Stream Geomorphology and Fish Community Structure in Channelized and Meandering Reaches of an Agricultural Stream

Kelly M. Frothingham

Department of Geography and Planning, Buffalo State College, Buffalo, New York

Bruce L. Rhoads

Department of Geography, University of Illinois, Urbana, Illinois

Edwin E. Herricks

Department of Civil and Environmental Engineering, University of Illinois, Urbana, Illinois

In environments dominated by human activity, such as the agricultural Midwest, channel morphology is strongly influenced by anthropogenic factors. Past research has shown that human-induced channel modifications, including stream channelization, affects both the abiotic and biotic components of a stream. However, connections between changes in geomorphological form and function and ecological conditions are still poorly understood. Knowledge of these connections is critical for successful approaches to stream naturalization. The objective of this research is to explore the linkage between geomorphological variability and ecological conditions in adjacent channelized and unchannelized reaches of an agricultural stream in Illinois. Geomorphological and fisheries data were collected in the headwaters of the Embarras River where channel maintenance for agricultural drainage produced a straight channelized reach adjacent to a meandering unchannelized reach. Site characterization involved topographic mapping of each reach and establishing permanent cross sections to document the full range of morphologic variability at the sites. Fish sampling was conducted approximately monthly to provide information on community structure in the meandering and channelized reaches. The meandering reach has greater morphological variability, both over time and space, than the channelized reach. The meandering reach also contains more fish and larger individual fish than the channelized reach, suggesting that increased geomorphological complexity results in increased fish abundance and total biomass. Fisheries analysis also indicates that fish-community structure varies temporally in both reaches with the greatest contrast occurring seasonally.
region of the United States has generated concern about the effects of humans on stream ecosystems. The concept of stream naturalization has been proposed as a management concept to address human and biophysical dimensions of environmental-quality issues in this human-dominated environment [Rhoads and Herricks, 1996; Rhoads and Monahan, 1997; Rhoads et al., 1999]. Naturalization aims to establish morphologically and hydraulically varied, yet dynamically stable [Rhoads, 1995] stream systems that are capable of supporting biologically diverse aquatic ecosystems. Successful implementation of naturalization strategies requires an improved understanding of the geomorphological and ecological dynamics of human-modified streams [Frothingham et al., in press], as well as the effects of social interactions between scientists and nonscientists in community-based environmental decision-making [Rhoads et al., 1999].

Fluvial geomorphologists and aquatic ecologists both are interested in stream dynamics; however, the focus of these two disciplines differs in important ways. Geomorphologists primarily are interested in the interaction among flow properties, sediment transport, and channel morphology [Dietrich, 1987; Rhoads and Welford, 1991], whereas ecologists typically are concerned about the structure and function of aquatic communities [Osborne and Wiley, 1992; Aadland, 1993]. The potential linkage between geomorphology and ecology centers on a common interest in the physical properties of streams where geomorphological conditions define the amount, diversity, and structure of physical habitat. Ecologists recognize that spatial variability of physical properties, such as mean velocity, flow depth and substrate characteristics, has a strong influence on relationships between habitat and community structure and function [Aadland, 1993; Beebe, 1996; Gore and Hamilton, 1996; Fisher, 1997]. Channel morphology also has been acknowledged as an important factor in habitat diversity and species richness in streams [Southwood, 1977; Frissell et al., 1986; Gelwick, 1990; Osborne and Wiley, 1992; Aadland, 1993; Fisher, 1997; Kemp et al., 1999; Montgomery et al., 1999]. Fluvial geomorphologists, on the other hand, have developed theories and techniques related to the dynamic interaction between fluvial forms and processes [Hooke and Harvey, 1983; Dietrich, 1987; Rhoads and Welford, 1991]. These theories provide a foundation for an improved understanding of physical habitat and time-related changes in habitat conditions, but integration of geomorphological and ecological analysis has yet to be achieved for low-gradient streams in the agricultural Midwest.

Human-induced channel modification, referred to as stream channelization, affects both the abiotic and biotic components of a stream. Stream channelization results in decreased spatial variation of channel morphology and 3-D flow structure [Dietrich, 1987; Rhoads and Welford, 1991; Rhoads and Urban, 1997]. Physical processes impacted by channelization include pool-riffle development and alternate bar formation [Rhoads and Welford, 1991; Gregory et al., 1994]. Channelization also changes aquatic communities, reducing species richness and altering local community structure and function [Brookes, 1988; Swales, 1988]. The reduced species richness in channelized streams has been attributed mainly to decreased physical habitat diversity associated with uniform channel morphology [Frissell et al., 1986; Gelwick, 1990; Osborne and Wiley, 1992; Aadland, 1993].

In watersheds of East Central Illinois, stream channelization typically occurs in a piecemeal fashion, whereby only a few kilometers of a stream are modified in any particular project. As a result, streams are impacted most severely at the planform scale, i.e. the scale at which the planform characteristics of streams can be clearly discerned [Rhoads and Herricks, 1996; Frothingham et al., in press]. Differences in the spatial extent and timing of channelization has produced a diverse array of channel morphologies [Rhoads and Herricks, 1996], but the exact relation between geomorphological form and function and ecological conditions is still poorly understood. Such knowledge is critical for naturalization of these stream systems, which depends on an integrated eco-geomorphological approach to watershed management [Frothingham et al., in press].

The objective of this research is to explore how channel morphology is related to stream ecology using fish-community characteristics as an indicator of stream ecosystem condition or state. To achieve this objective, geomorphological and fish-community data are compared for an adjacent straight channelized reach and an unmodified meandering reach of an agricultural stream in East Central Illinois. The central hypothesis of this study is that increased spatial and temporal variability in stream geomorphology results in increased fish species abundance, biomass and richness.

**STUDY AREA**

Geomorphological and fisheries data were collected from adjacent meandering and channelized reaches in the headwaters of the Embarras River in Champaign County, IL (Figure 1). The Embarras River originates on the Urbana moraine at the southern edge of the Champaign-Urbana metropolitan area and flows south between the West Ridge and Philo moraines. The two study sites are located approximately 10 km south of Champaign-Urbana.

Channelization of the Embarras River began in the late 19th century and over the last 100 years many sections have been subject to repeated maintenance. The meandering reach is situated within an 800-m section of the Embarras
Figure 1. The Embarras River showing the location of the meandering and channelized reaches (*).

River that has not been channelized since at least the 1930s. This 800-m section represents unmodified channel conditions in the sense that channel dimensions and planform characteristics have fully adjusted to any past channelization and the river channel has been dynamically stable over the past several decades. The study reach within this unmodified section consists of a high-amplitude meander bend approximately 70 m in length (Figure 2). Bankfull channel width ranges from 13.0 to 18.0 m and bankfull depth is between 1.0 and 2.0 m. The channelized reach is located immediately downstream of the 800-m long un-channelized section. It is located at the upstream end of a 275-m section of the river that was straightened between 1973 and 1982 [Rhoads and Herricks, 1996; Rhoads and Urban, 1997]. This 275-m channelized section subsequently remained straight, but in 1996 channel maintenance was conducted to deepen the channel by 0.65 m and to regrade the channel banks to 3:1 side slopes. The channelized reach is 50 m long and has a trapezoidal channel cross section. Bankfull width varies between 13.0 and 16.0 m and bankfull depth is approximately 2.0 m (Figure 3).

METHODOLOGY

The field measurement program for each reach included: (1) mapping in detail the channel morphology, (2) documenting changes in channel form, and (3) electrofishing to assess fish community structure. Channel morphology was mapped in June 1997 using a total station. Two local benchmarks were established at each site for horizontal and vertical control; survey data were reduced to Cartesian (X,Y,Z) coordinates. Contour maps for each reach were generated from the coordinate information using the computer software package Surfer, which defines contours for a uniform grid of elevation data interpolated via kriging.

Changes in channel morphology were determined by conducting repeat surveys at monumented cross sections oriented orthogonally to the planform alignment of the bankfull channel (Figures 2 and 3). The cross sections encompass the full range of morphologic variability in the two reaches. Repeat surveys of the cross sections were conducted three times between October 1997 and June 1998.
Spatial variability of channel morphology within each reach was evaluated qualitatively by visually inspecting variations in bed elevation on contour maps. Temporal variability in channel morphology was defined by changes in the profiles of surveyed cross sections. Sediment dynamics were quantified in terms of net sediment accumulation or removal by volume within each reach between channel surveys. Calculations of net volumetric sediment flux were performed in Surfer by interpolating a uniform grid of elevation data from the survey information using kriging, and then differencing the interpolated elevation values for each grid node for successive surveys. Negative flux volumes indicate net deposition and positive flux volumes indicate net erosion.

Fish community sampling was conducted on a quasi-monthly basis from July 1997 through December 1998 at the straight and meandering reaches. Ten collections were obtained in the meandering and straight reaches [Tompkins,
RESULTS

Spatial Variability in Channel Morphology

Topographic mapping indicates that the meandering reach has greater spatial variability in channel morphology, and thus physical habitat, than the channelized reach (Figures 2 and 3). Topographic highs and lows occur throughout the meandering reach (Figure 2). Point bars are present along the inner bank of the upstream (cross-sections 5-8) and downstream (cross-sections 12-14) parts of the reach. Pools exist at the bend entrance (cross-section 1-3) and opposite the point bars at bend apices (cross-sections 6-8 and 12-14). The point bar-pool morphology produces pronounced asymmetry of channel cross sections, which are characterized by a nearly vertical cut bank and a gently sloping point-bar face (Figure 2). Cross-stream relief of the channel bed is as much as 0.75 m at the bend apices. Riffles between the pools have fairly symmetrical channel geometry (cross-sections 3-5 and 9-11). Longitudinal variation in the thalweg elevation between the riffles and pools is about 0.5 m.

The geometry of the channel in the channelized reach is essentially trapezoidal, reflecting recent channelization (Figure 3). Channel banks have uniform side slopes that extend to the edge of a relatively flat channel bottom. The elevation of the channel bed varies less than 0.1 m, except at the upstream end of the reach where a bar along the west bank produces local cross-stream relief of about 0.45 m. Longitudinal variation in bed elevation along the thalweg is less than 0.25 m throughout the reach.

Spatial Variability in the Fish Community

The fish collections were analyzed to assess differences in community structure between the meandering and the channelized reaches (Table 1). Species richness is similar in the channelized and meandering reaches, but fish abundance and biomass is greater in the meandering reach than in the channelized reach (Figures 4 and 5, Table 1). The fish community in these two reaches is composed mainly of mixed cyprinids, including various minnows and carp, and some additional benthic species like yellow bullhead and golden redhorse (Figures 4 and 5). Average fish abundance for the meandering reach exceeds that of the channelized reach by about 25%. Fish in the meandering reach also are, on average, twice as large as those in the channelized reach (Table 1).
Further analysis of fish collection data provides additional insight into the effects of spatial variability in geomorphological conditions on fish community structure. This detailed analysis examines the average number of fish, average length and difference ratios for number and length for the six most common species in the two reaches (Table 2). A positive value for the difference ratio indicates a greater value in the meandering reach; correspondingly, a negative value indicates a greater value in the channelized reach. For all species evaluated, with the exception of the Creek chub, more specimens were collected in the meandering reach and the average length is larger in the meandering reach than in the channelized reach. Although there is little difference in the annual community composition in morphologically varied and morphologically uniform reaches, there are clear differences in fish size/biomass characteristics. Fish in the meandering reach are larger, and generally occur in greater numbers than fish in the channelized reach.

### Table 1. Fish collection summary results

<table>
<thead>
<tr>
<th>Site</th>
<th>Meandering reach</th>
<th>Channelized reach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of species</td>
<td>28</td>
<td>27</td>
</tr>
<tr>
<td>Range of number of fish</td>
<td>192-850</td>
<td>151-495</td>
</tr>
<tr>
<td>collected per sampling campaign</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of fish</td>
<td>434</td>
<td>346</td>
</tr>
<tr>
<td>collected per sampling campaign</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average weight of fish</td>
<td>15 grams</td>
<td>6 grams</td>
</tr>
<tr>
<td>weighing greater than one gram</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent of fish weighing</td>
<td>4%</td>
<td>11%</td>
</tr>
<tr>
<td>less than one gram</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Temporal Variability in Channel Morphology

The repeat surveys of monumented cross sections show that the meandering reach exhibits greater temporal change in channel morphology than the channelized reach (Figures 6 and 7). At the entrance to the meandering reach (cross-section 1), erosion of a bar platform along the inner bank and deposition on the channel bed has transformed the geometry of the pool at this location (Figure 6). The most prominent channel change in the meandering reach involves systematic erosion of the outer cut bank, especially at bend apices. Bank erosion at the two apices (cross-sections 6 and 12) exceeds one meter per year (Figure 6). Maximum erosion has occurred at the downstream end of the reach (cross-section 14) where the outer bank has moved by about 2 m between 1997 and 1998. The cut bank erodes mainly through slab failures that introduce large blocks of bank material into the stream. These blocks alter local flow conditions near the bank and enhance physical-habitat diversity for fish. Net deposition is evident on point bars along the inner banks of the upstream (cross-section 6) and downstream (cross-sections 12) bends.

Changes in channel cross sections in the channelized reach are small and localized compared to those in the meandering reach (Figure 7). Minor systematic erosion is evident at the toe of the right (south) bank where flow is deflected laterally toward this side of the channel by the bar at the upstream end of the reach (cross-section 5). Overall, however, channel form in this reach is highly stable.

### Temporal Variability in Sediment Dynamics

Calculations of net sediment flux within each reach confirm that the meandering reach is more dynamic over time than the channelized reach (Table 3). Two time intervals were used to illustrate temporal variability in sediment flux: October 1997 to early June 1998 (June 1 and June 5 for the straight and highly sinuous reach, respectively) and early June to late June 1998 (June 25). The first eight-month period provided information for the entire winter/spring period, which included a variety of hydrological events ranging from baseflow to overbank conditions. The second, twenty-day interval was characterized by sustained near-bankfull to bankfull flow in the two reaches.

Erosion was the dominant process in both reaches; however, the volume of net erosion is greater in the meandering reach than in the channelized reach (Table 3). During the first interval net erosion in the meandering reach was an order of magnitude greater than in the channelized reach, whereas during the second interval it was about two times greater than in the channelized reach. The positive sediment flux for the meandering reach suggests that, over the period of record, erosion of cut banks exceeded deposition on point bars. Net sediment flux in the meandering reach for the twenty-day period in June 1998 is only slightly less than the net flux for the eight-month period from October 1997 until June 1998. This similarity in net flux illustrates the important influence of sustained bank-
full flow on the rate of channel-shaping processes. The net flux is nearly zero for the eight-month period at the channelized reach, suggesting that erosion and deposition approximately were balanced during this period of variable flow conditions. The channelized reach apparently was able to transfer downstream sediment evacuated from the meandering reach upstream. The comparatively large positive net flux during the twenty-day period confirms that bankfull events most strongly influence the rate of sediment dynamics in the channelized reach. The difference in net sediment flux between the channelized and meandering reaches indicates that the greater spatial variability of channel morphology in the meandering reach is associated with higher temporal rates of erosional and depositional processes.

**Temporal Variability in Fish Community Structure**

Given the similarity in community composition between the meandering and channelized reaches (Table 1), analysis of temporal variability of fish-community composition was performed for the meandering reach only. In this analysis, the fisheries collections from the meandering reach were used to cluster different collection dates based on the similarity in community composition (Jaccard coefficient of similarity for presence/absence data) and fish abundance (Euclidean distance coefficient for presence/abundance data). Both dendrograms indicate that the fish community changes through time (Figures 8 and 9). Adjacent months often are the most similar, whereas the largest dissimilarities generally are associated with different seasons. Therefore, the changes observed in community structure in the meandering reach are likely related to short term phenomenon such as changing flow stage and water temperature and seasonal migration or movement of fish [Chambers, 1994].

**DISCUSSION**

The findings of this study generally are consistent with those from other investigations comparing stream mor-
Figure 5. Fish community composition of the channelized reach.

Table 2. Fish collection and difference analysis comparison for adults

<table>
<thead>
<tr>
<th>Species</th>
<th>Average # collected unmodified meandering</th>
<th>Average # collected straight trapezoidal</th>
<th>Average # collected difference ratio (S:N)</th>
<th>Average length unmodified meandering (mm)</th>
<th>Average length straight trapezoidal (mm)</th>
<th>Average length ratio (S:N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluntnose Minnow</td>
<td>158</td>
<td>103</td>
<td>0.53</td>
<td>57</td>
<td>45</td>
<td>0.79</td>
</tr>
<tr>
<td>Central Stoneroller</td>
<td>56</td>
<td>45</td>
<td>0.20</td>
<td>66</td>
<td>57</td>
<td>0.86</td>
</tr>
<tr>
<td>Creek Chub</td>
<td>39</td>
<td>44</td>
<td>-0.13</td>
<td>98</td>
<td>63</td>
<td>0.64</td>
</tr>
<tr>
<td>Greenside Darter</td>
<td>4</td>
<td>3</td>
<td>0.75</td>
<td>71</td>
<td>60</td>
<td>0.85</td>
</tr>
<tr>
<td>Longear Sunfish</td>
<td>9</td>
<td>3</td>
<td>0.89</td>
<td>89</td>
<td>71</td>
<td>0.80</td>
</tr>
<tr>
<td>Striped Shiner</td>
<td>30</td>
<td>3</td>
<td>0.90</td>
<td>100</td>
<td>70</td>
<td>0.70</td>
</tr>
</tbody>
</table>
phologic variability and fish-community characteristics [Gorman and Karr, 1978; Schlosser, 1982; Swales, 1988; Gelwick, 1990; Lobb and Orth, 1991]. Results support the hypothesis that increased spatial variability in channel morphology results in improved habitat for fish. The meandering reach of the Embarras River, which has greater spatial variability in channel morphology than the channelized reach, contained more and larger fish than the channelized reach. This association suggests that availability of physical habitat, defined on the basis of stream morphol-
Figure 7. Changes in channel cross sections at the channelized reach for the period October 1997 through June 1998.

Stream geomorphology, has a detectable influence on ecological conditions in human-modified agricultural streams. No substantial difference in species richness was observed between the channelized and meandering sections of the Embarras River. Other work has shown that species richness in the Embarras River has remained relatively stable over the last 100 years [Hauser, 1999]. The similarity in community composition in this study reflects the mobility of fish and, considering that the sampled reaches are adjacent to one another, is not surprising. While the fish community in the
Table 3. Sediment flux results

<table>
<thead>
<tr>
<th>Site</th>
<th>Date</th>
<th>Volume of erosion (m³)</th>
<th>Volume of deposition (m³)</th>
<th>Net volume change (m³/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meandering reach</td>
<td>10/10/97-6/5/98</td>
<td>83.7</td>
<td>36.7</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>6/5/98-6/25/98</td>
<td>55.8</td>
<td>17.3</td>
<td>0.55</td>
</tr>
<tr>
<td>Channelized reach</td>
<td>10/3/97-6/15/98</td>
<td>16.8</td>
<td>17.5</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>6/1/98-6/25/98</td>
<td>26.1</td>
<td>11.0</td>
<td>0.29</td>
</tr>
</tbody>
</table>

meandering reach changed over time, the relationship of this temporal variability to channel morphology is uncertain. Fish community conditions were affected by short-term factors (i.e., weather-related hydrologic variability) and longer-term phenomenon (i.e., seasonal hydrological variability and temperature regimes). Although channel morphology/habitat changed during the period of fish sampling, the effects of these changes on fish-community structure could not be discerned from the type of information collected in this study.

The linkage between physical-habitat and fish community structure documented in this investigation represents a first step in the development of a knowledge base to guide integrated eco-geomorphological approaches to stream naturalization in East Central Illinois [Frothingham et al., in press]. Because naturalization may involve myriad management strategies, ranging from passive recovery to ecologically sensitive channel maintenance, a critical need exists for adequate knowledge to define the ecological benefits that will accrue from a particular style of naturalization. Without such knowledge, both the formulation of ecological goals and assessments of the capacity to attain these goals will be uninformed, increasing the risk of project failure. Concern about failure is especially acute in East Central Illinois where most naturalization projects are likely to be undertaken by drainage-district commissioners, who are concerned first and foremost about drainage, but who also have an interest in being environmental stewards [Rhoads et al., 1999]. The money to support drainage-district projects is raised through taxes imposed on landowners within a district. The commissioners feel obligated to use their neighbors tax dollars wisely and to demonstrate that expenditures produce tangible benefits.

The findings of this study also support the contention of drainage-district commissioners that a management trade-off exists between the static stability of a channelized reach and the dynamic stability of unmodified stream channels. Streams in East Central Illinois have low values of stream power [Rhoads and Herricks, 1996] and generally do not exhibit dramatic post-channelization adjustment, such as downcutting and channel widening [e.g., Harvey and Watson, 1986; Simon and Hupp, 1990] or rapid re-establishment of meanders [e.g. Brookes, 1988]. Many channelized streams in this region are statically stable [Rhoads and Urban, 1997; Urban, 2000]—a consequence that is viewed as desirable from a land-drainage perspective, but as undesirable ecologically. The lack of geomorphological recovery from human-induced disturbance prevents the development of physical habitat within morphologically homogenous channelized streams.

The findings here show that the dynamic stability of the unmodified meandering reach provides diverse physical habitat that locally enhances the abundance and biomass of fish communities. One approach to naturalization in East Central Illinois is to preserve meandering segments as “habitat islands” within extensively modified agricultural stream systems [Frothingham et al., in press]. This approach was used to protect the 800-m meandering segment from channelization in 1996 [Rhoads and Herricks, 1996]. However, drainage-district commissioners still perceive erosion rates in this section of the river as excessive [Rhoads et al., 1999]. This study confirms that the mean-
dering reach is migrating laterally; however, the rates of migration documented in this short-term field investigation are consistent with erosion rates in unmodified meandering segments of the Embarras River over the last 60 years [Rhoads and Urban, 1997; Urban, 2000] and with rates of erosion for other channels of similar size and drainage area [Hooke, 1980; Hooke and Redmond, 1992]. Those responsible for stream management in East Central Illinois, if they endeavor to improve environmental quality, should understand the dynamic aspects of river channels and the linkage of these dynamics, via processes that maintain spatial heterogeneity of physical habitat, to ecological conditions. Such understanding depends not only on the availability of accurate scientific information on eco-geomorphological linkages, an issue this study has aimed to address, but also on meaningful social interaction between scientists and local people [Rhoads et al., 1999].

**CONCLUSION**

This study has provided detailed data on the linkages between ecological conditions and morphological variability in a straight channelized reach and an unmodified meandering reach of an agricultural stream in East Central Illinois. The meandering reach has greater morphological variability over time and space, resulting in greater habitat diversity, fish abundance and fish biomass than the channelized reach. This finding is consistent with previous research that has emphasized availability of physical habitat as a key factor governing fish community characteristics in human-modified streams in the Midwest [Schlosser, 1982; Terhaar and Herricks, 1989]. Ongoing work is examining how the difference in morphological complexity between the two reaches influences three-dimensional flow characteristics, thereby creating a difference in the diversity of hydraulic habitat [Frothingham, 2001].

This study is part of a comprehensive research program that seeks to develop a knowledge base to guide stream-naturalization activities in East Central Illinois. The comprehensive program is based on a multiscale eco-geomorphological perspective [Frothingham et al., in press]. It combines historical analysis of fisheries [Chambers, 1994; Hauser, 1999] and stream-dynamics [Urban, 2000] with field-based analysis of current geomorphological and ecological conditions [Frothingham, 2001] to better understand eco-geomorphological linkages in agricultural stream systems. The knowledge emerging from this research will underpin efforts to develop stream-management alternatives that promote dynamically stable stream systems capable of supporting biologically diverse aquatic ecosystems.

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