Invertebrate | 12.03 (2.2) | 0.86 | 11.4 (1.5) | 0.59 | 10.79 (1.8) | 0.60 | | |
| Predator | 12.33 (1.0) | 0.51 | 11.85 (0.1) | 0.07 | 11.23 (1.0) | 0.50 | 0.078 | 0.914 |
| Herbivore/detritivore | 11.80 (2.2) | 1.06 | 11.18 (1.4) | 0.61 | 10.45 (1.0) | 0.44 | 0.085 | 0.021 |

*Omnivorous and detritivorous fishes*

Similar to macroinvertebrates, the range in $\delta^{13}$C values for detritivorous and omnivorous fishes varied by reach. The overall range of $\delta^{13}$C values for the detritivorous and omnivorous fishes only ranged from −24.4 to −21.8 (Table II; Figure 2). The $\delta^{13}$C values had the lowest range (3.7) in the urbanized reach but variability did not differ among reaches (Table II; $p = 0.409$).

Mean $\delta^{15}$N values of the omnivorous and detritivorous fishes were higher in enrichment of 15N in the low urbanized reach than in the intermediate and urbanized reaches ($p < 0.001$) with all species values ranging from 14.0 to 15.9 (Figure 2; Table II). The intermediate reach and the urbanized reach had similar ranges with $\delta^{15}$N values ranging from 12.8 to 14.1 and 12.0 to 14.4 respectively (Figure 2; Table II). However variability in

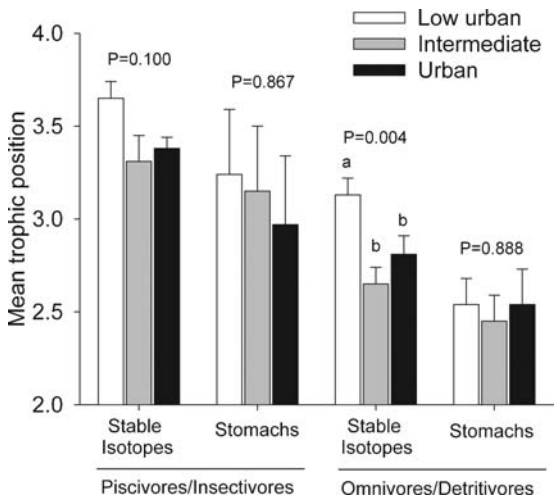


Figure 3. Mean trophic position based on stomach contents and stable isotope analysis for omnivore/detritivore and piscivore/invertivore fishes at each reach captured during summer 2006. Identical lower case letters represent mean trophic positions that were not significantly different among reaches

$\delta^{15}$N did not differ among reaches ($p = 0.976$). The low urbanized reach also showed higher stable isotope TP throughout most of the detritivorous and omnivorous species with 6 of the 7 species showing higher TP in the low urbanized reach compared to the intermediate and urbanized reaches. The intermediate and urbanized reaches show the detritivorous and omnivorous species consuming prey at a lower TP compared to the low urbanized reach ($p = 0.004$; Figure 3). However, this was not evident in the stomach contents analysis ($p = 0.888$).

*Piscivorous and invertivorous fishes*

Piscivorous and invertivorous fishes $\delta^{13}$C values range from $-23.7$ to $-20.9$, $-25.0$ to $-21.8$, and $-23.7$ to $-22.3$ in the low urbanized, intermediate, and urbanized reaches respectively (Table II; Figure 2). The low urbanized reach had the highest $\delta^{13}$C values (Table II, $p < 0.001$). Similar to detritivorous and omnivorous fishes, the urbanized reach had lower variability of $\delta^{13}$C; about half compared to the low urbanized intermediate habitat reaches (Table II, $p = 0.029$).

The low urbanized reach had higher ($p < 0.001$, Table II) $\delta^{15}$N for piscivorous and invertivorous fishes than in the intermediate and urbanized reaches, with the low urbanized reach values $> 15.8$ and in the intermediate and urbanized reaches values $< 15.7$ except for longnose gar (*Lepisosteus osseus*; Table II). Piscivorous and invertivorous species in the low urbanized reach tended to consume food at higher TPs than in intermediate and urbanized reaches, but this relationship was not significant for the stable isotope analysis ($p = 0.207$) or the stomach content analysis ($p = 0.867$; Figure 3). Four of the five piscivorous and invertivorous species consumed prey at a higher TP in the low urbanized reach, with species in the intermediate reach shown consuming prey at a significantly lower trophic level for 2 of the species.

*Stomach content and feeding guild analysis*

Stomach content analysis revealed that literature-based feeding guilds matched with the stomach contents. Detritivorous fish had greater than 50% of diet as algal/detritus, where piscivorous fish had 95–100% of diet as fish. Omnivorous fishes had a varied diet, but still had 41–64% algae/detritus (Table III). The TP calculated through stable isotope analysis tended to be related to TP calculated by stomach content analysis ($p = 0.076$; Figure 4). However, the slope differed from 1 ($p = 0.038$) because TP calculated by the stable isotope analysis tended to be higher than the stomach content TP for detritivores and omnivores and TP was higher than the stable isotope TP for the piscivorous species (Figure 3).

Table III. The mean proportion of diet items by dry weight consumed by each fish feeding guild in the low urban reach (rkm 229–235), intermediate reach (rkm 120–126), and urbanized reach (rkm 24–30) sampled in the Kansas River during summer 2006. Values in parenthesis represent 1 standard error

| Guild | Reach | Fish | Aquatic Macroinvertebrates | Terrestrial Macroinvertebrates | Zooplankton | Algae/Detritus |
|---|---|---|---|---|---|---|
| Detritivore | | | | | | |
| | Low urban | 0.0 | 1.2(0.7) | 0.0 | 24.4(16.0) | 74.4(16.3) |
| | Intermediate | 0.0 | 44.7(17.6) | 5.4(5.4) | 0.0 | 50.0(18.9) |
| | Urban | 0.0 | 4.9(4.9) | 0.0 | 0.0 | 95.1(4.9) |
| Omnivore | | | | | | |
| | Low urban | 6.8(5.8) | 28.7(9.4) | 1.5(1.3) | 18.7(9.2) | 44.3(10.5) |
| | Intermediate | 0.3(0.3) | 21.6(7.5) | 4.5(4.4) | 9.9(6.8) | 63.7(9.5) |
| | Urban | 11.0(7.5) | 21.3(8.9) | 5.8(5.1) | 20.8(9.5) | 41.0(11.3) |
| Invertivore | | | | | | |
| | Low urban | 7.7(7.7) | 49.3(10.8) | 0.0 | 0.0 | 43.0(10.6) |
| | Intermediate | 4.7(4.7) | 65.7(10.4) | 0.0 | 0.0 | 30.0(9.3) |
| | Urban | 0.0 | 56.1(12.8) | 4.9(4.9) | 0.0 | 39.0(11.6) |
| Piscivore | | | | | | |
| | Low urban | 100.0(0) | 0.0 | 0.0 | 0.0 | 0.0 |
| | Intermediate | 95.5(4.5) | 4.5(4.5) | 0.0 | 0.0 | 0.0 |
| | Urban | 97.0(3) | 3.0(3) | 0.0 | 0.0 | 0.0 |

## DISCUSSION

Land use and instream habitat alterations may have caused changes in the food web of the Kansas River fish community. Instream and riparian habitat differed throughout the river changing from a heterogeneous instream habitat areas to areas dominated by an urban riparian zone with homogeneous instream habitat. This corresponded to urban areas that were deeper and had fewer braided channels and islands, which is consistent with Paukert and Makinster (2009) who documented more variable habitat with areas of islands, log jams, rip rap and more channels in the heterogeneous reach of the Kansas River. The reduction of instream habitat in urban areas of the river indicates homogenization of these habitats (Lenat and Crawford, 1994; Yoder *et al*., 1999; Paukert and Makinster, 2009).

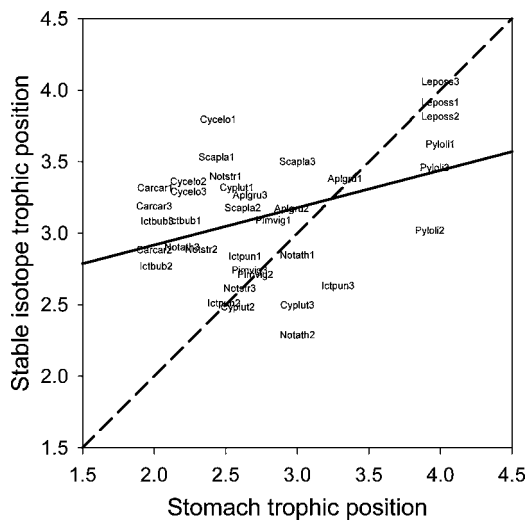


Figure 4. Stomach content trophic position versus stable isotope trophic position for each fish species in the Kansas River in summer 2006. Species codes are listed in Table I, and the numbers associated with each species represents the low urbanized (1) reach, the intermediate (2) reach, and the urbanized (3) reach. The dashed line represents the expected slope (slope = 1) and the solid line represents the observed slope

Higher enrichment of 15N may occur with high nitrogen loading in streams from agriculture (e.g. Kendall, 1998), and in the Kansas River higher agriculture land use was located near our low urbanized reach (Eitzmann and Paukert, in press). However, nitrate levels at three sites on the Kansas River (one site within 16 km downstream of each of our reaches) from 2006 did not differ throughout the river and total nitrogen was actually highest in the urbanized reach (A. Stahl, Kansas Department of Health and Environment, unpublished data). Therefore, the high $\delta^{15}$N values in the low urbanization reach may not necessarily be due to high nitrogen loads from agriculture. Species tended to feed at a higher trophic level in the low urbanization reach suggesting that the loss of instream habitat in the intermediate and urbanization reaches has more of an effect on the food web than increased nitrogen values. This is consistent with other studies (Dvorak and Best, 1982; Cyr and Downing, 1988) which showed that habitat complexity is positively correlated with availability of more variable food resources.

Two of the fish species appeared to be higher in $\delta^{15}$N than would be expected (e.g. blue sucker and river carpsucker). These two fish were classified as invertivores and detritivores, respectively, but TP indicated blue sucker to be piscivorous and river carpsucker to be omnivorous. A few possible reasons for this are (1) there was an unmeasured 15N enriched food source, (2) the species have diet shifts throughout the year or (3) blue sucker and river carpsucker possibly fractionated $\delta^{15}\text{N} > 3.4‰$. The first explanation is less likely for blue sucker because their stomach samples contained mostly trichoptera larvae, but stable isotope analysis indicated a TP similar to piscivores. However, the trichopteran larvae consumed by the blue suckers may have been occupying the deep, high velocity areas that blue sucker inhabit, which were not sampled. The second reason is possible for both species because the stomach content analysis was only a snapshot of what these species were consuming at that instant in time. Therefore, it is unknown what the species were consuming weeks or months before the time of collection. The river carpsucker consumed mostly algae and detritus (which were not measured). The third explanation is possible for both species because of variability in enrichment. Post (2002) indicated that a TP enrichment of 3.4‰ of $\delta^{15}$N is an observed average over many trophic pathways with enrichment ranging from ~2 to 5‰. Also, Mill *et al.* (2007) found that $^{15}\text{N}/^{14}\text{N}$ fractionation was significantly higher than 3.4‰ for herbivores. Therefore, blue sucker and river carpsucker may show higher fractionation of $\delta^{15}$N than other taxa or were feeding on diet items that were not collected for stable isotope analysis leading to increased and biased TP.

There was lower variation in $\delta^{13}$C in the urbanized reach for all feeding levels, which suggests the reduction of habitat was related to the compression of food web, and a less diverse resource bass (Mercado-Silva *et al.*, 2008). Finlay *et al.* (1999) related $\delta^{13}$C values to flow indicating that habitats with higher flows were more depleted in $\delta^{13}$C, and related this to the increase in the supply rate of $CO_2$ to benthic algae because discrimination against $\delta^{13}$C occurs during photosynthesis with increase in $CO_2$ (Calder and Parker, 1973; Pardue *et al.*, 1976). Although enrichment of 13C was similar among reaches, there was higher variability in $\delta^{13}$C in the low urbanization reach suggesting higher variability in flows, which is likely because of increased habitat complexity (e.g. more channels and islands) in the low urbanization reach. The algal sources in the low urbanization reach are most likely assimilating the $\delta^{13}$C at different rates in the different habitats, therefore, causing the higher variation in the $\delta^{13}$C values (Finlay, 2001, 2004). This is similar to findings by Gido *et al.* (2006), who found higher enrichment and less variability in 13C values for fishes in secondary channels and suggested this was due to low velocity and a narrow range of habitats in the secondary channels, causing most of the organisms in the secondary channels to feed on similar items. In contrast, the urban reach had reduced habitat complexity (based on our instream and riparian analysis) and the lowest variability in $\delta^{13}$C for all taxa suggesting that carbon was from similar basal algal sources and species are converging on these same resources.

Although many studies have determined the effects of land use and instream habitat on density and diversity of taxa (e.g. Poulton *et al.*, 2003; Walters *et al.*, 2003; Allan, 2004), relatively few studies have evaluated the effects of land use and instream habitat on the food web. In the low urban areas fish appeared to use the more diverse carbon sources likely made available through the diversity of habitats. Our study suggested that urbanization reduced habitat variability and also compressed the food web. Homogenization of habitat reduces species diversity within a community (Jones and Clark, 1987; Limburg and Schmidt, 1990; Wang *et al.*, 1997) and may be linked to the homogenization of the food web. Habitat diversity is essential for native fluvial fishes in large rivers (Galat and Zweimüller, 2001), and our study indicates that habitat diversity may be related to food webs and TP of fishes. Therefore, restoring natural habitats (e.g. sand bars, grass islands, secondary channels etc.) in the Kansas River may help increase habitat diversity and aid in native fish restoration.

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