Climate-Driven Flood Effects on Channel Stability, Sedimentation, and Freshwater Mussel Habitat in Rivers Draining the Ozark Highlands

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Abstract

The frequency of intense precipitation events and large magnitude floods in rivers draining the Ozark Highlands has been increasing over the past 40 years due to recent climate change. Higher energy flood regimes can degrade channel habitats due to channel instability, bank erosion, and fine sediment deposition. This study was conducted to assess changes in stream channel morphology along segments of Roubidoux Creek and the Big Piney River on the Fort Leonard Wood Military Reservation, Missouri to address concerns about habitat loss for freshwater mussels and evaluate the spatial distribution and causes of accelerated channel activity. Freshwater mussels typically live in stream habitats with stable channel beds and banks, permanent baseflow with moderate flood flows, and in mixed sized substrates free of contamination. A GIS based assessment of the stream channel geomorphology was conducted using leaf-off aerial photographs from 1995, 2007, and 2015. Stream channel bank and bar features were digitized and classified according to planform change and bar sediment activity. Field surveys were also conducted to assess in-stream channel sedimentation, bank erosion, and sediment and runoff inputs from tributaries. Our results show overall channel widening of 3% on the Big Piney River and 9% on upper segments of Roubidoux Creek during the 20-year study period, with local disturbance zones increasing channel width by over two-times in some cases. Bank erosion rates and increased bar areas were correlated with channel width increases. Over the two time periods (1995-2007 and 2007-2015), bank erosion rates increased in Roubidoux Creek but remained constant in the Big Piney River. Flow regulation by two impoundments on the Big Piney River may be controlling bank erosion rates. Low mussel densities were associated with unstable channel reaches with high bank erosion rates, bar area changes, and fine sediment depths. This study helps address our understanding of the response of channel morphology and sedimentation to increased climate-driven flooding and effects on freshwater mussel habitats in the Ozark Highlands.

Introduction

Excessive inputs of fine sediment cause physical channel instability and biological habitat degradation in river ecosystems (Wood and Armitage, 1997; Owens et al., 2005). Fine sediment (i.e., sand, silt, and clay) loads to the channel can increase siltation rates, clog substrate pore spaces, and reduce available habitat in gravel and cobble deposits on the channel bed in both riffle and pool habitats (Wood and Armitage, 1997). However, sediment impacts on channel stability and habitat degradation can vary depending on particle size and sediment source (James et al., 2021). Typically, fine sediment refers to particles <2 mm in diameter, however, sediment sizes up to 8 mm (very fine to fine gravel) or larger can negatively impact pore space habitats in the channel bed. Embeddedness of fine sediment in the streambed can restrict the flow of oxygenated water to sediment-dwelling organisms. Fine sediment loads in Ozark streams are related to geology and land use with highest suspended sediment yields in watersheds with more erodible silty soils, higher relief, and relatively large areas of agricultural and urban land.

The purpose of this study is to assess channel and sediment characteristics and evaluate channel bed and bank stability within the segments of Big Piney River and Roubidoux Creek located within Fort Leonard Wood in the Missouri Ozarks. In addition, channel stability trends will be compared to known locations of freshwater mussel beds to evaluate substrate-habitat relationships. Declines in mussel assemblages have been found throughout the Ozarks Highlands (Williams et al., 1992; Watters, 2000). The main threats to mussel populations in the Ozarks - Meramec River Basin were reported to be excess sedimentation, altered stream geomorphology and flow, effects on riparian vegetation and condition, impoundments, and invasive species (Hinck et al., 2011, 2012). A declining trend in mussel abundance over the past two decades and relatively low numbers of living mussels has also been observed in mussel surveying within the Fort Leonard Wood Military Reservation (FLW) (Sternburger et al., 1998; Barnhart et al., 2004; Lohraff, 2012; Maynard et al., 2017). Accordingly, there are ongoing concerns about the causes of historical and recent reductions in the number of mussel beds in the rivers on FLW (Maynard et al., 2017).

The goal of this study is to provide insight on channel stability within segments of Roubidoux Creek and the Big Piney River on the Fort Leonard Wood Military Reservation. The specific objectives of this study are to 1. Investigate stream channel morphology changes (channel width, bank erosion, and bar area) over a 25-year period using GIS and aerial photography. 2. Evaluate fine sediment deposition through field surveying of glide areas. 3. Provide implications of channel instability on mussel habitat within FLW.

Physical Habitat Stressors

Higher storm runoff rates can accelerate soil erosion, increase the frequency of high-energy floods, and cause channel instability including bank erosion (James et al., 2021). Climate and discharge records indicate that flood magnitude and frequency in the Ozark Highlands has increased significantly over the past thirty years due to recent climate change (Foreman, 2014; Pavlowsky et al., 2016; Heimann et al., 2018). Across the Midwest United States peak streamflow has been increasing due to the frequency of larger magnitude (> 2-3 in) rain events (Heimann et al., 2018). The persistence of large floods can change the size, location, and supply of channel bottom and bar substrates and force a change in channel form (Costa and O'Connor, 1995; Swanson et al., 1998; Phillips, 2002; Poff, 2002). Stream bank erosion caused by hydrological disturbances is a source of fine sediment and gravel to the stream and can lead to overall stream widening, reduction in channel sinuosity, and loss of canopy cover (Cluer and Thorne, 2014). Previous studies have shown increased sedimentation and flow alterations can lead to habitat degradation and population declines in fish, crayfish, and macroinvertebrates (Di Maio and Corkum, 1995; Lynch et al., 2019).

Historical land clearing through timber harvest, poor agricultural soil conservation practices and urban development has left a legacy of soil erosion, nutrient loss, and excess sediment deposited on valley floors throughout the Midwest (Potter et al., 2004; James et al., 2021). Through a combination of increased runoff, higher soil erosion rates, and more frequent floods due to soil and vegetation disturbances in the late 1800s and early 1900s, suspended sediments were deposited at accelerated rates on floodplains to depths of over 2 m along some Ozark rivers (Owen et al., 2011; Pavlowsky et al., 2017; Pavlowsky and Meyer, 2018). Water quality regulations put emphasis on suspended sediment loads but do not address the degree of fine sediment deposition on streambeds that affects benthic organisms (Jones et al. 2012). Mussel beds tend to suffer under high rates of fine-grained deposition or siltation (Box and Mossa, 1999; Watters, 2000; Owens et al., 2005; Hauer, 2015; Niraula et al., 2017). In general, mussels tend to do best in a mixture of sediment sizes with coarse stable substrates formed by gravel and cobble that infilled or slightly covered with sand and silt during low flow periods. Too much fine sediment may cover mussel beds, form unstable substrates, and create sediment quality problems (Wood and Armitage 1997; Box and Mossa, 1999; McRae et al., 2004; Leitner et al., 2015).

Accelerated rates of bank erosion can rapidly deposit sediment, creating reaches of instability and degrading habitat. In the classic model of channel migration, channel form and size remain generally constant while erosion occurs gradually on the leading or outside bank and deposition occurs on the inside bank. However, during high rates of bank erosion, channel position changes quickly and excess sediment is deposited over previously stable substrate allowing little time for mussels to move and adapt to new locations. Key et al., (2021) found a significant effect of bank erosion rates >0.6 m/yr on reduced occurrence of mussels. In situations where flood regime is increasing, channel widening can also occur where both banks may erode, widening the active channel and introducing excessive bank material to the channel. In general, mussel abundance and diversity increase with channel width as there is more habitat available (McRae et al. 2004; Gangloff and Feminella, 2007). However, while high rates of channel erosion can widen the channel to increase potential habitat, good conditions of channel stability with normal flow and erosion rates are required for optimum mussel habitat (McRae et al., 2004; Gangloff and Feminella, 2007; Allen and Vaughn, 2010; Randklev et al., 2019; Key et al., 2021).

Study Area

FLW is located primarily in Pulaski County southwest of Waynesville and south of St. Robert, Missouri. The FLW property covers approximately 62,000 acres on the Salem Plateau and is bordered by Roubidoux Creek on the west and the Big Piney River on the east (Figure 1). Roubidoux Creek is divided into two segments for the purposes of this study. The upper segment of Roubidoux Creek flows across the southern property boundary at Missouri State Highway 17 for 15 km in a northerly direction to where it flows off the base into Pulaski County. The lower segment of Roubidoux Creek begins where it reenters base property near FLW E in the northwest corner of base property. It then flows for 9 km and exits FLW below Polla Road bridge at approximately 9.5 km above its confluence with the Gasconade River.

Geology, Soils, and Land Use

The Big Piney River and Roubidoux Creek watershed areas on FLW have similar geology consisting of Ordovician age sedimentary clastic and carbonate rocks with varying chert content (Blanc, 2001; Wilkerson, 2004). Typical stratigraphy includes three horizontally bedded formations: the Jefferson City dolomite and sandstone exposed on uplands, the Roubidoux sandstone and dolomite, and the deeper Gasconade dolomite and sandstone (Harrison et al., 1996; Wilkerson, 2004). The more soluble carbonate bedrock units have developed a karst topography consisting of sinkholes, caves, losing streams, and springs on FLW property and surrounding region (Imes et al., 1996; Wilkerson, 2004; Richards et al., 2012). While Big Piney River is perennial for its entire length on FLW, flow in Roubidoux Creek is intermittent in some segments where losing streams are located (Imes et al., 1996; Follum et al., 2015). The upper segment of Roubidoux Creek remains perennial, the middle and lower segments of the creek are intermittent. Of the 59.5 km of Roubidoux Creek evaluated during this study, 70% are perennial, 17% are intermittent with isolated pools remaining, and 13% is intermittent going completely dry for some time during the year.

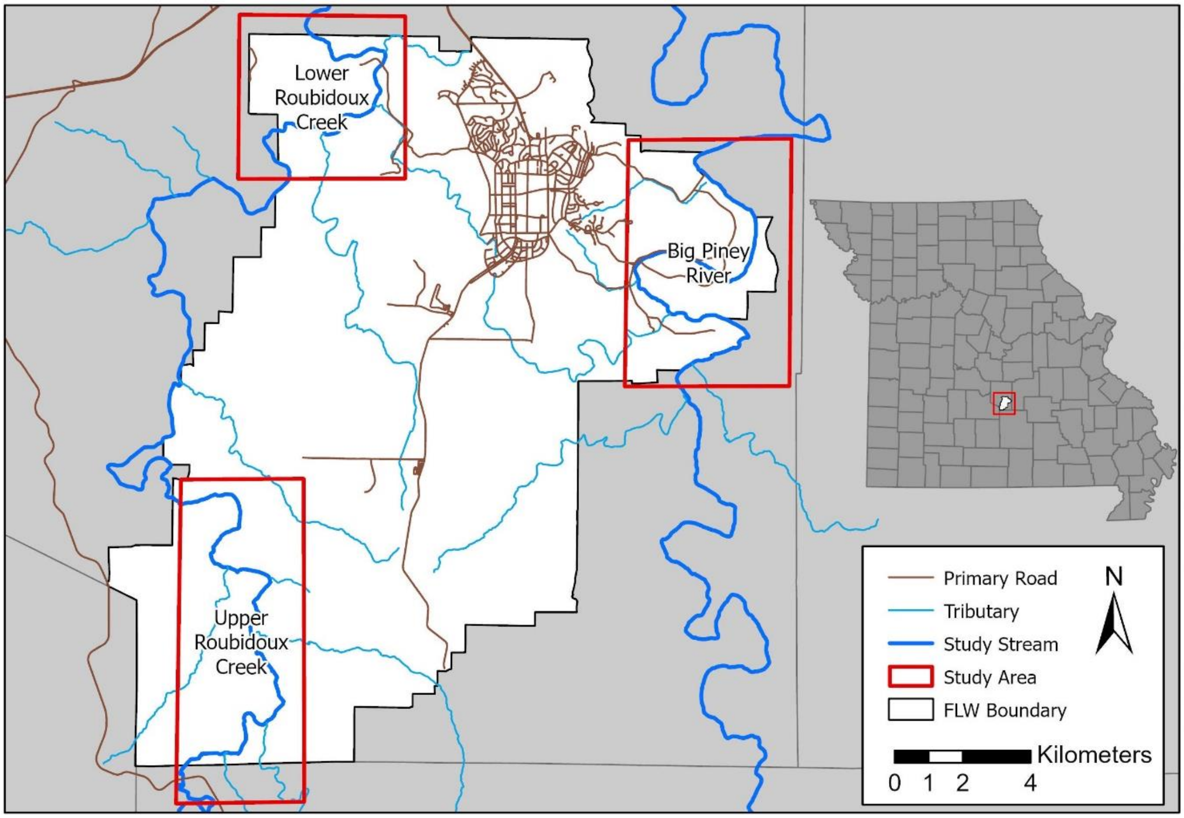

Figure 1. Regional setting of the study areas.

Soils are similar in both watersheds consisting of mostly silty to sandy loams with high to moderate percentages of chert (Wilkerson, 2004; Richards et al., 2012; NRCS, 2019). Floodplain soils are described as frequently flooded with slopes ranging from 0 to 3 percent. They are formed in alluvial parent materials generally composed of overbank deposits of a meter or more of silt loam with some sand layers overlying gravelly channel deposits at depth.

The majority of the Big Piney and Roubidoux Creek watersheds are forested, with forested areas covering 64% and 67% respectively. Secondary land use in the Big Piney and Roubidoux Creek watersheds was hay/pastureland, composing 28% and 23% respectively. Developed areas compose approximately 6% of both watersheds. Land use has remained the same since the 1990s, except for slight (<6%) decreases in forested areas and slight increases in developed areas. Land use for the sub-watersheds was derived from the NLCD 2019 (CONUS) dataset.

Hydrology

Mean annual discharge has increased by 6% on the Big Piney River and Roubidoux Creek during the period from 2000 to 2020 at the two nearest USGS gages on each stream (Nos. 06930060 and 06930000 – Big Piney River and 06928420 and 06928300 – Roubidoux Creek). Mean seasonal discharge has also increased from 2000-2009 to 2010-2020 for both streams. The largest increases in discharge have occurred in the spring and early summer months (March – June). During this period, runoff rates are more sensitive to rainfall due to the occurrence of cooler weather and leaf-off conditions for deciduous trees when evapotranspiration and canopy interception rates are at their minimum. While discharge trends on the Big Piney are similar at both gaging stations, Roubidoux Creek is more variable. On Roubidoux Creek, the downstream gage often recorded lower annual discharges compared to the upstream gage. This is probably the result of lower monthly rainfall and higher evapotranspiration rates during the summer and the loss of flow to seepage or into swallow holes in the bed along losing segments where karst occurs. In fact, the lower portion of Roubidoux Creek is typically dry with no baseflow for 2-3 months in the summer or early fall.

On Big Piney River at USGS gage No. 06930000, flood frequency analysis of the annual peak series over 30-year intervals shows that the magnitude of flood discharges has increased dramatically across a range of recurrence intervals from 1958-1987 to 1988-2017. Compared to the earlier period, the peak discharge for a recent flood of given frequency has increased in the Big Piney River on FLW as follows: bank-full Q or 1.5-year RI, 16%; 5-year RI, 32%, 10-year RI, 40%; 25-year RI, 50%; 50-year RI, 58%, and 100-year RI, 66%. The evidence for increasing flood trends in Big Piney River has been supported by the results of other studies of recent floods in the Ozark Highlands region, mainly being attributed to recent climate change effects (Pavlowsky et al., 2016; Heimann et al., 2018).

Additionally, two 3 m high dams constructed between 1940-1960 are located on Big Piney River. The dams were created for water supply intake (upstream dam) and military training (downstream dam) for Fort Leonard Wood. Dams regulate flow by decreasing water surface slope and therefore reduce stream power, sediment transport, lateral channel instability, and active bar deposition. These effects can potentially help maintain and stabilize mussel beds.

Methods

Channel Planform Assessment

Aerial photographs of FLW and bordering rivers were acquired for the 1990's, 2007, and 2015 to determine temporal changes of stream channel positions. These years were chosen because all the photographs were taken during the leaf-off season, which allows maximum visibility of the river corridors including banks, bars, and wet areas of the channels. Aerial photographs came from Missouri Spatial Data Information Service (MSDIS). Spatial resolution was less than 1 m.

Channel reaches were assessed according to rates of planform change (channel widening and bank erosion) and bar sediment activity (area) (Martin and Pavlowsky, 2011; Owen et al., 2011; Wang et al., 2020). Channel areas were digitized as polygon features within ArcGIS Pro and defined by landforms within the channel delineated by bank lines. Active channel dimensions and a centerline were digitized to approximate the main flow line of the channel. In addition, bars and islands within the active channel were also digitized as polygon features. Temporal changes to channel planform dimensions and areas, bank locations, and bar size and locations were identified by overlaying channel and bar polygons from different aerial photograph years.

Channel analysis was based on comparisons of landform attributes between different time periods within polygon river cells arranged in a downstream series with equal lengths. The cells were delineated by creating point features along the stream channel centerline every 0.5 km and then creating a line across the active channel polygons perpendicular to the channel centerline. River cells were labeled by their upstream river. Cell width varies according to the orientation of active channel bank lines on both sides of the main channel. The 500 m cell length used in this study is approximately equivalent to one-half of the geomorphology-defined reach length of the main channel at 6-10 channel widths (Rosgen, 1996).

Channel Widening and Disturbance Reach Classification: A buffer was applied to each thalweg centerline with the buffer distance determined by the maximum point-to-point error between the aerial photos (Martin and Pavlowsky, 2011). After the buffers were applied, geoprocessing tools were used to generate new polygons in reaches where the buffers did not overlap to locate areas of possible channel movement or widening. Each area was individually inspected in the field to determine if the channel has widened considerably due do local variability in sediment transport and channel activity to form an active reach or disturbance zone (Jacobson and Primm, 1994; Jacobson and Gran, 1999; Martin and Pavlowsky, 2011). As designated for this study, disturbance zones are classified as places where the width of the channel area is greater than 1.5 times the channel width of the upstream and downstream reaches in non-overlapping areas. Disturbance zones on the Big Piney River and Roubidoux Creek were classified and compared to mussel bed locations from prior biological surveys to evaluate the effects of persistent channel instability on mussel density.

Field Assessment Procedures

In-channel physical habitat was assessed in stream channel units for sediment and bank erosion indicators on the Big Piney River and Roubidoux Creek using both qualitative and quantitative field methods. Mapping points of field sites were collected with an iPad and a Bad Elf GNSS Surveyor. Georeferenced photographs were also taken. Data collection during canoe surveys included sediment diameter and depth, bank properties, and tributary sediment inputs.

Fine-Grained Sediment: Fine-grained sediment deposits on the channel bed were assessed by measuring the tile probe depth to refusal at six locations within the glide and three locations on the downstream riffle crest (Pavlowsky et al., 2017). A 1.2 m long hand-held tile probe was used to determine the depth of fine-grained sediment deposited over coarser bed sediment to determine sediment storage on the channel bed. In the glide unit, two transects were positioned at one-half and one channel width upstream from the riffle crest. On each transect, one sample was collected in the middle of the wetted channel with the other two sample locations spaced at a distance of one-third channel width from the center sample on both the right and left sides of the channel. Refusal depth approximates the channel bed elevation during a large flood (i.e., scour depth) and indicates the fine sediment supply (Pavlowsky et al., 2017; Jordan, 2019).

Bank Erosion Index: The channel bed and both right and left banks were assessed at intervals of approximately every 5-7 channel widths typically along pools. The spacing of sampling sites averaged 344 m on the Big Piney River, 373 m on the Roubidoux Creek-upper segment, and 344 m on the Roubidoux Creek-lower segment. Data collection included bank height, water depth, bed substrate, and qualitative bank evaluations (Pavlowsky and Martin, 2009). Qualitative data were included to evaluate bank stability for approximately one river width of bank line on the right and left sides at each site. This evaluation included the percentage of the bank consisting of fine grain material, protection from bars and/or roots, and percent of bank eroded, slumped, stable or artificial.

Results

Channel Width and Disturbance Zones

Landform analysis using aerial photographs was used to assess the downstream variations in channel width during the 20-year study period from 1995 to 2015. Average channel width for the

Big Piney River increased slightly (3%) during the study period from 76 m in 1995 to 78 m in 2015. Channel width along the river at 500 m intervals generally ranged from 50 to 60 m (Figure 2). However, channel width increased by more than two-times within three reaches from

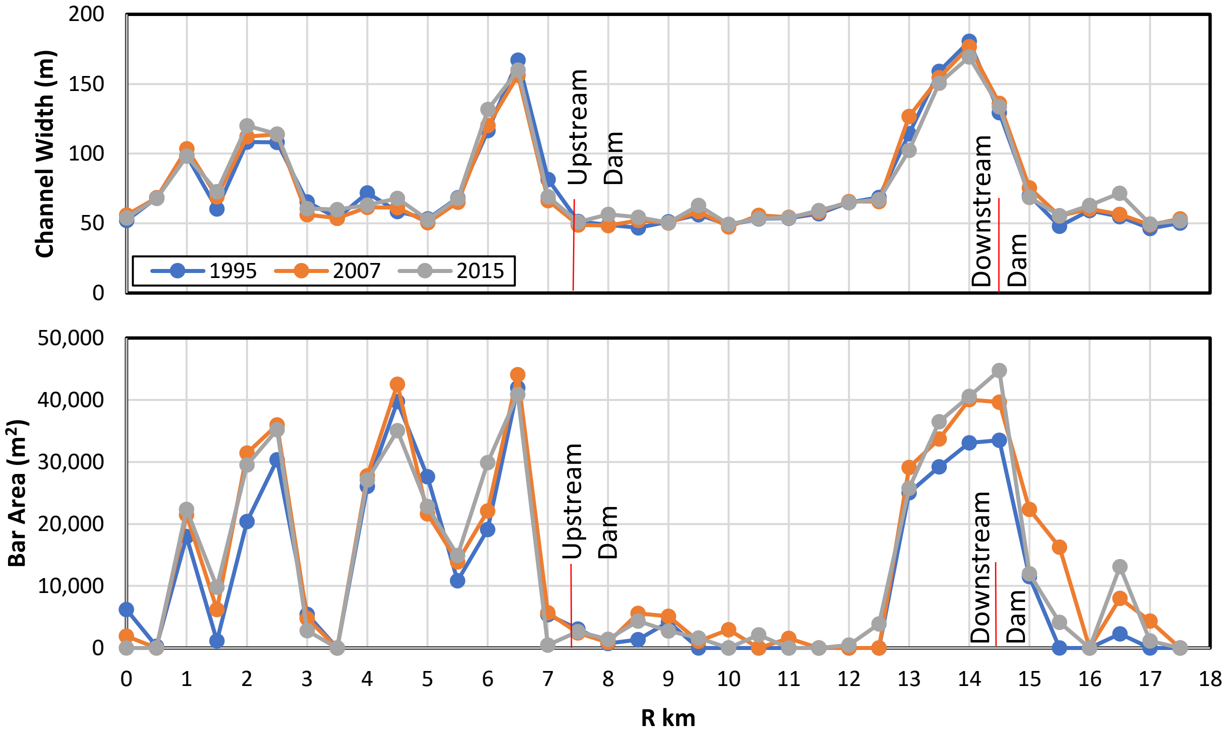

Figure 2. Channel width and bar area on the Big Piney River.

R-km 0.5-2.5, 5.5-7, and 12.5-14.5. The increase in channel width in the most upstream reach was associated with the occurrence of two disturbance zones at R-km 1 and 2.05. However, increases in channel width to greater than 160 m occurred at locations about 0.5-1 km above two dams probably due to higher pool elevations, wider floodplains prior to dam construction, and channel widening caused by aggradation of sand and gravel in the impoundment (Figure 2). The lack of significant changes in channel width above the two dams during the study period suggests that channel form had already adjusted to flow changes caused by dam construction prior to 1995. Channel widening by over 10 m since 1995 has occurred in association with the disturbance zone at 2.05 km.

Average channel width for the upper segment of Roubidoux Creek increased (9%) during the study period from 45 m in 1995 to 49 m in 2015. Reach to reach variations in channel width were greater in this segment compared to the Big Piney River (Figures 2 & 3). Channel width per 500 m sub-reach in Roubidoux Creek generally ranged from 30 to 60 m in the relatively narrow valley upstream of R-km 10 and then increased downstream to 40 to 80 m (Figure 3). There were three reaches containing disturbance zones where channel width increased by more than 1.3-times the regular trend at R-km 10.5-11, 13.5-14.5, and 16.5-17.5 (Figure 3). Obvious locations of increased channel width include R-km 7-8, 13.5-15, and 16.5-17.5 with the two downstream sites being associated with disturbance zones.

Overall channel width for the lower segment of Roubidoux Creek did not change much during the study period with average values of 52 m in 1995, 49 m in 2007, and 53 m in 2015. Channel width generally ranged from 40 to 60 m upstream of R-km 50 and 35 to 45 m below (Figure 4).

This is interesting since aerial photographs and hydrological studies indicate that perennial flow starts again near R-km 49-50 with intermittent flow extending upstream to approximately R-km 25-28 in a karst losing channel that is seasonally dry (Imes et al., 1996). There are two reaches where channel width during the 20-year period increased by approximately 20 m at R-km 40-41 and 48-50 (Figure 4). Channel bed and bar areas at R-km 48-50 have been affected by both channel modifications and construction near the Polla Rd bridge and disturbance zone.

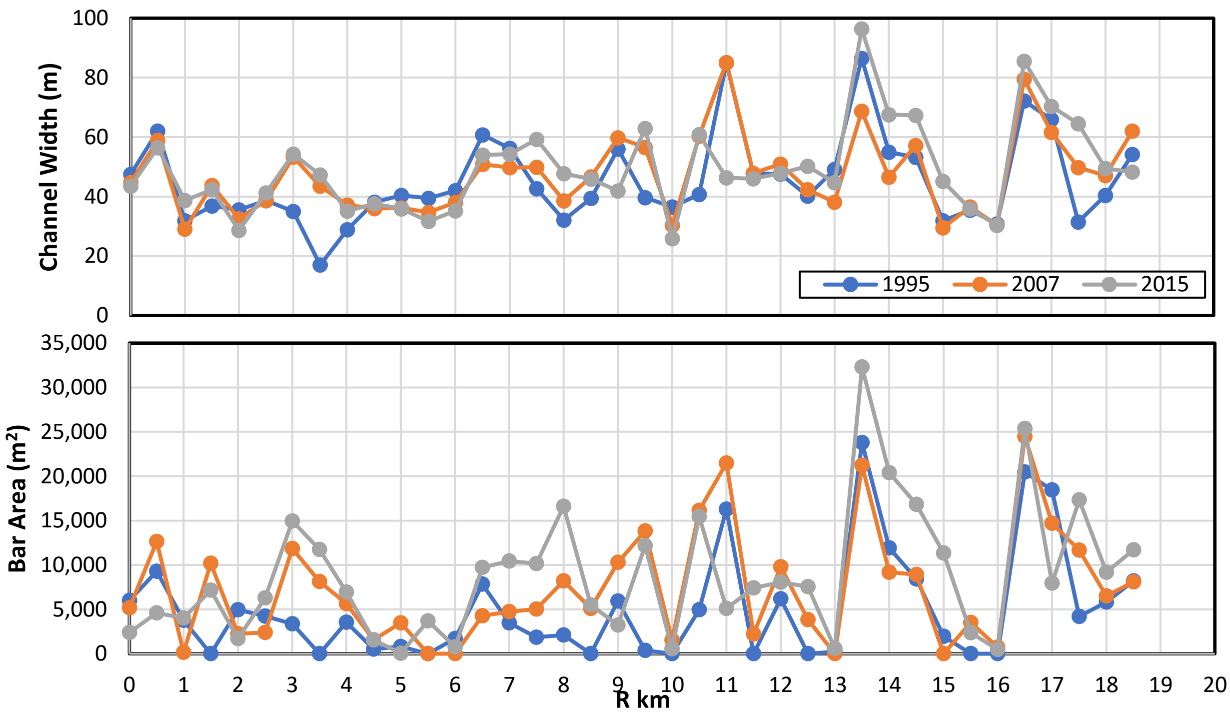

Figure 3. Channel width and bar area on Upper Roubidoux Creek.

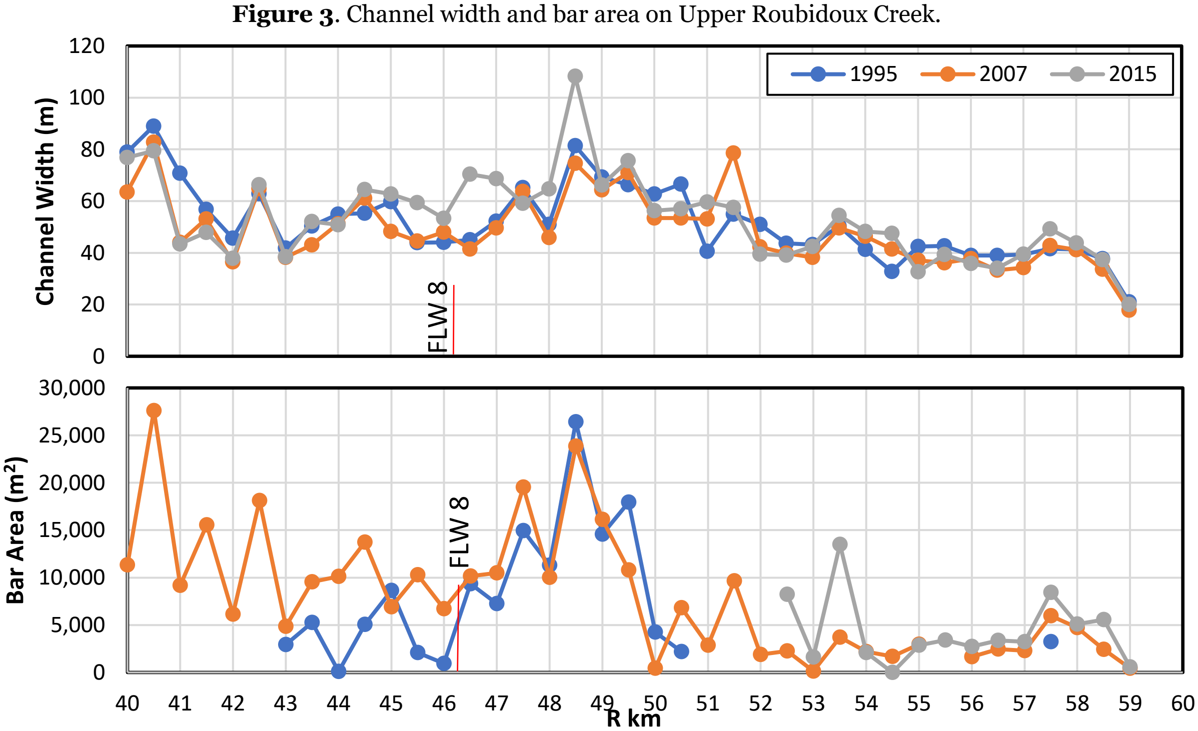

Figure 4. Channel width and bar area on Lower Roubidoux Creek.

Bank Erosion and Bar Area

Longitudinal trends for bank erosion rates along Big Piney River tended to follow width and bar area trends. Wider channels often occur within disturbance zones where unstable flows and erratic deposition of relatively large volumes of sediment can increase secondary (or cross-channel) flow velocities and bank erosion rates. From 2005 to 2015, bank erosion rates generally ranged from 0-0.9 m/yr with 53% of the assessed channel length indicating no bank erosion. However, there is some evidence that the river is responding to an increased flood regime. First, high bank erosion rates (>0.6 m/yr) are occurring along relatively narrow reaches at R-km 3, 3.5, 4.5, 8.5, and 11 (Figure 5). This pattern suggests that stable sections of the river are widening in response to chronic increases in flooding and stream power and not just as the result of local variations in flow conditions and channel instability. Second, the flanking "by-pass" channel that formed along the left side of the lower dam at R-km 14.5 has been getting wider suggesting that more floods are driving channel widening, but it is possible that the flanking channel may still be adjusting to its "new" location in flanking the dam by gradually changing its location, form, and bed substrate as channel bed grade and cross-sectional area recover to pre-dam conditions. Field assessments of bank conditions on the Big Piney were relatively good with 33% stable, 28% root protected, 16% bar protected, and 23% eroding.

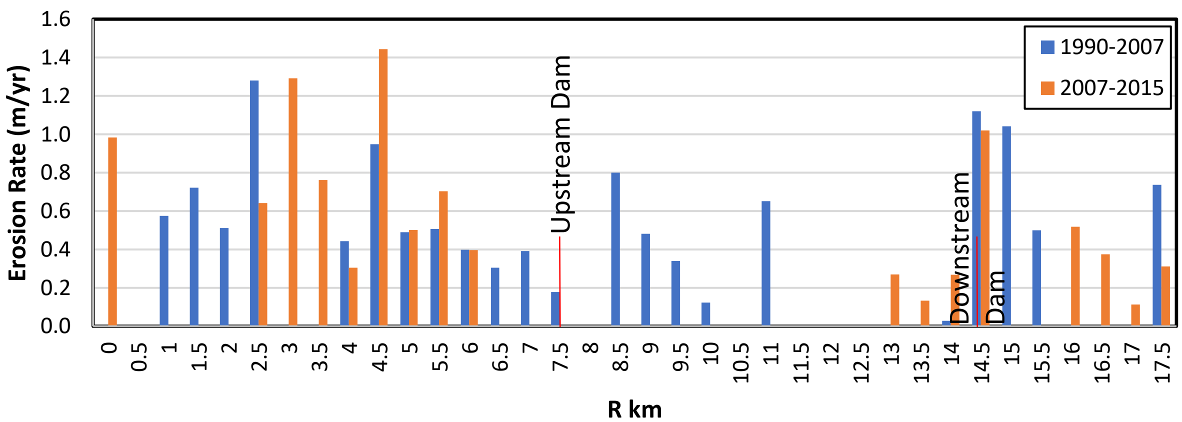

Figure 5. Bank erosion rates on the Big Piney River.

Bank erosion rates along the upper segment of Roubidoux Creek also tended to follow width and bar area trends (Figure 6). Bank erosion rates generally ranged from 0.1-1.4 m/yr with only 3% of the assessed channel length indicating no bank erosion from 2005 to 2015. Bank erosion rates upstream of R-km 9 near the confluence of Musgrave Hollow are usually low with just a few sites indicating erosion rates >0.6 m/yr during the earlier period from 1990-2007 (Figure 6). In this segment, valley widths are relatively narrow and bedrock control may be limiting channel migration rates. Below R-km 9, bank erosion rates generally increase to >0.6 m/yr and the frequency of disturbance zones also increases. Field assessments of bank conditions found that banks were rated as stable due to the proximity of resistance of rock outcrops. However, banks had slightly more eroded and slumped areas (30%) than in the Big Piney (21%).

In the lower segment of Roubidoux Creek, bank erosion rates did not follow channel width and bar area trends as well as in the other segments (Figure 7). Bank erosion rates generally range from 0-2.1 m/yr with only 38% of the assessed channel length indicating no bank erosion from 2005 to 2015. Relatively high rates of bank erosion (>1 m/yr) were indicated between R-km 43.5 and 51.5 where disturbance zones occur along >50% of the channel length near the lower end of intermittent flow above and below the FLW8 low water bridge including the elevated bridge at Polla Road. In addition, relatively high rates of bank erosion (>0.6 m/yr) were found downstream of the FLW boundary between R-km 55 and 58.5 (Figure 7). While the sample size of field assessments was relatively low, the lower segment of Roubidoux Creek contained the highest percentage of bank length in poorest condition with very few stable banks (8%) and many banks where potentially mobile gravel bars provided toe protection (38%).

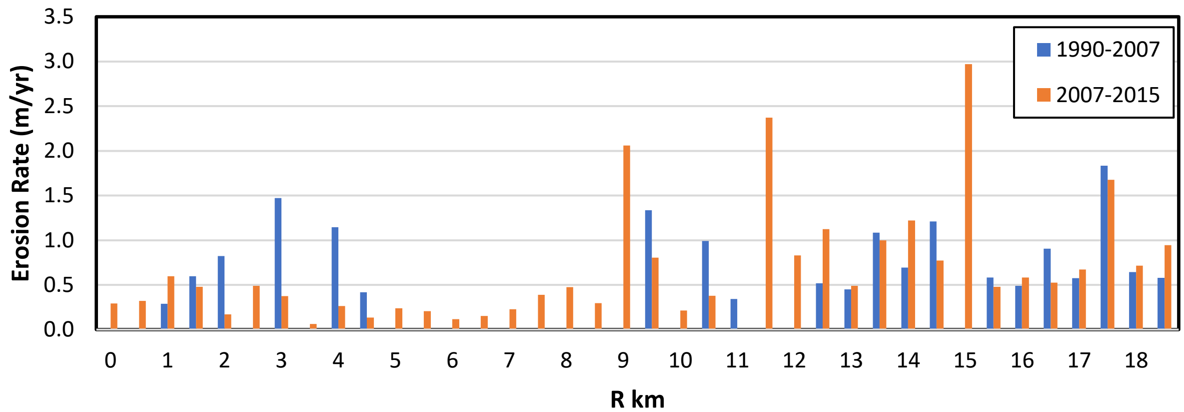

Figure 6. Bank erosion rates on Upper Roubidoux Creek.

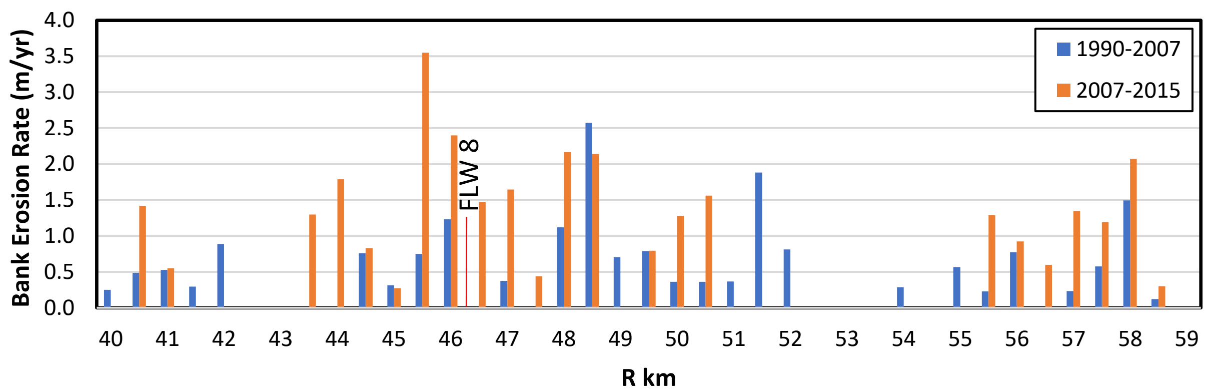

Figure 7. Bank erosion rates on Lower Roubidoux Creek.

Fine Sedimentation

Glide channel units typically were 20-50 m in channel length and covered areas ranging from 450 to 2,400 m^2 in Big Piney River and 200 to 1,200 m^2 in Roubidoux Creek (Table 1). The median of the mean probe depth values decreased by segment in the order: 45 cm in Upper Roubidoux Creek; 28 cm in Lower Roubidoux Creek; and 25 cm in Big Piney River. In Big Piney River, the location of highest glide sediment storage was 2,800 m^3 below the southern FLW boundary (R km 0.8) located above a disturbance zone and just below a tributary confluence where excess sediment deposition would be expected. Disturbance zones and stable reaches had similar average probe depths 0.33 m and 0.35 m, respectively. However average sediment storage volume was three times greater in stable reaches than in active reaches. In the upper segment of Roubidoux Creek, probe depths in the glides were greater in disturbance reaches, but again sediment storage volumes were higher in stable reaches. In the lower segment of Roubidoux Creek, both average probe depth and sediment storage in glides were about two-times higher within disturbance zones compared to stable reaches.

The fine sediment assessed in this study was composed mostly of sand, with some silt and fine gravel. Accumulations of muddy or silt-clay deposits in the channel were not common and only occurred locally in a few cases. Field observations suggested that much of the fine sediment was

Table 1. Glide sediment storage.

Big Piney River				Upper Roubidoux Creek				Lower Roubidoux Creek			
R km	Glide Area (m^2)	Mean Probe Depth (m)	Sediment Storage (m^3)	R km	Glide Area (m^2)	Mean Probe Depth (m)	Sediment Storage (m^3)	R km	Glide Area (m^2)	Mean Probe Depth (m)	Sediment Storage (m^3)
0.8	2400	1.17	2800	4.08	300	0.45	135	41.59	900	0.26	236
2.23	1000	0.44	443	5.75	300	0.48	144	41.95	500	0.08	39
4.6	600	0.28	167	6.65	200	0.77	154	43.2	500	0.15	73
6.62		0.21		8.2		0.41		43.55	300	0.24	73
8.15	1200	0	0	9.5	1200	0.26	314	43.85	600	0.33	200
8.95	1500	0.16	235	10.6	200	0.2	39	45.32	600	0.63	380
11.1	1200	0.21	250	11.45	300	0.66	197	46.41	500	0.13	64
13.4	450	0.36	161	13.6	300	0.28	84	47.39	900	0.86	771
14.8	800	0.25	199	14.95	300	0.74	221	48.17	900	0.61	552
				16	900	0.42	381	48.59	400	0.29	114
				17	225	0.54	122				

coming from bank erosion on the main channel or tributaries since erosion rates were high and the color and texture of the glide sediment was similar to upstream bank sources. This preliminary survey of fine sediment depths and volumes in glides indicates that fine sediment is available to degrade physical habitat and that significant deposition occurs upstream of riffles in glide units, probably during the falling limb of floods as turbulence wains and riffle crest begin to impound channel flows. However, it is not known to what degree these fine sediment deposits may be affecting mussel habitat.

Implications for Mussels

Both Big Piney River and Roubidoux Creek show evidence of geomorphic disturbances that can degrade physical habitat. Bank erosion trends indicate relatively high rates of lateral channel migration and planform change along some segments. High bank erosion rates are associated with channel instability, bed sediment reworking, and fine sediment inputs and embeddedness in Big Piney River and Roubidoux Creek. Thus, the average bank erosion rate per cell was used as a proxy for unstable geomorphic activity that can degrade mussel habitat. The most recent period (2007-2015) assessed bank erosion rates was used to develop a channel instability classification scheme based on three levels of erosion rates. Bank erosion rates >0.6 m/yr were reported to reduce mussel presence in Ozark streams (Key et al., 2021). Therefore, channel cells with bank erosion rates >0.6 m/yr were classified as high risk to mussels. Moderate risk cells were classified according to erosion rates between 0.1 and 0.5 m/yr, with low-risk cells having bank erosion rates at <0.1 m/yr. (Table 2).

In general, mussel density values were 5-10 times higher for Big Piney Creek compared to Roubidoux Creek. But in contrast to Big Piney Creek, disturbance zones contained higher mussel densities than stable reaches in Roubidoux Creek. Average mussel densities were 2.4 #/km for stable reaches and 4.9 #/km for disturbance zones. However, 19 of the 20 mussels recovered from disturbance zones in 2012 came from just one relatively stable location in a straight and narrow valley with moderate bank erosion rates at R-km 6.5-7.25. Further, while there are nine disturbance zones mapped in the upper segment of Roubidoux Creek, only two samples were in disturbance zones. Mussel density relationships with bank erosion rates were also affected by low sampling rates. Average mussel density by decreasing bank erosion risk was as follows: high risk, 0 #/km; moderate risk, 4 #/km, and low risk, 1 #/km (Table 2). The use of this classification scheme to predict mussel density and understand channel habitat distribution is preliminary. But in the Big Piney River where sample size and distribution among the geomorphic classes were good, relatively strong relationships between increased channel stability and higher mussel densities were indicated. In both survey years, mussel densities were greatest in the low bank erosion class (7.9 – 25.9 #/km) and lowest in the high bank erosion class (0 - 6 #/km).

Table 2. Mussel density by geomorphic condition.

		Survey (km)		Live Mussels (#)		Density (#/km)	
	Reach Class	2012	2016	2012	2016	2012	2016
Upper Roubidoux Creek	Disturbance Zone	2.2	4.4	20	3	9.1	0.7
	Stable Segment	2.3	4.1	11	0	4.8	0
	High Bank Erosion	*	2	*	0	*	0
	Moderate Bank Erosion	4	6	30	3	7.5	0.5
	Low Bank Erosion	0.5	0.5	1	0	2	0
Big Piney River	Disturbance Zone	3.8	3.8	1	0	0.3	0
	Stable Segment	10.7	10.7	394	84	36.9	7.9
	High Bank Erosion	3	3	18	0	6.0	0
	Moderate Bank Erosion	3	3	157	17	52.3	5.7
	Low Bank Erosion	8.5	8.5	220	67	25.9	7.9

* Not Surveyed

Conclusions

Increased geomorphic activity due to increases in flood magnitudes and frequency in the Ozarks are the variables found to be most important concerning mussel habitat degradation in the upper segment on Roubidoux Creek (55% in disturbance zones) and Big Piney River (29% in disturbance zones) (Foreman, 2014; Pavlowsky et al., 2016; Heimann et al., 2018). Karst effects (losing stream segments and intermittent flow) are the limiting factor for mussel habitats on Lower Roubidoux Creek within FLW. However, disturbance zones in Lower Roubidoux Creek comprise 58% of the length in the study area, so channel instability is also a problem there.

Changes in stream geomorphology have been identified as a threat to mussel populations in Missouri watersheds (Hinck et al., 2011, 2012). In this study, relatively large changes in channel form occurred in reaches where mussel populations declined over the past two decades. In Big Piney River, stable reaches with consistent widths, low rates of bed and bar area change, and low bank erosion rates contained higher numbers of mussels. However, channel activity on Upper Roubidoux Creek was more variable and mussels were found in less abundance in both 2012 and 2017 surveys compared to the Big Piney River. High bank erosion rates >0.6 m/yr have been shown to be associated with a reduction of mussel presence in Ozark rivers (Key et al., 2021). In this study, mussels tended to be found in greater abundance in stable reaches with low to moderate bank erosion rates (<0.6 m/yr).

Fine sediment deposition can cover mussel beds and form unstable bed substrates in which mussel beds can be disturbed during high flow events (Wood and Armitage, 1997; Box and Mossa, 1999; McRae et al., 2004; Allen and Vaughn, 2010; Leitner et al., 2015). Excessive sediment deposition has been identified as a threat to mussel populations in other Missouri watersheds (Hinck et al., 2011, 2012). While there were sampling limitations for the analysis of physical habitat and mussel density presented in this report, reaches with greater depths of fine sediment deposition in glide channel units were generally associated with channel instability and reduced mussel populations. On the Big Piney River, reaches with the greatest number of mussels in 2016 had an average glide sediment depth of 0.15 m, while reaches with fewer mussels had greater sediment depths (>0.3 m). On the upper segment of Roubidoux Creek, sediment depths were also positively correlated with channel instability and mussel population decline, but only one reach contained mussels in the 2017 survey.

In conclusion, both Big Piney River and Roubidoux Creek on Fort Leonard Wood have been affected by a long history of land use effects including historical settlement and land-clearing, urban development, dam and crossing construction, and now, increased flooding due to climate change. It is possible that the more energetic flood regime is driving some of the recent channel adjustments observed such as bank erosion, channel widening, and fine sediment deposition that can degrade mussel habitat. Overall, Big Piney River can be considered geomorphologically stable in most reaches, possibly due to gradient control effects of the two dams that limit stream power. On the other hand, Roubidoux Creek is in poorer geomorphic condition and indicates unstable banks and beds in many reaches. Valley width is relatively narrow in the upper segment which may enhance stream power during floods. Seasonal drying of the channel and bridge crossings in the lower segment may have also degraded channel stability. A preliminary analysis indicates that freshwater mussel beds appear to remain viable in more stable channel reaches. More study is needed to identify the specific factors causing channel instability and the relationship of channel habitat condition to freshwater mussel density.

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