Anthropogenic Influences Affect the Nongame Fishes of the Yellowstone River

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Abstract

I examined attributes of the nongame fish assemblage along the length of the lower Yellowstone River to assess if fish species richness and fish abundances differed as a function of bank stabilization, cultivated lands and developed lands in proximity to the river. I examined if land use changes, such as developed lands and cultivated lands in proximity to the Yellowstone River were associated with the presence of bank armor. Our data did not directly support the claim that development or agriculture is directly associated with the presence of bank stabilization structures; however, land use changes may have other unanticipated landscape scale effects on the fishes of the Yellowstone that are not directly related to armoring. I found that sampling river bends within areas of intensive cultivation had depressed species richness estimates. Bank stabilization is becoming increasingly prevalent on the banks of the Yellowstone River, but it remains unclear exactly how this anthropogenic modification is affecting the nongame fishes. That is, bank stabilization may negatively affect fishes, but the results from this study fail to support this hypothesis.

Keywords: Yellowstone River, land use, land change, fisheries, nongame fishes, landscape ecology
Introduction

Over half of the world’s large river systems are fragmented as a result of humans curbing river systems to meet their energy, transportation and water needs (Nilsson et al 2005). While the effects of large dams on riparian ecosystems have been well documented (Baron et al 2002; Nilsson et al 2005), large rivers are exposed to a number of anthropogenic stressors that are poorly explored. Some of these stressors include bank stabilization, diversion dams, water withdrawals, and altered depth and sediment regimes from dammed tributaries. Such river perturbations often result in changes in channel morphology, depth, and fish habitats (Zale and Ryder 2003). These perturbations alter local river flow and have detrimental effects on fish assemblages.

The Yellowstone River remains the largest undammed river in the continental United States, yet it still faces all of the anthropogenic stressors and subsequent river perturbations listed above. The Yellowstone River is suffering from declining numbers of fishes, some of which are endangered, but the specific effects of development and bank stabilization are unknown on these fishes (Bowen et al 2003; Bramblett and White 2001; Hesse et al 1989; Jaeger et al 2005; McMahon and Gardner 2001; Pegg and Pierce 2002; Zale and Ryder 2003). Because the Yellowstone is undammed, its fishes have a good chance of recovery if the specific effects of the anthropogenic stressors can be assessed and subsequently modified. Therefore, this river is an ideal river to study the effects of anthropogenic river modifications on fish assemblages.

Reports of the Yellowstone’s declining fish species may be indicative of a greater problem on the level of fish assemblages. Bank stabilization is constructed for the purposes of preventing agricultural lands, residential and urban lands, and transportation
structures (such as roads, railroads and bridges) from eroding into the river. However, bank stabilization, which directly alters river flow, also results in concomitant changes in the hydrograph and the amounts of sediment in the water. These alterations in flow regimes influence large river aquatic communities (Hesse et al 1989; Pegg and Pierce 2002). In general terms, the effects of altered hydrographs and flow favor the abundance of more generalized species because bank stabilization functions as a disturbance for aquatic communities. These river modifications lead to the decline of specialist species, thus leading to the disruption of assemblage structure (Pegg and Pierce 2002). Evidence from studying sturgeon in the Yellowstone River show that this disruption may be the result of the stabilization methods changing the abundance and availability of fish habitats (Bramblett and White 2001).

Researchers have shown that these alterations in river flow have detrimental effects on individual fish species (Bramblett and White 2001; Hesse et al 1989; Jaeger et al 2005; Zale and Ryder 2003). Bowen and colleagues (2003) summarized some of the Yellowstone’s species of utmost concern. The pallid sturgeon *Scaphirhynchus albus* is listed as an endangered species (USFWS 1990), and the sturgeon chub *Macrhybopsis gelida* (USFWS 1995) and the sicklefin chub *Macrhybopsis meeki* (USFWS 1995) may be on the endangered species list soon if conservation efforts are not improved. Additionally, in 1998 the USGS added five more species that are indigenous to the Yellowstone River to their list of special concern: the blue sucker *Cycleptus elongates*, the flathead chub *Platygobio gracilis*, the paddlefish *Polyodon spathula*, the plains minnow *Hybognathus placitus*, and the western silvery minnow *Hybognathus argyritis*. Since many fishes share similar habitat and life cycle features, it follows that the data for
these individual species is indicative of multiple fish species, but until now, the specific effects of anthropogenic disturbances on the fish assemblages along the Yellowstone River had not been addressed. Is it possible that bank stabilization and land use changes are the cause?

Given the declining numbers of individual species as an indication, our study assessing the effects of bank stabilization and anthropogenic land use on the nongame fish assemblages of the lower Yellowstone is overdue. While the Yellowstone River is subject to multiple types of anthropogenic stressors, the effects of bank stabilization and human development in the riparian corridor are the focus of this article.

First, the association between bank stabilization and anthropogenic land use in the riparian corridor is assessed. There are multitudes of agricultural lands in eastern Montana located in the floodplain of the Yellowstone River. In addition, residential and urban development continues to expand both in and around the cities that line the River. Thus, it follows that riprap and other bank stabilization structures, which are constructed to protect developed lands, are likely associated with the development in the riparian corridor. Second, I address the association between cultivated and developed land prevalence and fish species richness and fish abundances. Land use changes tend to be unidirectional (Mustard et al 2004), thus it is critical for us to assess the current and growing trajectory of land use in the Yellowstone’s riparian corridor. Third, the association between the prevalence of bank stabilization and fish species richness and abundance is explored. Bank stabilization causes a lateral disconnect between the river channel and its floodplain; this disconnect leads to changes in flow and sediment that
subsequently affects the development and persistence of islands, bars and other habitats that are imperative for fish viability (Hesse et al. 1989).

**Methods**

The Yellowstone River was stratified into 13 segments using the city of Billings, the 6 diversion dams (Huntley, Waco, Rancher, Meyers, Cartersville, and Intake), major tributaries (Big Horn, Tongue, Powder, and O’Fallon), and the town of Sidney (approximate transition zone from cobble to sand substrate) (M. Duncan, unpublished data). Sampling sites were randomly chosen within each of these 13 segments. The sampling sites (i.e., river bends) consisted of three continuous macrohabitats: channel crossover (CC), inside bend (IB), and outside bend (OB). Additional secondary (SC) and seasonal secondary channels (SSC) were sampled when present.

Figure 1 shows the Yellowstone River in Montana. Grey circles indicate all study sites on the map; the two blue circles indicate two representative sites, which are explored in detail on the right side of Figure 1. Three mini-fyke nets were set within each macrohabitat to ensure adequate and representative sampling of the study site. Sites were sampled between 1 July and 31 October, 2009. The nets were set between 4-5 p.m. and all fish were collected between 8-9 a.m. All fish were counted and their species documented. Catch per unit effort (CPUE) was calculated by determining the abundance of fish at each sampling site and dividing that by the number of nets set at each site. This calculation normalizes the CPUE to account for more complex habitats, where more nets were set. The Menhinick (1964) index of species richness was used because the sample size varied from site to site. The Menhinick index of species richness was calculated as the ratio of the number of species to the square root of the sample size.
A GPS location was taken at the center of each of the sampling sites, and this point and its associated fisheries data was uploaded into ESRI ArcGIS 9.3 using the “Add x,y Data” function. This location was buffered for the spatial analysis of the data using the “Buffer” tool in the Spatial Analyst toolbox. A 5 km buffering radius was chosen because the inundation zone of the river is often 4 - 5 km in length, thus ensuring that the inundation zone of the river and the associated development and cultivated lands in the riparian corridor were included in the analysis. Note the gray circles on the right side of Figure 1 to appreciate the extent of the area analyzed in the buffered zones. ESRI ArcGIS 9.3 was used for all maps and spatial analysis.

GIS layers portraying land use (2001), habitat units (CC, pool type, etc) (2009), linear physical features inventory (riprap and other bank stabilization structures) (2003) and aerial photographs of the river (2001) were downloaded from the Montana GIS portal (www.nris.mt.gov/gis) and uploaded into ArcGIS. The raster land use layers were made into one continuous layer using the “Mosaic to New Raster” tool. The “Reclassify” tool was used to merge all subtypes of cultivated land into one raster type; that is Pasture/Hay, Row Crops, Small Grains, Fallow and Urban/Recreation Grasses were reclassified into one raster type, which I refer to as cultivated. Similarly, the “Reclassify” tool was used to merge all subtypes of developed land into one raster type; Low Intensity Residential, High Intensity Residential, and Commercial/Industrial/Transportation grids were reclassified into one raster type, which I refer to as developed. A 2 m buffer was generated around all sides of the linear bank stabilization layer using the “Buffer” tool. This buffered bank stabilization layer was then converted to a raster layer using the
“Polygon to Raster” tool (10 m cells, using the maximum combined area formula) to facilitate the Zonal Statistics calculations.

The “Zonal Statistics as Table” tool was used to calculate the area of cultivated lands, urban lands, and bank stabilization within the 5 km buffered regions for each sampling site. The “Join” tool was used to link the three Zonal Statistics tables (one table for each cultivated lands, urban lands, and bank stabilization) to the fisheries data. The “Export” tool was used to generate the data file. All statistical calculations and data plots were completed in the computing package R.

Results

Surprisingly, based on a multiple linear regression model I found no evidence that the area of bank stabilization within a 5 km radius of a fisheries site is a function of cultivated or developed lands (Figure 2) \( (p = 0.3097, F\text{-stat} = 1.221 \text{ on 2 and 29 d.f.}) \).

A total of 32 fisheries sites were included in the analyses. In total, 335 mini-fyke nets were set and 10,150 fish were caught. The mean number of species caught at a site was 31.375 species. Histograms of species richness, CPUE and log(CPUE) are shown in Figure 3. CPUE was natural logarithm transformed to correct for the distinctly skewed CPUE values; throughout this paper, log(CPUE) refers to taking the natural logarithm of CPUE.

It was anticipated that a negative linear trend in CPUE and species richness would be observed as cultivation and development land use increased within the 5 km buffer. However, after plotting CPUE and species richness for all sites as a function of cultivation and development, there was no apparent linear trend in the data, with the exception of the relationship between species richness and cultivated lands (Figure 4).
There is no evidence of a linear relationship between CPUE and area of developed lands (\(p = 0.50, \text{F-stat} = 0.467\) on 1 and 30 d.f.), species richness and area of developed lands (\(p = 0.067, \text{F-stat} = 3.615\) on 1 and 30 d.f.), and CPUE and area of cultivated lands (\(p = 0.154, \text{F-stat} = 2.316\) on 1 and 30 d.f.). However, there is evidence of a negative linear relationship between species richness and cultivated lands (\(p = 0.039, \text{F-stat} = 4.66\) on 1 and 30 d.f.). It is estimated that a 100 km\(^2\) increase in developed lands within a 5 km radius of a river bend will result in a 0.00273 unit decrease in species richness (95\% confidence interval from 0.00531 to 0.000147 units) (see Figure 4, bottom left).

Species richness and CPUE did not vary as a function of area of bank stabilization within the 5 km buffer (Figure 5). Neither species richness nor CPUE are linearly associated with the area of bank stabilization (\(p = 0.49, \text{F-stat} = 0.485\) on 1 and 30 d.f. and \(p = 0.23, \text{F-stat} = 1.514\) on 1 and 30 d.f., respectively).

**Discussion**

The Yellowstone River has a large number of threatened and declining fish, but does not have the additional ecosystem fragmentation and disruption caused by large dams. This study is the first to take a landscape ecology approach to understanding the specific effects of bank stabilization and land use changes on the fishes of the Yellowstone River.

With respect to the effects of land use on species richness and CPUE, the lack of clear trends may be due to the limits of the data. These data were collected in one year (2008) and are limited to 32 different sites. The effects of development land use changes may be ecologically profound, but I may not have been able to detect these effects because of my small sample size and few sites located in proximity to such development.
That is, there were simply too few sites in highly developed areas to discern an appreciable trend in how development affects the fisheries metrics that I analyzed. In contrast to the development land use, there are a greater proportion of cultivated lands surrounding the river. It is likely that I was able to detect the relationship between areas of cultivated land use on fish species richness because our study sites incorporated varying areas of cultivated lands, in spite of our small sample size (Figure 4).

Regardless of the fact that our results were not conclusive with respect to the relationship between bank stabilization and land use, riprap is expensive and stabilized banks are not constructed on economically dispensable lands (Schmetterling et al 2001). While this lack of a trend is puzzling, it may be explained as a scaling issue; that is, the 5 km buffer is too large of an area to detect a direct association between land use and bank stabilization and it is only the land use in direct proximity to the river that explains the degree of bank stabilization. However, the 5 km buffer was used for these analyses because it answered the question of interest: is there an association between bank stabilization and anthropogenic land use in the riparian corridor?

While this study failed to show that bank stabilization negatively affects CPUE and species richness, this may be due to deficiencies in the data. There were relatively few of the 32 sites that were in the proximity of stabilized banks, making it difficult to appreciate how differing areas of bank stabilization affect the Yellowstone’s fishes. However, there have been multiple studies showing that bank stabilization disturbs fish habitats (Bowen et al 2003; Hesse et al 1989; Jaeger et al 2005; Schmetterling et al 2001; Zale and Ryder 2003). Ongoing research is currently furthering the approach taken in this report with the goal of assessing the direct effects of bank stabilization on the
Yellowstone’s fishes (A.M. Reinhold, unpublished data). By obtaining this valuable information and investigating assemblage structure in bank stabilized, cultivated and urban regions of river, policymakers can then be influenced to alter development strategies, so that the river features that support healthy fish assemblages can be preserved and restored.

**Conclusions**

The implications of this study for the landscape ecology of the Yellowstone’s fishes are profound. Land use change tends to be unidirectional, changing from frontier to cultivated to developed (Mustard et al 2004). This study showed that increasing cultivation was associated with depressed species richness on the Yellowstone River. Bank stabilization, which negatively affects fish habitat, is only constructed in areas of human land use. Therefore, it is likely that as land use changes continue in the future, there will be more bank stabilization structures constructed on the Yellowstone.

The future of the Yellowstone River’s fishes likely depends on our understanding the critical thresholds of land use change, the bank stabilization that likely accompanies this change, and advising policymakers of the most meaningful zoning restrictions that will protect the critical habitat in the riparian zone. This study takes the first steps in appreciating the effects of these land use changes on the Yellowstone’s fishes and provides the justification for a landscape ecology approach to understanding how land use changes affect a large river’s fishes.

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Figure Captions

Figure 1. Map of Study Area and Representative Sites. See figure.

Figure 2. Lack of a relationship between bank stabilized area with area of cultivated and developed lands. There is no evidence that the area of bank stabilization varies as a function of the area of cultivated and developed lands within a 5 km radius of the Yellowstone River (p = 0.3097, F-stat = 1.221 on 2 and 29 d.f.).

Figure 3. Histograms of species richness, CPUE and log(CPUE) for the fisheries sampling sites. CPUE values were log transformed such that linear regression models of CPUE could be performed.

Figure 4. The relationships between cultivated and developed land use and fisheries metrics within a 5 km radius of fisheries sampling sites. A negative linear trend in fisheries metrics was only observed when species richness is plotted as a function of area of cultivated lands.

Figure 5. The relationships between bank stabilization area and fisheries metrics within a 5 km radius of fisheries sampling sites. There is no evidence of a negative linear trend in fisheries metrics and area of bank stabilization.
Figures

Figure 1. Map of Study Area and Representative Sites

The undammed Yellowstone River extends 1078 kilometers from Yellowstone National Park into the confluence with the Missouri River in North Dakota. The lower Yellowstone, which is the focus of this study, extends for approximately 812 km. The study sites are shown with gray circles on the map of Montana (above). At right, representative sites (26 and 16) are mapped at greater resolution (1:15,000). The river is in blue, cultivated lands are in yellow, and developed lands are in orange. Areas of fisheries sampling sites are depicted at far right (resolution 1:10,000).
Figure 2. Lack of a relationship between bank stabilized area with area of cultivated and developed lands.
Figure 3. Histograms of species richness, CPUE and log(CPUE) for the fisheries sampling sites.
Figure 4. The relationships between cultivated and developed land use and fisheries metrics within a 5 km radius of fisheries sampling sites.
Figure 5. The relationships between bank stabilization area and fisheries metrics within a 5 km radius of fisheries sampling sites.
References


