Effect of Instream Sand Dredging on Fish Communities in the Kansas River USA: Current and Historical Perspectives

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ABSTRACT

Relatively few studies have examined the ecological effects of instream sand and gravel mining, which occurs in many streams and rivers worldwide. The objective of this study was to evaluate fish community composition at sand dredged and unmodified (control) sites in the Kansas River, Kansas. Fish and habitat sampling were conducted at two control sites and one dredged site in September 1979 and 1980. The same sites and one additional dredged site were sampled in September 2006. In 2006, dredged sites were deeper and had slower current velocities than control sites. Similarity indices determined that fish community at control sites in 2006 were 80% similar to the same sites in 1979 and 1980, despite 26 years between sampling. Dredged sites had more variable species composition, but one site still had large-river species (blue sucker, shovelnose sturgeon), which were sampled above the actual dredge in fast, shallow water. Native river fish species were similarly present in 1979-1980 and 2006, but lentic and non-native fishes (e.g., centrarchids), although still in low abundance, increased in 2006 particularly in dredged sites. These results suggest that sand dredging provided habitats that were suitable for lentic fishes, but other anthropogenic effects (reservoir construction, urbanization) also likely contributed to fish assemblage changes in the Kansas River

INTRODUCTION

Instream sand and gravel mining is relatively common in streams and rivers throughout the world, but there has been concern of the ecological effects of these operations. Sand and gravel are essential materials for construction, and high-quality material is often found in rivers and streams (Kondolf 1997, Meador and Layer 1998). However, instream dredging may have adverse physical effects, including head cutting, streambed degradation, and channel widening (Kondolf 1997, Brown et al. 1998, Meador and Layer 1998), which can alter or destroy fish habitat. Dredging can also create low-velocity habitats that are unsuitable for fishes that prefer swift water. The lower velocities may decrease scouring and increase sediment deposits, which may be unsuitable for invertebrates or as spawning areas for fish (Padmalal et al. 2008).

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The effect of dredging on the distribution and abundance of fishes has been mixed. Sportfish (centrarchid species) were reduced in dredge sites in the Brazos River, Texas and gravel-bed streams in Arkansas (Forsage and Carter 1973, Brown et al. 1998), whereas few differences occurred in the Tennessee River (Nelson 1993) or California streams (Harvey 1986). The scientific evidence on the ecological effects of instream mining are limited (Meador and Layer 1998), and therefore agencies evaluating these effects have little information on which to base their decisions.

In the Kansas River, sand dredging has resulted in bank erosion, riverbed degradation, and channel widening and has been implicated (in part) in the decline of native benthic fishes (Sanders et al. 1993, Quist et al. 1999). To provide insight on the effects of instream dredging on fishes in the Kansas River, we sampled two sites currently being dredged and two sites that have not been dredged (control). Cross et al. (1982) sampled dredged and control sites in 1979 and 1980 in the Kansas River. Our control sites and one dredge site were in the same location as that study and therefore provided an opportunity to compare fish communities in dredge and control sites over a 26 year period. The objectives of this study were 1) to compare fish community composition and habitat at dredged and undredged sites in fall 2006, and 2) to compare fish communities in the same dredged and control sites from fall 1979 and 1980 to 2006.

MATERIALS AND METHODS

Study area

The Kansas River is a sand-bed river in eastern Kansas that begins at the junction of the Republican River and Smoky Hill River and flows 274 km east to the confluence of the Missouri River in Kansas City, Kansas. The river is typically shallow (<1.5 m) with a braided channel (Makinster and Paukert 2008), with the deepest sections in the lower 26 km where the river is highly modified with rock revetments and is channelized with water depths averaging about 3.0 m. The mainstem Kansas River has only one low-head dam at at rkm 83 (Eitzmann et al. 2007). Commercial instream dredging for sand and gravel has occurred on the Kansas River since the early 1900s, and commercial dredging companies are still dredging sand and gravel in the lower river reaches (Sanders et al. 1993).

There were two control (i.e., unmodified river reaches) and two dredged sites sampled in 2006, which are considered contemporary sampling sites for this study. The control sites were located at river kilometer (rkm) 39 (site C39) and rkm 37 (site C37). Dredged sites were located at rkm 35 (D35) and rkm 32 (site D32). Dredging at these sites accounted for 580,000 tons (54%) of material removed from the Kansas River in 2005 (J. Marx, U.S. Army Corps of Engineers, unpublished data). Control sites were in the same location for both historical (1979 and 1980) and contemporary (2006) sampling. However, historical sampling at the dredged sites was located at rkm 35 (D35) and rkm 26 (D26). No contemporary sampling was conducted at D26 because this dredge site was no longer active. However, site D35 was in the same location in 1979-1980 and 2006.

Fish sampling

Fish sampling was conducted in September 1979 and 1980, and September 2006. Seining was conducted on 15 September in 1979 and 13 September in 1980; boat electrofishing was conducted on 6 September 1980. Contemporary seining and electrofishing was conducted on 22-23 September 2006. All sampling was conducted at similar low flows (47-62 m^3/s), which were 25-35% of mean September flows for the period from 1917-2007. The sampling protocol consisted of four electrofishing samples and 12 seine hauls at each site. Equal effort for each gear was used at each site so comparisons of fish community composition among sites could be made, and any bias associated with a specific gear would be consistent among sites. Sampling at the dredge sites was conducted relative to five transects (Fig. 1). In the contemporary control sites, sampling also was conducted relative to five transects. This was similar to Cross et al. (1982) except that historical sampling at control sites included only two transects. Electrofishing was conducted over 200 m segments in nearshore areas. Seining was with a 4.5 m by 1.2 m seine with 64-mm mesh for 25 m. Habitat sampling was conducted only in 2006 and consisted of 15 measurements of water velocity (at 0.6 depth; cm/s) and depth (m) at each site. All large-bodied fishes collected were measured (nearest mm) and released immediately. Small bodied fishes were preserved in 10% formalin and later enumerated in the laboratory. For the historical analysis, seining was combined for 1979 and 1980 so it could be compared to electrofishing (1980) data.

Data analysis

Data were pooled for each site and the fish community composition was compared (e.g., percentage of an individual species compared to all that were collected at that site). Species riches and the Shannon-Weiner diversity index were used to assess fish assemblage composition at each site (Krebs 1999). We also used the percent similarity index (PSI) and Jaccard's index to compare fish assemblages among sites and between years. The Jaccard's index uses binary (presence/absence) data and ranges from 0 (no species in common) to 1 (all species in common; Kwak and Peterson 2007). The PSI ranges from 0 (no species in common) to 100 (identical species composition) and uses the relative abundance data (Krebs 1999, Kwak and Peterson 2007). We calculated similarity indices for three separate analyses. The first analysis compared similarity among contemporary sites to determine if control sites were more similar to each other than dredged sites. Because we hypothesized that downstream effects of dredging would be more pronounced than upstream effects, the second analysis separated the contemporary samples using only the data from downstream of the actual dredge hole (i.e., fish collections from transects C, D, and E; Fig 1). Third, we calculated similarity indices from contemporary and historical sites to determine if sites within years (or within control or dredged locations) were more similar. We used an analysis of variance (ANOVA) to determine if mean PSI or Jaccard's index differed between comparison of similarity among control, dredge, and mixed (control vs. dredge) sites, regardless of year.

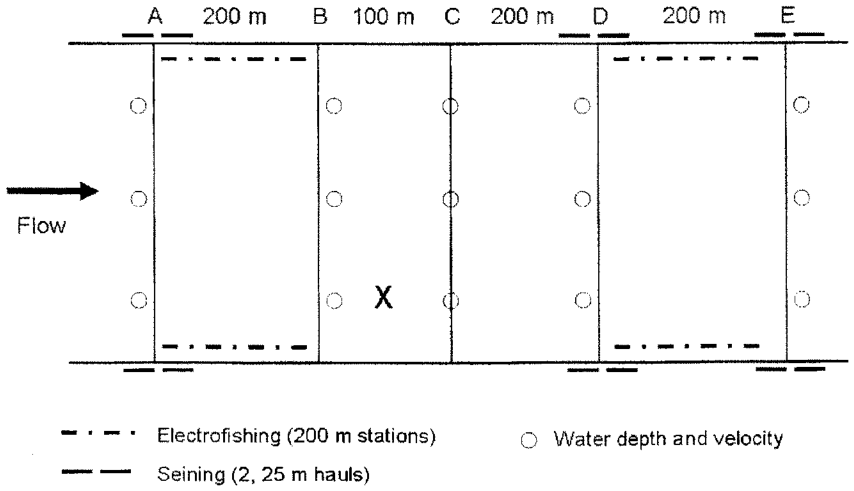

Figure 1. Schematic of the sampling design at each dredged and control site on the Kansas River. The relative location of the dredge hole, when present, is indicated with an X. Modified from Cross et al. (1982).

Table 1. Proportional abundance of fishes collected in the Kansas River at two control (C) and two dredged (D) sites in September 1979-1980 and 2006. A value of 0.0 indicates that a species was collected but was <0.1 in proportional abundance.

Common and scientific name	1979-1980				2006			
	C39	C37	D35	D26	C39	C37	D35	D32
Acipenseridae								
Shovelnose sturgeon (*Scaphihynchus platorynchus*)							0.1	
Hiodontidae								
Goldeye (*Hiodon alosoides*)	0.0							
Clupeidae								
Gizzard shad (*Dorosoma cepedianum*)	0.2	0.3	0.5	2.7	0.5	0.1	1.2	3.0
Cyprinidae								
Central stoneroller (*Campostoma anomalum*)				0.0				
Grass carp (*Ctenoopharyngogon idella*)						0.1		
Common carp (*Cyprinus carpio*)	0.3	0.2	0.1		0.1	0.1	0.3	
Bullhead minnow (*Pimephales vigilax*)	2.8	3.2	1.0	4.4	3.3	1.3	3.5	17.9
Bluntnose minnow (*Pimephales notatus*)	0.0	0.1	0.0	1.0	0.1	0.1	0.1	3.9
Fathead minnow (*Pimephales promelas*)				0.0				0.1
Suckermouth minnow (*Phenacobius mirabilis*)					0.1	1.8	0.3	0.1
Shoal chub (*Macrhybopsis hyostoma*)			0.2					
Silver chub (*Macrhybopsis storeiana*)	0.1							
Redfin shiner (*Lythrurus umbratilis*)							0.2	0.1
Red shiner (*Cyprinella lutrensis*)	79.6	69.6	86.4	46.1	84.3	69.2	78.8	37.1
Rosyface shiner (*Notropis rubellus*)					0.0			
Sand shiner (*Notropis ludibundus*)	8.1	10.7	6.4	38.8	1.3	19.8	3.3	7.6
Emerald shiner (*Notropis atherinoides*)	0.1	0.1	0.0	0.9	1.0	2.6	3.9	4.9
Catostomidae								
River carpsucker/quillback (*Carpiodes carpio*/*C. cyprinus*)	8.1	14.6	4.1	3.9	3.6	2.0	2.1	1.9
Blue sucker (*Cycleptus elongatus*)		0.0			0.1	0.2	0.1	
Smallmouth buffalo (*Ictiobus bubalus*)							0.1	
Shorthead redhorse (*Moxostoma macrolepidotum*)			0.1		0.1			0.1
Ictaluridae								
Channel catfish (*Ictalurus punctatus*)	0.1	0.1	0.1	0.3	0.7	1.5	0.8	0.1
Flathead catfish (*Pylodictis olivaris*)	0.0	0.2	0.4	0.0	0.1	0.1	0.2	0.1
Slender madtom (*Noturus exillis*)			0.0					
Stonecat (*Noturus flavus*)			0.3					
Poeciliidae								
Western mosquitofish (*Gambusia affinis*)					3.4	0.6	1.2	6.7
Moronidae								
White bass (*Morone chrysops*)	0.1	0.2		0.2			1.0	
Centrarchidae								
Bluegill (*Lepomis macrochirus*)		0.2		0.2	0.5	0.1	2.4	12.9
Black crappie (*Pomoxis nigromaculatus*)								0.1
Green sunfish (*Lepomis cyanellus*)	0.0	0.0		0.0	0.0			0.2
Longear sunfish (*Lepomis megalotis*)							0.1	0.6
Orangespotted sunfish (*Lepomis humilis*)			0.0	1.0			0.4	1.1
White crappie (*Pomoxis annularis*)	0.1	0.2	0.1	0.1			0.3	1.5
Percidae								
Slenderhead darter (*Percina phoxocephala*)						0.1	0.0	0.0
Sciaenidae								
Freshwater drum (*Aplodinotus grunniens*)	0.2	0.1	0.2	0.2	0.8	0.3	0.6	0.1

In this analysis we compared mean similarity among control sites (e.g., C39 from 1980 to C39 from 2006, C39 from 1980 to C37 in 1980, C39 in 1980 to C37 in 2006, etc.), among dredge sites (e.g., D35 from 1980 to D32 in 2006, D35 in 1980 to D35 in 2006, etc.), and mixed sites (every comparison of control and dredge sites). This resulted in six control, six dredged, and 16 mixed comparisons for each metric (PSI and Jaccard's index).

An ANOVA was used to determine if mean depth or current velocity differed among the four contemporary sites. We also computed the coefficient of variation (CV; Zar 1996) of depth and current velocity to determine how variable these measurements were at each site. We recorded maximum depth at each site to further quantify differences in depth among sites. Because we hypothesized that habitat above the actual dredge hole at dredged sites may be more similar to that of control reaches, we conducted a similar ANOVA using velocity and depth calculations only from transects A and B in the dredged and control sites.

RESULTS

Comparisons within contemporary sites

In September 2006, electrofishing collected 514 fish (18 species) at control sites and 1,167 individuals (21 species) in dredged sites (Table 1). These samples consisted of 51.1% red shiners (*Cyprinella lutrensis*) in dredged sites and 25.1% in control sites. Seining collected 3,890 fish (13 species) at control sites and 2,408 individuals (21 species) at dredged sites. Red shiners comprised of 69.2% to 84.3% of fishes collected by electrofishing and seining at control sites, and 37.1% to 78.8% in dredged sites.

Contemporary control sites were most similar to each other, but dredged sites were not similar in species composition (Fig. 2). The highest PSI was for sites C39 and C37 (79%), but C39 was also very similar to D35 (76%). Site C37 was also similar to D35 (77%), suggesting species composition was similar among sites C39, C37, and D35. However, site D32 was substantially different from all other sites. The highest Jaccard's index was between sites D32 and D35 (0.71), indicating fish species presence was most similar at dredged sites. In 2006, nine fish species were only collected at dredged sites- black crappie (*Pomoxis nigromaculatus*), fathead minnow (*Pimephales promelas*), longear sunfish (*Lepomis megalotis*), orangespotted sunfish (*Lepomis humilis*), redfin shiner (*Lythrurus umbratilis*), smallmouth buffalo (*Ictiobus bubalus*), shovelnose sturgeon (*Scaphihynchus platorynchus*), white crappie (*Pomoxis annularis*), and white bass (*Morone chrysops*). Only three species were unique to control sites- grass carp (*Ctenoopharyngogon idella*), rosyface shiner (*Notropis rubellus*), and stonecat (*Noturus flavus*). Of the six centrarchids collected in 2006, all were collected in D32, and four were collected in D35. In contrast, only bluegill (*Lepomis macrochirus*) and green sunfish (*Lepomis cyanellus*) were collected at control sites (Table 1). However, centrarchid abundance was still relatively low, accounting for 0.1 to 0.5% of the fishes in control sites, and 3.2 to 16.4% of fishes in dredged sites.

Sampling at dredged sites collected the highest species diversity and richness (Fig. 3). Species richness at control sites ranged from 17 to 20, compared to 24 to 25 in dredged sites. Species diversity followed a similar pattern, with higher diversity in the dredged sites. The percentage of red shiners collected by electrofishing and seining at D32 was 37% compared to 69-84% in other sites (Table 1). Site D32 also had the higher proportional abundance of non-native bullhead minnow (*Pimephales vigilax*), which account for 17.9% of the fish collected by seining and electrofishing.

When sites were separated into those above and below the actual dredge hole (i.e., transects A-B; transects C-E; Fig. 1), fish communities at control sites were more similar to each other than the dredged sites. The PSIs for comparisons between above and below the actual dredge were 88% (C39) and 81% (C37) for control sites, whereas PSIs of dredged sites were 28% (D32) and 37% (D35). The Jaccard's index values from the control sites were 0.70 (C39) and 0.59 (C37), whereas at dredged sites they were 0.67 (D32) and 0.50 (D35). Although dredged sites did not substantially differ in their species presence between above and below the actual dredge hole, species relative abundance was substantially different.

Downstream of the actual dredge (transects C-E; Fig. 1), control and dredged sites were most similar to each other (Fig. 2). Although similarity of species presence was relatively consistent across all comparisons (Jaccards; 0.48-0.74), species composition was substantially different (PSI; 16-84%). Site D32 was the least similar site compared to all other sites; PSI was >50% only when compared to site D35. The only shovelnose sturgeon collected was at site D35A, and blue sucker (*Cycleptus elongates*), a species in need of conservation in Kansas, was collected at both control sites (five fish) and above the dredge hole at site D35A (one fish).

Depth and velocity comparisons

Mean depth (F=10.35; DF=3, 56; P<0.001) and current velocity (F=23.08; DF=3, 56; P<0.001) differed among sites for all transects combined (Table 2). Control sites were shallower (<1.0 m mean depth) and had the faster current velocities (0.44 to 0.48 cm/s) compared to dredged sites. In addition, D32 had the highest variability in flows, as evident by higher CVs. Depth and current velocity differences above the actual dredge were primarily attributed to one site (site D32) being different from all other sites. Mean

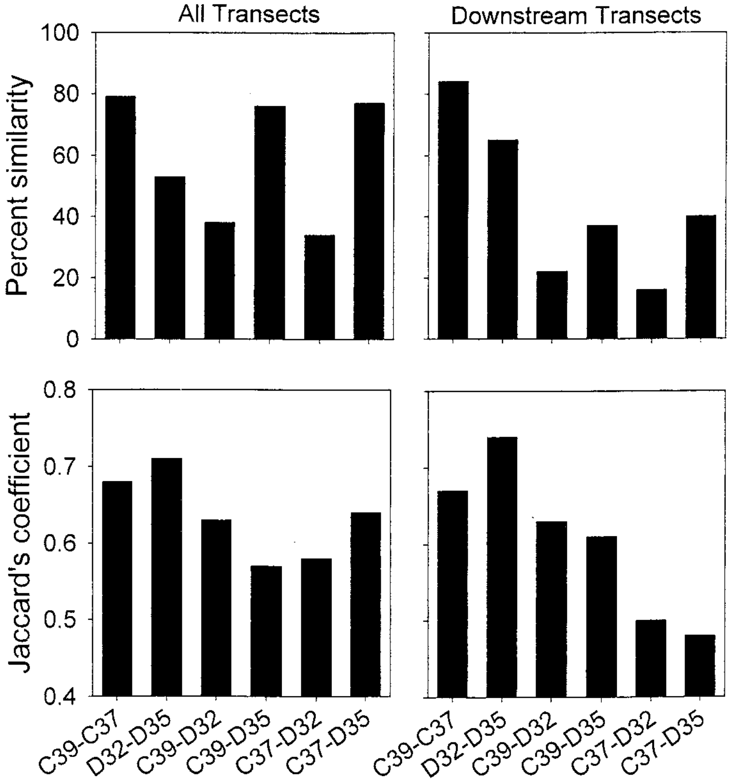

Figure 2. Percent similarity and Jaccard's coefficient for comparison of two dredged sites (D32, D35) and two control sites (C39, C37) for all transects combined and for only downstream transects.

depth for transects A and B were similar among sites C39, C37, and D35, but site D32 was at least three times deeper than any other site. Current velocity followed the same pattern, with site D32 having low current velocities. In contrast, site D35 was similar in current velocity to control sites.

Contemporary and historical comparisons

A total of 6,092 fish from 14 species was collected at control sites by seines in September 1979 and 1980, whereas seining at dredged sites collected 7,060 individuals from 21 species. Electrofishing collected 65 individuals (10 species) at control sites and 122 individuals (eight species) at dredged sites. Red shiner comprised of 69.8% to 79.6% of all fishes collected by electrofishing and seining in control sites, whereas red shiner comprised of 46.1% to 86.4% in dredged sites (Table 1). Bullhead minnow accounted for 1.0% to 4.4% of all fishes collected in seines and electrofishing in control sites, and 2.8% to 3.2% in dredged sites.

Historical sampling produced 18 species at control sites and 22 species at dredged sites (Table 1), whereas contemporary sampling produced 21 species at control sites and 27 at dredge sites. Central stoneroller (*Campostoma anomalum*), goldeye (*Hiodon alosoides*), slender madtom (*Noturus exilis*), shoal chub (*Macrhybopsis hyostoma*), and silver chub (*Macrohybopsis storeiana*) were collected only in the 1979-1980 sampling. Black crappie, grass carp, longear sunfish, redfin shiner, rosyface shiner, smallmouth buffalo, slenderhead darter (*Percina phoxocephala*), western mosquitofish (*Gambusia affinis*), and shovelnose sturgeon were only collected in the 2006 sampling. Emerald shiner (*Notropis atherinoides*) was typically in higher relative abundances in dredged sites. When comparing sites of the same location sampled 26 years part, the percentage

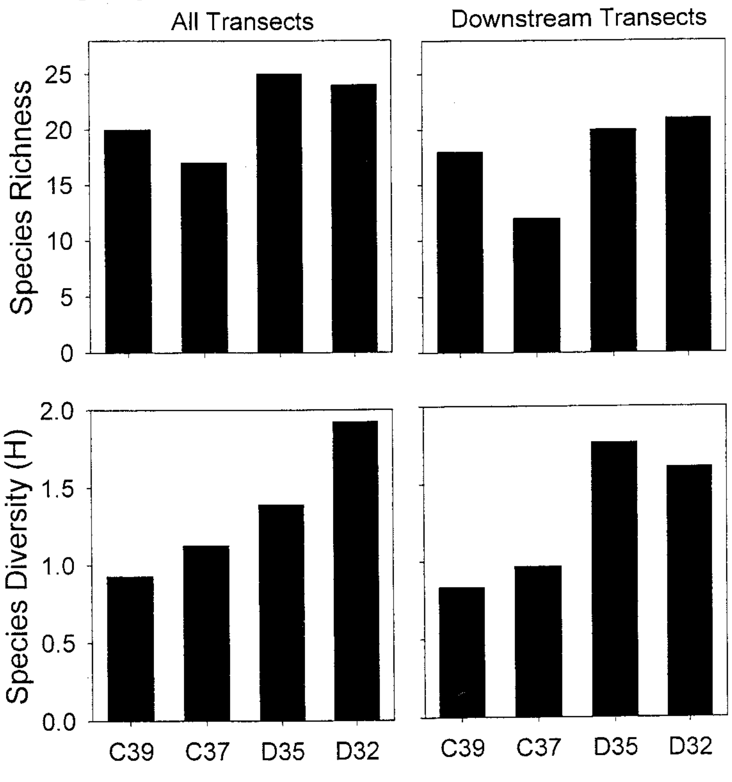

Figure 3. Species richness and diversity (Shannon Weiner diversity index; H) for all transects combined and for only downstream transects.

of similarity was high for C39 (88%) and the dredge sites (D35; 87%), whereas C37 was only marginally similar (52%).

Mean similarity was highest among control sites, regardless of year sampled. Mean similarity was higher (83%) among control sites than among dredge sites (61%) or between dredge and control sites (mixed; 71%)(F=246, DF=3, 25, P<0.001). A similar trend was evident for the Jaccard's index (F=418, DF=3, 25, P<0.001) with control sites having the highest similarity (0.65) followed by mixed (0.56) and dredged sites (0.55). Species presence and composition was most similar among control sites, even with 26 years between sampling events, but dredged sites had highly variable species composition and presence.

DISCUSSION

Fish communities in dredged sites were highly variable and less consistent than control sites, regardless of year sampled. Habitat degradation in rivers create environments where fishes are more temporally and spatially variable (Johnson et al. 1995). Therefore, the low similarity at dredged sites compared to control sites may be a result of the habitat degradation at the dredged sites. Dredged sites had higher proportion of lentic fishes such as centrarchids, gizzard shad, and emerald shiner; however, the percentage was still very low because of the dominance of red shiner. Also, the impacts of reservoirs in structuring fish assemblages is well documented (e.g., Marchetti and Moyle 2001, Gido et al. 2002), and the dredged sites in this study may resemble a reservoir environment (deep water, low velocity). These habitats contained more generalist and lentic species (e.g., centrarchids, red shiners, gizzard shad), which has been indicated as a sign of habitat degradation in large rivers (Galat and Zweimueller 2001, Weigel et al. 2006). Many centrarchids collected in the Kansas River were a result of impoundments and river regulation (Sanders et al. 1993), are often piscivorous or insectivorous (Cross and Collins 1995), and may prey on or compete for food resources with large-river obligate species such as the catostomids.

Table 2. Summary statistics of the habitat variables at control (C39 and C37) and dredge sites (D35 and D32), September 22-23, 2006 in the Kansas River, Kansas for all transects combined, and for transects just above the actual dredge (transects A and B).

	Site					
	C39	C37	D35	D32	F	P
All transects						
Depth (m)						
Mean	0.73^{a}	0.79^{a}	1.51^{c}	2.80^{b}	10.35	<0.001
Maximum	1.2	1.4	3.4	7.2		
CV	38	45	67	73		
Velocity (cm/s)	0.44^{a}	0.48^{a}	0.29^{c}	0.07^{b}	23.08	<0.001
CV of velocity	35	34	66	113		
Transects A and B						
Depth (m)						
Mean	0.78^{a}	0.80^{a}	0.62^{a}	3.81^{b}	9.86	<0.001
Maximum	1.1	1.2	0.8	7.2		
CV	42	40	22	62		
Velocity (m/s)	0.39^{a}	0.43^{a}	0.45^{a}	0.06^{b}	8.97	<0.001
CV of velocity	25	47	38	144		

Large river fishes still did inhabit dredged sites (e.g., blue sucker, shovelnose sturgeon), but they were collected upstream of the actual dredge hole at site D35 where flows and depths resembled control sites. The sites upstream of the actual dredge area were directly above the nickpoint of the dredging operations, which has high stream power (Kondolf 1997) with high current velocities that were similar to control sites.

Contemporary fish assemblages in 2006 differed among sites, but this was not directly attributed only to dredging activities. The most drastic fish assemblage differences occurred on the deepest dredged site with the lowest water velocities (D32), which contained many lentic species that may have come from tributary reservoirs (Sanders et al. 1993, Weigel et al. 2006). However, the scale of sampling also affected our results. When the analysis was conducted on transects downstream of the dredge, more lentic species were collected in one dredged site. In contrast, the upstream transects on one dredged site, which had similar water velocities and depth as the control sites, had similar fish assemblages as the control sites and likely provided the fast-water habitats preferred by many of the large river fishes (Cross and Collins 1995). In contrast, upstream transects on site D32 were still similar to the deepwater, low velocity dredge hole that may have been preferred habitats for generalists and centrarchids (Weigel et al. 2006).

Nine fish species were collected in 2006 but not in 1979-1980. Three are common to tributary reservoirs or small impoundments (black crappie, grass carp, and longear sunfish). In addition, six of the species not collected in fall 1979-1980 (black crappie, longear sunfish, redfin shiner, smallmouth buffalo, suckermouth minnow, and shovelnose sturgeon) were collected during other months sampling in the same area during 1979 to 1981 (Cross et al. 1982). Species that were common in 1979-1980 and 2006 (red shiner, sand shiner [*Notropis ludibundus*]) are generalists and may have dominated the fish assemblages for a long time (Peters and Shainost 2005). Prairie stream fishes are tolerant to harsh environmental conditions (Bramblett et al. 2005, Fischer and Paukert 2008) and have persisted because of these high tolerances.

Sand dredging in the Kansas River may have created altered habitats that are more suited to tolerant lentic fishes like centrarchids, but declines in native fish assemblages in the Kansas River also has occurred prior to dredging. Haslouer et al. (2005) indicated the majority of the declines in large river fishes were most dramatic since the 1950s as a result of water diversions, tributary impoundment, and other anthropogenic effects. Some large-river fishes have not been documented in the Kansas River for 20 years or more (e.g., western silvery minnow [*Hybognathus argyritis*], sicklefin chub [*Macrhybopsis meeki*], sturgeon chub [*Macrhybopsis gelida*]) and therefore may have been extirpated or severely reduced in abundance even prior to 1979 and 1980. Although the loss of these fishes cannot be directly linked to dredging, these fishes typically prefer the swift currents of large rivers (Cross and Collins 1995). Therefore, creation of low-velocity habitats at dredged sites may not be suitable for large-river fishes, and efforts to reintroduce these fishes or provide suitable habitat could be hampered by these low-velocity habitats.

This study provided insight on the effect of dredging on fish assemblages in large rivers, a topic with little scientific information (Meador and Layer 1998). Many countries currently prohibit instream sand and gravel mining, but this is still common in the US and Canada, even though the ecological consequences are becoming more apparent (Kondolf 1997). Downstream impacts of dredging need to be evaluated, and there is little to no research on the cumulative effects of dredging, particularly on sites dredged year after year (Harvey and Lisle 1998). Because Great Plains fish assemblages are tolerant of extreme conditions and typically are habitat generalists (Bramblett et al. 2005, Fischer and Paukert 2008), the differences we detected in fish assemblages between dredged and control sites are even more dramatic and suggest that even tolerant, generalist fish assemblages may be affected by anthropogenic activities. However, additional sampling is necessary to determine if our results were based on natural variability in these highly variable environments (Gido et al. 2002).

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