INTEGRATION AND INTERPRETATION OF RECENT YELLOWSTONE RIVER FISH RESEARCH

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by

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Executive summary

I reviewed recent studies conducted on the Yellowstone River to address anthropogenic factors that influence the river's fish assemblages. The primary anthropogenic factors from these reports include hydrographic alteration, altered connectivity, bank stabilization, the importance of and changes in the availability of side channels, and introduced species. Hydrographic alteration caused by water withdrawals, damming of tributaries, and climate change have caused declines in annual average discharge, annual peak discharge, minimum discharge, and earlier baseflow conditions. Altered tributary hydrology also affects connectivity, geomorphology, habitat, and life histories of main-stem fishes.

The natural hydrograph is often considered the "master variable" that most strongly influences riverine ecosystems, and aquatic species have evolved life history strategies primarily in direct response to the natural flow regime. Hydrographic changes may cause changes in fish populations by altering habitat, temperatures, water chemistry, nutrient dynamics, energy flow, and sediment delivery. These anthropogenic changes are altering the evolutionary relationships between the hydrograph and fish behavior, perhaps most critically for spawning and early life history. Human dimensions are fundamental drivers of altered hydrology. For example, Yellowstone River water rights are over allocated by up to 118 times the mean annual discharge. Given the vagaries and evolving nature of the legal and political landscape surrounding Montana water rights, the actual degree of future dewatering and effects on fishes are difficult to predict. Also, the majority of irrigation water withdrawal structures are not screened and the magnitude of fish loss by entrainment is not known.

Connectivity in riverine ecosystems occurs on four dimensions: longitudinal (upstream-downstream), lateral (river channel-floodplain), vertical (river channel-groundwater), and temporal (time, from behavioral response time to evolutionary time). Connectivity, both longitudinal, and between the main stem and tributaries is a fundamental element in the life history of riverine fish. The Yellowstone River is longitudinally fragmented by six diversion dams, and the individual and cumulative effects on fish passage is unknown, although each dam allows some upstream fish passage during certain conditions. Main-stem to tributary connectivity is pervasive and probably critical ecologically; nearly three-quarters of abundant forage species such as Western Silvery Minnow and Flathead Chub use both main-stem and tributary habitats during their life histories. Moreover, removal of fish passage barriers on tributary streams has been demonstrated to result in changes in tributary fish assemblages.

Bank stabilization can alter main-channel habitat by providing novel habitat (i.e., large boulder substrate), causing channel bed degradation, channel width reduction, and increased stream gradient. Moreover, bank stabilization alters lateral habitats by reducing lateral connectivity and channel migration, thereby reducing the formation and maintenance of backwaters, braids, and side channels.

On the upper Yellowstone River, riprap-stabilized banks were used by juvenile salmonids, probably because the riprap provided cover that was lacking along natural banks. However, lateral habitats such as side channels and backwaters were also heavily used by juvenile salmonids, and bank stabilization may reduce the availability of such habitats.

Shallow, slow current velocity (SSCV) habitats are important for fishes, particularly larval, juvenile, and small fishes. However, bank stabilization decreases lateral connectivity, thereby reducing the overall amount of side channel and overbank SSCV area.

The loss in side channels exceeded the gain in side channels from the 1950s to 2001. Sixty-seven side channels were lost, 39 side channels were gained, which represented a 10.4% net loss in side channel area from the 1950s to 2001. Loss of side channels probably has negative consequences for Yellowstone River fish because side channels are important habitat for fish in the Yellowstone River during runoff, side channel availability influences main channel fish assemblages at scales of up to 3 km upstream and downstream, and bank stabilization and side channels were often associated with shifts in the identity and abundance of the fish assemblages in different or opposite directions. This suggests that bank stabilization has caused the fish assemblages to change from the pre-stabilization condition, and that side channels influence fish assemblages to remain more similar to the pre-stabilization condition. Stabilized alluvial pools were significantly deeper than their non-stabilized counterparts whereas depths were similar at stabilized and reference bluff sites probably because lateral channel migration and scour are in relative equilibrium at naturally erosion-resistant bluff pools. Therefore, a potential mechanism whereby bank stabilization influences fish assemblages is by creating deeper pools at stabilized alluvial river bends.

Catch rates for Sand Shiners and Flathead Chubs in some non-stabilized river bend types suggest that bank stabilization may reduce local Sand Shiners and Flathead Chub abundance. Spiny Softshells avoided stabilized alluvial pools, but Burbot preferred riprapped alluvial pools and bluff pools, probably because Burbot commonly prefer large substrates.

Ecological theory and field studies suggest that side channels are crucial habitats for fish, amphibians, reptiles, birds, and other riverine animals because of the habitat heterogeneity they provide. Side channels provided important habitat for the Yellowstone River shoreline fish assemblage during runoff. Overall fish catch rates, catch rates of the most common species (Western Silvery Minnow, Longnose Dace, Flathead Chub, and Emerald Shiner), and species richness were generally greater in side channels than main channels during early and late runoff. Overall fish catch rates were up to nine time higher relative to main channel catch rates. Fish assemblage structure also differed between side channels and main channels during runoff, but not during baseflow. Differences in fish variables was probably due to SSCV patch size which was larger in side channels, rather than physical habitat parameters at fish capture locations which were similar. This conclusion is supported by modeling results that indicate that during runoff, SSCV is limited and that it is primarily found in side channels.

Both bank stabilization and side channels influenced Yellowstone River fish assemblages, and bank stabilization and side channels were often associated with shifts in fish assemblages in different or opposite directions. This suggests that bank stabilization has caused the fish assemblages to change from the pre-stabilization condition, and that side channels influence fish assemblages to remain more similar to the pre-stabilization condition. Moreover, these changes were best explained by measuring bank stabilization and side channels at coarse spatial scales (i.e., up to 3 kilometers both up and downstream of sampling locations). A potential mechanism whereby bank stabilization influences fish assemblages is by creating deeper pools at stabilized alluvial river bends.

Anthropogenic bank modifications increase lateral river confinement, decrease side channel and overbank SSCV area, thereby reducing the overall amount of SSCV habitat availability. Juvenile salmonids, especially Mountain Whitefish, rapidly occupied side channels upon inundation, suggesting that when available, side channels are important habitats for juvenile salmonids. Habitat modifications that reduce the frequency or duration of side-channel inundation, or reduce side channel formation rates, would probably decrease juvenile salmonid habitat and possibly recruitment.

Spiny Softshell turtles in the Yellowstone River preferred secondary channels in all seasons except winter, when they preferred bluff pools. This pattern is generally concordant with habitat use in the Missouri river in Montana where Spiny Softshells used shallow, slow, lateral habitats such as inundated tributary mouths and floodplains during all seasons but winter.

The Yellowstone River is a stronghold of native fish diversity. There are 56 fish species total of which 20 species (36%) are nonnative. However, in terms of abundance, most nonnative fish are rare. The high abundances of native species and low proportion of nonnative species relative to other large rivers such as the Missouri River also indicate that the lower Yellowstone River maintains productive and diverse native fish assemblages. An exception is Rainbow Trout and Brown Trout in the salmonid zone of the river. Rainbow Trout can hybridize with native Yellowstone Cutthroat Trout, but this hybridization is reduced because Rainbow Trout and hybrids spawn earlier than Yellowstone Cutthroat Trout. Brown Trout are predaceous, and consume native fishes, but the effect of the presence of Brown Trout on the native fish populations has not been quantified.

Smallmouth Bass are rare to abundant in the lower two fish zones. Other nonnative fish species with potential to influence native fish assemblages include Common Carp, Northern Pike, White Bass, Rock Bass, Green Sunfish, and Walleye. Walleye can hybridize with native

Sauger but hybridization are apparently very low (<3%). Other nonnative fishes prey on and may compete with native fishes, but their effect on the ecosystem has not been quantified.

Introduction

The Yellowstone River is the longest unimpounded river in the conterminous United States, and as such is a rare model of the structure and function of a large western river ecosystem (White and Bramblett 1999). Nonetheless, a variety of anthropogenic factors influence the river's fauna. The Yellowstone River's natural snowmelt-driven hydrograph has been altered (Watson 2014), it's longitudinal (Helfrich et al. 1999), lateral (Reinhold et al. 2014), and main stem to tributary (Duncan et al. 2012) connectivity has been altered (Schilz 2012), a variety of structures such as bank revetments (i.e., riprap), flow deflection structures (i.e., barbs, jetties, spur dikes), and flow confinement structures (i.e., levees, berms, dikes) have been installed along the banks and in the floodplain (Zale and Rider 2003; Bowen et al. 2003a; 2003b; Reinhold et al. 2014), and several nonnative fish species are present (White and Bramblett 1999).

A number of recent studies have been conducted that have inference regarding the influence of these anthropogenic factors on the fish assemblage on the Yellowstone River. These studies include published scientific papers, unpublished reports, and a Master's thesis.

The objectives of this report were to:

1. Summarize, interpret, and integrate the conclusions regarding anthropogenic effects on the fish assemblage from several recent research projects (Helfrich et al. 1999, Bowen et al. 2003a, 2003b, Zale and Rider 2003, Jaeger et al. 2008, Duncan et al. 2012, Reinhold et al. 2014, Watson 2014) in support of the Yellowstone River Conservation District Council (YSRCDC) Technical Advisory Committee (TAC) Cumulative Effects Analysis (CEA).
2. Identify and report on other relevant and feasible spatial fisheries information to the TAC for consideration and scoping for inclusion into the reach narratives.
3. Identify information from the reports regarding potential best management practices (BMPs) as it relates to the Yellowstone River fish assemblages.

Methods

I summarized the reports into the following format: Title, Authors, Affiliations, Date published, Abstract, Introduction, Study area, Goal, Objectives, Methods, Results, and Discussion. I edited all of the manuscripts into a shorter, more concise format by removing literature citations, tables and figures, scientific names, and statistical jargon, while attempting to retain meaning by condensing written material. Although most of the remaining text in the condensed versions presented here is in author's own words, I am responsible for any changes in meaning associated with my edits. My intention was to provide an abridged version of the manuscripts in this report for quick and handy reference. Those seeking more detail should refer to the original manuscripts, pdfs of which are provided to the TAC here as part of my final report.

Following my review and summarization of the manuscripts, I added my interpretation regarding the following topics for each individual manuscript: Conclusions on anthropogenic effects on fish, Implications for BMPs, and Spatial fisheries information. I then integrated the conclusions regarding anthropogenic effects on the fish assemblage from all of the manuscripts collectively as well as in the context of the larger scientific literature and summarized the inferences from all the manuscripts regarding best management practices. Some of the written content in this report comes from previous reports on which I was a coauthor, therefore I acknowledge my coauthors Ann Marie Reinhold, Mike Duncan, and Al Zale.

Results and discussion

Rivers are perhaps the most highly threatened ecosystems globally because of their long history of human uses including water supply, irrigation, generation of electricity, and waste disposal (Malmqvist and Rundle 2002). Ultimate anthropogenic forcing factors for riverine ecosystems are ecosystem destruction (urban and agricultural expansion, water abstraction), habitat alteration (hydrological alterations, siltation, riparian alterations), water chemistry alterations (from industrial, agricultural, mining, and urbanization), and species addition and removal (Malmqvist and Rundle 2002).

My review of the eight manuscripts revealed five general topic areas that have inference with regard to anthropogenic effects on the fish assemblage. These topic areas were hydrographic alteration, altered connectivity, bank stabilization, the importance of and changes in the availability of side channels, and introduced species. My summary presented below uses these topic areas as a conceptual framework.

Hydrographic alteration

Watson (2014) assessed long term (1898-2007) and recent (1970-2007) trends in the hydrographs of the Yellowstone River and its tributaries using data from 18 USGS Hydro-Climatic Data Network Stations. Data were generally available for these stations for the period from 1898 to 2007 (Watson 2014).

Watson (2014) evaluated seven null hypotheses regarding trends in the following variables: average annual discharge, peak discharge, minimum discharge, average monthly discharges, center-time discharge (the date of the water year when half of the flow has passed the gauging station), date of maximum daily mean flow, and the date when flows return to baseflow conditions. The null hypotheses were evaluated for two temporal periods: the historic period (i.e., over the entire period of record) and the recent period (i.e., from 1970 to 2007). The results of his statistical analyses yield inference on the direction and statistical significance of temporal hydrological trends; however, they do not produce estimates of the actual magnitude of change in these variables or definitive ascribe causes to any trends. Watson (2014) also reviewed the physical and political water-related history in the Yellowstone River basin, inventoried all 2008 water rights for the basin, evaluated trends in irrigated agriculture development in the basin over the time period 1946 to 2008, inventoried and quantified all known consumptive withdrawals from the Yellowstone River and its tributaries in 2006 using information from municipal, industrial, irrigation agriculture and livestock sources, and conducted a physical inventory of surface water withdrawals to estimate the number of main-stem surface water users.

Annual average discharge declined significantly at 9 stations on the Shields, Boulder, Bighorn, Tongue, and Powder rivers, and on the Yellowstone River at Sidney during the historic period. Annual average discharge declined significantly at 15 stations during the recent period, including those listed above as well as the Clarks Fork Yellowstone, and the Yellowstone River at Livingston, Billings, Miles City, and Sidney (Watson 2014).

Annual peak discharge declined significantly at nine stations during the historic period, including stations on the Boulder, Bighorn, Tongue, and Powder rivers, and on the Yellowstone River at Miles City and Sidney. During the recent period, annual peak discharge declined significantly at five stations on the Boulder, Stillwater, Bighorn, Tongue, and Powder rivers (Watson 2014).

Minimum discharge declined significantly at six stations on the Shields, Boulder, Clarks Fork Yellowstone, and Tongue rivers, and increased significantly at five stations on the Bighorn, and Powder rivers, and on the Yellowstone River at Miles City during the historic period. During the recent period, minimum discharge declined significantly at nine stations on the Boulder, Clarks Fork Yellowstone, Bighorn, Tongue, and Powder rivers, and on the Yellowstone River at Sidney (Watson 2014).

Monthly discharges changed similarly throughout the basin by season regardless of river, with only a few deviations. The majority of the 18 sites on the 8 rivers experienced declines during late spring, summer, and early fall months (May-October), while showing increases in monthly discharges during the other months (Watson 2014).

Center-time discharge was significantly earlier at two stations during the historic period, and at three stations for the recent period. Most stations had earlier runoff. Annual peak discharge was significantly earlier at Livingston over the historic period and significantly earlier at Livingston and the Clarks Fork of the Yellowstone over the recent period (Watson 2014).

Baseflow conditions occurred significantly earlier in the year at stations on the Boulder, Stillwater, Clarks Fork Yellowstone, and Powder rivers during the historic period, and at all of these stations as well as at Livingston and Billings on the Yellowstone River and on the Bighorn and Tongue rivers during the recent period (Watson 2014).

Yellowstone River water rights are over allocated by up to 118 times the mean annual discharge (Watson 2014). Taken at face value, this suggests that the Yellowstone River could be severely dewatered in the future, leading to catastrophic effects on fish populations. However, given the vagaries and evolving nature of the legal and political landscape surrounding Montana water rights, the actual degree of future dewatering and effects on fishes are difficult to predict. Even so, alterations of the annual hydrograph from conditions under which native fish evolved has potentially profound consequences for fish assemblages.

A physical inventory of pumps and diversion structures indicated that only 16% of 687 irrigation withdrawal structures were screened to prevent fish entrainment. Therefore, fish entrainment is probably a considerable source of mortality for Yellowstone River fishes. For example, prior to screening, fish entrainment at the Intake Diversion Canal included 25 native fish species and involved an estimated 382,609 to 809,820 individual fish during an annual irrigation season (Hiebert et al. 2000). Moreover, elimination of entrainment at all diversion dams would reduce adult Sauger mortality by an estimated 24-30%, and reduce juvenile Sauger mortality even more because juveniles experience higher entrainment rates than adults (Jaeger et al. 2005).

In summary, Watson (2014) reports that trends toward reductions in volume of discharge, magnitude of annual peak and minimum flows, and spring, summer, and fall monthly average flows have occurred in the Yellowstone River basin, with more pronounced changes since 1970. Timing of discharge has shifted to the majority of volume earlier in the year, and an earlier return to baseflow was strongly indicated. Declines in magnitude and volume of discharge have occurred in the main-stem Yellowstone from Livingston to Sidney, and in the major tributaries. Yellowstone River water is severely over allocated, and the majority of irrigation diversion and pumps are not screened to prevent entrainment of fish.

The magnitude of flow reductions and temporal changes in the hydrograph are not identified in Watson (2014), the causes of these changes are not known with certainty, and the thresholds of hydrological change required to alter fish assemblages are not well understood (Poff et al. 2010). Potential causes of altered hydrology include damming of Yellowstone River tributaries (particularly the Yellowtail Dam on the Bighorn River which began filling Bighorn Lake in 1965), withdrawals of surface and ground water (Watson 2014), and climate change. These changes to the hydrology of the Yellowstone River basin may influence the fish assemblages. A river's hydrograph is often considered the "master variable" that most strongly influences riverine ecosystems (Poff et al. 1997; Bunn and Arthington 2002; Poff et al. 2010). Important mechanisms link hydrology to aquatic biodiversity; flow is a major determinant of physical habitat, aquatic species have evolved life history strategies primarily in direct response to the natural flow regime, flow-dependent longitudinal and lateral connectivity supports populations of riverine species, and the invasion and success of introduced species is often facilitated by altered flow regimes (Bunn and Arthington 2002). As such, changes in the Yellowstone River's annual hydrograph are potentially of profound concern. However, the relationship between statistically significant temporal trends in hydrological variables and the abundance and distribution of fish remains unknown and difficult to predict.

Reductions in flows would reduce the amount of aquatic habitat, potentially bringing fish into closer proximity, thereby increasing the rates of ecological interactions such as predation, competition, and transmission of disease or parasites. Reduction in flows will reduce river stage which could affect the availability of and suitability of fish habitats. For example, habitats that are at higher elevations, such as seasonally inundated side channels and floodplain habitats could be dewatered, thereby reducing the availability of important shallow, slow current velocity habitats, and reducing energy transmission between terrestrial and aquatic ecosystems.

Reductions in flows may cause warmer water temperatures, which may have a number of influences on the fish assemblage. For example, fish distributions may shift upstream as species seek their preferred temperatures. However, although thermal regimes may shift longitudinally, other components of the ecosystem such as channel slope, riverbed substrate, position of spawning tributaries, and fragmentation structures such as diversion dams will not, and may preclude simple shifts in the longitudinal distributions of Yellowstone River fish in response to temperature. Warmer water contains less oxygen, which although rarely limiting in rivers, may affect fish distributions. Altered thermal regimes may change ecosystem productivity and lead to altered food webs. Reduced flow volumes will concentrate pollutants and may thereby affect fish. Angling mortality for salmonids generally increased with water temperatures above 20° C (Boyd et al. 2010). Perhaps most importantly, reductions in flows may increase the anthropogenic demands for water and thereby lead to further reductions in flow.

Altered timing of peak runoff will probably concomitantly alter the relationship between fish reproduction and hydrology. Hydrologic spawning cues may be disrupted or shifted temporally, with uncertain consequences for survival of fish early life history stages. Earlier onset of baseflow could also alter the relationships between reproduction, growth, temperature, habitat, and bioenergetics under which the Yellowstone River fish assemblage evolved. Altered synchronicity between riverine ecosystem processes and fish life-history stages may result in changes in fish species distribution and abundance.

Reductions in tributary inflows will probably reduce connectivity between the main stem-Yellowstone River and its tributaries. Connectivity between main-stem rivers and tributaries supports higher fish species richness in both the main-stem river and the tributary. Connectivity on the river segment scale is influenced by dispersal barriers such as intermittently dry reaches, and movements between rivers and tributaries often coincide with hydrological cues such as high water periods. Reduced flow in tributaries may alter cues for fish movement between tributaries and the main stem, reduce tributary habitat volume and quality, and reduce within-tributary movement.

The Shields, Boulder, Clarks Fork Yellowstone, and Stillwater rivers as well as other smaller tributaries are used by trout for spawning (Scott Opitz, MT FWP, personal communication). Introduced Rainbow Trout threaten native Yellowstone Cutthroat Trout by hybridization. Altered hydrology or warming of these and other tributaries may alter their suitability as spawning habitats and affect survival rates of early life history phases. Cutthroat and Rainbow Trout in the Yellowstone River basin use many of the same tributaries for spawning, but hybridization risk is reduced because Rainbow Trout and hybrids spawned in April and May whereas Yellowstone Cutthroat Trout spawned in June and July (DeRito et al. 2010). However, earlier and lower runoff, and potentially warmer temperatures may reduce temporal separation of Rainbow and Cutthroat Trout and lead to higher rates of hybridization. Such a compression of spawning periods has been observed by fish biologists in recent years (Scott Opitz, MT FWP, personal communication).

Changes to the natural hydrograph also occur as a result of damming of main-stem rivers. Bowen et al. (2003b) used two-dimensional hydrodynamic simulation modeling to examine the effects of flow regulation from Fort Peck Dam on the spatiotemporal dynamics of shallow, slow current velocity (SSCV) habitat patches in the unregulated Yellowstone River and the regulated Missouri River in Montana and North Dakota. The Yellowstone River differed from the Missouri river in the following regards: SSCV area was larger, SSCV patch density and size was more dynamic within and between years, SSCV habitat occurred more often in side-channel margins, vegetated islands, and floodplains during runoff and in side channels, bars, and margins of vegetated islands during baseflow, whereas on the Missouri River, spatial distribution of SSCV was more constant and base flow SSCV was found primarily over large sand bars.

The altered spatiotemporal dynamics of SSCV caused by main-stem damming and resultant flow regulation probably have consequences for riverine food webs and fish assemblages. On the Yellowstone River, the dynamics of SSCV and floodplain interaction probably benefit the growth and survival of small fish because native fish species on the Yellowstone River have evolved life history behaviors that match the dynamics of SSCV as a habitat and inundation of the floodplain as an energy source. Small fish may benefit from increased availability of SSCV patches as SSCV patch size increases during recession and base flow. Such habitat diversity and increased SSCV patch size may allow for increased segregation of species and sizes of fish, thereby decreasing potential competition and predation risk. Moreover, nutrients, invertebrates, and organic debris are exported from side channels and inundated floodplain areas (Junk 1989), and probably contribute to the condition, growth, and survival of small fish. In contrast, on the regulated Missouri River, SSCV patches were less dynamic and there was less floodplain interaction because there was little variation in discharge. This potentially results in less nutrient and food export, less SSCV habitat diversity, and less reduction in competition and predation. The contrast in SSCV dynamics between the Yellowstone and Missouri rivers serves as a reasonable basis to predict potential effects of damming and flow regulation on the Yellowstone River because the two rivers were probably comparable prior to the construction of Fort Peck Dam.

Dams on tributaries of the Yellowstone River affect conditions in the main-stem. Although the Yellowstone main stem is unimpounded, 31% of its drainage basin lies upstream of dams (Koch et al. 1977). Dams fragment fish populations by preventing movement and also alter ecological conditions. The serial discontinuity concept (Ward and Stanford 1983) conceptualizes the ecological effects of main-stem dams with regard to their placement along the longitudinal river continuum (Vannote et al. 1980). A dam placed on the lower reaches of a main-stem river is predicted to shift primary production, nutrient levels, turbidity, substrate size, and water temperatures to those found farther upstream on an undammed river (Ward and Stanford 1983). Yellowtail Dam was installed on the lower reaches of the Bighorn River in 1967; this dam transformed a sediment-laden, warm-water prairie river into a blue-ribbon tailwater trout fishery. This transformation in turn affected the Yellowstone River by reducing sediment load, peak discharge, and scouring flows, and causing cooler summer and warmer winter water temperatures as well as preventing long-distance fish movements between Yellowstone and Bighorn rivers. Reductions in sediment inputs can cause channel incision (Simon and Darby 1999) and consequently side-channel dewatering (Wohl 2004). The largest reductions in braiding since the 1950s occurred between the Bighorn and Powder rivers (Thatcher and Boyd 2007). Moreover, unvegetated bars were historically common on the Yellowstone River below the Bighorn River (Koch et al. 1977; Silverman and Tomlinsen 1984), but many of these bars have been replaced by vegetated islands (Thatcher et al. 2008).

Impoundments on the Bighorn and Tongue rivers probably influence the spatiotemporal dynamics of SSCV habitats and vegetated floodplain inundation on the Yellowstone River. Therefore, effects of Yellowstone River tributary impoundment may be similar to, but less extreme than those seen on the Missouri River (Bowen et al. 2003). Specifically, the present-day Yellowstone River may have less variation in mean SSCV patch size, patch density, and location of patches, as well as less area of inundated woody vegetation than the pre-settlement Yellowstone River. Bank stabilization and construction of levees and floodplain dikes have probably also reduced Yellowstone River SSCV dynamics and floodplain interaction. Because the Yellowstone River biota evolved within a setting of snowmelt-driven hydrology and a river corridor absent of anthropogenic lateral constraints, it is reasonable to assume that any alterations to fluvial geomorphic processes have affected the riverine ecosystem and its native fishes.

Installation of dams on the Bighorn River has blocked fish movements and also reduced the ecological suitability of the Bighorn River and the Yellowstone River below the confluence of the Bighorn River for turbid water fishes such as Shovelnose Sturgeon, Flathead Chub, Goldeye, Plains Minnow, Western Silvery Minnow, Sturgeon Chub, and Sauger. Of these seven species, only Flathead Chub appear to be secure in the Bighorn River basin (Wyoming State Wildlife Action Plan 2010). Shovelnose Sturgeon movements were blocked by Yellowtail Dam and a reintroduction program for them was initiated in 1996 in the Bighorn River in Wyoming (Wyoming State Wildlife Action Plan 2010). Sturgeon Chub formerly occupied the Bighorn River, but are now extirpated there. Moreover, Sturgeon Chub populations in the Yellowstone River almost certainly extended upstream to the mouth of the Bighorn River, however no sturgeon cub were captured above the Tongue River during extensive sampling (Duncan et al. 2012; Reinhold et al. 2014). Sauger in the Bighorn River basin in Wyoming are now isolated from Yellowstone River populations (McMahon 1999). Sauger have also declined in the Yellowstone River in the vicinity of and below the confluence of the Bighorn River, probably due to reduced temperatures, reduced sediment yield and associated turbidity, dampened spring peak flows that cued upstream migration, diversion dams, and habitat changes (McMahon 1999).

BMP implications

Changes in magnitude and timing of the Yellowstone River hydrograph are probably attributable to anthropogenic water use, damming of tributaries, and climate change. Therefore, management practices that encourage water conservation and temporal distribution of in-stream flows will correspondingly reduce the effects of anthropogenic water withdrawals. Moreover, societal changes that diminish the magnitude and rate of climate change will in turn reduce the magnitude and rate of change in the Yellowstone River ecosystem. Maintaining or reestablishing longitudinal connectivity may allow fish to move in response to altered thermal regimes. Managing angling pressure during periods of warm water may enhance survival of sport fishes, particularly in cold-water river reaches.

Watson (2014) provided recommendations for improved water management to benefit water users and native fish species in the Yellowstone River Basin in Chapter 4 of his draft Master's Thesis, which I summarize and review below. These recommendations seem to be suitable as the basis for BMP development, so they are also presented here.

"The key improvements recommended in the water management system are to: 1) finalize the statewide general adjudication, 2) re-evaluate the water reservation hierarchy in the Yellowstone River Basin 3) review water policies and clarify ambiguities, 4) develop comprehensive, effective monitoring of water use statewide, and 5) consideration of these recommendations, along with an adequate consideration for instream flows for native fishes, in Montana's new State Water Plan."

Altered connectivity

Connectivity in riverine ecosystems occurs on four dimensions: longitudinal (upstream-downstream), lateral (river channel-floodplain), vertical (river channel-groundwater), and temporal (time, from behavioral response time to evolutionary time; Ward 1989). Longitudinal connectivity is a central factor shaping riverine biological communities (Junk 1989; Cote et al. 2008). Connectivity between the main-stem river and its tributaries is also important (Duncan et al. 2012), because many fish species use tributaries during some part of their life history.

The main-stem Yellowstone River has been longitudinally fragmented by six diversion dams. The diversion dams typically span the entire width of the river, and range from 1 to 3.2 m in height (Helfrich et al. 1999). Side channels are present at Intake, Ranchers Ditch, Waco-Custer, and Huntley Diversion dams and these probably allow an unknown amount of fish passage when discharge is sufficient. A limited amount of upstream fish passage (10 species) has been documented at all six dams, although it is not usually know whether a fish passed over the dam or via the side channel (at those dams with side channels), or how many fish passed. No longitudinal distributions of small fish species were unequivocally associated with diversion dams (Duncan et al. 2010).

Although some fish species can pass each of the diversion dams under certain conditions, the extent thereof, and the discharge conditions under which fish movement is hindered or blocked are unknown. Evidence suggests that passage at diversion dams may be a function of the size of the fish. For example, Sauger are more abundant, but smaller below Intake Diversion Dam (Jaeger et al. 2005). Documenting passage of large fish species and individuals is most common because these species are suitable for attachment of radio transmitters. Movements of smaller fish species are more difficult to monitor, and non-game fish species movements are rarely-monitored; therefore, very little is known regarding the passage of the majority of the 56 fish species found in the Yellowstone River, including ecologically-important forage fishes and species of concern such as Sturgeon Chub and Sicklefin Chub. Moreover, the cumulative effects of all six diversion dams on the longitudinal distribution and abundance of all Yellowstone River fish species is not known with certainty. Synopses of the information regarding fish passage at the six main-stem diversion dams is presented below.

Intake Diversion Dam is located at river kilometer 115 near Glendive, Montana. A side channel is present on the right side of the river, and upstream fish passage using the side channel is reported to be possible at flows above 22,954 cfs (White and Bramblett 1992) to 30,000 cfs (Intake supplemental EA 2014). Fish species have been documented passing upstream of the dam under certain flow conditions, but it is not usually known whether the fish passed over the dam itself or passed via the side channel. Paddlefish pass during years of above-average flow (Stewart 1992), at flows above 44,990 cfs (Peterman 1979), and Shovelnose Sturgeon (White and Bramblett 1992; Bramblett 1996), Walleye (Graham et al. 1979), and Sauger (Graham et al.

1977; Jaeger et al. 2005) have been observed passing Intake. However, Intake Diversion Dam probably restricts juvenile Sauger movement, because catch rates and juvenile abundance were higher below the dam than above (Jaeger et al. 2005). There were 69 documented events of upstream passage by radio-tagged Blue Sucker, 2 by Burbot, 3 by Channel Catfish, 3 by Shovelnose Sturgeon, and 2 by Spiny Softshells during 2005-2009 (Jaeger et al., in preparation).

Helfrich et al. (1999) evaluated passage at Intake diversion dam and documented low numbers of marked fish (Goldeye, Sauger, Walleye, Smallmouth Buffalo) passing upstream of the dam and no consistent size differences in fish below and above dam, but Shovelnose Sturgeon were more abundant below dam, and more species were captured below dam.

No radio-tagged Pallid Sturgeon passed upstream of the dam during 1992-1994 (Bramblett and White 2001), however five adult radio-tagged Pallid Sturgeon (four males and one gravid female) passed the dam by using the side channel between 27 May and 4 June, 2014. Discharge during the passage period ranged from 46,900 to 63,800 cfs. The female Pallid Sturgeon is thought to have spawned in the Powder River (Mike Backes, unpublished data).

Cartersville Diversion Dam is located at river kilometer 379 at Forsyth, Montana. No side channel bypasses the diversion dam. It has long been thought to be a barrier to Shovelnose Sturgeon because they were present below, but not above Cartersville (Haddix and Estes 1976; Stewart 1990). Although Helfrich et al. (1999) captured three Shovelnose Sturgeon above the dam in 1997, Shovelnose Sturgeon are considered functionally absent above Cartersville Diversion Dam (Jaeger et al. 2008).

Sauger have been documented passing Cartersville Diversion Dam (Graham et al. 1979; Jaeger et al. 2005). There were 17 documented events of passage by radio-tagged Blue Sucker, 6 by Burbot, 1 by Channel Catfish, and 1 by a Spiny Softshell during 2005-2009 (Jaeger et al., in preparation). Recapture of a floy-tagged Sauger and a floy-tagged Channel Catfish indicated that they had passed Cartersville Diversion Dam (Mike Ruggles, FWP, personal communication). However, Helfrich et al. (1999) found no consistent size differences in fish of multiple species below and above the dam.

Meyers Diversion Dam (also known as Hysham or Yellowstone Diversion Dam), is located at river kilometer 447 near Hysham, Montana. No side channel bypasses the diversion dam. Telemetered Sauger were documented passing upstream of this diversion dam (Jaeger et al. 2005) and there were four documented events of passage by Blue Sucker, and two by Channel Catfish during 2005-2009 (Jaeger et al., in preparation). Recapture of a floy-tagged Sauger and a floy-tagged Channel Catfish indicated that they had passed Meyers Diversion Dam (Mike Ruggles, FWP, personal communication).

Ranchers Ditch Diversion Dam is located at river kilometer 470, which is about 4 river kilometers below the confluence of the Bighorn River. A side channel bypasses the diversion dam, but it appears from examination of aerial imagery that this side channel also has a diversion or is possibly blocked by a dike. Telemetered Sauger were documented passing upstream of this diversion dam (Jaeger et al. 2005) and passage by one Channel Catfish was documented during 2005-2009 (Jaeger et al., in preparation). Recapture of a floy-tagged Sauger and a floy-tagged Channel Catfish indicated that they had passed Ranchers Ditch Diversion Dam (Mike Ruggles, FWP, personal communication). However, Ranchers Ditch Diversion Dam has been modified to increase elevation subsequent to these documented passage events, therefore it is not known if any fish passage occurs currently (Mike Ruggles, FWP, personal communication).

Waco (also known as Custer) Diversion Dam is located at river kilometer 509. A side channel bypasses the diversion dam. Telemetered Sauger were documented passing upstream of this diversion dam (Jaeger et al. 2005), and one Burbot and one Channel Catfish passed it during 2005-2009 (Jaeger et al., in preparation). Recapture of a floy-tagged Sauger and a floy-tagged Channel Catfish indicated that they had passed Waco Diversion Dam (Mike Ruggles, FWP, personal communication).

Huntley Diversion Dam is located at river kilometer 566 at Huntley, Montana. A side channel and a small artificial channel bypass the diversion dam. No Sauger were documented passing the dam, but this dam was probably not encountered by telemetered Saugers (Jaeger et al. 2005). Low numbers of marked fish (White Sucker, Common Carp, Goldeye, Brown Trout, Shorthead Redhorse, Longnose Sucker, and Flathead Chub) were documented to have passed the dam, and no consistent size differences existed in fish below and above dam (Helfrich et al. 1999)

Connectivity between main-stem rivers and tributaries is important because many fish species use both habitats at some point in their life histories. Connectivity between main-stem rivers and tributaries also supports higher fish species richness in both the main-stem river and the tributary (Schaefer and Kerfoot 2004), and headwater streams that are distant from main-stem rivers typically have fewer fish species than similarly-sized adventitious streams that are directly connected to main-stem rivers (Osborne and Wiley 1992; Schaefer and Kerfoot 2004; Hitt and Angermeier 2008).

Connectivity between the lower Yellowstone River and its tributaries is crucial for Western Silvery Minnows, Flathead Chubs, and Sand Shiners (Duncan et al. 2010). Nearly three-quarters of Western Silvery Minnows, Flathead Chubs, and half of Sand Shiners used both main-stem and tributary habitats during their lifetimes (Duncan et al. 2010). These three species were three of the four most abundant small fish species in the Yellowstone River below the Tongue River (only Emerald Shiner were more abundant in this reach of the Yellowstone River). As such, they are almost certainly important food items for large game fish species such as Sauger and Channel Catfish, for the endangered Pallid Sturgeon, as well as for other predators such as fish-eating birds. Forage fish such as these three minnow species make up much of the primary and secondary consumer biomass in the Yellowstone River's food web and therefore are critical components of energy flow in a functioning ecosystem. The magnitude of dispersal between the main-stem and tributaries increased with tributary basin area (Duncan et al. 2012). Therefore, the larger the tributary, the more energy flow between the tributary and main-stem. Western Silvery Minnows and Flathead Chubs have experienced range reductions and population declines elsewhere (Pflieger and Grace 1987; Hesse et al. 1993; Harland and Berry 2004; Haslouer et al. 2005; Kral and Berry 2005) whereas Sand Shiners remain abundant throughout much of their range (Warren et al. 2000).

The relative importance of Western Silvery Minnows, Flathead Chubs, and Sand Shiners as forage for endangered Pallid Sturgeon may be related to the degree to which these three species are benthically oriented (because Pallid Sturgeon are presumably benthic predators), and the degree to which they occupy main-stem habitats. Therefore, I suspect the following order of importance for these three species as Pallid Sturgeon forage: Flathead Chub, Western Silvery Minnow, and Sand Shiners. Flathead Chub and Western Silvery Minnow are roughly equally abundant to Sand Shiners and have a larger body size, so provide much energy to higher trophic levels. In the Missouri River above Fort Peck Reservoir, juvenile (age-6 and age-7) Pallid Sturgeon consumed primarily fish (90% by wet weight), however Sturgeon Chub and Sicklefin Chub, made up 79% of the number of identifiable fish in juvenile Pallid Sturgeon stomachs (Gerrity et al. 2006). In the Yellowstone River, Sturgeon Chub range upstream as far as the Tongue River, and Sicklefin Chub are found primarily below Intake (Duncan et al. 2012). Therefore, Pallid Sturgeon diet probably varies longitudinally on the Yellowstone River.

Reestablishing connectivity on tributary streams can result in changes to tributary fish assemblages (Shilz 2012; Mike Backes, Montana Fish, Wildlife and Parks, unpublished data). In 2011, a canal crossing at the mouth of Pryor Creek that blocked fish movements from the Yellowstone River was replaced with a siphon that allowed for fish passage into Pryor Creek. Fish abundance increased 45%, flathead chub abundance increased 58%, and Index of Biotic Integrity (Bramblett et al. 2005) scores increased 34% the reach above the former barrier the year after barrier removal (Schilz 2014). On the Tongue River, the Muggli bypass was installed in 2008 to allow fish to bypass the T&Y Diversion Dam, which was thought to have blocked passage of all fish ascending the Tongue River. Since 2008 the Muggli bypass has allowed passage of 28 fish species, including five species (Goldeye, Freshwater Drum, Sturgeon Chub, Bigmouth Buffalo and Smallmouth Buffalo) that were not documented upstream of T&Y Dam prior to bypass construction. The Muggli bypass allows multiple Yellowstone River fish species to ascend an additional 169 miles of the Tongue River that prior to 2008 were restricted to 20 river miles (Mike Backes, Montana Fish, Wildlife and Parks, unpublished data).

BMP implications

The effects of diversion dams on the ecological connectivity of the six Yellowstone River diversion dams is not well understood. The degree of mitigation by natural or artificial bypass channels is also unknown. However, it appears that Cartersville Diversion Dam effectively blocks many fish species, and in particular, Shovelnose Sturgeon. Providing for fish passage at Cartersville would probably extend the distribution of Shovelnose Sturgeon and benefit other native fish species. Research that quantifies the ecological and population effects of the diversion dams would enable managers to assess priorities and develop mitigation strategies. The installation of additional diversion dams would have uncertain, by likely negative consequences on the Yellowstone River fish assemblage.

Connectivity between the Yellowstone River main stem and its tributaries is required for some fish species to complete their life cycles. Maintenance of main stem-tributary connectivity both in terms of physical barriers and physical and ecological conditions will contribute to the overall ecological integrity of both the main-stem river and its tributaries. Connectivity between the main-stem Yellowstone River and its tributaries appears to be essential for at least three of the four most abundant small forage fishes in the ecosystem. Connectivity should be preserved between tributaries and the Yellowstone River. New water diversions or culverts should be designed to allow for fish passage. Existing barriers should be considered for redesign and modification to allow for fish passage. A general guideline is that the larger the tributary in question, and the closer to the Yellowstone River the structure, the higher the importance for the ecosystem and the higher the priority for allowing fish passage.

Bank stabilization

The alteration of large rivers by physical anthropogenic structures such as bank stabilization results in changes in riverine habitats such as main-channel bed degradation, channel width reduction, and increased stream gradient (Stern et al. 1980; Heede 1986; Shields et al. 1995). Moreover, bank stabilization reduces floodplain connectivity and natural riverine processes such as lateral channel migration and the formation of backwaters, braids, and side channels (Leopold 1964; Stern et al. 1980; Shields et al. 1995; Schmetterling et al. 2001; Auble et al. 2004; Florsheim et al. 2008).

Bank stabilization was associated with decreases in fish abundances in some rivers (Buer et al. 1984; Li et al. 1984; Swales et al. 1986; Knudsen and Dilley 1987; Thurow 1988; Beamer and Henderson 1998; Peters et al. 1998; Oscoz et al. 2005) increases in others (Knudsen and Dilley 1987; Binns 1994; Binns and Remmick 1994; Avery 1995; White et al. 2010), or had no effect (Madejczyk et al. 1998; McClure 1991). Similarly, fish species richness was decreased (Oscoz et al. 2005), increased (White et al. 2010), or unchanged (Madejczyk et al. 1998) in stabilized reaches. Changes in fish assemblage structure (Eros et al. 2008; Madejczyk et al. 1998) or size-class distributions (Eros et al. 2008) have occurred in bank-stabilized reaches. Thus, bank stabilization has uncertain and possibly multifaceted consequences for fish assemblages.

The discrepancies in the findings of previous studies may result from differences in rivers. In artificially or naturally homogenous rivers, bank stabilization may provide habitat diversity that is otherwise lacking (Schmetterling et al. 2001; Zale and Rider 2003), and cause localized increases in fish density and species richness. Conversely, in unaltered or relatively heterogeneous rivers, moderate amounts of bank stabilization may have little or no effect on the fish assemblages. Moreover, with the exception of studies by Zale and Rider (2003) and White et al. (2010), all studies of the effects of bank stabilization in large rivers have been conducted in regulated rivers (Michny 1988; Garland et al. 2002; Eros et al. 2008; Schloesser et al. 2012) where the effects of bank stabilization may be confounded by or interact with the effects of dams.

Zale and Rider (2003) compared juvenile salmonid use of altered bank habitats to use of natural, unaltered bank habitats on the upper Yellowstone River. Juvenile salmonid use of barbs and jetties was similar to that of natural outside bends, and use of riprap sections was higher than that of natural outside bends. Juvenile salmonid recruitment from main-channel habitats was probably not negatively affected by bank stabilization. However, the amount of recruitment from main-channel habitats relative to recruitment from other areas such as side channels, backwaters, and tributaries is not known. Habitat modifications that directly or indirectly reduce the frequency or duration of side-channel inundation, or reduce side channel formation rates, would probably decrease juvenile salmonid habitat and possibly recruitment.

Bowen et al. (2003b) evaluated the relationships between the level of channel modification (bank stabilization structures, i.e., riprap, jetties, barbs, levees) and shallow, slow current velocity habitats on three reaches (4.2 to 6.3 km in length) of the Yellowstone River in Park County, Montana.

This study demonstrated that SSCV area increases with increasing discharge and peaks during peak runoff. It appears that the juvenile salmonid's biological needs and the physical habitat conditions are synchronized because the highest abundance of YOY salmonids, which are small and weak swimmers, coincides with high SSCV habitat availability in side channels and overbank areas, when main channel habitats have the highest prevalence of fast and deep water. However, anthropogenic bank modifications increase lateral river confinement, decrease side channel and overbank SSCV area, thereby reducing the overall amount of SSCV habitat availability.

SSCV availability was lowest in the Livingston reach, which was also the reach that was the most anthropogenically modified. The Livingston reach is naturally confined on the east bank by a high valley wall and confined on the west bank by levees and riprap. As a result, the Livingston reach had the lowest overall SSCV area, because this reach generally had less SSCV attributable to side channels and overbank areas, particularly during bankfull flows. The Livingston reach also had the highest proportion of SSCV attributable to modified banks, which may be important habitats for juvenile salmonids (Zale and Rider 2003). However, Zale and Rider (2003) also stress the importance of side channels as important juvenile salmonid habitat, and side channel area has probably been lost in the Livingston reach. Lateral confinement probably also reduces large woody debris recruitment and retention which provides modest amounts (8% to 22%) of SSCV during high flows.

The inference of Bowen et al. (2003b) with regard to effects on fish is based on the assumption that SSCV is an important habitat component for juvenile salmonids, and in particular YOY salmonids during runoff. Substantial basis for this assumption exists in the literature; moreover the fisheries research project (Zale and Rider 2003) that accompanied this work supports the assumption in this setting. As noted by the authors, "Effects of reduced juvenile abundances during runoff on adult numbers later in the year will depend on (1) the extent of channel modification, (2) patterns of fish displacement and movement, (3) longitudinal connectivity between reaches that contain refugia and those that do not, and (4) the relative importance of other limiting factors."

Reinhold et al. (2014; Chapter 2) examined the relationship among the frequency of floodplain dikes and areal changes in side channels from the 1950s to 2001 on the main-stem Yellowstone River from its confluence with the Clarks Fork Yellowstone River near Billings, Montana, downstream to its confluence with the Missouri River. The loss in side channels exceeded the gain in side channels from the 1950s to 2001. Sixty-seven side channels were lost, 39 side channels were gained, and 91 remained stable. Floodplain dikes were correlated with the net loss of 3.0 km^2 of side channel area, which represented a 10.4% net loss in side channel area from the 1950s to 2001. Loss of side channels probably has negative consequences for Yellowstone River fish because side channels are important habitat for fish in the Yellowstone River during runoff, side channel availability influences main channel fish assemblages at scales of up to 3 km upstream and downstream, and side channels shifts assemblage structure in ways opposite of bank stabilization (Reinhold et al. 2014).

Reinhold et al. (2014; Chapter 4) examined the relationships of main-channel fish assemblages and bank stabilization and side channels in five segments of the Yellowstone River from near Billings, Montana, downstream to its confluence with the Missouri River. Both bank stabilization and side channels influenced fish assemblages, and bank stabilization and side channels were often associated with shifts in the identity and abundance of the fish assemblages in different or opposite directions. This suggests that bank stabilization has caused the fish assemblages to change from the pre-stabilization condition, and that side channels influence fish assemblages to remain more similar to the pre-stabilization condition.

Moreover, these changes were explained by measuring bank stabilization and side channels at coarse spatial scales (i.e., up to 3 kilometers both up and downstream of sampling locations), as well as at finer scales. This suggests that bank stabilization and side channels may influence fish on both a “neighborhood scale” (i.e., including neighboring upstream and downstream river bends) and on a “local scale” (i.e., the individual river bend). Stabilized alluvial pools were significantly deeper than their non-stabilized counterparts probably because bank stabilization halted lateral channel migration but increased vertical scour. Conversely, depths were similar at stabilized and reference bluff sites probably because lateral channel migration and scour are in relative equilibrium at erosion-resistant bluff pools. Therefore, a potential mechanism whereby bank stabilization influences fish assemblages is by creating deeper pools at stabilized alluvial river bends.

Duncan et al. (2012) detected a few differences in fish catch rates between stabilized and non-stabilized pool types. Catch rates for Sand Shiners in bluff, terrace, and alluvial pools were significantly higher than in some stabilized pool types. Catch rates for Flathead Chub in bluff and terrace pools were significantly higher than in stabilized alluvial pools. Stabilization may therefore reduce local Sand Shiners and Flathead Chub abundance. Jaeger et al. (2008) described seasonal movement patterns and habitat use of adult Blue Sucker, Burbot, Channel Catfish, Shovelnose Sturgeon, and Spiny Softshells. Spiny Softshells avoided riprapped alluvial pools, but no fish species avoided riprapped habitats. Burbot preferred riprapped alluvial pools and bluff pools, probably because Burbot use large substrates (Edsall et al. 1993; Dixon and Vokoun 2009; Eick 2012).

BMP Implications

Because bank stabilization influences the Yellowstone River fish assemblage, management activities that focus on this aspect of the ecosystem will probably influence the fishery. Specific BMP implications include considering the spatial context of bank stabilization projects and side channel availability. The amount of existing bank stabilization on a scale of a few kilometers influenced the strength of the relationship between fish assemblages and bank stabilization. Therefore, small bank stabilization projects in reaches with mostly natural banks may have limited effects on the fishery. However, in reaches with a moderate extent of existing bank stabilization, additional bank stabilization may elicit larger shifts in the fish assemblage. In areas with extensive existing bank stabilization, fish assemblages have probably shifted away from the pre-stabilization condition, and any management actions that allow for unaltered riverine function—specifically increases in side channel availability, may shift the assemblage towards the pre-stabilization condition. Protection of existing side channels will ensure their continued availability to the fishery. However, we have no inference regarding how many side channels must be maintained to maintain fish assemblage structure, or how many side channels can be lost before threshold shifts in the fish assemblage occur. However, riverine processes that allow for continued existence, maintenance, and formation of side channels will enhance the continued maintenance of the fishery.

Preserving presence of side channels and access of peak runoff flows to overbank floodplain areas will help preserve SSCV habitat. Preserve geomorphic processes that facilitate and maintain side-channel creation, maintenance, and inundation, i.e. no diking of side channels, maintaining streambed elevation, preventing non-equilibrium streambed degradation, allowing lateral channel migration, prevent dewatering that lowers river stage and dewaters side channels. Consider research to determine the role of main-channel bank modifications on side-channel creation, maintenance, and inundation.

Altered side channels

Ecological theory (Junk 1989) and empirical field studies (Ellis et al. 1979; Brown and Hartman 1988; Copp 1997; Gurtin et al. 2003; Zale and Rider 2003; Beechie et al. 2005) suggest that side channels are crucial fish habitats because of the habitat heterogeneity they provide. Fish species richness was positively associated with increased habitat heterogeneity in the upper Mississippi River (Ellis et al 1979; Koel 2004). Lateral connectivity is also important; twice as many fishes were found in connected aquatic floodplain habitats than in disconnected habitats in the impounded lower Missouri River (Galat et al. 1998). However, the extensive bank stabilization and altered hydrographs in the upper Mississippi River and the lower Missouri River confound the inference of these studies because both bank stabilization and altered hydrographs reduce side channel inundation both spatially and temporally. Therefore, the limited amount of remaining side channel habitats may have concentrated fish.

Side-channel loss reduces lateral connectivity, habitat heterogeneity, and habitat suitability for fish and other animals. Reductions in lateral connectivity may have detrimental effects on the biodiversity and biomass of fish (Junk 1989; Miranda 2005) amphibians (Tockner et al. 2006), turtles (Bodie et al. 2000), birds (Rumble and Gobeille 1998; Rumble and Gobielle 2004), and other riverine organisms (Amoros and Bornette 2002).

Reinhold et al. (2014) examined the importance of side channels to the Yellowstone River fish assemblage in two ways. First, they determined if fish assemblage structures in SSCV habitats differed in side channels and main channels in alluvial and bluff geomorphic river-bend types during early runoff, late runoff, and base flow. Second, they examined the influence of bank stabilization and side channels on the structure of the main-stem Yellowstone River fish assemblage from Laurel to Sidney, Montana, during late summer and early autumn base flow conditions 2009-2011 and compared depths and velocities of stabilized and reference pools to determine if bank stabilization was altering local fish habitat.

Side channels provided important habitat for the Yellowstone River shoreline fish assemblage during runoff (Reinhold et al. 2014). Overall fish catch rates, catch rates of the most common species (Western Silvery Minnow, Longnose Dace, Flathead Chub, and Emerald Shiner), and species richness were generally greater in side channels than in main channels during early and late runoff. Overall fish catch rates were up to nine times higher relative to main channel catch rates. Fish assemblage structure also differed between side channels and main channels during runoff, but not during baseflow. During baseflow, catch rates were generally not different, however the composition of the catch varied between side channels and main channels (Reinhold et al. 2014).

Physical habitat variables (water velocity, depth, water temperature, DO, water clarity, and specific conductance) at the sites of net deployment in side channels and main channels were similar within hydroperiod, so probably did not explain the differences in side channel and main channel fish assemblages (Reinhold et al. 2014). However, side channels probably provided larger patches of suitable habitat for small fish during runoff (Bowen et al. 2002b), where they may have been less susceptible to aquatic predators and downstream displacement. These results support existing studies demonstrating that access to heterogeneous habitats throughout different hydroperiods is important for fish assemblages and that connectivity between main channels and side channels helps maintain diverse fish assemblages (Reinhold et al. 2014).

Both bank stabilization and side channels influenced Yellowstone River fish assemblages, and bank stabilization and side channels were often associated with shifts in the identity and abundance of the fish assemblages in different or opposite directions (Reinhold et al. 2014). This suggests that bank stabilization has caused the fish assemblages to change from the pre-stabilization condition, and that side channels influence fish assemblages to remain more similar to the pre-stabilization condition. Moreover, these changes were explained by measuring bank stabilization and side channels at coarse spatial scales (i.e., up to 3 kilometers both up and downstream of sampling locations), as well as at finer scales. This suggests that bank stabilization and side channels may influence fish on both a "neighborhood scale" (i.e., including neighboring upstream and downstream river bends) and on a "local scale" (i.e., the individual river bend). A potential mechanism whereby bank stabilization influences fish assemblages is by creating deeper pools at stabilized alluvial river bends (Reinhold et al. 2014).

Zale and Rider (2003) concluded that side channels may be important natural nursery areas for juvenile salmonids in the Yellowstone River in Park County because juvenile salmonid habitat was rare along the main-channel banks of the upper Yellowstone River. Moreover, side channels provide SSCV habitat during runoff when such habitat is negligible in the main channel. However, although juvenile salmonid densities in side channels were not exceptional, juvenile salmonids, especially Mountain Whitefish, rapidly occupied side channels upon inundation, suggesting that when available, side channels are important habitats for juvenile salmonids. Bowen et al (2003a) demonstrated that SSCV area increases with increasing discharge and peaks during peak runoff. However, anthropogenic bank modifications increase lateral river confinement and decrease side channel and overbank SSCV area, thereby reducing the overall amount of SSCV habitat availability. SSCV availability was lowest in the Livingston reach, and this reach generally had less SSCV attributable to side channels and overbank areas, particularly during bankfull flows (Bowen et al 2003a). The Livingston reach also had the highest proportion of SSCV attributable to modified banks, which may be important habitats for juvenile salmonids (Zale and Rider 2003). However, Zale and Rider (2003) also stress the importance of side channels as important juvenile salmonid habitat, and side channel area has probably been lost in the Livingston reach. Habitat modifications that reduce the frequency or duration of side-channel inundation, or reduce side channel formation rates, would probably decrease juvenile salmonid habitat and possibly recruitment.

Spiny Softshells in the Yellowstone River preferred secondary channels in all seasons except winter, when they preferred bluff pools (Jaeger et al. 2008). This pattern is generally concordant with habitat use in the Missouri river in Montana where Spiny Softshells used shallow, slow, lateral habitats such as backwatered tributary mouths and inundated floodplains during all seasons except winter (Tornabene 2014). These habitats were typically near shore with shallow depth, slow to no water velocity, fine substrates, and higher water temperatures than in the main stem. Such areas seem to be important during this period because some turtles moved considerable distances, aggregated, and showed interannual fidelity to particular tributary confluences (Tornabene 2014). Spiny softshells hibernate on the river bottom in winter, and select deeper water with moderate current velocities between the shoreline and thalweg, where they are not displaced by swift velocities, have adequate oxygen, and are deep enough to be safe from ice jams (Tornabene 2014). Bluff pools are slower and deeper than other pool types and probably provide adequate habitat for overwintering hibernacula.

Bowen et al. (2003b) modeled SSCV spatiotemporal dynamics at three reaches on the lower Yellowstone River. During the rising limb of the hydrograph, SSCV patches were located primarily in side channels and back-flooded tributaries. At peak flow, flooding of vegetated island and side channels where leaf litter accumulated provided organic material to the river. During the recession and base-flow periods, SSCV migrated into the main channel and large side channels and formed large patches. SSCV area during recession and base flow was about double that available during runoff (Bowen et al. 2003b). This modeled pattern of SSCV availability indicates that SSCV is limited during runoff, and that it is found in side channels, thereby indicating the importance of side channels in providing SSCV habitat. Concordant with these models, Reinhold et al. (2014) found that overall fish catch rates, catch rates of the most common species, and species richness were generally greater in side channels than main channels during early and late runoff.

BMP implications

Extensive side-channel losses may have detrimental consequences for lower Yellowstone River fish assemblages. Management practices that preserve side channels and the riverine processes that create and maintain side channels will ensure that these important fish habitats continue to exist. Restoration or reconnection of altered side channels will benefit the fish assemblage.

Introduced species

The Yellowstone River is a stronghold of native fish diversity. There are 56 fish species total of which 20 species (36%) are nonnative. However, in terms of abundance, most nonnative fish are rare. The high abundances of native species and low proportion of nonnative species relative to other large rivers such as the Missouri River (R. Wilson, USFWS, unpublished data; T. Haddix, MFWP, unpublished data) also indicate that the lower Yellowstone River maintains productive and diverse native fish assemblages. Exceptions are Rainbow Trout and Brown Trout in the salmonid zone of the river (White and Bramblett 1992). Rainbow trout can hybridize with native Yellowstone Cutthroat Trout, but this hybridization in reduced because Rainbow Trout and hybrids spawn earlier than Yellowstone Cutthroat Trout (DeRito et al. 2010). Brown trout are predaceous, and consume native fishes, but the effect of the presence of Brown Trout on the native fish populations has not been quantified.

Smallmouth Bass are rare to abundant in the lower two fish zones (White and Bramblett 1992). Smallmouth Bass are potentially competing with Sauger, because their diet overlaps almost completely as indicated by table isotopic tissue analysis (Rhoten 2011). Walleye isotopic signatures did not overlap those of Sauger (Rhoten 2011), however both Sauger and Walleye are upper trophic level piscivores, so competition for food is possible. Walleye can hybridize with native Sauger but hybridization does not appear to be an immediate threat because hybridization rates in the Yellowstone River were less than 3% (Bingham et al. 2011). Other nonnative fish species with potential to influence native fish assemblages include Common Carp, Northern Pike, Yellow Bullhead, White Bass, Rock Bass, Bluegill, Pumpkinseed, and Green Sunfish. These nonnative fishes prey on and may compete with native fishes, but their effect on the ecosystem has not been quantified.

BMP Implications

Continue to prohibit introduction of nonnative fish species. Consider research to evaluate the distribution, abundance and ecological effect of Smallmouth Bass to begin to identify management implications of Smallmouth Bass on the Yellowstone River fish assemblage.

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Summaries of recent reports

Title: Influence of low-head diversion dams on fish passage, community composition, and abundance in the Yellowstone River, Montana

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Abstract: The influence of three low-head irrigation diversion dams on the fish communities in the middle Yellowstone River was examined by down- and upstream electrofishing and trammel net comparisons of fish distribution, relative abundance, .and size-structure. Fish passage at Huntley and Intake dams was evaluated by mark-recapture techniques in July and September following maximum annual discharge. Catostomids and cyprinids dominated the fish community at all sites. Mean relative abundance (Catch per unit effort; CPUE) ranged from 1.58 to 5.13 fish/min, but no significant differences were detected between sites. Shovelnose Sturgeon were consistently more abundant in the trammel net and electrofishing collections downstream of Cartersville and Intake dams. Species richness ranged from 7 to 24, depending on site and sampling method, but did not differ between down- and upstream sites. Of 4,430 fish (37 species) marked downstream of Huntley Dam, 13 fish (7 species) passed upstream and 3 fish (2 species) of the 1,032 fish marked upstream passed downstream during high flows in June 1997. Of 4,080 fish marked downstream of Intake Dam, 17 fish (4 species) passed upstream in June 1998. Fish species (swimming ability) appeared to be related to dam passage, but fish size was not an important variable. Our results suggest that fish passage was feasible at individual dams at high flows for some species such as Sauger, White Sucker, Goldeye, Shorthead Redhorse, Walleye, and Common Carp. However, the six dams in series on the Yellowstone River represent a cumulative fish passage challenge that, in combination, may ultimately restrict fish distributions and limit abundance, especially during low flows in dry years. Enhancing natural bypass channels and constructing artificial riffles may be useful strategies for promoting fish passage at low-head dams.

Introduction: Although no high dams block the Yellowstone River or impound its waters, nearly one-third of its drainage area is dammed and six low-head (run-of-the-river) dams on the main channel divert water for irrigation. The Huntley, Waco-Custer, Ranchers Ditch, Yellowstone, Cartersville, and Intake diversion dams create cascades with 1-4-m hydraulic heads. No fish passage structures (fish ladders or lifts) are incorporated into these dams, and movement of fish over or around the dams presumably occurs only at high river discharge during snow-pack runoff from May through June. Unlike high dams that have been widely implicated in significant reductions in anadromous fishes throughout the western United States, little is known about the impacts· of low-head dams as potential barriers to fish dispersal, and less is known about the movements of nonanadromous fishes. Dams can block or delay spawning migrations; restrict dispersal to nurseries, feeding sites, and optimal habitat; concentrate predators; promote stress and disease; and reproductively isolate and extirpate fish and mussels.

Goal: The purpose of this study was to determine if low-head irrigation diversion dams in the middle and lower Yellowstone River inhibit fish passage and fragment fish communities.

Objectives: The authors characterized fish distribution, relative abundance, species richness, and length structure of populations upstream and downstream of three diversion dams (Huntley, Cartersville, and Intake) and examined the movement of marked fish at Huntley and Intake dams in. July and September after maximum annual discharge.

Study sites and methods: Fish communities were evaluated at three of the six low-head dams located on the middle and lower Yellowstone River: Huntley Diversion Dam, Cartersville Diversion Dam and Intake Diversion Dam. During this study, record annual peak flows (80,100 cfs) occurred in June 1997 at Billings, below maximum discharge but above mean peak flows (63,710 cfs) occurred in June 1997 at Forsyth, and near normal mean peak flows (44,300 cfs) occurred in June 1998 at Sidney.

To evaluate fish passage, we collected fish down- and upstream of Huntley Dam in April 1997 and at Intake Dam in May 1998 by electrofishing, and marked them to identify whether they were captured above or below the dam. After the initial marking, fish populations down- and upstream of each dam were resampled in July and September after annual high flow. During the July sampling, unmarked fish collected down- and upstream were marked with a right pelvic and a right pectoral fin clip, respectively.

To determine relative abundance and size composition, fish populations were sampled by electrofishing at sites downstream (N = 18) and upstream (N = 27) of Huntley Dam during 2-6 successive days in July and September 1997, downstream (N = 5) and upstream (N = 8) of Cartersville Dam during 4 days in September 1997, and downstream (N =25) and upstream (N = 70) of Intake Dam during 4 days each in July and September 1998. All sites were located within 5 km of the dams. All major riverine habitats (pools, riffles, and runs) were represented and data were pooled across habitat type to provide a composite sample of the fish community at each sampling site and month.

Trammel nets were drifted at sites downstream (N= 18) and upstream (N=9) of Huntley Dam and downstream (N=8) and upstream (N=8) of Cartersville Dam during July and September 1997.

The authors compared fish abundance (CPUE) and species richness at randomly selected sites down- and upstream or the three dams. Because electrofishing and trammel nets are not uniformly efficient or directly comparable, data from each were analyzed separately. The authors tested the null hypothesis that mean relative abundance, species richness, and fish length were similar at sites down- and upstream of the dams. Fish passage was defined as demonstrated movements of marked fish between capture and recapture locations above or below a dam.

Results: The authors collected a total of 37 fish species (11 introduced species at Huntley, Cartersville, and Intake dams. Catostomids and cyprinids dominated the fish community. Certain species such as Sauger, bigmouth buffalo, Blue Sucker, black crappie, freshwater drum, and Shovelnose Sturgeon were collected only downstream at Cartersville and Intake dams. Paddlefish were collected only downstream of Intake Dam during fish marking collections in May 1998.

Mean relative abundance (CPUE) was not significantly different between down- and upstream sites within dams and months for both electrofishing and trammel net collections. Catch-per-unit-effort values were significantly (P<0.027) lower in July at Intake Dam than at Huntley Dam for electrofishing and trammel net collections, but fish abundance was similar at all sites and dams in September. No consistent species-specific differences in abundance at sites above and below dams were evident except that Shovelnose Sturgeon were significantly ($P < 0.05$) more abundant in trammel nets below Cartersville Dam and electrofishing samples below Intake Dam.

Species richness ranged from 7 to 24, depending on the site and sampling methods. It did not differ among sites, dams, or months except that greater numbers of species occurred in the electrofishing collections downstream of Intake Dam in September 1998.

Only limited numbers (0.004%) of marked fish of certain species were recovered upstream of Huntley and Intake dams despite high flows. Of 4,430 fish (37 species) marked downstream of Huntley Dam in May and July 1997, 13 fish (7 species) passed upstream and 3 (2 species) of the 1,032 marked fish upstream passed downstream of the dam. Of 4,080 fish marked downstream of lntake Dam in May and July 1998, 17 fish (4 species) passed upstream of the dam, and none of the 1,470 fish marked upstream were recovered downstream. At Huntley Dam, about half the fish moved upstream in July and the other half in September, but all the fish that moved downstream did so in September. At Intake Dam, all recaptured fish moved upstream in July. The natural bypass channels at Huntley and Intake dams were open only during June-August, and were dry and impassable in September each year.

The passage of certain taxa, notably catostomids, cyprinids, salmonids, and percids was evident. Of the 37 species marked, 10 species were recovered after moving upstream of Huntley and Intake dams. Passage was unrelated to abundance, because relatively uncommon species such as Brown Trout, Common Carp, Sauger, Walleye, and Smallmouth Buffalo were recovered upstream, which suggests that swimming ability or some other behavioral attribute may favor their passage. Fish size was unrelated to passage. Although mean lengths of most species recaptured after passage were larger than the population averages, the proportion of recaptures (0.004%) was too small to permit a meaningful comparison.

No consistent differences in size (mean length) of the most widely distributed and abundant fish species collected were evident between down- and upstream sites within dams and months. Shorthead Redhorse collected upstream were larger than those downstream of Huntley Dam, but were similar in size at Cartersville and Intake dams. Goldeye collected upstream of Huntley and Intake dams in July were larger than those collected downstream, but were similar in length at both dams in September. Flathead Chubs collected downstream of Huntley and Cartersville dams were larger than those collected upstream, but were similar in size at Intake Dam. Differential gear efficiency was apparent in comparisons of electrofishing and trammel net collections. Electrofishing consistently collected greater numbers of species (16-24) than trammel nets, and this technique accounted for all recoveries of marked fish that exhibited passage. However, larger-sized open-water species such as Shovelnose Sturgeon and paddlefish were collected more frequently in trammel nets.

Discussion: Our results indicate that Huntley, Cartersville, and Intake dams did not create disjunct fish populations and do not represent complete barriers to the passage of certain fish species, especially at high flows in wet years. The authors did not detect a consistent pattern of differences in fish abundance, species richness, or mean length between down- and upstream comparisons within dams or months. As expected, some differences in fish abundance (CPUE), species richness, and fish lengths among dams and months were evident, probably as a result of longitudinal variation in fish communities, habitats, primary productivity, fish behavior and movement.

The recovery of marked fish upstream of Huntley and Intake dams demonstrated that fish passage either over the dams or in the natural bypass channels was feasible, especially for strong-swimming species (White Sucker, Longnose Sucker, Shorthead Redhorse, Common Carp, Goldeye, Flathead Chub, Walleye, Sauger, Smallmouth Buffalo, and Brown Trout) during high flows. Downstream recovery of a White Sucker and two Shorthead Redhorse marked above Huntley Dam indicated that two-way (bidirectional) passage over or around this dam occurred. Distribution patterns suggest that upstream passage of some fish species (Sauger, Walleye, Shovelnose Sturgeon, and paddlefish) that otherwise may be expected to be collected at Huntley Dam, may be restricted by the series of dams downstream.

Record annual river discharge in June 1997 at Huntley Dam, normal high flows in June 1998 at Intake Dam, and the presence of high-flow natural bypass channels at both dams probably promoted fish passage. However, fish passage may be inhibited or precluded at other seasons and during dry years. From September to March of each year the natural bypass channels were dry and impassable. Shovelnose Sturgeon were not collected at Huntley Dam, were rare upstream of Cartersville Dam, but were common at Intake Dam. Paddlefish were collected only downstream of Intake Dam (May 1998) where they are present in large concentrations. Sauger were common at Intake Dam, rare at Cartersville Dam, and not collected at Huntley Dam.

Although fish passage was evident at Huntley and Intake dams, relatively few (30) marked individuals passed down- or upstream despite high flows. Recoveries of marked fish were limited by the finite number of marked fish relative to the high abundance of unmarked fish (handling time), poor visibility (turbidity), high river flows and velocities, and restricted sampling intensity and frequency. Possibly many fish either did not move or were moving considerable distances beyond our sampling sites, both of which would limit recaptures. Two marked White Suckers were recaptured a substantial distance (> 4 km) upstream of Huntley Dam.

Recaptures of marked fish in the natural bypass channel at Huntley Dam suggest that some fish will use overflow channels, if available, to bypass dams during high flows. Fish passage in the overflow channels at Huntley and Intake dams was possible only during the months of high runoff (June-July), and then only during wet years. Because the inlet and outlet of the natural channel at Huntley and Intake dams were over 100 m down- and upstream of the dam, fish in the immediate vicinity of the dam would have difficulty finding the upstream entrance to this natural channel, especially at low flows. Alternative passages (natural or artificial) that extend fish passage to periods beyond high flows may greatly benefit fish populations during times when adults migrate upstream to spawning habitats and juveniles move to nursery areas and overwintering habitats.

Swimming ability may be related to fish passage, because strong swimming species (10), notably White Sucker, Shorthead Redhorse, Longnose Sucker, Goldeye, Common Carp, Brown Trout, Sauger, Walleye, Smallmouth Buffalo and Flathead Chub exhibited dam passage in this study, whereas 27 other species did not. Swimming performance of salmonids is related to species and body size, among other variables, but little is known about the swimming ability of nonsalmonids. The swimming ability and passage of nonmigratory native fishes at stream road crossings in Arkansas was inversely related to water velocity and reduced even at the normally recommended <40 cm/s. In this study, fish size did not appear to be related to fish passage because the mean size of species that passed the dam was similar to the population averages, bur too few fish were recaptured to clearly distinguish this relation.

Dams create good habitat (ambush and resting structure) for concentrating predators where they can consume migrating fish that are delayed and disoriented by barriers, spillway turbulence, and high velocity flows. Predation by squawfish and striped bass has had a significant impact on out-migrating juvenile salmonids at dams. Although we did not detect concentrations of predators at Huntley, Cartersville, or Intake dams, Burbot, Smallmouth Bass, largemouth bass, Northern Pike, and Channel Catfish may be seasonally abundant.

A single low-head dam may not constitute a major threat to fish passage, depending on its dimensions and site hydrological conditions, but a series of low-head dams may present a serious cumulative fish passage challenge that can gradually alter fish distribution and abundance, species richness, and size-structure over rime. Some fish species (bigmouth buffalo, Sauger, Blue Sucker, freshwater drum, Shovelnose Sturgeon, and paddlefish) were collected only at Cartersville and Intake dams, which suggests that their upstream distribution may be restricted by the combined impacts of Waco Custer, Ranchers Ditch, Yellowstone, and Huntley diversion dams, particularly during low-water (drought) years. Alternatively, the upstream distribution of some of these species may be limited by a combination of upstream physicochemical characteristics (water quality and habitat) and low-head barriers. Diversion dams on the Yellowstone's tributary streams further reduce fish accessibility to spawning and rearing habitat.

Alternatives for fish passage mitigation at low-head dams include (1) adding artificial riffles, although the efficacy of these on native fishes is unknown; (2) including conventional fish ladders, elevators, or locks, although these may prove to be inefficient for nonsalmonids; and (3) completing dam removal, although downstream sedimentation and other issues are concerns, Design criteria for artificial riffle passage systems are maximum drop heights, critical flow velocities, water depth, and location of inlet structure. These systems are relatively inexpensive to construct and maintain, can be integrated with natural river landscapes, and may be passable for many of the native species, including those with poor swimming abilities.

More information is needed on the cumulative effects of dams on upstream migrations and downstream dispersal of native fishes. Species-specific behavioral responses to low-head dams need to be fully explored, as does the efficiency of natural and artificial bypasses. The authors found that fish will use natural channels to bypass dams at high flows. The authors also suggest that rock riprap on the downstream face of the Yellowstone River dams promoted fish passage by creating velocity refuges and resting habitat. Enhancing natural bypass channels or creating new ones may offer cost-effective alternatives to other remedies. Considering the negative consequences of altering the natural flow regime of rivers and severing ecological connectivity with dams, and the costs associated with river restoration, new methods for promoting fish passage and for diverting irrigation water need to be explored.

Conclusions on anthropogenic effects on fish: Huntley, Cartersville, and Intake dams did not create disjunct fish populations or represent complete barriers to the passage of certain fish species, especially at high flows in wet years. At Huntley and Intake dams fish passage either over the dams or in the natural bypass channels was demonstrated for strong-swimming species (White Sucker, Longnose Sucker, Shorthead Redhorse, Common Carp, Goldeye, Flathead Chub, Walleye, Sauger, Smallmouth Buffalo, and Brown Trout) during high flows. However, fish passage may be inhibited or precluded for other species and at other seasons and during dry years. At Huntley Dam White Sucker and Shorthead Redhorse passed the dam in a downstream direction. Distribution patterns suggest that upstream passage may be restricted by the series of dams. Although this study demonstrated that some upstream passage occurred, the amount of passage over or around diversion dams in comparison to the expected movement had the dam not been present was not estimated. Therefore the magnitude of potential limitation of movement caused by diversion dams on the Yellowstone River remains unknown.

Spatial fisheries information: Diversion dams are identified by river kilometer. Fish sampling sites are spatially identified only as being above or below diversion dams.

BMP implications: The effects of diversion dams on the ecological connectivity of the six Yellowstone River diversion dams is not well understood. The degree of mitigation by natural or artificial bypass channels is also unknown. Research that quantifies the ecological and population effects of the diversion dams would enable managers to assess priorities and develop mitigation strategies. The installation of additional diversion dams would have uncertain consequences on the Yellowstone River fish assemblage.

Scientific rigor: High; this is a published, peer-reviewed study. However, the study is limited in the amount of passage over or around diversion dams in comparison to the expected movement had the dam not been present was not estimated. Therefore the magnitude of potential limitation of movement caused by diversion dams on the Yellowstone River remains unknown.

Title: Comparative Use of Modified and Natural Habitats of the Upper Yellowstone River by Juvenile Salmonids

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Goal: To assess the extent to which changes in aquatic habitats caused by bank stabilization (riprap revetment), (flow deflection barbs, jetties, spur dikes, and fish groins), and flow confinement structures (berms, levees, or dikes) affect juvenile salmonid habitat in the upper Yellowstone River.

Objectives: 1. Compare juvenile salmonid use of altered bank habitats to use of natural, unaltered bank habitats on the upper Yellowstone River; and 2. Determine juvenile salmonid use of lateral, ephemeral side-channel habitats during periods of high runoff on the upper Yellowstone River.

Study area: Reach 1: Yellowstone River from Mallard's Rest Fishing Access Site to 450 m upstream of Nelson's Spring Creek (10.7 river km, but with a 2.4-km reach from Pine Creek bridge downstream omitted), Reach 2: from Carter's Bridge Fishing Access Site downstream to Mayor's Landing Fishing Access Site (8.1 river km).

Methods: This study included two study components: a *Comparative Use Study* and a *Side Channel Study*.

Comparative Use Study: Six bank types were identified (inside bend, outside bend, straight, riprap, jetty, barb). Eight sites of each of the six bank types were randomly selected in Reach 1, and six sites of each bank type were randomly selected in Reach 2. Each site consisted of a 50-m long reach of shoreline. There were 48 sites and 470 samples total. Fish were sampled using electrofishing in spring, summer, and fall of 2001 and 2002. Only juvenile (age-0) salmonids were considered in the analysis.

Fish abundances (expressed as number of juvenile salmonids captured at each 50-m site) were tested for significant differences.

Habitat (water velocity, water depth, sample-area width, and substrate) was measured at 1-m intervals along six transects at continuous-shoreline sites and at 7 transects at deflection structure sites.

Side Channel Study: Eleven and 15 ephemeral side channel sites were sampled in May 2001 and May 2002, respectively, using 3 or 4-pass backpack electrofishing.

Results: *Comparative Use Study*: 2,415 juvenile Rainbow Trout (66.7%), 932 juvenile Brown Trout (25.8%), 169 juvenile Mountain Whitefish (4.7%), 102 juvenile Yellowstone Cutthroat

Trout (2.8%), and 1 juvenile brook trout (< 0.1%) were captured. Mean capture probability was 0.743 and did not vary significantly among bank types.

Mean numbers of Rainbow Trout captured were significantly higher at riprap sites (8.304) than at any other bank type, except jetty sites (7.692). Rainbow trout mean catch was significantly lower at inside bends (0.769) than at any other bank type, and second lowest at straight reaches (3.359). Mean Rainbow Trout catch was not significantly different at outside bends (5.684), barbs (4.974), and jetties (7.692).

Juvenile Brown Trout abundance at outside bends and jetties was lower in Reach 2 than in Reach 1, so each reach was analyzed with ANOVA separately. "In Reach 1, mean abundances at inside bends (0.354) and straight sections (1.229) were lowest. Mean abundances at barbs (1.896), outside bends (2.313), jetties (3.250), and riprap (3.625) were not significantly different. In Reach 2, mean abundances at inside bends (0.133) and outside bends (0.774) were lowest, but mean abundances at jetties (1.400) and straight sections (2.233) were not significantly higher than at outside bends. Mean abundance at barbs (2.333) was significantly higher than at outside bends, but was not significantly different from mean abundances at jetties and straight sections. Mean abundance was highest in riprap (3.774), but was not significantly different from abundances at barbs and straight sections."

For all trout species combined, "mean abundance at inside bends (1.038) was lowest, followed by straight sections (5.103). Mean abundances at barbs (7.436) and outside bends (7.747) were not significantly different. Mean abundance at jetties (10.449) was not significantly different from mean abundances at barbs or riprap (12.203), but abundance at riprap was significantly higher than at barbs. Abundances were significantly different among seasons ($P < 0.0001$) and between reaches ($P < 0.0001$) but not between years ($P = 0.5614$)."

Inclusion of Mountain Whitefish in the analysis resulted in essentially the same conclusions for Rainbow Trout abundances and for all salmonids in aggregate.

Side Channel Study: Use of ephemeral side channels by juvenile Mountain Whitefish and trout was extensive and colonization of inundated side channels was rapid. Fish were observed moving into side channels as they filled, although side channels were flowing only 3 to 10 days in 2001 and 7 to 21 days in 2002. On average, each 50-m sample unit contained about 6.3 juvenile trout and 8.9 juvenile Mountain Whitefish.

Discussion: *Comparative Use Study*: In general, juvenile salmonid use of barbs and jetties was similar to that of natural outside bends, and use of riprap sections was higher than that of natural outside bends. Bank stabilization does not *directly* decrease juvenile salmonid habitat along the main channel of the upper Yellowstone River, therefore juvenile salmonid recruitment from main-channel habitats should not be affected by bank stabilization. However, indirect, geomorphically-derived effects of bank stabilization (e.g., incision, aggradation, changes in bank lengths) may affect juvenile salmonid habitat, but evaluation of such effects were outside the scope of the study design.

This is in contrast to the findings of other studies in coldwater streams, most of which showed negative effects on fish. The simplest explanation is that at present most natural banks in the study area are structurally simple and are poor juvenile salmonid habitat, and that bank stabilization increases habitat complexity and roughness which attracts juvenile salmonids. The effects of bank stabilization are probably site-specific. In rivers with simple or degraded habitats, artificial structures may increase habitat diversity and be beneficial for fish. Conversely, where natural habitats are structurally heterogeneous, artificial structures may decrease habitat diversity and value for fish.

An important consideration for evaluating the effects of bank stabilization is where juvenile habitat exists and whether juvenile habitat is limiting. In the Yellowstone River, this study documented an overall mean of 7.3 juvenile salmonids per 50-m reach at main-channel sites. This is substantially lower than juvenile abundances in the Henry's Fork, Ruby River, and Poindexter Slough. Therefore, it seems probably that main-channel banks are not especially important juvenile-rearing habitats and that recruitment occurs from other habitats such as tributary streams, spring creeks, and upstream reaches, or side channels, backwaters, and other off-channel habitats. This study was limited in that they did not know how important main-channel banks were to recruitment of salmonids to the Yellowstone River. A comprehensive assessment of recruitment dynamics of salmonids in the upper Yellowstone River would provide managers with an understanding of which habitats (e.g., tributaries, spring creeks, backwaters, side channels, upstream reaches) actually produce the juvenile fish that later become catchable adults and therefore may require protection.

Also not known was the relative importance of juvenile recruitment in maintaining salmonid populations, compared to other factors such as habitat and food for sub-adult and adult fish, as well as spawning habitat. If bank stabilization negatively affects any of these important life history components, the fact that bank stabilization did not limit main-channel habitat for juvenile salmonids may be irrelevant. The low densities of juvenile salmonids along main-channel banks may have been related to the scarcity of large woody debris. It was not known whether this scarcity is natural, indicative of an altered river, or an anomaly caused by the 1996 and 1997 floods. Further, all non-salmonid fish were ignored. Because of these limitations, the authors stress that their findings should not be construed to mean that bank stabilization is "good for fish" in general. The authors say that the adult salmonid abundance monitoring conducted by Montana Fish, Wildlife, and Parks is an effective means to detect whether changes in adult salmonid abundances are occurring.

Side Channel Study: Side channels may be important natural nursery areas for juvenile salmonids, considering the relative paucity of boulders, large woody debris, and other cover and roughness elements along the main-channel banks of the upper Yellowstone River. Moreover, side channels provide shallow slow current velocity habitat during runoff when such habitat is negligible in the main channel.

It is not possible to compare and evaluate the relative importance of side channels and main-channel banks because the data were collected following different sampling approaches. The side channel sampling was 3 or 4-pass backpack electrofishing depletion sampling; this produced estimates of absolute abundance and densities. The main-channel bank sampling was single pass boat-based electrofishing; this produced number of fish per 50-m sampling reach data. However, it was apparent that juvenile salmonid densities in side channels was not exceptional, but juvenile salmonids, especially Mountain Whitefish, rapidly occupied side channels upon inundation. Because this study was conducted during low-water years, periods of side-channel inundation were only 3 to 21 days. The short inundation period coupled with the relatively high densities of juvenile salmonids suggests that when available, side channels are important habitats for juvenile salmonids.

Conclusions on anthropogenic effects on fish: Juvenile salmonid recruitment from main-channel habitats was probably not negatively affected by incremental increases in bank stabilization. However, the amount of recruitment from main-channel banks relative to recruitment from other areas such as side channels, backwaters, and tributaries is not known. Habitat modifications that reduce the frequency or duration of side-channel inundation, or reduce side channel formation rates, would probably decrease juvenile salmonid habitat and possibly recruitment.

Spatial fisheries information: The UTMs of all sampled shoreline sites and side channels are listed in the appendix. The number and density of juvenile trout and aggregate juvenile salmonids is listed for shoreline sites and side channels. The two study reaches are identified by listing their locations relative to landmarks such as Mallard's Rest Fishing Access Site (FAS), Nelson's Spring Creek, Carter's Bridge FAS, and Mayor's Landing FAS.

BMP implications: Preserve presence of side channels. Preserve geomorphic processes that facilitate and maintain side-channel creation, maintenance, and inundation, i.e. no diking of side channels, maintaining streambed elevation, preventing non-equilibrium streambed degradation, allowing lateral channel migration, prevent dewatering that lowers river stage and dewaters side channels. Consider research to determine the role of main-channel bank modifications on side channel side-channel creation, maintenance, and inundation.

Continue to monitor trends in adult salmonid density. If declines become evident, consider research to determine density bottlenecks, "a comprehensive assessment of recruitment dynamics of salmonids in the upper Yellowstone River system would provide managers with an understanding of which habitats (e.g., tributaries, spring creeks, backwaters, side channels, upstream reaches) actually produce the juvenile fish that later become catchable adults and therefore may require protection." Other research needs identified by the authors were: "additional sampling during years with higher discharges, both along main-channel banks and in side channels, would allow inference about the applicability of our findings under more normal conditions. Second, assessment of the effects of bank stabilization on non-game fishes, macroinvertebrates, and adult and sub-adult salmonids would provide a more holistic assessment of this issue."

Scientific rigor: Moderate. Although not published in the primary literature, this report was reviewed by Charles Dalby, Montana Department of Natural Resources and Conservation, Robert Hazlewood, U.S. Fish and Wildlife Service, Bradley B. Shepard, Robert S. Nebel, U.S. Army Corps of Engineers, and Michael Merigliano, University of Montana. Inference is based on statistical significance testing.

Title: Effects of Channel Modification on Fish Habitat in the Upper Yellowstone River Final Report to the USACE, Omaha. Open-File Report 03-476.

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Goal: The goal of the fish habitat study was to evaluate the effects of channel modification on shallow depth, slow current velocity (SSCV) habitat.

Objectives:

The specific research questions were:

1. Do different levels of channel modification change the amount or distribution of SSCV habitat at different sites?

2. Does availability of SSCV habitat vary among sections of river with different types of modified and unmodified banks?

3. How important is large woody debris in creating SSCV habitat?

4. What is the relative importance of main channel SSCV habitats compared to SSCV habitat available in side channels and other areas?

Study area: Habitat mapping and modeling work was conducted in three reaches that were selected to (1) represent the geomorphic setting where channel modification occurred or was likely to occur; (2) include different levels of intensity of channel modification; and (3) coincide with study reaches sampled during the fish population study. All study reaches were classified as being a wandering gravel-bed channel type. Reach one (named AA) started just downstream from Mallard's Rest Fishing Access and ended about 100 m upstream from the Pine Creek Bridge (river km 826.6 to 822.4). Reach two (TECCA) started downstream from Pine Creek Bridge and ended upstream from the confluence of Nelson's Spring Creek (river km 819.8 to 815.6). Reach three (Livingston, LVG) extended from just above Siebeck-9th Street Island to the Highway 89 Bridge (river km 806.3 to 800.0; Fig. 1).

Methods: As a general procedure, we used a two-dimensional hydrodynamic simulation model and a geographic information system (GIS) to generate habitat classification maps of each study reach for discharges typical during base flow (42 m3/s), snowmelt runoff (680 m3/s), and recession (142 m3/s). Names for flow rates associated with modeling work (base flow, runoff, and recession) were selected to orient the reader to the hydrologic cycle. Model results apply to flow rates regardless of their timing in the year. Each site was subdivided into bank types: straight, outside bend, point bar, inside bend, overbank, side channel, riprap, barb, and jetty.

The authors used output from the hydrodynamic model and the bank type map in a GIS to determine the amount and distribution of SSCV habitat (ca. < 90 cm deep, < 45 cm/s velocity; < 3.0 ft deep, < 1.5 ft/s) among modified and unmodified river sections. The definition for SSCV habitat used in this study was based on habitat data from recent fish collections in the upper Yellowstone River (Al Zale, personal communication).

Results: *Channel Modification and SSCV Habitat among Sites*: In all three reaches as discharge increased, the total area inundated increased, the percent of the site classified as modified decreased, and the amount of SSCV habitat increased. The LVG reach had roughly double the amount of modification of either the AA or TECCA reach. The area of SSCV habitat per km was about the same at all three sites at the two lower discharges, but differed considerably at bankfull flow. At base flow (~42 m3/s), normalized SSCV was highest at LVG, but was lowest there at bankfull flow (~680 m3/s). Normalized SSCV varied by about 44% at LVG, by over 500% at TECCA and by 200% at AA for the same range of discharges. At bankfull flow, the amount of SSCV was highest at the two sites with the least amount of channel modification. Normalized SSCV at TECCA was 11.3 ha/km, compared to 5.91 ha/km at AA, and 4.21 ha/km at LVG.

Availability of SSCV Habitat Among Bank Types: At base flow, SSCV habitat was predominantly associated with unmodified main channel locations at TECCA and LVG (78% and 58%, respectively) and in side channels at AA (50%, Fig. 15). At all three sites, the proportion of SSCV habitat associated with unmodified main channel areas exceeded the proportion associated with modified banks. LVG had the highest proportion of SSCV habitat associated with modified banks of all the sites, at 19%. The basic pattern of SSCV distribution during recession was similar to that observed at base flow. However, the amount of SSCV occurring in side channels, point bars, and overbank areas was greater at the recession flow than at base flow; the relative contribution of modified channel areas to the total area of SSCV habitat remained small. Unlike the base flow scenario, however, the distribution of SSCV habitat appeared to be divided nearly evenly between main channel (modified and unmodified) and off channel areas.

The distribution of SSCV habitat at bankfull discharge was substantially different from the two lower discharges. At all three sites, nearly all the SSCV habitat occurred in locations other than the main channel. Slow, shallow habitat areas tended to be concentrated the most in overbank areas and side channels. Modified main channel areas appeared to be less significant contributors of SSCV habitat at bankfull discharge than at the lower flows.

Contribution of SSCV Attributable to Large Woody Debris: Deposits of LWD tended to be concentrated on point bars and overbank areas where they were inundated only at relatively high discharges. Consequently, LWD and willow thickets were relatively ineffective in creating SSCV habitat at low flows but provided modest increments at higher discharges. The largest accretions of SSCV attributable to LWD occurred at the TECCA site at bankfull flow, with an addition of 0.96 ha/km. The largest proportional contribution of SSCV occurred at LVG at bankfull discharge, with LWD accounting for 22% of the total SSCV area. At the other two sites, LWD accounted less than 10% of the bankfull SSCV habitat.

Contribution of SSCV Attributable to AA Barb Field: Simulation of the AA reach barb field showed the velocity patterns near the shore are substantially altered by the addition of projecting structures such as barbs. These results show the barbs are acting as intended. High velocities are being directed away from the bank, and the bank areas between barbs experience low near-shore velocities, often with an eddy producing low upstream velocities.

The accretion of SSCV habitat attributable to the barb field at AA was negligible at all simulated discharges. The SSCV contribution by LWD in the AA site was more than an order of magnitude greater than the contribution from the barb field at bankfull flow.

Comparison of Main Channel and Off-Channel SSCV Habitats: Most of the SSCV habitat at all three sites occurred in main channel locations at low flows and in off-channel areas at bankfull flow. Compared to base flow, the area at bankfull flow was about 50% greater at LVG, twice as large at AA, and five times greater at TECCA. At bankfull discharge, main channel areas contributed negligible amounts of SSCV habitat at all three sites, compared to side channel and overbank areas. Side channels, point bars, and overbank areas accounted for 97% of the SSCV habitat at AA, 95% at TECCA, and 90% at LVG. During a typical runoff discharge, main channel areas were dominated by high water velocities and large depths compared to overbank and side channel areas. These results highlight the importance of side channels and overbank as areas of SSCV habitat, particularly at higher discharges when the probability of downstream displacement for juvenile fish in main channel habitats is highest.

Discussion: At base flow, most SSCV occurred at unmodified bank types. However, the fisheries study by Zale and Rider found that juvenile salmonids were more abundant at modified banks than at unmodified banks. This suggests than factors other than hydraulic shelter influenced use of river banks by juvenile salmonids. Factors contributing to higher juvenile salmonid abundance along modified banks with boulder substrates may include increased visual isolation, predator avoidance, and habitat diversity.

Young-of-the-year fish are susceptible to displacement because of their small size and poor swimming ability. Emergence through runoff is a critical time, because the fish are small then and high current velocities are prevalent in certain habitats. Therefore, young-of-the-year fish often use SSCV habitats as refugia or nursery areas. During runoff, most SSCV habitat is located in side channels and overbank areas. Concordantly, Zale and Rider found that juvenile salmonids occupied ephemeral side channels as soon as they became inundated and that juvenile abundances increased with duration of side channel inundation.

SSCV habitat was more extensive at the upstream sites than at the Livingston site during runoff because the Livingston reach was laterally constrained and had reduced availability of side channels and overbank areas. The Livingston reach was constrained by a high-elevation valley wall on the east and riprap and levees on the west. In contrast, the two upper reaches had vast areas of SSCV habitat occurring in off-channel locations, either in ephemeral side channels, over inundated islands, or on the floodplain.

Large amounts of SSCV habitat occurred in side channels and overbank areas at flows ranging from bankfull to as low as 142 m3/s, indicating that SSCV habitat persists during runoff periods. Therefore, SSCV habitat are likely to be available for colonization by young salmonids, regardless of the discharge during the critical runoff period. This persistence can be largely attributed to a diversity of elevations in the braided portions of the Yellowstone River, i.e., multiple channels, point bars, islands, and floodplains that lie at different elevations relative to one another. The location of SSCV patches shifts with changing discharge, from overbank areas and side channels during high flows, and eventually to the main channel as discharge approaches base flow.

SSCV habitat was less persistent in confined channels where the wetted perimeter associated with a river cross-section increases less with stage increases than in an unconfined reach. Generally, in confined reaches as flow increases, shallow or slow water habitat is associated with the channel margins; mostly as a thin strip along the river margin at all but the lowest discharges. As a result the availability of SSCV habitat much more responsive to changes in discharge. At high flows, the marginal strip of SSCV is very narrow and at lower flows, it is broader.

The habitat dynamics associated with channel confinement can influence fish populations by affecting survival of early life stages. Studies of fish populations in confined rivers have revealed that (1) the adult fish population tends to be recruitment-driven, and (2) the number of recruits is highly correlated with the discharge and amount of available SSCV habitat during the runoff period. Thus, year class strength is typically very low in years of above-average runoff, but considerably larger during drought years when runoff is less.

Our study focused on availability of shallow, slow current velocity habitat because of its importance as a refugium and nursery for juvenile salmonids, particularly during periods of high discharge. Other habitat requirements include spawning habitat, adult habitat, and overwintering habitat. Populations of trout can be limited by a deficiency in any of these. Flow regime, especially summer low flows, are important in determining trout biomass. Low flows during summer that result in dewatering of important habitats, increased water temperature, or adverse effects on water quality could affect survival or limit carrying capacity. Similarly, the condition of fish at the beginning of winter and availability of overwintering habitat are very important in determining overwinter survival. Additional research and population monitoring should strive to determine which factors, including physical habitat, are most directly regulating numbers of adult salmonids.

Management Implications: The combined results from the fish population and fish habitat studies present strong evidence that during runoff, SSCV habitat is most abundant in side channel and overbank areas and that juvenile salmonids use these habitats as refugia. Channel modifications that result in reduced availability of side channel and overbank habitats, especially during runoff, will probably cause local reductions in juvenile abundances during the runoff period. The effect of local reductions during runoff on adult numbers later in the year will depend on the extent of channel modification, patterns of fish displacement and movement, longitudinal connectivity between reaches that contain refugia and those that do not, and the relative importance of other potential limiting factors.

River confinement, in itself, will probably not result in elimination of the trout population of the upper Yellowstone River. As the amount of confinement increases, however, we expect a concomitant reduction in the area and persistence of SSCV habitat. As the availability of SSCV habitat becomes more and more responsive to changes in discharge, we postulate that salmonid population dynamics will become more variable over time. The authors would expect the trout populations of the upper Yellowstone to become more recruitment-driven and more responsive to conditions during runoff, as has been observed in other confined trout streams.

This study intensively examined SSCV habitat availability at three representative study reaches. Additional ongoing research is using coarser grain data to evaluate SSCV habitat availability over a range of flood discharges within the study corridor from Point of Rocks to Mission Creek. This ongoing second phase will help provide context for the intensive fish habitat study as well as provide a measure of habitat availability in different channel types over a large, continuous reach. The extensive SSCV habitat evaluation and habitat maps will also serve as a foundation for integrated analyses of results from other studies conducted as part of the overall cumulative effects investigation.

Conclusions on anthropogenic effects on fish: This study demonstrated that SSCV area increases with increasing discharge and peaks during peak runoff. It appears that the juvenile salmonid's biological needs and the physical habitat conditions are synchronized. The highest abundance of YOY salmonids, which are small and weak swimmers, coincides with high SSCV habitat availability in side channels and overbank areas, when main channel habitats have the highest prevalence of fast and deep water. However, anthropogenic bank modifications increase lateral river confinement, decrease side channel and overbank SSCV area, thereby reducing the overall amount of SSCV habitat availability.

SSCV availability was lowest in the Livingston reach, which was also the reach that was the most anthropogenically modified. The Livingston reach is naturally confined on the east bank by a high valley wall and confined on the west bank by levees and riprap. As a result, the Livingston reach had the lowest overall SSCV area, because this reach generally had less SSCV attributable to side channels and overbank areas, particularly during bankfull flows. The Livingston reach also had the highest proportion of SSCV attributable to modified banks, which may be important habitats for juvenile salmonids. However, Zale and Rider also stress the importance of side channels as important juvenile salmonid habitat, and side channel area has probably been lost in the Livingston reach. Lateral confinement probably also reduces large woody debris recruitment which provides modest amounts (8% to 22%) of SSCV during high flows.

The inference of this study with regard to effects on fish is based on the assumption that SSCV is an important habitat component for juvenile salmonids, and in particular YOY salmonids during runoff. There is substantial basis for this assumption in the literature; moreover the fisheries research project that accompanied this work supports the assumption in this particular setting. As noted by the authors, "Effects of reduced juvenile abundances during runoff on adult numbers later in the year will depend on (1) the extent of channel modification, (2) patterns of fish displacement and movement, (3) longitudinal connectivity between reaches that contain refugia and those that do not, and (4) the relative importance of other limiting factors."

Spatial fisheries information: All of the habitat mapping and modelling including habitat class distribution maps, bank type classification maps and stream power maps was spatially explicit. However, actual X Y coordinates are not listed in this report. The U.S. Geological Survey, Fort Collins Science Center probably has spatial data associated with this project. The three study reaches are identified by listing their locations relative to landmarks such as Mallard's Rest Fishing Access Site (FAS), Nelson's Spring Creek, Carter's Bridge FAS, and Mayor's Landing FAS.

BMP implications: Preserve SSCV habitat by preserving presence of side channels and access of peak runoff flows to overbank floodplain areas. Preserve geomorphic processes that facilitate and maintain side-channel creation, maintenance, and inundation, i.e. no diking of side channels, maintaining streambed elevation, preventing non-equilibrium streambed degradation, allowing lateral channel migration, prevent dewatering that lowers river stage and dewaters side channels. Preserve geomorphic and successional processes that continue to provide recruitment of large woody debris to the active river channel. Minimize stochastic annual discharge-related fish recruitment dynamics by preserving side channel and overbank SSCV habitats.

Scientific rigor: Moderate. Although not published in the primary literature, "various versions of the content in this report were commented on by Al Zale, Brad Shepard, Chuck Dalby, and numerous others who remain anonymous". Results of this study consist mostly of output from a two-dimensional hydrodynamic simulation model and a geographic information system. The authors are recognized experts in modelling river habitats using this approach.

Title: Effects of Flow Regulation on Shallow-Water Habitat Dynamics and Floodplain Connectivity

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Abstract: Our study examined the effects of flow regulation on the spatiotemporal availability of shallow habitat patches with slow current velocity (SSCV patches) and floodplain inundation in the unregulated Yellowstone River and the regulated Missouri River in Montana and North Dakota. The authors mapped representative sites and used hydraulic models and hydrograph data to describe the frequency and extent of floodplain inundation and the availability of SSCV habitat over time during different water years. In the Yellowstone River the distribution, location, and size of SSCV patches varied but followed an annual pattern that was tied to the snowmelt runoff hydrograph. There was less variation in patch distribution in the Missouri River, and the pattern of habitat availability was influenced by flow regulation. Regulated flows and their effects on channel morphology and patterns of vegetation establishment resulted in 3.0–3.5 times less area of inundated woody vegetation during normal and dry years in the Missouri River compared with the Yellowstone River. The differences we observed in SSCV patch dynamics between rivers may have implications for fish populations and community structure through affecting the survival of early life stages. At a larger scale, the smaller area of vegetation inundated in the Missouri River suggests that nutrient cycling and the ecological benefits associated with a moving littoral zone are reduced by the altered flow and sediment regime in that river. Accurate assessments of the effects of flow alteration and successful efforts to restore riverine ecosystems will require consideration of physical and biotic processes that operate at multiple spatial and temporal scales.

Introduction: The character and persistence of large-river ecosystems are increasingly dependent on flow management and other human activities in river corridors. Human-induced changes in the river corridor and the fluvial geomorphological responses that follow disrupt functions that support healthy river ecosystems. Understanding how flow alteration affects large river ecosystems is particularly important given the level of alteration along most large alluvial rivers. Although the long-term viability of a species may be regulated by different factors at different life stages, poor recruitment arising from a lack of shallow-depth, slow-current-velocity (SSCV) habitat is a habitat-related bottleneck for many fish species. In this study we used the general tenets of patch dynamics and flood pulse concepts to guide an analysis of spatiotemporal variation in physical habitat in flow-regulated and unregulated reaches of two Great Plains rivers in the United States. Our study examined the effects of flow regulation on the spatiotemporal availability of SSCV habitat patches and floodplain inundation.

Goal: Examine the effects of flow regulation on the spatiotemporal availability of SSCV habitat patches and floodplain inundation.

Objectives: Compare spatiotemporal availability of SSCV patches and floodplain inundation in the unregulated Yellowstone River and in the regulated Missouri River in Montana.

Discuss the potential effects of changes in patch dynamics and floodplain inundation on fish communities.

Study area: The lower 114 km of the Yellowstone River, from the Missouri River confluence upstream to a low-head diversion dam at Intake, Montana, and a segment of the Missouri River extending from the Yellowstone confluence 260 km upstream to Fort Peck Dam, Montana. The lower Yellowstone River was represented by three study sites, Fairview, North Dakota, and Elk Island and Intake, Montana. Two sites, at Frazer and Culbertson, Montana, were used to describe the Missouri River study segment.

Methods: As a general procedure, we used a two-dimensional hydrodynamic simulation model and a geographical information systems (GIS) approach to generate habitat classification maps of each site for flows ranging from about 28 m3/s (1,000 cubic feet per second [cfs]) to more than 2,800 m3/s (100,000 cfs). The authors analyzed the distribution of SSCV habitat (depth less than 1 m, velocity less than 0.25 m/s) among seven mesohabitats within each study site: main channel, main-channel margin, secondary channels, secondary-channel margins, sand bars, vegetated islands, and floodplain. Floodplain connectivity was evaluated by quantifying the area of tree canopy in the inundation zone (CIZ) at various discharges. This method was chosen because semipermanent vegetation is a source of allochthonous nutrient input, provides structural cover for small fish, and is correlated with the extent of the present-day floodplain. The authors based the habitat time series analysis on the daily discharge records for water years 1997–2000.

Results:

Normalized class area

During recession and base-flow periods, average area of SSCV habitat was 47% greater in the Yellowstone River than the Missouri River, and about double that available during runoff. However, during rising and falling hydrograph limbs in the Yellowstone River, SSCV area decreased and then rebounded rapidly as stage increased further. Within the range of 500–2,000 m3/s (17,657-38,846 cfs), the flow was too deep or swift to provide SSCV habitat within the main channel. Once the side channels and islands became inundated by further rises in stage, the amount of SSCV area increased rapidly. A similar decrease in SSCV with increasing discharge was seen on the Missouri when excess storage was released from Fort Peck dam.

Patch Density and Mean Patch Size

On the Yellowstone River patch density and size varied with hydroperiod. Patch size was larger during recession and base-flow, whereas during runoff, patch size decreased and patch density increased. On the Missouri river, patch density and size were consistent across hydroperiod, because flows were relatively constant.

Spatial distribution of SSCV habitat

Spatial distribution of SSCV varied between the rivers, between the phases of the hydrograph, and also between wet years and dry years. During runoff on the Yellowstone in a wet year, SSCV was found in side-channel margins, vegetated islands, and floodplains. As flow receded, SSCV migrated and expanded into side channels, bars, and margins of vegetated islands. At base flow, SSCV migrated away from small side channels into the main channel and large side channels. On the Missouri, spatial distribution of SSCV was more constant; base flow SSCV was found primarily over large sand bars. In normal and dry water years, runoff SSCV on the Yellowstone was more associated with side channels and channel margins, whereas recession and base flow SSCV distribution was similar to that during the wet year.

Floodplain connectivity

The Yellowstone River had 3.0 to 6.4 time more floodplain connectivity (as measured by canopy area in inundation zone; CIZ) than the Missouri River.

Discussion: Due to the regulation of flow and sediment the Missouri River has degraded bed elevations and reduced channel migration, resulting in different channel dynamics and vegetation succession. However, the study was limited in that there was no pre-dam data for the Missouri River, and the number of representative reaches studied was limited to two on the Missouri River and three on the Yellowstone River.

On the Yellowstone River there was a consistent temporal sequence of SSCV patch dynamics. During the rising limb, SSCV patches were smaller but more abundant, and located primarily in side channels and back-flooded tributaries. At peak flow, SSCV was also over vegetated islands, and flowed a moving littoral zone, but was not common in over-bank floodplain. Flooding of vegetated island and side channels where leaf litter accumulated provided organic material to the river. During the recession and base-flow periods, SSCV migrated into the main channel and large side channels and formed large patches. SSCV area during recession and base flow about double that available during runoff.

In the Missouri River, SSCV was relatively static in location, size, and patch number. SSCV also occurred less often in vegetated areas, except during releases of excess storage during base flow; the unusual timing of energy exports probably reduced ecological benefits to organisms adapted to a natural flow regime.

The Yellowstone River had more inundation of vegetated areas, therefore more floodplain interaction. This was probably due to higher discharges on the Yellowstone River, rather than any differences in canopy area between the two rivers.

On the Yellowstone River, the dynamics of SSCV and floodplain interaction probably benefitted the growth and survival of small fish. Nutrients, invertebrates, and organic debris are exported from vegetated inundated areas. Small fish may benefit from increased habitat diversity within SSCV patches as SSCV patch size increases during recession and base flow. Such habitat diversity and increased SSCV patch size may allow for increased segregation of species and sizes of fish, thereby decreasing potential competition and predation risk.

On the Missouri River, SSCV patches were less dynamic and there was less floodplain interaction because there was little variation in discharge. This potentially results in less nutrient and food export, less SSCV habitat diversity, and less reduction in competition and predation.

Conclusions: Changes in flow and sediment regime in the Missouri River since the closure of Fort Peck Dam have altered river geomorphology downstream. The authors postulate that the interrelated effects of changes in geomorphology and altered flow regime contributed to differences in the dynamics of SSVC habitat patches and the extent of floodplain inundation between the Missouri and Yellowstone rivers. In the Yellowstone River, the distribution, location, and size of SSCV patches followed an annual pattern tied to the snowmelt runoff hydrograph: small, dispersed patches in side channels and tributary backwaters migrated to the main channel during recession and formed large, contiguous patches. Because of relatively constant discharge, variation in mean patch size, patch density, and location of patches was smaller in the Missouri River than in the Yellowstone River. Similarly, more consistent flows, and their effects on channel morphology and patterns of vegetation establishment resulted in 3.0–3.5 times less area of inundated woody vegetation during normal and dry years in the Missouri River than in the Yellowstone River. Based on evidence from other studies, the differences we observed in SSCV patch dynamics between the two rivers may have implications for fish populations and community structure by affecting the survival of early life stages. At a larger scale, the smaller area of inundated canopy in the Missouri River than in the Yellowstone suggests that nutrient cycling and ecological benefits associated with a moving littoral zone are reduced by alteration in flow and sediment regime in the Missouri River.

Conclusions on anthropogenic effects on fish: Fort Peck dam altered the hydrograph and sediment delivery, and caused channel degradation on the Missouri River. This alterations affected the spatiotemporal dynamics of shallow-depth slow-current-velocity (SSCV) habitats, and reduced vegetated floodplain inundation. Although this study did not directly assess fish populations, there is strong support from the literature that SSCV is a key habitat feature for riverine fishes, particularly larval and small fishes Moreover, the literature supports the concept that vegetated floodplain inundation facilitates the export of energy sources to a river. Therefore, it is reasonable to conclude that Fort Peck dam has probably caused substantial changes in the Missouri River fish assemblage.

Although the Yellowstone River does not have a main stem impoundment, two major Yellowstone River tributaries, the Bighorn and Tongue rivers, are impounded, and this probably influences the spatiotemporal dynamics of SSCV habitats and vegetated floodplain inundation on the Yellowstone River. Therefore, effects of Yellowstone River tributary impoundment may be similar to, but less extreme than those seen on the Missouri River. Specifically, the present-day Yellowstone River may have less variation in mean patch size, patch density, and location of patches, as well as less area of inundated woody vegetation than the pre-settlement Yellowstone River. Bank stabilization and construction of levees and floodplain dikes have probably also reduced Yellowstone River SSCV dynamics and floodplain interaction. Because the Yellowstone River biota evolved within a setting of snowmelt-driven hydrology and a river corridor absent of lateral constraints, it is reasonable to assume that any anthropogenic alterations to the fluvial geomorphic processes have affected the riverine ecosystem and its native fishes. The amount of change in fish assemblages is difficult to estimate, it is likely that fish distributions and abundances have changed, but unlikely that any fish species have been extirpated.

Spatial fisheries information: Although there is no fisheries information per se presented in this paper, the locations and lengths of the three Yellowstone River study sites and the two Missouri River study sites are identified by river kilometer.

BMP implications: Damming the Yellowstone River or otherwise altering the snowmelt runoff hydrograph or sediment dynamics would severely alter SSCV patch dynamics and floodplain interaction. This in turn would likely have negative effects on native fish survival and growth, particularly for juvenile fishes.

Preserve or restore side channels, vegetated islands, and tributary confluences; these provide SSCV habitat during runoff and peak flows.

Preserve or restore main channel and large side channel habitats; these provide large patches of diverse SSCV habitat during recession and base flows.

Vegetated islands and side channels that are periodically inundated provide energy such as nutrients, zooplankton, terrestrial and benthic invertebrates, and organic debris to main channel habitats.

Preserve dynamic fluvial geomorphologic processes that create and maintain diverse riverscapes.

Scientific rigor: High. This paper is peer-reviewed and published in the primary literature. Results of this study consist mostly of output from a two-dimensional hydrodynamic simulation model and a geographic information system. The authors are recognized experts in modelling river habitats using this approach. There is no statistical testing associated with output of these models; model output results are compared between the two rivers and during differing discharges.

Title: Movements and habitat use of Yellowstone River native fishes and reptiles and nesting distributions of native birds

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Date published: 2008

Introduction: The Yellowstone River is the longest free-flowing river in the contiguous United States, supports eight state-listed species of special concern, one federally-listed endangered species, and is a tier I Aquatic Conservation Focus Area in Montana Fish, Wildlife, and Parks Comprehensive Fish and Wildlife Conservation Strategy (CFWCS). Effective management is restricted by sparse information on Blue Sucker, Channel Catfish, Burbot, Shovelnose Sturgeon, Spiny Softshells, and Bald Eagles.

Blue Sucker in the Yellowstone River are potentially threatened by restriction of movements by diversion dams and chronic dewatering of tributaries, but information gaps regarding basic ecology prevent assessment of the extent of habitat disruption. Spawning in the Yellowstone drainage is thought to occur primarily in the Tongue River, although this area may have been lost as a result of dewatering during spawning periods. Recent studies indicate adult Blue Sucker may now inhabit the Yellowstone River only during non-spawning periods, and spawning and rearing habitats may have been eliminated.

Effective management of Channel Catfish and Burbot is limited by a lack of information. It appears that there are fewer juvenile Channel Catfish proceeding upstream past Cartersville Diversion and that this trend intensifies upstream of the four diversion dams above Cartersville Diversion Dam. The lack of juvenile Channel Catfish above Cartersville Diversion Dam suggests that the diversion dams are size-selective barriers and that suitable spawning and rearing habitat may not exist in these reaches. Moreover, routine sampling in these reaches indicates that Channel Catfish are only seasonally present, suggesting that long distance migrations occur. Even greater information gaps also exist regarding Burbot. Catches of Burbot in sampling efforts are highly variable suggesting dynamic seasonal and annual migration patterns. However no information regarding movement patterns, habitat use, and population ecology of Burbot in the Yellowstone River exists.

Shovelnose Sturgeon are abundant in reaches of the Yellowstone River downstream of Cartersville Diversion but are functionally absent upstream of this dam. However, this species was historically present and abundant well upstream of Cartersville Diversion but has probably been extirpated by the cumulative effects of flow alteration of the Big Horn River and installation of diversion dams on the Yellowstone River. Although Shovelnose Sturgeon distributions and abundances have declined in other large-river ecosystems, the relatively pristine reaches of the lower Yellowstone River probably support the highest densities of

Shovelnose Sturgeon range-wide making it an ideal location to characterize the ecology and habitat requirements of this species.

Spiny Softshells occur in the study area, yet very little is known about their distribution, movements, or habitat use. Bald eagles are federally endangered and a survey and inventory of the study area during nesting season will provide wildlife managers with accurate distribution, nest occupancy, and productivity data.

Goal: The objective of this study was to increase the knowledge base for ecologically and culturally important native Yellowstone River fish and wildlife to guide the formulation of management strategies that will benefit this unique ecosystem.

Objectives: 1.) Describe seasonal movement patterns and habitat use of adult Blue Sucker, Burbot, Channel Catfish, Shovelnose Sturgeon, and Spiny Softshells.

2.) Determine distribution and nesting success of bald eagles

Study area: The Yellowstone River from Park City, MT to the confluence with the Missouri River.

Methods: One hundred thirty-four Channel Catfish, 124 Burbot, and 40 Blue Sucker and Shovelnose Sturgeon were collected by electrofishing, drifting trammel nets, or setting baited hoop nets from April 2005 to May 2008 between Park City, MT (river km 632.5) and the confluence with the Missouri River (river km 0). Fifty-four Spiny Softshells were collected using baited hoop nets. Fish and turtles were captured at randomly-selected locations in eight reaches predicated on geomorphic differences and the presence of potential migratory barriers.

Fish and turtles in lower six reaches were relocated by boat at least twice per month from April through November and by aircraft one every three weeks from December through March. Fish and turtles in the upper two reaches were relocated by boat or aircraft at least once per month from May through February. Permanent receiving stations were placed at the Powder, Tongue, and Big Horn rivers, and Intake and Cartersville diversions to assess tributary use and movement beyond the study area.

Each year was divided into seasons based on a combination of hydrograph and life history characteristics. Spring was defined as the period from April 1 to the date at which discharge at Miles City increased to above 15,000 cfs and encompassed lowland runoff. Runoff was defined by the period during which discharge was greater than 15,000 cfs at Miles City and encompassed mountain runoff. Summer was defined as the period during which discharge was less than 15,000 cfs to September 30. Winter was defined as the period from October 1 to March 30.

Habitat type classification was predicated on geomorphic function (i.e. pool, crossover, side channel) and bank material (i.e. bedrock, alluvium, rip-rap) as described by Jaeger et al. (2006). Total availability of each habitat type during base flow and runoff periods was quantified using GIS software. Availability at base flow was calculated by considering the amount of habitat provided by all habitat types except seasonally inundated side channels. Availability during runoff included seasonally inundated side channels. Physical characteristics of each habitat type was determined using a stratified random sampling design. Habitat units of each habitat type were randomly selected for physical characterization. Within each selected habitat unit, velocity, depth, and substrate were measured at 100 randomly selected points.

Habitat use by individual fish was calculated for each season as the proportion of relocations that were made within each habitat type 2002.

Cottonwood galleries along the riparian corridor were visually scanned for bald eagle nests during nesting season. GPS coordinates of all bald eagle nest locations were recorded.

Results: Differences in width, average and maximum depth, average and bottom velocity, and percentage of boulder and bedrock substrate occur among habitat types (ANOVA; $P < 0.001$, Table 1). Main-stem pools at the valley margin (bluff, rip-rap valley margin) were generally longer and had lower average and bottom velocities than pools in the valley bottom (scour, rip-rap valley bottom). Armored pools (rip-rap valley margin, rip-rap valley bottom) generally had higher maximum and average depths, greater variability of depths, and a higher percentage of boulder and bedrock substrates than their unarmored equivalents (bluff pool, scour pool). Terrace pools had characteristics of pools at the valley margin and pools in the valley bottom. Channel crossovers were shorter, shallower, had higher velocities, and a lower percentage of boulder and bedrock substrates than other main-stem habitat types.

Net movement rates of Blue Sucker varied among seasons ($P<0.001$; Figure 4). Movements were primarily upstream during spring and runoff and were downstream during winter. Most Blue Suckers migrated out of the Yellowstone each winter and returned each spring. Blue Sucker did not use all habitats in proportion to their availability during any season ($P<0.05$). During spring, scour pools were selected, diversion dam pools were avoided, and all other habitat types were used in proportion to their availability. During runoff, diversion dam pools were selected, secondary channels were avoided, and all other habitats were used in proportion to their availability. Selection of diversion dam pools during periods of high movement rate is probably indicative of partially restricted passage at these structures. During summer and winter all habitats were used in proportion to their availability except secondary channels, which were avoided.

Net movement rates of Shovelnose Sturgeon varied among seasons ($P=0.015$). Movements were upstream and downstream during spring, runoff, and summer. Fish were relatively sedentary during winter. Fish made migrations to and away from possible spawning areas each year. Shovelnose Sturgeon did not use all habitats in proportion to their availability during any season (*P*<0.05). During spring channel crossovers were selected, secondary channels were avoided, and all other habitat types were used in proportion to their availability. During runoff and summer secondary channels were avoided and all other habitats were used in proportion to their availability. During winter channel crossovers and secondary channels were avoided and all other habitats were used in proportion to their availability.

Net movement rates of Channel Catfish varied among seasons (*P*=0.003). Movements were upstream and downstream during spring, runoff, and summer. Fish were relatively sedentary during winter. Channel Catfish did not use habitats in proportion to their availability during any season other than summer (*P*<0.05). During spring channel crossovers were avoided and all other habitat types were used in proportion to their availability. During runoff channel crossovers were selected and all other habitats were used in proportion to their availability. During summer and winter all habitats were used in proportion to their availability.

Net movement rates of Burbot varied among seasons (*P*<0.00; Figure 12). Movements were upstream and downstream during spring and winter and primarily downstream during runoff and summer. Burbot did not use habitats in proportion to their availability during any season (*P*<0.05; Figure 13). During spring, runoff, and summer Burbot selected bluff and rip-rap valley bottom pools, avoided scour pools, channel crossovers, and secondary channels, and used terrace and rip-rap valley margin pools in proportion to their availability. During winter rip-rap valley bottom pools were selected and all habitats were used in proportion to their availability.

Net movement rates of Spiny Softshells did not vary among seasons (*P*=0.906). Upstream and downstream movements occurred during all seasons, although turtles were relatively sedentary during winter. Spiny Softshells did not use habitats in proportion to their availability during any season (*P*<0.05; Figure 15). Secondary channels were selected during all seasons other than winter. Spiny Softshells generally demonstrated higher selection of unarmored pools (bluff, scour) than their armored equivalents (rip-rap valley margin and bottom). During winter, bluff pools were selected and all other habitats were used in proportion to their availability. Diversion dams were avoided during all seasons.

Bald eagle nests were observed throughout the study area. Nests were commonly occupied during multiple years.

Discussion: This report does not contain a Discussion section. The following is my interpretation of the results.

All five species occupied extensive reaches of the lower Yellowstone River, from the confluence of the Missouri River to varying distances upstream. Shovelnose Sturgeon had the most restricted longitudinal range, and are apparently blocked by Cartersville Diversion Dam. This population fragmentation has probably caused the extirpation of Shovelnose Sturgeon in the Yellowstone River above Cartersville Diversion Dam. The effects of the altered physical processes, and further fragmentation caused by dams on the Bighorn River may contribute to this extirpation. However, the presence of numerous Shovelnose Sturgeon just below Cartersville Diversion Dam indicates that if passage were provided at Cartersville, the Shovelnose Sturgeon would reclaim lost portions of their range above the dam.

Burbot had the longest longitudinal range, from the confluence to above Billings. Telemetered Channel Catfish occurred from the confluence to below Rancher Diversion Dam, but are known to occur at least as far upstream as Billings. Telemetered Spiny Softshells occurred from below Intake to above Billings, but did not use the lower 67 kilometers of the Yellowstone River. This is consistent with results of a standardized longitudinal trapping survey that indicated that Spiny Softshells were absent or rare below Intake. Blue Sucker occurred from the confluence to the Bighorn River.

Channel Catfish, Shovelnose Sturgeon, and Spiny Softshells were relatively sedentary in the winter. In contrast, Blue Sucker moved downstream in winter and Burbot winter movements were similar to those during spring and runoff. Blue Sucker apparently passed the Intake and Cartersville diversion dams because most Blue Sucker moved into the Yellowstone River from below the confluence during spring or runoff, and moved out of the Yellowstone River in summer or winter.

All five species selected or avoided certain habitat types during a portion of the year. Blue Sucker preferred scour pools in spring, possibly using these habitats for spawning or resting areas during their upstream migration from below the confluence. Blue Sucker avoided diversion dam pools in spring, perhaps indicating that they were not trying to pass diversion dams in earnest at this time during their upstream migration. However, Blue Sucker preferred diversion dam pools in runoff, perhaps indicating that they are trying to pass diversion dams, but cannot do so until discharge conditions allows for passage. Blue Sucker avoided secondary channels during summer and winter, perhaps because they prefer deeper or faster water in main channel thalweg areas during low-water periods.

Burbot preferred habitats with deeper and slower water, as well as boulder substrate, during most seasons. Bluff and rip-rap valley bottom pools were generally preferred; these pool types were deeper and slower than other pool types. Bluff pools have naturally-recruited large boulder substrate and riprapped pools have boulders that have recruited from riprap placements. Channel crossovers are shallower and faster than other pool types, and secondary channels are shallower than other pool types.

Channel Catfish generally used habitat types in proportion to their availability. However, they avoided crossovers in spring, and preferred crossovers during runoff. This finding differs from habitat preferences reported elsewhere such as Channel Catfish were found to prefer deep pools in Minnesota streams and wing dikes in the Mississippi River.

Shovelnose Sturgeon avoided secondary channels in all seasons, and preferred crossovers in spring, but avoided crossovers in winter. Shovelnose Sturgeon are rheophillic species, meaning that they tend to occur in areas with moderate to fast current velocities. Their preference for crossovers may also be related to higher availability of macroinvertebrates prey in the gravel and cobble substrates found there. However, during winter crossovers are probably avoided because maintaining position in relatively swift crossovers is energetically costly when temperature-mediated metabolic needs are reduced, feeding rates decline, and Shovelnose Sturgeon become relatively sedentary.

Spiny Softshells preferred secondary channels in all seasons except winter, when they preferred bluff pools. This pattern is generally concordant with habitat use in the Missouri river in Montana where Spiny Softshells used shallow, slow, lateral habitats such as backwatered tributary mouths and inundated floodplains during all seasons but winter. Spiny Softshells hibernate on the river bottom in winter, and select deeper water with moderate current velocities between the shoreline and thalweg, where they are not displaced by swift velocities, have adequate oxygen, and deep enough to be safe from ice jams. Bluff pools are slower and deeper than other pool types and probably provide adequate habitat for overwintering hibernacula.

Conclusions on anthropogenic effects on fish: Cartersville dam probably severely restricts passage of Shovelnose Sturgeon, which may lead to the extirpation of Shovelnose Sturgeon in upstream reaches. Apparently Blue Sucker were able to pass Intake and Cartersville diversion dams. Spiny Softshells avoided riprapped alluvial pools, but no fish species avoided riprapped habitats. Burbot actually preferred riprapped alluvial pools (and bluff pools), probably because they oriented to the large boulder substrates found there. Blue Sucker, Burbot, Channel Catfish, and Shovelnose Sturgeon all avoided secondary channels during one or more seasons. However, this is not surprising because all of these fish species are highly mobile large-river specialists and therefore probably prefer main-channel thalweg habitats. Spiny Softshells preferred secondary channels during all seasons except winter.

Spatial fisheries information: There are no spatially-explicit fisheries data in the report. However, I have all of the spatially-explicit data in possession and will be analyzing this as part of my contract with FWP, “Yellowstone River Native Fishes Movement and Habitat Selection Final Report”. For the FWP contract I will analyze and identify whether, at what time of year, and under what discharge range any diversion dams or natural riffles impeded passage, or allowed passage for any of these species. I will analyze and interpret habitat use by all species with respect to geomorphic reach type, movements to and habitat use of all tributaries to the Yellowstone River, particularly the Powder and Tongue Rivers and O’Fallon and Rosebud

Creeks, identify potential spawning reaches and individual spawning aggregations for all species, identify location and longitudinal extent of the home ranges of all radio-tagged species and individuals, and identify which longitudinal river reaches, geomorphic reach types, and habitat types are most important by season for each species. Much of the information from these analyses can go into the reach narratives.

BMP implications: Consider providing passage for Shovelnose Sturgeon and other fish species at Cartersville Diversion Dam. Secondary channels are important habitat for Spiny Softshells.

Scientific rigor: Moderate. This report is not published in the primary literature or peer-reviewed. Inference on habitat selection is based on statistical significance testing.

Title: Distribution, Habitats, and Tributary Linkages of Small and Nongame Fishes in the Lower Yellowstone River

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Overall abstract: The Yellowstone River is the longest unimpounded river in the conterminous United States. It has a relatively natural flow regime, which helps maintain diverse habitats and fish assemblages now unique in large rivers. The lower Yellowstone River supports a diverse nongame fish assemblage that includes several species of special concern. However, the small, nongame fish assemblage of the lower Yellowstone River remains inadequately studied; studies of small-bodied fishes have been limited to the Yellowstone River below Intake Diversion Dam. The authors compared efficiencies of several gears for sampling these fishes, determined the distribution and habitat use of these fishes in the Yellowstone River, and examined the movements of selected species between the Yellowstone River and its tributaries.

Prior to undertaking long-term monitoring projects, sampling gears and efforts need to be assessed to develop the most efficient sampling methods. The authors assessed the efficiency of fyke nets, seines, and otter trawls for sampling small fish in the shoreline and main channel habitats of the lower Yellowstone River to develop sampling methods. Fyke nets were more effective than seines at sampling the shoreline fish assemblage. Fyke nets consistently had higher catch rates ($P < 0.01$) and captured more species ($P < 0.01$) than seines. Two fyke net sets in each macrohabitat (channel crossover, inside and outside bends, and secondary channels) were enough to characterize the abundances and distributions of dominant species. However, we recommend three fyke net sets in each macrohabitat to develop complete species lists that include rare species. Otter trawls were the best gear for sampling small-bodied fish in main-channel habitats.

The authors captured 42 species (24 native and 18 nonnative) in the lower Yellowstone River with fyke nets. Native species composed over 99% of the catch. Emerald Shiners, Western Silvery Minnows, Flathead Chubs, Sand Shiners, and Longnose Dace composed nearly 94% of fyke net catch and were caught in every segment of the study area. The authors captured 24 species using otter trawls downstream of the Tongue River. Sturgeon Chubs, Channel Catfish, Flathead Chubs, Stonecats, and Sicklefin Chubs composed 89% of the otter trawl catch. The upstream distributional limit of Sturgeon Chubs was the Tongue River; only a few Sicklefin Chubs were captured above Intake Diversion Dam.

Spatial connectivity helps maintain population stability and viability for many organisms. However, difficulty in tracking the movements of small fishes had inhibited a complete

understanding of how connectivity and movement affect their populations. The authors used otolith microchemistry analysis to reconstruct the movements of Sand Shiners, Western Silvery Minnows, and Flathead Chubs in the lower Yellowstone River and its tributaries. All three species moved between the Yellowstone River and its tributaries. About 70% of Western Silvery Minnows and Flathead Chubs and 50% of Sand Shiners moved between main-stem and tributary habitats. The proportion of residents and dispersers varied among tributaries and species indicating that local conditions affect movement patterns of each study species differently.

Chapter 1: Evaluation of Sampling Methods for Small Nongame Fishes in the Lower Yellowstone River

Goal: Determine the most efficient methods for sampling small fishes along the shoreline and in the main channel of the Yellowstone River.

Objectives: Our objectives were to 1) compare the effectiveness of fyke nets and seines for sampling the shoreline fish assemblage of the Yellowstone River, 2) determine the sampling effort needed to capture 90% and 95% of the expected species at shoreline sampling reaches, and 3) assess the spatiotemporal efficiency of fyke nets and otter trawls for sampling small fishes in the lower Yellowstone River.

Study area: Our study area was the Yellowstone River between the confluences of the Clarks Fork and Missouri rivers.

Methods: The river was separated into 13 longitudinal segments and two to four reaches within each segment were randomly selected for sampling. Reaches (i.e., river bends) were comprised of three continuous (channel crossover, inside bend, and outside bend) and two discrete (secondary and seasonal secondary channels) macrohabitats when present. Each reach was classified as either an alluvial, bluff, terrace, stabilized alluvial, or stabilized bluff-terrace pool (Jaeger et al. 2005).

Fish sampling.—Three fyke nets (i.e., standard fyke net sampling) were randomly deployed in each macrohabitat. Depth and water velocity measurements were recorded at the mouth of each net. The substrates surrounding the mouth of nets were qualitatively categorized as silt, sand, gravel, pebble, cobble, boulder, or bedrock and assigned numerical values ranging from one to seven, respectively. Water temperatures were recorded at each reach.

When time and conditions permitted, at least one seine haul was completed within each macrohabitat at each sampling reach in 2008 and 2009. Seines were pulled downstream along the shorelines for 100 m. Dominant substrate was recorded for the areas sampled. Depth and velocity were both measured at nine randomly selected locations in the areas seined and means for each were calculated.

Otter trawls were used to sample Sicklefin Chub and Sturgeon Chub in the Yellowstone River downstream of the Clark's Fork River in 2008. To help restrict otter trawling efforts to probable Sicklefin Chub and Sturgeon Chub habitats in 2009 and 2010, longitudinal distributions for both species were estimated using 2008 otter trawl data. Trawls were attached to the bow of the boat and towed downstream in reverse for 300 m if no snags occurred. Data were discarded and another trawl was completed if a snag occurred prior to trawling 150 m or if snag prevented quick retrieval of captured fish from trawls longer than 150 m. Three tows were completed in each macrohabitat in each reach when conditions permitted. The length of each tow was measured using a handheld GPS unit. Trawls were not used in macrohabitats that were too short to deploy and retrieve nets without drifting into downstream macrohabitats. The length and number of trawls were also limited in outside bends, near bridges, and stabilized reaches because of recurring snags.

The authors randomly selected four gear efficiency test reaches for intensive sampling to estimate the sampling effort needed to capture 90% and 95% of expected small and nongame shoreline species using fyke nets and seines.

Data analysis.—Length frequency histograms from this study and other age and growth reports were used to classify fish as either age-0 (juveniles) or age-1 and older (adults).

The authors compared the effectiveness of fyke nets and seines in 174 randomly-selected paired seine and fyke net subsamples. Paired t tests were used to compare habitat characteristics, catch-per-unit-effort, species richness, diversity, evenness, and mean length between gears. The Shannon-Wiener function (H') was used to evaluate diversity and calculate evenness (J'). Percent similarity was used to compare species composition between the two gears.

Rarefaction curves, which estimate species richness for a given number of individual samples, were used to compare the species accumulation of fyke nets and seines. Linear regression was used to assess spatiotemporal changes in the CPUE of all three gears. The proportion of sites where *Macrhybopsis* spp. were captured with otter trawls was calculated. The proportion of tows needed to detect either species was also calculated for reaches where they were captured. Species accumulation curves were used to determine the sampling effort needed to catch 90% and 95% of the shoreline species expected at the four gear efficiency test reaches.

To assess how fyke net sampling effort affected the CPUE of the five dominant species we calculated the mean CPUE for those species using either two or three fyke net sets in each macrohabitat. Paired t tests were used to compare mean reach CPUE of the dominant species using either two or three fyke nets in each macrohabitat.

Results: The 174 fyke nets that were paired with seines captured 34,595 fish representing 10 families and 35 species, including 8 unique species not collected by seining. The 174 seine hauls captured 13,521 fish representing 8 families and 28 species, including 1 unique species. Emerald Shiners, Flathead Chubs, and Western Silvery Minnows were the dominant species in both gears. These three species together composed 78% of fyke net catch and 92% of seine catch. Fyke nets were more effective than seines at capturing benthic fish such as Longnose Dace, Stonecats, and suckers. Fyke nets also captured more small-bodied fishes such as Longnose Dace, fathead minnows, and Sand Shiners than seines. Characteristics of the habitats (substrate, depth, and water velocity) sampled with each gear were not significantly different (P = 0.12, 0.91, and 0.35, respectively). Water temperatures decreased as the sampling seasons progressed.

Mean CPUE, species richness, diversity (H'), and evenness (J') of fyke net catches were greater than those of seines ($P \le 0.01$). Mean CPUE of fyke net catches was greater than that of seines in inside bends and secondary channels. Mean species richness of fyke net catches was greater than that of seines in every macrohabitat. The mean percent similarity of catches from the two gears was 37% (SE = 2.41) and ranged from 0% to 100%. Rarefaction curves indicated that species richness was greater in fyke net catches than in those of seines at all abundances. However, species richness of catches was nearly the same for both gears after 500 individuals were captured.

Age-0 fish composed 60% (20,895 fish) of the fyke net catch as opposed to only 14% (1,866 fish) of the seine catch. Catch-per-unit-effort of adults was similar for fyke net (mean CPUE = 78.7 fish/net night; SE = 13.8) and seine catches (mean CPUE = 58.4 fish/100 m; SE = 8.2; P = 0.07). However, adult species richness of fyke net catches (mean = 3.7 species/net night; SE = 0.2) was greater than that of seines (mean = 2.7 species/100 m; SE = 0.2; $P < 0.01$). Fyke net sets captured six unique species (Bluegill, Brook Stickleback, Burbot, Sicklefin Chub, White Crappie, and Yellowstone Cutthroat Trout) of adult fish. Seines captured one unique species (freshwater drum). Zero catches of adult fish occurred in only 6% of the fyke net sets compared to 16% of the seine hauls.

Adult fyke net CPUE declined significantly ($r2$ = 0.04; P = 0.03) as the sampling season progressed whereas the CPUE of adults in seines remained constant. The CPUE and relative abundance of age-0 fish in fyke nets increased as the sampling season progressed. The CPUE of age-0 fish in seines increased, but not significantly, throughout the sampling season. However, the relative abundance of age-0 fish in seine catches increased later in the season.

Otter trawl catch varied both temporally and spatially. Mean otter trawl catch nearly doubled from the beginning to the end of the 2008 sampling season. *Macrhybopsis* spp. were captured in 6 of the 12 reaches sampled with otter trawls downstream of the Tongue River in 2008. In reaches where they were detected, at least one individual was captured in 61% of trawl tows. Over 98% of *Macrhybopsis* spp. were captured in main channel habitats (i.e., channel crossover, inside bend, and outside bend).

The expected species richness at the four gear efficiency test reaches sampled with 20 fyke nets in 2010 ranged from 11.7 to 21.7 species. Based on the accumulation curves, we estimated that three fyke nets were needed within each macrohabitat in each reach to capture at least 90% of the expected species in each reach using 20 fyke nets. Four fyke nets in each macrohabitat were needed to capture at least 95% of the species. Based on the regression models, the range of seine hauls needed to capture 90% of the observed species in the four reaches was from about 21 (Reach 3) to 8,400 (Reach 2). Seining did not result in the capture of any unique species in any of these reaches.

No significant differences existed between mean catches of Emerald Shiners (P = 0.51), Flathead Chubs (P = 0.42), Longnose Dace (P = 0.68), Sand Shiners (P = 0.71), and Western Silvery Minnows (P = 0.07) calculated using two and three fyke net catches in each macrohabitat. Species ranks for these species were the same for both sampling efforts.

Discussion: Fyke nets were more effective than seines at characterizing shoreline fish assemblages of the Yellowstone River because they captured more individual fish and more species of fish. Woody debris and other large substrates make seining difficult in many habitats where fyke nets can be easily deployed. Silt in many backwater habitats also made seining difficult and ineffective; backwaters are often the most productive areas of lotic environments and serve as nursery areas for many fishes. Moreover, in outside bends high water depths and velocities often make seining ineffective and unsafe.

Temporal variability in fyke net and seine catches may be caused by temperature variability and differing rates of recruitment of juveniles to each gear. Reduced catch rates of adults in fyke nets later in the season may have been caused by cold water temperatures, which reduces the vulnerability of warmwater species to passive sampling gears. Conversely, adult catch rates in seines, an active sampling gear, were relatively consistent throughout the entire sampling season. Seines had slightly larger mesh than fyke nets, which reduced the efficiency of seines to capture age-0 fish. Age-0 fyke net catch increased about two months after peak spring runoff as these fish grew large enough to be recruited to the gear. Limiting sampling to short time periods or temporally and spatially stratifying effort will help to limit biases associated with the proportional changes in the catches of adults and juveniles during the year.

The appropriate amount of effort depends on the objectives of a sampling effort. Two fyke net sets per macrohabitat are enough to characterize the dominant species (i.e., Western Silvery Minnow, Flathead Chub, Emerald Shiner, Longnose Dace, and Sand Shiners) at the reach scale. Three fyke net sets are needed to capture at least 90% of the expected species and four net sets are needed to capture 95%. However, limiting sampling effort to two fyke net sets in each macrohabitat could increase the number of reaches sampled, which will increase the number of vulnerable individuals, and may thus compensate for the decreased effort within a sampling reach. However, close attention should be paid to selecting sampling reaches in proportion to their availability, especially if strong habitat preference is likely or the sampling area is patchy.

Fyke nets and seines have different logistical and financial constraints. Active gears such as seines require only a single trip to a sampling location, but two trips must be made when fyke nets are used unless crews remain at the sampling location overnight. However, three crew members are needed to efficiently and safely sample using seines whereas only two are needed to deploy fyke nets. Gear deployment is easier with fyke nets than seines, therefore variability in sampling efficiency because of differences in among personnel may be less for fyke nets than seines, which probably results in more reliable sampling with fyke nets than with seines. Passive gears are also better than active gears at capturing mobile fish such as minnows. Although the initial monetary investment is higher for fyke nets than seines, the efficiency and reliability of fyke nets warrants their use.

Benthic trawls are the only viable option available for sampling small-bodied benthic fishes in the main channels of large rivers. Sampling during baseflow, rather than spring runoff, allowed better detection of potential snags and increased boat maneuverability, and helped to better identify the distribution of *Macrhybopsis* spp. in the lower Yellowstone River. Faster water velocities, shallower water, and shorter reach lengths limited trawling effectiveness upstream of Huntley Diversion Dam. However, the primary objective of otter trawling was to determine the distribution, abundance, and habitat use of Sicklefin Chubs and Sturgeon Chubs. Although Sturgeon Chubs were historically found upstream of the Bighorn River, they are currently thought to be restricted to the Yellowstone River below the Tongue River (USFWS 2001; Chapter 2). Sicklefin Chub distribution is limited to reaches downstream of the Powder River (Chapter 2). Therefore, otter trawl sampling upstream of Cartersville Diversion Dam is probably unnecessary unless conservation efforts restore Sturgeon Chubs to their historic range. Sampling secondary and seasonal secondary channels with otter trawls is also not essential as both species tend to occupy only main channel habitats.

The relatively large mesh sizes of our otter trawls probably contributed to low catch rates of *Macrhybopsis* spp. Several trawl designs have recently been evaluated for sampling benthic fishes. Small meshed trawls (e.g., the mini-Missouri trawl; Herzog et al. 2009) should be tested on Sicklefin Chubs and Sturgeon Chubs in the Yellowstone River; such trawls may provide more accurate abundance estimates and more precisely identify upstream ranges of these species in the river than the trawls we used.

The authors recommend using fyke nets throughout the entire river and otter trawls downstream of Cartersville Diversion Dam for future monitoring efforts. Two fyke net sets in each macrohabitat should be enough to characterize the structure of the Yellowstone River shoreline fish assemblage in a reach and monitor long-term changes in the distribution and abundance of dominant species. However, greater sampling effort (i.e., three or four subsamples in each macrohabitat) is needed to more accurately quantify the distribution and abundance of rare species.

Conclusions on anthropogenic effects on fish: This study focused on fish sampling methods, there is no inference on anthropogenic effects.

Spatial fisheries information: Although this study collected and used fisheries data, these data are presented here only as it pertains to comparisons of sampling methods. The spatial fisheries data associated with this study is explicitly analyzed in the second chapter of this report.

BMP implications: The appropriate amount of sampling effort depends on the objectives of the project. Two fyke net sets per macrohabitat are enough to characterize the dominant species (i.e., Western Silvery Minnow, Flathead Chub, Emerald Shiner, Longnose Dace, and Sand Shiners) at the reach scale. Three fyke net sets are needed to capture at least 90% of the expected species and four net sets are needed to capture 95%. However, limiting sampling effort to two fyke net sets in each macrohabitat could increase the number of reaches sampled, which will increase the number of vulnerable individuals, and may thus compensate for the decreased effort within a sampling reach.

Scientific rigor: Moderately high. Although not peer-reviewed or published in the primary literature, this report has undergone review by Drs. Al Zale and Bob Bramblett as well as FWP review. Inference is based on statistical significance testing.

Chapter 2: Distribution and Habitat Use of Small Nongame Fishes in the Lower Yellowstone River

Introduction: Most large rivers in the United States have been altered by humans therefore much of the information on large river fishes is from altered systems. The Yellowstone River is the longest unimpounded river in the conterminous United States and supports at least 37 native fish species representing 12 families. The Yellowstone River includes a clear, coldwater zone, a transition zone, and a turbid, warmwater zone as well as a shift from cobble to sand substrate. This combination of factors provides a unique model of the natural structure and function of large-river fish assemblages.

Small nongame fish are ecologically important, yet little is known about them in the Yellowstone River. Two species are of particular concern: Sicklefin Chub and Sturgeon Chub. Other nongame species experiencing declines in abundance or distribution elsewhere that inhabit the Yellowstone River include Flathead Chub and Western Silvery Minnow. Understanding the ecology of these species in the naturally-functioning Yellowstone River may help provide information needed to develop conservation strategies elsewhere.

Goal: Acquire a better basic understanding of the small fishes of the lower Yellowstone River.

Objectives: Our objectives were to 1) determine which small nongame fishes were abundant, common, or rare in the lower Yellowstone River, 2) determine the longitudinal distribution of these species, 3) determine what habitat types these species used, and 4) determine whether diversion dams fragmented populations of small fish in the lower Yellowstone River.

Study area: The Yellowstone River between the confluences of the Clarks Fork and Missouri rivers (615 river kilometers; 382 river miles).

Methods: *Fish sampling*.—Sampling occurred in the Yellowstone River between the confluences of the Clarks Fork and Missouri rivers from 2008 to 2010 using the standard fyke net sampling methodology described in Chapter 1. Otter trawl sampling in 2009 and 2010 was limited to those habitats below the Tongue River. Main channel habitats were defined as areas in and adjacent to the thalweg. Three depth and velocity measurements (beginning, midpoint, and end) were recorded 0.3 m above the bottom with a Marsh-McBirney Flo-Mate portable current meter for each trawl, and a mean was calculated.

Fish processing.—Fish were processed using the methods described in Chapter 1.

Data analysis.—Only age-1 and older (adults) were included in our analysis. Limiting analysis to adult fish presents a more stable representation of species abundances and distributions by eliminating variability caused by inconsistent spatial and temporal abundances of juvenile fish that have not yet recruited to the adult population.

The authors tested for differences in adult fyke net catch-per-unit-effort (CPUE; Kruskal-Wallis by ranks) among years, segments, pool types, and macrohabitats for fishes in aggregate, species with relative abundances greater than 5% of the total catch, and species of conservation priority (Flathead Chub and Pallid Sturgeon). Post hoc pairwise comparisons between pool types or macrohabitats were performed using the Mann-Whitney (Wilcoxon) rank sum test when the Kruskal-Wallis test identified significant differences ($P < 0.05$) in CPUE among habitat medians. Longitudinal discontinuities in assemblage structure between segments were assessed using the percent similarity index. Mann-Whitney rank sum tests were also used to assess differences between areas where Pallid Sturgeon were or were not detected. Contour plots were used to examine longitudinal and habitat (i.e., water velocity and depth) trends in CPUE for selected species.

Results: *Fyke net catch.*—The authors captured 42 fish species (24 native and 18 nonnative) representing 12 families. Native species composed 99% of the total adult catch. Cyprinids (minnows; 12 native and 3 nonnative species) composed 97% of the catch. Catostomids (suckers; 6 native species) composed 1% of the catch. Centrarchids (sunfishes; 7 nonnative species) composed 1% of the catch.

Adult CPUE differed among years ($P = 0.03$) with catch rates increasing from 2008 to 2009 ($P = 0.01$). However, CPUE was not different in 2009 and 2010 ($P = 0.23$). Adult CPUE differed among segments ($P = 0.01$). Catch rates were high from O'Fallon Creek to Sidney (segments 11 and 12) and declined both upstream and downstream. Catch rates were not different in pool types ($P = 0.44$) or macrohabitats ($P = 0.48$).

Species richness was low in segments 1, 8 and 13 and increased immediately downstream of the Bighorn and Powder rivers. Three longitudinal discontinuities were observed in assemblage structure. The greatest difference in assemblage structure in adjacent sampling segments occurred between segments 1 and 2. Other discontinuities occurred between segments 5 and 6 and segments 11 and 12.

Emerald Shiner, Western Silvery Minnow, Sand Shiners, Longnose Dace, and Flathead Chub, were the five most abundant species, represented 94% of the total catch, and were captured in every segment. Emerald Shiners composed 47% of the total catch and at least 25% of the catch in segments 7 to 13, but were most abundant in segments 11 and 12. Most (79%) of the total Emerald Shiner catch was from nets in which 100 or more individuals were captured. Although Emerald Shiner CPUE was similar among pool types ($P = 0.20$) and macrohabitats ($P = 0.72$), CPUE was highest in water velocities from 0.3 to 0.6 m/s.

Western Silvery Minnows occupied the entire study area and were abundant in some reaches, but no trends in their CPUE existed among segments. Most (78%) of the total Emerald Shiner catch was from nets in which 100 or more individuals were captured. Western Silvery Minnow

CPUE was similar among pool types (*P* = 0.401) and macrohabitats (*P* = 0.32). However, the CPUE of Western Silvery Minnows was generally high in water velocities less than 2.0 m/s.

Sand Shiners were captured throughout the study area but did not account for more than 25% of the catch in any sampling reach. Just over half (51%) of the total Sand Shiners catch was from nets in which 100 or more individuals were captured. Sand Shiners CPUE was greater in bluff and terrace pools than in other pool types (*P* < 0.01) but was similar among macrohabitats (*P* = 0.28). Sand Shiners CPUE was greatest in water velocities less than 2.0 m/s.

Longnose Dace were captured in segments 1 through 6 (Clarks Fork to Rancher Diversion Dam). Nets that captured at least 100 Longnose Dace (< 1% of nets) accounted for 18% of the total catch of the species. Longnose Dace CPUE was similar among pool types (*P* = 0.64), but different among macrohabitats (*P* = 0.05). Longnose Dace CPUE was greatest in water velocities faster than 1.0 m/s.

Flathead Chubs were captured in nearly every reach but in low abundances; more than 100 adults occurred in only two net sets. Catch rates were higher between O'Fallon Creek and Sidney, Montana (segments 11 and 12), than in most upstream reaches. Flathead Chub CPUE was greater in bluff and terrace pools than in other pool types (*P* = 0.01) but similar among macrohabitats (*P* = 0.40) and highest catches were in water velocities below 0.8 m/s.

Four of the five sucker species occupied large portions of the lower Yellowstone River, but catch rates and relative abundance were low. White Sucker and Longnose Sucker CPUE was greatest upstream of Rancher Diversion Dam in water velocities less than 0.2 m/s. River Carpsucker were captured in low abundances in each reach below Huntley Diversion Dam in slow water velocities. Shorthead Redhorse were captured along the entire river downstream of Billings in slow water velocities. Mountain Suckers were captured upstream of the Bighorn River in moderate water velocities.

Sunfishes were captured throughout much of the study area in low abundances. Sixty-three percent of the sunfish were captured in seasonal secondary channels. Sunfish were typically restricted to slow water velocities.

Stonecats represented 1% of the total fyke net catch and were captured in all segments. Brook stickleback were captured in low abundances upstream of Sidney. Goldeye were also captured throughout the study area in low abundances. Channel Catfish, Sauger, and Smallmouth Bass were also captured. Channel Catfish were found primarily in main channel habitats downstream of the Bighorn River. Sauger distribution was restricted to reaches downstream of Meyers Diversion Dam. Smallmouth Bass were captured between Huntley Diversion Dam and the Tongue River.

Otter trawl catch.—The authors captured adults of 24 species (21 native and 3 nonnative) representing 9 families. Five species each composed over 5% of the catch: Sturgeon Chub

(38%), Channel Catfish (22%), stonecat (12%), Flathead Chub (11%), and Sicklefin Chub (6%). Sturgeon Chub CPUE was greatest from O'Fallon Creek to Intake Diversion Dam in main channel habitats with mean depths of 1.3 m and mean water velocities of 0.8 m/s. Flathead Chub CPUE was greatest in shallow depths from the Tongue River to Intake Diversion Dam. Sicklefin Chub CPUE was greatest downstream of Intake Diversion Dam in main channel habitats with mean depths of 2.0 m and mean water velocities of 0.8 m/s.

Seven Pallid Sturgeon ranging in size from 185 to 347 mm were captured in four reaches downstream of Intake Diversion Dam. Pallid Sturgeon were captured in inside and outside bends and crossovers and in a variety of pool types. No differences existed in mean depths (P = 0.69) or water velocities (P = 0.12) for trawl deployments between areas where Pallid Sturgeon were (depth = 2.0 m; velocity = 0.7 m/s) or were not (depth = 2.0 m; velocity = 0.9 m/s) detected.

Discussion: Although we captured 42 fish species, just five species—Emerald Shiner, Western Silvery Minnow, Sand Shiners, Longnose Dace, and Flathead Chub—made up 94% of the total catch. All five species occurred from the mouth of the Clark's Fork to the confluence with the Missouri River. Emerald Shiner and Longnose Dace had the strongest longitudinal patterns, with Emerald Shiner most common below the Bighorn River and Longnose Dace common from the Clarks Fork to Waco Diversion Dam. Western Silvery Minnows attained their highest relative abundance from Billings to the Tongue River.

Longitudinal trends in the lower Yellowstone River fish assemblage were evident based on species distributions and discontinuities in assemblage structure. The relatively low similarity between sampling segments upstream of the Bighorn River are probably caused by the change in physical conditions from a clear, coldwater environment to a turbid, warmwater river. Reaches upstream of Huntley Diversion Dam were dominated by Longnose Dace, which is a coldwater species that occupies fast water velocities. Emerald Shiners and Western Silvery Minnows, which are eurythermal species, increased in abundance downstream of Billings and began to dominate the small, nongame fish assemblage below the Bighorn River. Similarity was higher downstream of the Bighorn River than upstream, probably because maximum water temperatures and turbidity began to stabilize in segments downstream of the Bighorn River.

The distribution of some species may have been a function of local habitat characteristics (e.g., substrate and water velocity) rather than longitudinal patterns. Sand Shiners were captured in habitats composed primarily of small substrates, which upstream of Sidney are mostly restricted to backwaters (i.e., seasonal secondary channels) and tributary mouths (M. Duncan, personal observation). Most centrarchids prefer slow water velocities, which primarily restricts their distribution to seasonal secondary channels or main channel habitats with slow water velocities. The uncommon co-occurrence of multiple centrarchids in reaches may also be a result of local introductions from nearby farm ponds or tributary populations and that main-stem recruitment and movement among isolated backwater habitats may be low.

The longitudinal trend in CPUE of adult fish in the lower Yellowstone River may be a consequence of multiple factors. The Yellowstone River transitions from a clear, coldwater environment to a turbid, warmwater river near Billings. Therefore, water temperatures and turbidities were not ideal for many species resulting in relatively low fish abundances in this stretch of river. The high catch rates between O'Fallon Creek and Sidney were a result of exceptionally high catches (> 1,000 fish) of Emerald Shiners, Western Silvery Minnows, and Sand Shiners in several fyke nets. The surprisingly low CPUE of fyke net catches below Sidney was probably a result of the transition to sand substrate in this segment.

Although the lack of historical data precludes any inferences on population trends, exceptional maximum lengths, the presence of multiple age classes, high catch rates of native species, and a low relative abundance of nonnative species indicate that the lower Yellowstone River supports a relatively intact small nongame fish assemblage. The maximum lengths of most of the native cyprinids captured in our study are close to or exceed the reported maximum lengths for each species. The growth rates and longevity of native cyprinids in the Yellowstone River may be indicative of high quality habitat. The high abundances of native species and low proportion of nonnative species relative to other large rivers such as the Missouri River (R. Wilson, USFWS, unpublished data; T. Haddix, MFWP, unpublished data) also indicate that the lower Yellowstone River maintains productive and diverse native fish assemblages.

Several native cyprinids maintain widespread and abundant populations in the lower Yellowstone River while their distributions and abundances have declined elsewhere. Western Silvery Minnows were formerly common in the Missouri River Basin, but have experienced widespread declines in abundance and distribution caused by the damming and channelization of large main-stem rivers. Western Silvery Minnows are common throughout the entire lower Yellowstone River especially in slow habitats with silty or sandy substrate. The high abundances of Western Silvery Minnows is probably a result of the Yellowstone River's natural flow regime, which creates and maintains these slow-velocity habitats, which are now uncommon in much of the Missouri River. Similarly, Flathead Chubs have experienced decreased abundances and ranges throughout much of their historical range, yet remain common throughout the lower Yellowstone River. The authors observed high levels of main stem-tributary connectivity of Western Silvery Minnow and Flathead Chub. This connectivity probably functions to allow these species to complete their life cycles, and in turn to maintain large main-stem populations (Chapter 3).

Sturgeon Chubs and Sicklefin Chubs are priorities for conservation and have been listed or considered for listing as species of concern, vulnerable, threatened, or endangered. However, the Yellowstone River remains a stronghold for both species. Sicklefin Chubs were primarily restricted to reaches below Intake Diversion Dam whereas Sturgeon Chubs were captured as far upstream as the Tongue River confluence. Both species were captured in nearly every reach below Intake Diversion Dam. Our results differed from other studies in that we found Sicklefin Chubs to be more abundant than Sturgeon Chubs in main channel habitats below Sidney, whereas other studies found the opposite. These conflicting results may be because of differences in gear efficiencies or interannual variability of the two populations. Continued monitoring is needed to accurately assess these two species in the lower Yellowstone River.

Sicklefin Chubs, Sturgeon Chubs, and Flathead Chubs co-occurred at many reaches in the lower Yellowstone River. High habitat heterogeneity created by a natural flow regime in the Yellowstone River may provide suitable habitat and food resources, which enables these three fishes to coexist in the lower Yellowstone River.

The Pallid Sturgeon we captured were all relatively young and probably hatchery-reared individuals as there has not been any documented recruitment of wild-spawned fish to this population for decades. Although our sample size is small, the Pallid Sturgeon captured in our trawls used slightly shallower depths with faster water velocities than Pallid Sturgeon captured in the Missouri River. Differences in habitat use between Pallid Sturgeon in the Yellowstone and Missouri rivers may be a result of availability rather than preference. Controlled flows decrease channel migration and incise main channel habitats, which limits shallow habitats along the main channel margins. The Pallid Sturgeon we captured occupied slightly shallower habitats than larger, wild Pallid Sturgeon in the lower Yellowstone River. Sturgeon Chub and Sicklefin Chub, the primary prey of juvenile Pallid Sturgeon in the Missouri River, are restricted in the Yellowstone River to reaches downstream of the Tongue River and may limit the upstream distribution of larger piscivorous juvenile Pallid Sturgeon. Restoring Sturgeon Chub populations between the Tongue and Bighorn rivers, where they historically occurred, may help to increase Pallid Sturgeon distribution and abundances in the Yellowstone River.

Several of the diversion dams on the Yellowstone River limit fish movement during baseflow. However, no longitudinal fish species distributions or assemblage structure discontinuities were unequivocally associated with any of the six diversion dams.

Minor discontinuities in assemblage structure occurred at Rancher and Intake diversion dams because of changes in Emerald Shiner, Sand Shiners, and Western Silvery Minnow abundances. However, artificial and natural side channels or high spring flows may facilitate enough passage, which coupled with long main-stem reaches and connectivity to tributaries, may help maintain viable populations upstream of these structures. For example, the dissimilarity in assemblage structures above and below Rancher Diversion Dam might be caused by changes in turbidity and water temperature downstream of the Bighorn River rather than a lack of fish passage.

Sand Shiners CPUE declined above Huntley Diversion Dam. Sand Shiners are often associated with warm water temperatures and small substrates, so may be near their upstream longitudinal limit due to cool water temperatures and large cobble substrates above Huntley Diversion Dam. The transition from sand to cobble substrates near Sidney rather than Intake Diversion Dam probably limits the upstream distribution of Sicklefin Chubs in the lower Yellowstone River. The CPUE and the percentage of reaches where Sicklefin Chubs were captured declined gradually upstream of Sidney. The shift in substrate particle sizes at Sidney is also probably responsible for the relatively low percent similarity of fish assemblages between segments 11 and 12.

The Yellowstone River supports a diverse and relatively structurally and functionally intact small nongame fish assemblage, which is a rarity. The diverse habitat found in the Yellowstone River supports many species that are experiencing declining abundances and distributions elsewhere. This study provides baseline data for future monitoring efforts and previously unavailable information on abundance, distribution, and habitat use of important prey species, which can be used to help direct the management and conservation of valued endangered and game species in the lower Yellowstone River.

Conclusions on anthropogenic effects on fish: This study detected a few differences in catch rates between stabilized and non-stabilized pool types. Catch rates for Sand Shiners in bluff, terrace, and alluvial pools were significantly higher than in some stabilized pool types. Catch rates for Flathead Chub in bluff and terrace pools were significantly higher than in stabilized alluvial pools. These results suggest that stabilization may reduce local Sand Shiners and Flathead Chub abundance.

In the Missouri River above Fort Peck Reservoir, juvenile (age-6 and age-7) Pallid Sturgeon consumed primarily fish (90% by wet weight), however Sturgeon Chub and Sicklefin Chub , comprised 79% of the number of identifiable fish in juvenile Pallid Sturgeon stomachs. Sturgeon Chub range upstream as far as the Tongue River, and Sicklefin Chub are found primarily below Intake Diversion Dam (Chapter 2). Therefore, Pallid Sturgeon diet probably varies longitudinally on the Yellowstone River.

No longitudinal fish species distributions or assemblage structure discontinuities were unequivocally associated with any of the six diversion dams.

Spatial fisheries information: Study segments are identified by landmarks such as tributary confluences or diversion dams and the latitude and longitude of each sampling reach is listed in Table 2.1. Latitude and longitude of otter trawl samples are listed in Table 2.3. Associated raw fish collection data are not cross-referenced with these locations explicitly, but fyke net catch rates for each study segment are listed in Table 2.5. More specific digital data for fish catches could be obtained from Montana State University.

BMP implications: This study was not explicitly designed to discover anthropogenic effects. However, this study did establish much previously unknown information concerning the identity, distribution, and habit use of small fish in the Yellowstone River. It establishes relative abundance longitudinally along the Yellowstone River from the Clarks Fork to the Missouri River. This information can be used to assemble and evaluate species lists for specific projects and impacts which can then for the basis for evaluating anthropogenic effects associated with projects or impacts.

Scientific rigor: Moderately high. Although not peer-reviewed or published in the primary literature, this report has undergone review by Drs. Al Zale and Bob Bramblett as well as FWP review. Inference is based on statistical significance testing.

Chapter 3: Population Connectivity of Three Prairie Cyprinids in the Lower Yellowstone River and its Tributaries

Introduction: Dispersal facilitates population connectivity and directs the interactions of individuals across the landscape. Connectivity typically increases population viability by buffering against temporally variable habitats, attenuating the effects of perturbations, permitting the colonization of new habitat patches, reducing inbreeding depression, and reducing competition. This is especially true for many species living in small habitat patches, which are inherently less stable than larger patches.

Naturally-functioning prairie streams and rivers historically covered much of the interior United States. The hydrology and assemblage structures of prairie streams naturally varied seasonally and interannually, creating instability in the distributions and abundances of fishes. However, prairie streams are becoming increasingly fragmented thereby increasing the instability of these habitats and their fish populations. Intermittent discharge in small prairie streams can lead to unavoidable and intolerable water temperatures, salinities, turbidities, and hypoxic conditions in the absence of hyporheic recharge. Habitat shifts or increased predation may also occur in small isolated pools containing predators. Flooding can increase lateral and longitudinal connectivity, but extirpations may also occur depending on the timing of the event. Although prairie fishes may be more resilient to perturbations than other fishes, which helps to prevent local extirpations, recovery from extirpations may be slow because of extended isolation from source populations. Isolation of small tributary populations in suboptimal habitats may result from diversion dams and main-stem reservoirs that have fragmented river networks. This combination of factors makes conservation of many prairie fishes difficult, especially when little is known about their movements.

Although the effects of population connectivity on stream fish assemblages have been thoroughly addressed, examining the specific role of dispersal in structuring assemblages of small fish is difficult. Telemetry is not feasible for monitoring movements of most prairie stream fishes because their small size precludes attachment of transmitters. Mark-recapture studies are often short-term assessments limited to short stream segments that result in distance-weighted movement data. Although mark-recapture studies may provide habitat-use data, they lack the reliability to detect most large-scale movements over the entire lives of fish, which is information needed to develop large-scale conservation strategies.

Analysis of natural chemical markers in the bones of fish has proven to be a reliable technique for directly monitoring the movements and environmental histories of many fishes. Otolith microchemistry and isotopic analyses are used for assessing natal origins, juvenile dispersal, and adult movements. Trace element and isotope concentrations of otoliths reflect the surrounding environment and remain unchanged following deposition on the otolith allowing accurate and precise determination of fish movements among unique habitat patches if distinct chemical variation exists and individuals remain in locations long enough to incorporate signatures of those environments into otoliths. The ratio of 87Sr:86Sr is often used for isotopic analysis when geologic age differences and variable weathering processes exist within a watershed. The authors hypothesized that strontium isotopic analysis of fish otoliths would be a viable technique for determining movements among the main-stem Yellowstone River and its tributaries given the geological variability in the YRB.

Western Silvery Minnows , Flathead Chubs , and Sand Shiners are common in the Yellowstone River (Chapter 2) and many of its tributaries. Because these fishes live in both environments, they are ideal subjects to assess potential movements between the main-stem and its tributaries. Western Silvery Minnows and Flathead Chubs have experienced range reductions and population declines elsewhere whereas Sand Shiners remain abundant throughout much of their range. Knowledge of species-specific movements between the Yellowstone River and its tributaries may help identify why Western Silvery Minnows and Flathead Chubs are more susceptible to perturbation than Sand Shiners. For example, we can identify habitat fragmentation as a reason for decreasing abundances and distributions of Flathead Chubs and Western Silvery Minnows if it is determined that these species require access to tributaries or long connected main-stem segments. Fisheries managers can also use this information to identify important populations, migration corridors, or nursery areas needed to maintain unique life histories and essential ecosystem services that these species provide in large river systems.

Goal: Gain an understanding of movements of Western Silvery Minnows, Flathead Chubs, and Sand Shiners between tributaries and the main-stem lower Yellowstone River.

Objectives: Our objectives were to 1) determine the proportions of resident and dispersing individuals of selected species in the lower Yellowstone River and its tributaries, and 2) identify dispersal patterns of these selected species.

Study area: Our study area was the Yellowstone, Tongue, and Powder rivers and Sunday, O'Fallon, and Cabin creeks.

Methods: The 87Sr:86Sr ratios were measured from water samples in 17 locations throughout the YRB and in general, the large tributaries (Tongue and Powder rivers) had relatively high 87Sr:86Sr ratios, the small tributaries (Sunday, O'Fallon, and Cabin creeks) had low ratios, and the ratios in the Yellowstone River downstream from the Clark's Fork were intermediate. The upper and lower 87Sr:86Sr limits for the Yellowstone River were 0.70972 and 0.70909, respectively. The upper and lower 87Sr:86Sr limits for the Powder River were 0.71085 and 0.71035, respectively. The upper and lower 87Sr:86Sr limits for the Tongue River were 0.71004 and 0.70881, respectively. Signatures less than 0.70909 (the lower limit for the Yellowstone River) were representative of small tributaries for otoliths collected from fish captured at all sites other than the Tongue River or the reach immediately downstream of the Tongue River confluence (see below for site locations). Signatures less than 0.70881 were representative of small tributaries for fish captured in the Tongue River or in the Yellowstone River immediately downstream of the Tongue River.

Otolith microchemistry.—The authors captured 188 Sand Shiners, 169 Western Silvery Minnows, and 182 Flathead Chubs from 10 different locations in the lower YRB during the spring and summer of 2009 and 2010. Total length (TL; mm) of each fish was measured before it was placed on ice for transportation to the laboratory where it was stored frozen until its otoliths were extracted.

Following extraction and preparation of otoliths, an ICP-MS coupled with a 213-mm laser ablation system was used to measure isotopic concentrations of 86Sr and 87Sr along a transect on each otolith. An "otolith profile" representing ambient 87Sr:86Sr ratios of inhabited environments over the lifetime of each fish was produced.

Data analysis.— An otolith profile exhibiting 87Sr:86Sr ratios entirely within the range of expected values for the location where the fish was captured represented a resident. An otolith profile with 87Sr:86Sr ratios outside the signature of the location where the fish was captured was considered a disperser. Dispersers were further classified as main-stem to tributary or tributary to main-stem dispersers based on the natal origin of the fish, which was determined using the core 87Sr:86Sr value, and any subsequent movements, which were determined using 87Sr:86Sr values outside of the core and capture locations. Tributary-tributary dispersers were fish with otolith profiles or capture locations that included at least two of the three tributary categories (i.e., Powder River, Tongue River, and small tributary). Otolith profiles containing 87Sr:86Sr values between river signatures were indicative of fish that inhabited mixing zones of the Yellowstone River and its tributaries as has been observed in other otolith microchemistry studies.

Results: *Otolith microchemistry.*—Four life history strategies of fish captured in the Yellowstone River were identified using otolith profiles: main-stem resident, main-stem disperser (hatched in the Yellowstone River and moved into a tributary), tributary disperser (hatched in any tributary and moved into the Yellowstone River), and tributary-tributary disperser (inhabited multiple tributaries, but captured in the Yellowstone River). Four life history strategies of fish captured in tributaries were identified: tributary resident, main-stem disperser (hatched in the Yellowstone River and moved into the tributary in which it was captured), tributary disperser (hatched in a tributary and subsequently moved into the Yellowstone River), and tributary-tributary disperser (hatched in one tributary but captured in another). Movement patterns varied among the three study species and sampling locations. The authors were unable to distinguish Tongue River residents from main-stem dispersers because 87Sr:86Sr values overlapped between the Tongue and Yellowstone rivers.

Fifty percent of all Sand Shiners were dispersers. The Sand Shiners we captured in the Yellowstone River were from a mixed population of roughly equal main-stem residents, main-stem dispersers, and tributary dispersers. About 50% of the Sand Shiners captured in the Powder and Tongue rivers were tributary-tributary dispersers. The remaining Sand Shiners captured in the Powder River were either main-stem or tributary dispersers. The remaining Sand Shiners captured in the Tongue River were either residents or main-stem dispersers. At least 90% of the Sand Shiners captured in each of the three small tributaries were residents, and none were tributary dispersers.

Seventy-two percent of all Western Silvery Minnows captured were dispersers. Most of the Western Silvery Minnows captured in the Yellowstone River were main-stem dispersers that had returned to their natal habitat or residents. Over half of the Western Silvery Minnows captured in the Powder and Tongue rivers were tributary-tributary dispersers. Most of the remaining Western Silvery Minnows captured in the Powder River dispersed from the Yellowstone River. There was only one tributary dispersing Western Silvery Minnow captured in the Powder River, and none were Powder River residents. Thirty percent of Western Silvery Minnows captured in the Tongue River were either residents or main-stem dispersers. Western Silvery Minnows captured in O'Fallon Creek were all either tributary dispersers or main-stem dispersers. In contrast, Sunday and Cabin creeks had 67% and 80% tributary resident Western Silvery Minnows, respectively. However, many of these were age-0 fish; the few large individuals that were captured were dispersers.

Seventy-one percent of all Flathead Chubs were dispersers. The movement pattern proportions of Flathead Chubs captured in the Yellowstone River were similar to those of Western Silvery Minnows. Most Flathead Chubs captured in the Powder and Tongue rivers were tributary-tributary dispersers. The Powder River also had main-stem and tributary dispersers, but had no tributary residents. The Tongue River also had either main-stem dispersers or tributary residents. Flathead Chubs captured in O'Fallon Creek were either main-stem dispersers or tributary dispersers; there were no tributary residents captured. In contrast, Sunday and Cabin creeks had 40% and 55% tributary resident Flathead Chubs, respectively. However, many of these were age-0 fish; the few large individuals were dispersers.

Discussion: Dispersal between the Yellowstone River and its tributaries was pervasive among the three fish species we studied. About two thirds of all fish captured in the Yellowstone River had dispersed to tributaries at some point in their life history. Among tributaries, dispersal rates declined with watershed area. Dispersal was universal among fish from the Powder River; 100% of fish had dispersed to either the Yellowstone or another tributary. Whereas over half the fish from O'Fallon Creek were dispersers, only about 30% of fish from Sunday Cabin creeks were dispersers.

Dispersal rates also differed among fish species, and differences were most pronounced in smaller tributaries. It appears that Sand Shiners have largely insular populations in small streams, as well as main-stem populations that disperse between main-stem and both tributary habitats. However, most Western Silvery Minnow and Flathead Chubs are dispersers, regardless of capture location.

The differences in dispersal rates among the three study species might provide some insight into the reasons for their current distribution and status in the Mississippi River Basin. Sand Shiners dispersed between main-stem and tributary habitats less than Western Silvery Minnows and Flathead Chubs. Therefore, Sand Shiners, which remain abundant throughout much of their range, may need only limited or periodic dispersal to sustain main-stem and tributary populations. Conversely, we observed that relatively high proportions of Western Silvery Minnows and Flathead Chubs were dispersers in the lower YRB, and that few adult Western Silvery Minnows or Flathead Chubs were tributary residents. This may indicate that both main-stem and tributary environments are needed for them to complete their life histories. The Yellowstone River's natural flow regime, lack of main-stem reservoirs, and well-connected tributaries, which are now unique may explain the continued persistence and of Western Silvery Minnows and Flathead Chubs in the Yellowstone River. In contrast, Western Silvery Minnows and Flathead Chubs have declined in abundance and distribution in much the Missouri River Basin, which has largely been attributed to the damming of main-stem rivers.

The large spatial differences in Strontium isotope ratios among the Yellowstone River and most of its tributaries allowed us to identify movement of Sand Shiners, Western Silvery Minnows, and Flathead Chubs between main-stem and most tributary environments in the lower YRB. However, overlapping 87Sr:86Sr signatures between the Yellowstone and Tongue rivers prevented us from distinguishing Tongue River residents from Yellowstone River dispersers, which probably led to underestimated dispersion rates for fish captured in and around the Tongue River.

Our study provides the first conclusive evidence of large-scale movement of small-bodied cyprinids and provides inference on the consequences that loss of connectivity between main-stem and tributary habitats could have on prairie stream fishes. Inadequate connectivity between main-stem rivers and their tributaries as well as habitat fragmentation within tributaries typically decreases population viability. The authors recommend that conservation strategies identify and help maintain important habitats and life history strategies of small nongame fishes at the landscape level instead of managing streams or rivers on an individual basis. Future studies could investigate movement patterns of species of special concern such as Sturgeon Chub, which occur in both the Yellowstone and Powder rivers, identify important spawning and nursery habitats, and potentially assess the expansion and source of nonnative fish populations.

Conclusions on anthropogenic effects on fish: Connectivity between the lower Yellowstone River and its tributaries is crucial for Western Silvery Minnows, Flathead Chubs, and Sand Shiners. Nearly three-quarters of Western Silvery Minnows, Flathead Chubs, and half of Sand Shiners used both main-stem and tributary habitats during their lifetimes. These three species composed three of the four most abundant small fish species in the Yellowstone River below the Tongue River. Only Emerald Shiner were more abundant in this reach of the Yellowstone River. As such, they are almost certainly important food items for larger game fish species such as Sauger and Channel Catfish, for the endangered Pallid Sturgeon, as well as for other predators such as fish-eating birds. Forage fish such as these three minnow species make up much of the primary and secondary consumer biomass in the Yellowstone River's food web and therefore are critical components of energy flow in a functioning ecosystem. The magnitude of dispersal between the main-stem and tributaries increases with tributary basin area. Therefore, the larger the tributary, the more energy flow between the tributary and main-stem.

I speculate that the relative importance of these three minnow species as forage for endangered Pallid Sturgeon is related in part to the degree to which these three species are benthically oriented, and also the degree to which they occupy main-stem habitats. I suspect that the order of importance for these three species as Pallid Sturgeon forage items is as follows: Flathead Chub, Western Silvery Minnow, and Sand Shiners. Flathead Chub and Western Silvery Minnow are roughly equally abundant to Sand Shiners and have a larger body size, so provide much energy to higher trophic levels. In the Missouri River above Fort Peck Reservoir, juvenile (age-6 and age-7) Pallid Sturgeon consumed primarily fish (90% by wet weight), however Sturgeon Chub and Sicklefin Chub , comprised 79% of the number of identifiable fish in juvenile Pallid Sturgeon stomachs. In the Yellowstone River, Sturgeon Chub range upstream as far as the Tongue River, and Sicklefin Chub are found primarily below Intake Diversion Dam (Chapter 2). Therefore, Pallid Sturgeon diet probably varies longitudinally on the Yellowstone River.

Spatial fisheries information: Locations of fish sampling sites are identified as being 10 river kilometers above or below tributary confluences. As such, these locations could probably be assigned to YRCDC reaches. Water chemistry (strontium isotopes) sample locations are identified descriptively and by dots on a maps, but precise sampling locations are not included.

BMP implications: Connectivity between the main-stem Yellowstone River and its tributaries is essential for at least three of the four most abundant small forage fishes in the ecosystem. Connectivity should be preserved between tributaries and the Yellowstone River. New water diversions or culverts should be designed to allow for fish passage. Existing barriers should be considered for redesign and construction to allow for fish passage. A general guideline is that the larger the tributary in question, and the closer to the Yellowstone River the structure, the higher the importance for the ecosystem and the higher the priority for allowing fish passage.

Scientific rigor: Moderately high. Although not peer-reviewed or published in the primary literature, this report has undergone review by Drs. Al Zale and Bob Bramblett as well as FWP review. Inference is based on statistical significance testing.

Title: Anthropogenic Habitat Change Effects on Fish Assemblages of the Middle and Lower Yellowstone River

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Overall abstract: The Yellowstone River remains the longest unimpounded river in the conterminous United States. However, bank stabilization and floodplain dikes have altered its fish habitat. Therefore, I surveyed fish habitat and fish from Laurel to Sidney, Montana, to (1) quantify changes to side channels attributable to linear bank stabilization and floodplain dikes, (2) compare the habitat use of side channels to main channels by small fish during runoff and base flow, and (3) determine if bank stabilization and side channels influenced main-channel fish assemblages during base flow.

Floodplain dike frequency, but not linear bank-stabilization extent, directly correlated to a net loss of side channels from the 1950s to 2001. However, side channels provided important fish habitat. Fish catch rates were similar between side and main channels during base flow, but not during runoff when catch rates in side channels were several times higher than in main channels and assemblage structure differed between side and main channels. Shallow, slow-current velocity (SSCV) habitats were slightly slower in side channels and SSCV patches were larger in side channels than in main channels during runoff, but not during base flow. These habitat differences likely partially explained the patterns in fish catch rates between channel types.

During base flow, fish assemblages in main channels varied with bank-stabilization extent and side-channel availability in alluvial (unconfined) and bluff (confined) river bends. Bank stabilization and side channels had different and sometimes opposite influences on fish assemblage structure. Influences of bank stabilization and side channels on fish relative abundances varied depending on species and river bend geomorphology. Assemblage responses to side channels were more consistent and widespread than to bank stabilization, and more fish species were associated with side channels than bank stabilization. Physical differences probably contributed to the assemblage differences between reference and stabilized river bends; stabilized alluvial pools were deeper than reference alluvial pools. The strengths of the relationships among fish assemblages, bank stabilization, and side channels were spatial scale-dependent; optimum scales ranged from less than 200 m to 3,200 m up- and down-stream, suggesting that bank stabilization and side channels influenced fish across multiple spatial scales.

Chapter 1: Introduction: Alteration of large rivers by physical anthropogenic structures such as bank stabilization has uncertain consequences for fish assemblages. Banks are stabilized to prevent erosion of agricultural, residential, and urban lands, and to protect transportation structures such as roads, railroads, and bridges. However, such alterations result in concomitant changes in local main-channel bathymetry such as main-channel bed degradation, channel width reduction, and increased stream gradient. Moreover, bank stabilization may decrease floodplain connectivity and normal riverine processes such as lateral channel migration and the formation of backwaters, braids, and side channels.

Stabilization of Yellowstone River banks has been controversial because it is the longest undammed river in the contiguous United States and its floodplain is largely intact. The effects of anthropogenic stabilization structures on the lower Yellowstone River fish assemblage were unknown at the onset of this study. For example, it was unknown how much, if any, side channel habitat had been lost, and fish use of lower Yellowstone River side channels had never been quantified. Moreover, the potential effects of bank stabilization on the Yellowstone River fish assemblage had not been examined directly in the middle and lower Yellowstone River from Laurel to Sidney, Montana. The authors quantified (1) changes in Yellowstone River side-channel areas from the 1950s to 2001 and determined if anthropogenic structures influenced these changes, (2) the habitat use of Yellowstone River fish of side channels and main channels during different hydroperiods, and (3) the responses of the main-stem Yellowstone River fish assemblages to bank stabilization and side channels using a spatially-explicit framework.

Study area: The Yellowstone River originates in northwestern Wyoming, flows north to Livingston, Montana then generally northeast to its confluence with the Missouri River in North Dakota. The basin size of this 8th order stream is 182,336 km^2. Its hydrology is driven by snowmelt with peak runoff usually occurring in June. The Yellowstone River's hydrology is altered by dams on two of its major tributaries (the Bighorn and Tongue rivers) and by water withdrawals of 1.8 x 109 m^3 annually. Much of this water is removed by six main-stem low-head irrigation diversion dams from Huntley to Intake, Montana.

The study area was the main-stem Yellowstone River from its confluence with the Clarks Fork Yellowstone River near Billings, Montana, downstream to its confluence with the Missouri River. The Yellowstone has gravel and cobble substrates above river kilometer 50; it is a sand-bed river downstream of river kilometer 50. Channel slope generally decreases from 0.140% near the Clarks Fork confluence to 0.046% near the Missouri River confluence.

The study area is characterized by diverse geomorphologies that are influenced by valley-wall constriction or lack thereof. Reaches with valley-wall constriction are meandering or straight, whereas unconstrained reaches are braided or anabranching with islands). Historically, unvegetated bars were common, but many of these bars have been replaced by vegetated islands.

Anthropogenic alterations to the Yellowstone's fluvial geomorphology included in-stream linear bank armoring, floodplain levees, dikes, and removal of riparian vegetation. Linear bank armoring consisted of rock and concrete riprap constructed longitudinally along river banks to prevent bank erosion. Floodplain levees consisted of earthen ridges constructed around developed lands to prevent inundation during high flows. Dikes were of two types: wing dikes and floodplain dikes. Wing dikes consisted of rock or concrete riprap deflection structures to direct currents away from the banks on which they were located. Floodplain dikes consisted of embankments of earth and rock constructed perpendicular to channel flow in side channels to restrict flows. Forty-nine species from 15 families compose the fish assemblage.

Chapter2: Cumulative Effects of Floodplain Dikes and Linear Bank Stabilization on Yellowstone River Side Channels

Abstract: Braiding and complexity of the Yellowstone River decreased from the 1950s to 2001, in part because of a loss of side channels. Side-channel persistence depends on a balance between side channel losses and gains. However, anthropogenic floodplain modifications may perturb this balance. The authors hypothesized that installation of floodplain dikes in side channels accelerated the rate of side-channel loss from the 1950s to 2001 thereby disrupting the normal balance. The authors quantified the losses and gains in side channels and investigated the relationship between side-channel turnover and dike frequency. Side-channel losses exceeded side-channel gains in both number and areal extent and were greater where dikes were more common; no relationship existed between side-channel gains and dike frequency. Diking therefore probably caused reductions in Yellowstone River side channel number and areal extent.

Introduction: The Yellowstone River is the longest undammed river in the contiguous United States and its floodplain has been described as largely intact. However, Yellowstone River channel complexity has decreased over the last 60 years; both braiding and river complexity declined markedly from the 1950s to 2001 in anabranching and braided reaches. Damming of the Bighorn and Tongue rivers altered the natural hydrologic regimes of these tributaries and reduced sediment inputs into the Yellowstone River. Reductions in sediment inputs can cause channel incision and consequently side-channel dewatering. The largest reductions in braiding since the 1950s occurred between the Bighorn and Powder rivers. Floodplain erosion-control structures may also contribute to channel simplification. Floodplain levees, riprap bank stabilization, and dikes constructed to protect economically valuable lands and transportation structures from erosion can restrict lateral channel migration, accelerate side channel loss, and attenuate side channel formation). In particular, floodplain dikes directly block or reduce scouring flows in side channels and thereby cause them to atrophy or become abandoned.

Side-channel loss reduces lateral connectivity, habitat heterogeneity, and habitat suitability for fish and other animals. Reductions in lateral connectivity may have detrimental effects on the biodiversity and biomass of fish amphibians, turtles, birds, and other riverine organisms.

Goal: The authors hypothesized that floodplain dikes accelerated side-channel loss, and therefore we quantified the areal changes in side channels in the lower Yellowstone River from the 1950s to 2001 and related these changes to the frequency of floodplain dikes.

Study area: The study area was the main-stem Yellowstone River from its confluence with the Clarks Fork Yellowstone River near Billings, Montana, downstream to its confluence with the Missouri River.

Methods: Bank-full areas were digitized from scour zones (wet or dry channels without vegetation; Tony Thatcher, unpublished data) from aerial photographs from the 1950s and 2001. Bank-full areas were classified and digitized as side channels or main channels.

Main channels were of two types: single-thread or split. Side channels were of two types: primary side channels and secondary side channels. Dikes were rarely built on secondary side channels because mid-channel bars and islands were not subject to anthropogenic land use. Therefore, our analyses of anthropogenic effects on side-channel losses and gains focused exclusively on primary side channels.

The authors created a transition matrix by overlaying the 2001 channel configuration atop the 1950s channel configuration. The authors then classified the intersecting areas of the channel configurations such that the result was two polygon layers: primary side channels that were lost and those that were gained from the 1950s to 2001 (Figure 2.3c).

The authors used digital elevation models (DEMs) and aerial photography to identify floodplain dikes. The authors calculated the total area of side-channel loss and gain, and the total number of dikes within each 16-km section.

The authors used ordinary least squares (OLS) regression to determine if the frequency of dikes was correlated with side-channel loss or gain or both. The authors regressed side-channel losses and gains separately (as opposed to net change) because this resulted in a more direct hypothesis test.

Results: The loss in side channels exceeded the gain in side channels from the 1950s to 2001. Sixty-seven side channels were lost, 39 side channels were gained, and 91 remained stable. The total area of side-channel loss was 10.1 km^2, whereas the total area of side-channel gain was 7.1 km^2. The total area of side channels was 28.8 km^2 in the 1950s and 25.8 km^2 in 2001. Therefore, 10.4% of side channel area was lost from the 1950s to 2001. Side-channel loss was positively correlated with the frequency of dikes (linear regression: t1, 30 = 2.22, P = 0.034, Moran's I = -0.024) whereas side-channel gain was not (t1, 30 = 1.01, P = 0.322, Moran's I = -0.040).

Discussion: The lower Yellowstone River is a dynamic fluvial landscape wherein side-channels are gained and lost. Side channels are gained by channel switching or channel bifurcation, lost by avulsion, main channel incision, and sedimentation, and maintained by scouring flows. Floodplain dikes may reduce or eliminate scouring flows in side channels resulting in side channel atrophy or abandonment. At the landscape scale, side-channel persistence requires a balance between side-channel gains and losses. However, our results suggest that floodplain dikes have perturbed this balance on the Yellowstone River.

The net loss of side channels changed fish habitat availability on the lower Yellowstone River and this change may be detrimental to fish. Seasonally inundated side channels and the shallow, slow-moving habitats that they provide are important habitats for small fish during high-flow conditions. Fish use was up to nine times greater in side-channels margins than in main-channel margins during runoff in the lower Yellowstone River (Chapter 3). During runoff, increased water velocities may reduce the suitability of main channels for small fish because they are susceptible to displacement. Therefore, the loss of side channels resulted in a direct loss of heavily used fish habitat (Chapter 3), may have reduced local fish abundance and richness (Chapter 3), and caused shifts in fish assemblage structure (Chapters 3 and 4).

Our study was the first of which we are aware that quantified the relationship between floodplain dikes and side-channel dynamics in an undammed and relatively unaltered large river-floodplain ecosystem. Although the Yellowstone River has a largely intact floodplain, substantial side-channel losses have occurred, some of which probably resulted from floodplain dikes. However, floodplain dikes, dammed tributaries, bank hardening, and levees probably interacted synergistically to accelerate the rates of side-channel loss. Therefore, management practices that preserve and maintain side channels may be important long-term conservation strategies.

Conclusions on anthropogenic effects on fish: Floodplain dikes were correlated with the net loss of 3.0 km^2 of side channel area, which represented a 10.4% net loss in side channel area from the 1950s to 2001. Loss of side channels probably has negative consequences for Yellowstone River fish because side channels are important habitat for fish in the Yellowstone River during runoff, side channel availability influences main channel fish assemblages at scales of up to 3 km upstream and downstream, and side channels shifts assemblage structure in ways opposite of bank stabilization.

Spatial fisheries information: No fisheries information is presented in this chapter. GIS shapefiles of side channel polygons in the 1950s and 2001 and locations of floodplain dikes could be obtained from Montana State University.

BMP implications: Preserve existing side channels by minimizing installation of floodplain dikes. Riverine processes that allow for continued existence, maintenance, and formation of side channels will enhance continued maintenance of the fishery.

Scientific rigor: Moderately high. Although not peer-reviewed or published in the primary literature, this report has undergone review by Ann Marie Reinhold's graduate committee at MSU, as well as TAC and FWP review. Inference is based on statistical significance testing.

Chapter 3: Use of Side Channels by a Large-River Fish Assemblage

Abstract: The availability of side channels has decreased on the lower Yellowstone River from the 1950s to 2001. However, empirical evidence from the upper Yellowstone River and other rivers suggested that the shallow, slow-velocity habitats in side channels may provide important fluvial fish habitat. The authors compared fish assemblages in side and main channels in alluvial and bluff river bends during early and late snowmelt runoff, and base flow. Catch rates were greater in side channels than in main channels throughout runoff in alluvial river bends. Catch rates were greater in side channels than in main channels in bluff river bends during early runoff, but not during late runoff. Catch rates were not different between side channels and main channels in either alluvial or bluff river bends during base flow. Species compositions differed between side channels and main channels throughout hydroperiods, largely because of rare species. Proportional assemblage compositions in side and main channels were different during runoff, but not during base flow, in both alluvial and bluff river bends. Water velocities were slower and patches of shallow, slow current-velocity habitats were larger, in side channels than in main channels during runoff, but not during base flow. These physical dissimilarities may have differentially structured the side-channel and main-channel fish assemblages during runoff.

Introduction: Rivers and their floodplains form dynamic mosaics of habitat patches that vary in complexity depending on river geomorphology, floodplain topology, and flow regime. Side channels provide unique habitats such as large, shallow, slow current-velocity (SSCV) patches that vary in importance seasonally as a function of river discharge. During runoff, seasonally-inundated SSCV patches probably provide refugia for small fish because high water velocities can displace small fish, especially larvae. Anthropogenic alterations to the Yellowstone River floodplain are reducing side channel availability and, consequently, fish habitat heterogeneity (Chapter 3).

Goal: To determine if fish assemblage structures in SSCV habitats differed in side channels and main channels in alluvial and bluff geomorphic river-bend types during early runoff, late runoff, and base flow.

Methods: River bends were randomly selected and each river bend was sampled three times with fyke nets: once during early runoff, once during late runoff, and once during base flow. Depth, velocity, water chemistry, and water transparency were measured at each net deployment.

The authors used multiple methods to assess the potential differences between side-channel and main-channel assemblages during runoff and base flow. Potential differences between side- and main-channel water velocity, depth, temperature, DO, water clarity, and conductivity were modeled with ordinary least squares regression.

Results: Forty-five species representing 15 families of fish were captured. Western Silvery Minnow, Longnose Dace, and Flathead Chub were the three most widespread, commonly captured fishes.

Catch rates.—In alluvial river bends during early runoff, mean catches of all species combined were 4.05 times greater in side channels than main channels (95% confidence interval [CI] from 2.70 to 6.06 times greater). Mean catches of Western Silvery Minnow, Longnose Dace, Flathead Chub, Sand Shiners, and Emerald Shiner were significantly greater in side channels than main channels.

In bluff river bends during early runoff, mean catches of all species combined were 8.93 times greater in side channels than main channels (95% CI from 4.36 to 18.39 times greater). Mean catches of Western Silvery Minnow, Longnose Dace, Flathead Chub, Sand Shiners, and Emerald Shiner were significantly greater in side channels than main channels.

In alluvial river bends during late runoff, mean catches of all species combined were 2.31 times greater in side channels than main channels (95% CI from 1.55 to 3.44 times greater). Mean catches of Western Silvery Minnow, Flathead Chub, and Sand Shiners were significantly greater in side channels than main channels. However, mean catches of Longnose Dace and Emerald Shiner were not significantly different between side and main channels. In bluff river bends during late runoff, mean catches of all species combined were not significantly different in side and main channels. Mean catches of Western Silvery Minnow were greater in side channels than main channels, but mean catches were not significantly different between side channels and main channels for Longnose Dace, Flathead Chub, Sand Shiners, and Emerald Shiner.

In alluvial river bends during base flow, mean catches of all species combined were not significantly different in side and main channels. Catches were not significantly different between side channels and main channels for Western Silvery Minnow, Longnose Dace, Flathead Chub, Sand Shiners, and Emerald Shiner.

In bluff river bends during base flow, mean catches of all species combined were not significantly different in side and main channels. Mean Western Silvery Minnow catches were greater in main channels than in side channels, but catches were not significantly different between side and main channels for Longnose Dace, Flathead Chub, Sand Shiners, and Emerald Shiner.

Assemblage Composition and Structure.—In alluvial river bends throughout runoff, the species compositions and fish assemblage structures differed between side and main channels. Species richness was greater in side channels than main channels in most river segments.

In bluff river bends throughout runoff, the species compositions and fish assemblage structures differed between side and main channels. Species richness was consistently greater in side channels than main channels in all river segments.

In alluvial river bends during base flow, the species compositions differed between side and main channels, but the assemblage structures were not significantly different between side and main channels. Side-channel and main-channel species richness varied by segment.

In bluff river bends during base flow, the species compositions differed between side and main channels, but the assemblage structures were not significantly different between side and main channels. Species richness was consistently greater in main channels than side channels in all river segments.

Physical Habitat.—The velocity, depth, water temperature, DO, water clarity, and specific conductance were similar in side channels and main channels within hydroperiod at alluvial and bluff river bends. Exceptions were velocity during early and late runoff in bluff and alluvial river bends, and depth and DO during late runoff in alluvial river bends.

Discussion: Shallow, slow-current velocity habitats may provide small fish protection from aquatic predators, velocity refugia, and facilitate increased fish growth rates. Yellowstone River SSCV habitats were heavily used by fish and the patterns of SSCV habitat use – side or main channel – were strongly tied to hydroperiod.

Differences in physical habitats of SSCV patches may have influenced fish habitat use and assemblage structure. Fish assemblage structure and current velocities differed between SSCV habitats in side channels and main channels, a consistent with findings that fluvial fish assemblage structures can be tightly coupled with velocity gradients. Moreover, observed differences in depth between side-channel and main-channel SSCV habitats during late runoff in alluvial river bends may help explain why side-channel catches were generally greater than main-channel catches in alluvial and not bluff river bends during this hydroperiod.

The authors propose that the size and spatial context of SSCV patches influenced their use by Yellowstone River fish. During runoff, SSCV habitat patches were concentrated along main-channel margins and larger in side channels than in main channels. Therefore, side channels probably provided large patches of suitable habitat for small fish. In contrast, main-channel SSCV was limited to narrow portions of channel margins that were bordered by deep water with swift currents, which may have caused fish in main-channel SSCV habitats to be susceptible to aquatic predators, downstream displacement, or both. Such edge effects may have reduced the suitability of main-channel SSCV habitats for small fish during runoff. By contrast, during base flow, SSCV habitat patches were larger and well distributed within and among main and side channels; over half of SSCV habitat patches were located in main channels. If patch size influenced habitat use, the availability of large patches in the main channel during base flow may explain why fish were not concentrated in side channels during this hydroperiod. In sum, fish habitat use between main and side channel habitats followed the availability of large SSCV patches from lateral (i.e., side channels) to main channel habitats.

The authors also compared water chemistry between side and main channels because fish have thermal, DO, and turbidity tolerances. However only DO differed between side and main channels and the difference was small and not significant except in one of six comparisons. The authors also examined potential differences in specific conductance; a difference in specific conductance would have suggested that nutrient availability, primary productivity, or both differed between side and main channels. However, specific conductance was similar in side and main channels. Therefore, SSCV patch size, spatial patch context, and current velocity, rather than water quality, were concordant with the patterns in fish habitat use and assemblage structure.

Although most fish species were captured in both main channels and side channels, some rare fish were captured exclusively in side channels or main channels. This result was consistent with empirical evidence that many fish move laterally on diel and seasonal bases, whereas other fish are side-channel or main-channel residents. In our study, most of the fishes that were captured in side channels exclusively during either runoff or base flow were rarely captured, except for black crappie. Black crappies were captured solely in side channels during runoff. Side channels may have had more suitable habitat than main channels for black crappie during runoff because little to no current-velocity and abundant cover make excellent black crappie habitat. Moreover, black crappies have been known to shift habitats with seasonal variations in abiotic conditions, and this may explain why black crappie used both side and main channels during base flow.

Most of the fishes that were captured solely in main channels during either runoff or base flow were rarely captured, except for Goldeye. Goldeye shifted from using both side channels and main channels during runoff to exclusively using main channels during base flow. This shift in habitat use may have occurred because Goldeye are frequently found in fast currents and the main channel is the primary location of fast currents during base flow. This result illustrates that the habitat suitability of side and main channels may vary with hydroperiod.

Our results support existing studies demonstrating that access to heterogeneous habitats throughout different hydroperiods is important for fish assemblages and that connectivity between main channels and side channels helps maintain diverse fish assemblages. The disparity in side-channel and main-channel fish habitat use and assemblage structure during runoff was probably because side channels offered slower velocities and larger SSCV patches. River geomorphology governs the spatial organization of habitat patches, but some anthropogenic activities reduce side channel availability (Chapter 2) and therefore the availability of these habitat patches. Extensive side-channel losses may have detrimental consequences for lower Yellowstone River fish assemblages.

Conclusions on anthropogenic effects on fish: Side channels provide important habitat for the Yellowstone River shoreline fish assemblage during runoff. Overall fish catch rates, catch rates of the most common species (Western Silvery Minnow, Longnose Dace, Flathead Chub, and Emerald Shiner), and species richness were generally greater in side channels than main channels during early and late runoff. Overall fish catch rates were up to nine time higher relative to main channel catch rates. However, during baseflow, catch rates were generally not different between side channels and main channels, and the composition of the catch varied.

Physical habitat variables (water velocity, depth, water temperature, DO, water clarity, and specific conductance) were similar at the sites of net deployment in side channels and main channels within hydroperiod, so probably did not explain the differences in side channel and main channel fish assemblages. However, side channels probably provided larger patches of suitable habitat for small fish during runoff, where they may have been less susceptible to aquatic predators and downstream displacement. Our results support existing studies demonstrating that access to heterogeneous habitats throughout different hydroperiods is important for fish assemblages and that connectivity between main channels and side channels helps maintain diverse fish assemblages.

Spatial fisheries information: Fish sampling sites are not presented in this report. However, GPS coordinates for all sites are available from MSU, and Ann Marie Reinhold has already provided fish sampling summary statistics by reach to the TAC.

BMP implications: Extensive side-channel losses may have detrimental consequences for lower Yellowstone River fish assemblages. Management practices that preserve side channels and the riverine processes that create and maintain side channels will ensure that these important fish habitats continue to exist. Restoration or reconnection of side channels will benefit the fish assemblage.

Scientific rigor: Moderately high. Although not peer-reviewed or published in the primary literature, this report has undergone review by Ann Marie Reinhold's graduate committee at MSU, as well as TAC and FWP review. Inference is based on statistical significance testing.

Chapter 4: Spatially-Dependent Responses of a Large-River Fish Assemblage to Bank Stabilization and Side Channels

Abstract: The alteration of large rivers by anthropogenic bank stabilization has uncertain consequences for fish assemblages. Bank stabilization in our study area is especially controversial because the public values the Yellowstone River as the longest unimpounded river remaining in the conterminous United States. We hypothesized that bank stabilization changed main-channel fish assemblage structure by altering main-channel habitats and that side channels influenced main-channel fish assemblage structure by providing habitat heterogeneity. We hypothesized that bank stabilization and side channels would influence fish assemblage structure differently, but that both would be scale-dependent. We developed a spatially-explicit framework to test these hypotheses. Fish assemblage structure varied with bank-stabilization extent and side-channel availability; however, not all assemblage subsets were influenced. Nevertheless, bank stabilization and side channels had different and sometimes opposite influences on fish assemblages. Assemblage responses to side channels were more consistent and widespread than to bank stabilization; more fishes positively correlated with side channels than bank stabilization. Influences of bank stabilization and side channels on fish relative abundances varied depending on species and river bend geomorphology. Physical differences probably contributed to the assemblage differences between stabilized and reference river bends; stabilized alluvial pools were deeper than reference alluvial pools, but depths of stabilized and reference bluff pools did not differ. The strengths of the relationships among fish assemblages, bank stabilization, and side channels were spatial scale-dependent; optimum spatial scales ranged from less than 200 m to 3,200 m up- and down-stream, suggesting that bank stabilization and side channels influenced fish across multiple spatial scales.

Introduction: The alteration of large rivers by anthropogenic structures such as bank stabilization has uncertain consequences for fish assemblages. However, such alterations result in changes in local main-channel bathymetry and reduces floodplain connectivity and natural riverine processes such as lateral channel migration and the formation of backwaters, braids, and side channels.

Bank stabilization alters fish habitat and probably fish habitat suitability, albeit ambiguously. In some rivers, bank stabilization was associated with decreases in fish abundances and fish species richness, increases in others, or had no effect. Changes in fish assemblage structure or size-class distributions have occurred in bank-stabilized reaches. Thus, bank stabilization has uncertain and possibly multifaceted consequences for fish assemblages.

The discrepancies in the findings of previous studies may result from differences in rivers. In highly altered or naturally homogenous rivers, bank stabilization may provide habitat diversity that is otherwise lacking, and cause localized increases in fish density and species richness. Conversely, in unaltered or relatively heterogeneous rivers, moderate amounts of bank stabilization may have little or no effect on the fish assemblages. Moreover, most studies of the effects of bank stabilization in large rivers have been conducted in regulated rivers where the effects of bank stabilization may be confounded by or interact with the effects of dams.

Differences in study approaches may also underlie differences in the results of previous research. For example, previous studies differed with regard to the fish taxa studied and the spatial scales at which effects were examined. Many previous studies were limited to a single family of fish (e.g., salmonids) or particular age classes (e.g., juveniles). Moreover, failing to account for spatial scale-dependence or side channel availability may lead to differing conclusions.

Ecological theory and empirical field studies suggest that side channels are crucial fish habitats because of the habitat heterogeneity they provide. Lateral connectivity is also important. However, many study areas are confounded with bank stabilization and altered hydrographs because both bank stabilization and altered hydrographs reduce side channel availability and remaining side channel habitats may have concentrated fish.

The Yellowstone River has many side channels, many reaches with and without bank stabilization, and lacks the confounding influence of main-stem dams, making it an excellent location to study the effects of bank stabilization and side channels.

The authors hypothesized that bank stabilization and side channels would influence fish assemblage structure differently, but that both would be scale-dependent. The authors targeted our sampling and analyses to include the entire Yellowstone River fish assemblage to address this hypothesis. Moreover, we explicitly examined the potential scale-dependence in the relationships between fish assemblages and bank stabilization, and fish assemblages and side channels. In addition, we compared depths and velocities of stabilized and reference pools to determine if bank stabilization was altering local fish habitat.

Objectives: Determine if main-channel fish assemblages varied as a function of bank stabilization and side channels. Compare depths and velocities of stabilized and reference pools to determine if bank stabilization was altering local fish habitat.

Methods: The sampling design was a nested hierarchy. The authors divided the study area into five longitudinal segments. The authors randomly selected stabilized and reference alluvial and bluff sites (i.e., river bends) from braided and anabranching reaches within segments.

Fish sampling was conducted during late summer and autumn base flow conditions. Fish sampling occurred in mesohabitats: inside bends of pools, outside bends of pools, and channel crossovers. The authors sampled fish with fyke nets, bag seines, otter trawls, electrofishing, and trammel nets. Fyke nets, bag seines, and boat electrofishing were used to sample fish along shorelines. Trammel nets and otter trawls were used to sample the fish in the thalweg in each mesohabitat.

The authors used existing digitizations of bank stabilization, flow lines, and channel margins for all spatial analyses. The authors used ArcGIS Network Analyst to identify all bank stabilization and side channels around the center of each subsample and at 50-m, 100-m, 200-m, 400-m, 800-m, 1,200-m, 1,600-m, 2,000-m, 2,400-m, 2,800-m, and 3,200-m upstream and downstream distances from the center of the sampling site. The authors calculated bank-stabilization and side-channel rates by dividing the length of bank stabilization by the length of the main channel borders.

Catch per unit effort (CPUE) was calculated for all species captured by each gear type. The fish-assemblage subset captured by each gear at each geomorphic site type was analyzed separately. Each species was modeled at the twelve bank-stabilization and side-channel spatial scales, and all combinations thereof. The combination of bank-stabilization and side-channel spatial scales that maximized the adjusted R2 for each species was selected as the best-fitting model, and the only model from which coefficients were considered.

Each site was surveyed with an Acoustic Doppler Current Profiler (ADCP) during base flow 2011 to address whether depths and velocities differed significantly between stabilized and reference pools.

Results: The fish assemblage structures of fish captured in shorelines differed significantly with bank-stabilization rates at alluvial sites and bluff sites, except for the assemblage subset sampled with seines at bluff sites. The assemblage structure of the trammel-netted assemblage subset differed significantly with bank-stabilization rates at alluvial sites, but not at bluff sites. The structure of the otter-trawled assemblage subset did not differ significantly with bank-stabilization rates at alluvial sites.

The assemblage subsets sampled with electrofishing and trammel nets at alluvial sites differed significantly with side-channel rates; however, the structure of the assemblage subsets sampled with fykes, seines, and otter trawls at alluvial sites did not differ significantly with side-channel rates. The assemblage structures of fish captured in shorelines at bluff sites differed significantly with side-channel rates; however, the structure of the trammel-netted assemblage subset was not significantly different with side-channel rates at bluff sites.

The spatial scales at which bank-stabilization and side-channel rates were calculated influenced how well the assemblage subsets were explained. The strengths of the relationships among fish assemblages, bank stabilization, and side channels were spatial scale-dependent; optimum spatial scales ranged from less than 200 m to 3,200 m up- and down-stream.

Longitudinal influences were of primary importance in structuring the assemblage subsets. However, some segments had similar assemblage structures (e.g., assemblage subset captured by seines in Segments 3-5).

The variation in the assemblage subsets was often well explained by bank stabilization and side channels, indicating that bank stabilization and side channels were of secondary importance in structuring the assemblage subsets. Nevertheless, the eigenvectors for bank-stabilization and side-channel rates consistently differed from, and often opposed one another, suggesting that the effects of bank stabilization on the fish assemblage opposed the effects of side channels.

The correlations between bank-stabilization and side-channel rates and assemblage structure varied by river segment. Differences in bank-stabilization and side-channel eigenvector directionality across segments suggest that the influences of bank stabilization and side channels on assemblage structure differed by river segment. However, the influences of bank stabilization and side channels on the assemblage subsets sampled with trammel nets and otter trawls in alluvial river bends were more consistent across river segments.

Stabilized alluvial pools were deeper and had a greater variance in depths than reference alluvial pools. The mean depths of stabilized alluvial pools were 0.41 m deeper than reference pools with an associated confidence interval from 0.01 m deeper to 0.81 m deeper. The maximum depths of stabilized alluvial pools were 1.26 m deeper than reference pools with an associated 95% CI from 0.39 m deeper to 2.13 m deeper. The maximum variances in depths were 0.92 m greater in stabilized alluvial pools than reference alluvial pools with an associated 95% CI from 0.09 m greater to 1.76 m greater. No significant differences existed in the mean velocities, maximum velocities, or variance in velocities between stabilized and reference alluvial pools.

No significant differences existed between the mean depths, maximum depths, and variances in depths of stabilized and reference bluff pools. No significant differences existed between the mean velocities, maximum velocities, or variances in velocities of reference and stabilized bluff pools.

Discussion: The authors hypothesized that bank stabilization would alter Yellowstone River fish assemblage structure. The proportional compositions of species differed significantly as a function of bank stabilization. However, there was much overlap in the species compositions of stabilized and reference sites, consistent with similar investigations of the upper Mississippi River, the Kansas River, and the lower Missouri River.

All assemblage subsets sampled in shorelines differed significantly as a function of bank stabilization, except for those sampled with seines in bluff sites; however, the directionality of the differences varied with longitudinal river segment. This longitudinal variation was probably related to longitudinal differences in the fish assemblage. For example, the majority of the

Segment 1 fyke catch was benthic invertivores (Longnose Dace and age-0 catostomids) whereas the majorities of fyke catches in Segments 2 through 5 were either pelagic herbivores (Western Silvery Minnow), benthic invertivores (Flathead Chub), or pelagic invertivores (Emerald Shiner). These taxonomic and ecologically disparate species were probably not ecological analogs and therefore varied in their responses to bank stabilization.

The mechanisms underlying the shifts in the assemblage subsets captured in shorelines may have been related to the direct alteration of bank habitat. Rock and concrete riprap bank-stabilization structures provided novel, artificial habitats for fish. Interstices in stabilization structures may have provided suitable habitat for fish that may not have inhabited outside-bend and channel-crossover banks if not stabilized. Additionally, bank stabilization structures may have altered fish assemblages by altering food availability for invertivores, because local macroinvertebrate abundances may have been greater along stabilized banks.

The influences of bank stabilization on the assemblage subsets sampled in alluvial thalwegs were generally consistent across river segments, although only the shifts in the trammel-netted subset were statistically significant. These differences may have been longitudinally consistent because the widespread, commonly captured fish were essentially ecological analogs across river segments. Trammel-net catches were largely composed of benthic invertivores and Goldeye across river segments, although the relative abundances of benthic invertivores (i.e., Longnose Sucker, Shorthead Redhorse, and Shovelnose Sturgeon) varied taxonomically by river segment.

The responses of the trammel-netted assemblage subsets to bank stabilization varied with site geomorphology, possibly because of the disparate effects of bank stabilization on depths in alluvial and bluff pools. Stabilized alluvial pools were significantly deeper than their non-stabilized counterparts probably because bank stabilization halted lateral channel migration but increased vertical scour. Conversely, depths were similar at stabilized and reference bluff sites probably because lateral channel migration and scour are in relative equilibrium at erosion-resistant bluff pools.

The authors hypothesized that side channels and bank stabilization would affect the fish assemblage differently. Several fish assemblage subsets differed as a function of side channel availability and the influences of side-channels often opposed the influences of bank stabilization on the fish assemblage subsets. Moreover, bank stabilization can alter fish habitat by limiting side channel availability. Therefore, side-channel conservation or restoration may be appropriate mitigation strategies in rivers with bank stabilization.

Side channels increase habitat heterogeneity by providing habitats frequently not found in main channels, including shallow, slow current velocity habitats. Shallow habitats reduce the risk of small fish to piscivory. Additionally, water velocity, substrate, shading, food availability, and piscivore density influence stream fish growth rates and may differ between side and main channels. Not surprisingly, use of side and main channels differs for many fishes. Such differences in fish habitat use, and potentially habitat preference may explain why main-channel relative abundances of some fish decreased as a function of side-channel availability. Although the extent to which fish move laterally between side channels and main channels is unknown for Yellowstone River fish, river bends with side channels had more small-bodied fish than river bends without side channels and lateral movements of these fish between side and main channels may underlie some of the differences observed in the assemblage subsets sampled with fyke nets and seines.

The authors hypothesized that the effects of bank stabilization and side channels would be scale-dependent. The results support this hypothesis; a variety of spatial scales from fine to coarse explained the variation in the fish assemblage relationships to bank stabilization and side channels.

Other researchers proposed that bank stabilization may increase fish species richness and diversity at finer spatial scales by creating novel bank habitat, but may have negative consequences for fish at coarser spatial scales by altering normal riverine function. This suggests that bank stabilization influences at least two processes that structure fish assemblages – one at finer spatial scales and another at coarser spatial scales. Implicit in this hypothesis is the assumption that the extent of bank stabilization has reached a threshold by which riverine function is altered and that the altered function is important for fish. The authors tested a somewhat different, but related hypothesis; however, our results provided no clear support for this hypothesis because we observed only one set of high R^2 values for bank stabilization for each assemblage subset, providing evidence that bank stabilization influences assemblage structure at one spatial scale. However, bank stabilization on the Yellowstone River may not have been extensive enough to alter riverine function or our coarsest spatial scale may not have been "coarse enough" to effectively assess this hypothesis.

Our study demonstrated the importance of considering a range of spatial scales when examining the effects of landscape drivers on fluvial biota. The authors provided a novel method for incorporating fluvial landscape heterogeneity in fisheries research in a large, braided river. The authors identified physical habitat differences between stabilized and reference river bends and structural differences in the Yellowstone River fish assemblage that corresponded to bank stabilization. Although the lower Yellowstone River is one of the least-modified temperate rivers of its size, bank stabilization has nevertheless had an effect on its fish assemblage. Conservation of side channels may be important mitigation for some of the effects of bank stabilization on fish because the changes in fish assemblage structure associated with bank stabilization were consistently different from, and often opposite to changes in fish assemblage structure associated with increased availability of side channels.

Conclusions on anthropogenic effects on fish: Both bank stabilization and side channels influenced fish assemblages, and bank stabilization and side channels were often associated with shifts in the identity and abundance of the fish assemblages in different or opposite directions. This suggests that bank stabilization has caused the fish assemblages to change from the pre-stabilization condition, and that side channels influence fish assemblages to remain more similar to the pre-stabilization condition. The strengths of the relationships among fish assemblages, bank stabilization, and side channels were spatial scale-dependent; optimum spatial scales ranged from less than 200 m to 3,200 m up- and down-stream, suggesting that bank stabilization and side channels influenced fish across multiple spatial scales. A potential mechanism whereby bank stabilization influences fish assemblages is by creating deeper pools at stabilized alluvial river bends (relative to unstabilized alluvial pools).

Spatial fisheries information: Spatially-explicit locations of fish sampling sites are not presented in this report. However, GPS coordinates for all sites are available from MSU, and Ann Marie Reinhold has already provided fish sampling summary statistics by geomorphic reach to the TAC.

BMP implications: Because both bank stabilization and side channels influence the Yellowstone River fish assemblage, management activities that focus on these two aspects of the ecosystem will probably influence the fishery. Specific management implications from our study include considering the spatial context of bank stabilization projects and side channel availability. The amount of existing bank stabilization on a scale of a few kilometers often influenced the strength of the relationship between fish assemblages and bank stabilization. Therefore, small bank stabilization projects in reaches with mostly natural banks may have limited effects on the fishery. However, in reaches with a moderate extent of existing bank stabilization, additional bank stabilization may elicit larger shifts in the fish assemblage. In areas with extensive existing bank stabilization, fish assemblages have probably shifted away from the pre-stabilization condition, and any management actions that allow for unaltered riverine function—specifically increases in side channel availability, may shift the assemblage towards the pre-stabilization condition. Protection of existing side channels will ensure their continued availability to the fishery. However, we have no inference regarding how many side channels must be maintained to maintain fish assemblage structure, or how many side channels can be lost before threshold shifts in the fish assemblage occur. However, riverine processes that allow for continued existence, maintenance, and formation of side channels will enhance the continued maintenance of the fishery.

Scientific rigor: Moderately high. Although not peer-reviewed or published in the primary literature, this report has undergone review by Ann Marie Reinhold's graduate committee at MSU, as well as TAC and FWP review. Inference is based on statistical significance testing.

Chapter 5: Conclusions and Management Implications

The lower Yellowstone River remains perhaps the least-modified temperate river of its size in the conterminous United States but nonetheless is perturbed by anthropogenic factors. We determined that both bank stabilization and side channels influenced its fish assemblages.

Bank stabilization influenced both physical habitat and fish assemblage structure (i.e., species richness and abundance). Bank stabilization was associated with deeper alluvial pools and linear riprap provided novel bank habitat (Chapter 4). Floodplain diking, but not linear bank stabilization, was associated with reductions in side-channel areas (Chapter 2). However, linear bank stabilization was associated with structural shifts in the fish assemblage and these shifts were scale-dependent (Chapter 4). This suggests that linear bank stabilization (e.g., riprap) influences fish at multiple scales.

Side channels influenced fish assemblages and provided important physical habitat. Total catch rates, commonly-captured individual-species catch rates, and numbers of species were generally greater in side channels than in main channels during runoff, but not during base flow (Chapter 3). Fish assemblage structure also differed between side and main channels during runoff, but not during base flow (Chapter 3). During runoff, the velocities in the shallow, slow current velocity (SSCV) habitat patches were slightly slower, and SSCV patch sizes were generally larger in side channels than in main channels (Chapter 3). These differences in velocity or SSCV patch size possibly contributed to the differences in the fish assemblages between side and main channels. Side-channel availability also influenced main-channel fish assemblage structure. During base flow, fish assemblages in main channels varied with side-channel availability in alluvial (unconfined) and bluff (confined) river bends. Structural shifts in the main-channel base-flow fish assemblage were scale-dependent (Chapter 4). This again suggests that the spatial context of side channels is important when considering the effects of side channel availability on fish assemblages. Shifts in fish assemblage structure attributable to side channels were consistently different from, and often opposed, the shifts in assemblage structure associated with bank stabilization (Chapter 4). Moreover, more gear-specific fish assemblage subsets were significantly associated with side channels than bank stabilization.

Because both bank stabilization and side channels influence the Yellowstone River fish assemblage, management activities that focus on these two aspects of the ecosystem will probably influence the fishery. Specific management implications from our study include considering the spatial context of bank stabilization projects and side channel availability. The amount of existing bank stabilization on scales of up to a few kilometers influenced the strength of the relationship between fish assemblages and bank stabilization. Therefore, small bank stabilization projects in reaches with mostly natural banks may have limited effects on the fishery. However, in reaches with a moderate extent of existing bank stabilization, additional bank stabilization may elicit substantial shifts in the fish assemblage. In areas with extensive existing bank stabilization, fish assemblages have probably shifted away from the pre-stabilization condition, and any management actions that allow for unaltered riverine function—specifically increases in side-channel availability, may shift the assemblage towards the pre-stabilization condition. Although we have no inference regarding how many side channels can be lost before threshold shifts in the fish assemblage occur, our study illustrates the importance of side channels for fish. Therefore, the protection of existing side channels and the processes that create and maintain them will provide maximal benefit to the preservation of the Yellowstone River fish assemblage.

Title: Yellowstone River Hydrograph Trends, Water Rights, and Usage

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Overall abstract: The Yellowstone River and its tributaries are an important case study for water struggles in the highly arid western landscape. In the following chapters I: 1) evaluated seven variables used to characterize the volume and timing of discharge in the Yellowstone River and tributaries for long term (1898-2007) and more recent trends (1970-2007) using 18 USGS Stream gauge stations, 2) quantified all current (2008) water rights in the greater YRB, evaluated trends in water use, and conducted a physical inventory of all surface water withdrawals from the Yellowstone River and tributaries, 3) I assess, in a general way, water management needs in the Yellowstone River Basin (YRB) as discerned from the results in the previous chapters and in relation to the needs of native fishes and other biota in the river and provide recommendations for improved Montana water management to benefit water users and native fish species. Declines in volume and magnitude of annual and seasonal discharges are present in the basin, more so in areas where there are no water storage facilities. Timing of flows are occurring earlier in the year throughout the basin, leaving less water in the later summer and fall when water demands are the greatest. Rights to water greatly over allocate the water resources in the basin, though some rights can be considered duplicate and non-consumptive. The estimate of water use and the physical inventory reveal issues of potential resource misuse. There are numerous changes in water policy Montana water managers should consider if water is to remain available in the YRB.

Chapter 1: Physical and political water related history in the Yellowstone River Basin

Introduction: In the twenty-first century, increasing demand for the limited supplies of water is expected to play an important role in the economic development and quality of life in the Western United States. In addition, projected changes in climate in the western United States are expected to result in increased air temperatures and longer growing seasons, placing further demands on water supplies.

Most of the important western rivers where water demands are projected to increase contain ecologically distinct native fish communities. In these locations, water development has negatively impacted water quantity and water quality available to native faunas, imperiling the native fishes far more than what is occurring in the eastern United States.

Increasing water withdrawals for expanding irrigated agriculture, industries and municipalities have the potential to affect both the quantity and quality of available habitat for the native faunas. Numerous studies have shown that these water withdrawals may create especially acute problems during the low water periods of summer, which is also often the peak period for water demands for irrigation and other uses.

In assessing the extent and impacts of water use on native fishes of Montana, one serious limitation is the lack of adequate documentation of the quantities of water withdrawn seasonally and annually. The Yellowstone River, one of the least-regulated large rivers in the arid west with no storage dams on the main stem, provides an important source of water for irrigation, industrial, energy, and municipal purposes to Wyoming, Montana, and North Dakota. The river also provides important recreational and ecological benefits and it is important to balance water related development in the Yellowstone with instream flow requirements for sustaining fish populations and other aquatic life.

Major concerns exist for the future of the river and its biota. Accurate information on irrigation water withdrawal is especially crucial because irrigation is the largest off-river use of water in the YRB.

Objectives: The objectives of this study are to 1) assess the long term trends and recent changes in the hydrograph of the Yellowstone River and its tributaries, including trends in magnitude and timing of peak flows, seasonal flows, and base flows; 2) inventory and quantify all current water rights for the Yellowstone River and its tributaries, including all state permitted water rights, all federal reserved and appropriated water rights, and all other water reservations held on the rivers; 3) inventory and quantify all withdrawals from the Yellowstone River and its tributaries; 4) update physical inventory and compare actual use with permitted use of water in the basin; 5) identify water management needs in the YRB as discerned from the results of my research from the previous objectives and in relation to the needs of native fishes and other biota in the river. Future research can then be developed to more thoroughly assess effects of present and future water demand and withdrawals on the native fish fauna.

Study area: The study area is the YRB of Wyoming, Montana, and North Dakota. The Yellowstone River main stem and tributary discharges fluctuate greatly from year to year depending on snow accumulation and snowmelt runoff patterns. Mountain snowpack is the primary source of water; main-stem mean discharges are 5 to 10 times greater during spring runoff than during the fall and winter months.

Background on Yellowstone River water issues: The YRB and its water have a long history of usage by humans. During the last century, development and manipulation of water resources within the basin for mining and energy industries, irrigation, municipal and other consumptive uses has altered the hydrograph of the river and its major tributaries. Over the period 1911-1960, the Yellowstone's annual discharge averaged 11.5 billion m^3/year(9.3 maf) whereas over the more recent period 1967-2006 it has averaged only 10.6 billion m^3/year (8.6 mafAs a quasi-natural river, the Yellowstone in particular with no great means of storage, may be strongly impacted by increased demand for water and climate change.

Mining, oil and energy industries: The YRB has immeasurable amounts of natural resources, many of them require water for extraction, transportation, and refinement processes. As of 2008, the majority of energy production and mining uses for water in the basin came from the Fort Union coal formation in eastern Montana, strategic metal production from the Stillwater Mining Complex of the Beartooth Mountains, and three oil refineries located along the Yellowstone River.

Agricultural uses: Agricultural activities in the YRB consists primarily of livestock production and irrigated and dryland crop production. The YRB contains more than 505,900 irrigated hectares (1.25 million acres. In 1997, nearly 26,000,000 m^3/ day of surface water and 350,000 m^3/ day of groundwater were used for agriculture alone and all the other water uses in the basin (public supply, domestic, commercial, industrial, thermoelectric power, and mining) adds to less than 1 percent of the total withdrawn.

Municipal uses: Municipal and domestic water use in the basin is largely ground-water, and accounts for approximately 27 percent of the total ground-water use in the basin. Larger, surface water, municipal water works are present on the main stem of the Yellowstone River and provide water to the Montana cities of Laurel, Billings, Miles City, and Glendive.

Fisheries and other recreational uses: There are also strong economic and ecological incentives for retaining water in the Yellowstone River for fisheries and other recreational uses. The upper and portions of the middle Yellowstone and its tributaries, including the Shields, Boulder, Stillwater and Bighorn Rivers, support world-renowned trout fishing. The lower Yellowstone River also supports popular recreational fishing for Paddlefish, Shovelnose Sturgeon, Sauger, Walleye, Channel Catfish, Northern Pike, and Burbot. The quasi-natural lower Yellowstone River is also a key ecological repository for numerous native species that have suffered declines throughout the Missouri River Basin due to habitat loss and declining flows.

Historical water law and policy decisions: Yellowstone River water issues pertaining to usage and allocation in Montana date back more than a century, before statehood in 1889. Under the Doctrine of Prior Appropriation in Montana, water rights may be acquired by both riparian and non-riparian landowners. The doctrine allows the withdrawal of water regardless of the diminution of the instream flow. In 1950, the Yellowstone River Compact was ratified by Montana, North Dakota, and Wyoming as a mechanism for allocating the water of the Clarks Fork of the Yellowstone, Bighorn, Tongue, and Powder Rivers among the states.   In the years following ratification of the Compact, the Yellowstone River has been confronted by the same factors associated with human economic development that were threatening nearly all other large rivers in the arid west. In 1973, the Montana Water Use Act went into effect. The Act largely made the procedure for acquiring and changing water rights an administrative process overseen by the Montana Department of Natural Resources and Conservation. Adjudication is a very important step for any state to validate and quantify their water demands and historic use. Statewide adjudication of water rights in Montana was ordered in 1979. Though the statewide adjudication has been ongoing since the late 1970's, the Water Adjudication Bureau, part of MT DNRC, must complete the examination of the remaining 57,000 claims (as of 2005) by June 30, 2015.

Montana Board of Natural Resources and Conservation granted 6.78 billion m^3 (5.5 maf) of the to be the minimum instream flow requirements for fish and wildlife. Although this instream flow allocation was seen in some quarters as a major accomplishment for the conservation of fish and aquatic life, many factors prevent this allocation from guaranteeing protection. Any water rights held before the establishment of the instream reservations in 1973 are senior, and many of them have not yet been adjudicated, meaning that the rights are subject to change. Once the river and its tributaries are fully adjudicated, it could potentially affect the water available for all reservations made in 1973. Also, federal and Indian reserved water rights exist that are yet to be developed. In 1989, the Montana Legislature passed House Bill 707 permitting a program for private water leasing for instream flow. This approach allows MTFWP to better provide instream flows to restore and enhance flows on streams previously dewatered by senior water rights. In 2008, Montana sued the state of Wyoming for failing to meet provisions set by the Yellowstone River Compact during recent years of drought.

In the coming decades, water use demands are expected to increase as additional lands adjacent to the river are brought under irrigation, coal-bed methane and other energy resources are increasingly developed, municipal use increases, coal production continues to increase, and projected global climate change increases the persistence of droughts in the upper Great Plains region. It is the responsibility of the owners of the water course, the state of Montana, to meet these challenges by ensuring that sufficient water is allocated for appropriate and essential stream flow for a range of uses, including the needs of fish and other aquatic life.

Chapter 2: Trends in Yellowstone River Basin water supply as interpreted through hydrologic analysis

Abstract: The Yellowstone River and its tributaries are an important case study in the changes in magnitude and timing of discharges brought about by a changing human landscape, increased water demand, and climate change. In this chapter I assessed long term trends (1898-2007) and recent changes (1970-2007) in the hydrographs of the Yellowstone River and its tributaries using data from 18 USGS Hydro-Climatic Data Network Stations. I evaluated seven variables used to characterize the discharge: 1) annual discharge, 2) magnitude of discharge, 3) absolute annual minimum discharge, 4) monthly discharge, 5) date when half of

annual volume passed station, 6) date when maximum daily mean occurred, and 7) date when discharge returned to baseflow. Declines in volume and magnitude of annual and seasonal discharges are present in the basin, more so in areas where there are no water storage facilities. Timing of flows are occurring earlier in the year throughout the basin, leaving less water in the later summer and fall when water demands are the greatest. The appearances of significant trends have increased since the 1970's, and it is expected that they will continue without serious changes in the basin. Lessened flows and altered timing stands to greatly affect all users of water in the basin, as is occurring in the rest of western North America.

Introduction: In the past century there have been substantial declines in annual discharges documented throughout many of the rivers and streams of the western United States. These changes in water supply and in consumption have been measured as large changes not just in the magnitude of river and stream discharges but also in the timing of runoff and ultimately the quantity and duration of base flows. The magnitude of peak discharge can be affected by anthropogenic activities such as irrigation withdrawals, land use practices increasing runoff and decreasing groundwater recharge, damming of rivers, as well as changes in climate.

Observed changes in the timing of discharges have been most commonly characterized as an earlier peak and an earlier runoff pattern. Earlier runoff and declining annual discharge can result in less water available for late summer demands for municipal, industrial, and irrigation uses. Earlier runoff can also result in a protracted period of baseflow conditions and in severe cases can result in decreases in average baseflow because of diminished groundwater recharge.

Ecological processes can be regulated by the timing of peak discharge and by the timing and magnitude of baseflows. Decreased volume, earlier discharge, and lower and longer periods of base flows can have negative impacts on the local fauna and a river's ecological functioning during the dry season.

Irrigation withdrawals are the largest of all water withdrawals in the basin and persist through late summer into the fall with many water permits expiring as late as the 31st of October. Determining the effects of this dominant water use on the natural hydrograph in the basin is crucial to understanding potential effects on fish and other aquatic life.

In this chapter, my objective is to assess long term trends and recent changes in the hydrographs of the Yellowstone River and its tributaries based on timing and magnitude of peak flows, seasonal flows, and base flows. Detailed time series analysis will be used to test statistical validity of any apparent trends.

Objective: To assess long term trends and recent changes in the hydrographs of the Yellowstone River and its tributaries based on timing and magnitude of peak flows, seasonal flows, and base flows. Detailed time series analysis will be used to test statistical validity of any apparent trends.

Methods: To evaluate the hydrographs within the Yellowstone River Basin (YRB), I used data downloaded online from 18 United States Geological Survey (USGS) Hydro-Climatic Data Network stations on the Yellowstone River and its seven major tributaries: Shields River, Boulder River, Stillwater River, Clarks Fork of the Yellowstone, Bighorn River, Tongue River, and Powder River.

Seven variables used to characterize the discharge, four for aspects of volume and three for aspects of timing, were obtained or computed from the USGS records. The four variables chosen to depict discharge volume were: 1) annual discharge, i.e., the total volume of discharge past a station during an individual water year (October 1 to September 30), 2) magnitude of peak discharge, i.e., the largest magnitude of daily averaged discharge past a station within an individual water year, 3) absolute annual minimum discharge, i.e., smallest annual magnitude of daily averaged water flowing past a station within an individual water year, and 4) monthly discharge – i.e., average discharge during each month at a station. Three of the four variables have one value per year per station and the fourth variable (mean monthly discharge) had 12 values per year per station. The three variables chosen to depict timing of discharge were 5) date during the water year when half of the annual volume of flow has passed a station, 6) date during the water year when the maximum daily mean was achieved, 7) date of return to baseflow (discharges below the 50th percentile flows) after spring rise.

The four volume variables-- annual discharge, peak discharge, annual minimum discharge, and average monthly discharge (in m^3/s),were calculated based on daily statistics from the USGS gauging records for the entire period of record at all 18 stations.

The first timing variable (the date of the water year when half of the flow has passed the gauging station) was calculated using historic daily averages from the USGS gauging records for the entire period of record at 9 of the 18 stations (1-5, 8, 11, 15, and 18) to detect for trends in timing of center mass of discharges in the basin.

For the second timing variable (annual peak discharge), I obtained peak discharge values and dates of occurrence for each water year from the USGS gauging records for the entire period of record at all 18 stations. I then fit the Julian date with the water year calendar and found the water year day that the peak discharges occurred.

For the third timing variable (baseflow), I obtained daily mean discharges from the USGS gauging records for the entire period of record for 17 of the 18 stations and computed the date discharges returned to baseflow. Baseflow was identified as when the discharge was equaled or exceeded 50% of the time, also known as Q50.

Seven null hypotheses were evaluated:

1.) There were no changes or trends in annual discharges in the Yellowstone River Basin.

2.) There were no changes or trends in magnitude of peak discharges in the Yellowstone River Basin.

3.) There were no changes or trends in magnitude of absolute annual minimum discharge in the Yellowstone River Basin.

4.) There were no changes or trends in average monthly discharges in the Yellowstone River Basin.

5.) There were no changes or trends in date of the centertime (CT) measurements in the Yellowstone River Basin.

6.) There were no changes or trends in the date of maximum daily means in the Yellowstone River Basin.

7.) There were no changes or trends in the date when flows return to baseflow conditions in the Yellowstone River Basin.

Last, to illustrate the general characteristics of the seven hydrologic variables (four volume, three timing) throughout the Yellowstone River basin two long-term averages were computed for the available records, one the average from 1895 to 1969, and the other the average from 1970 to 2007. The mean annual discharge clearly depicts the differences in the sizes of the tributaries, while also providing a measure of their importance as contributors to the Yellowstone River system.

Results: Overall, annual discharges, magnitudes of peak discharges, and baseflows tended to decline on the tributaries free of upstream reservoirs. Runoff also tended to occur earlier in more recent years.

Magnitude of Discharge:

Annual Average Discharge.—There were highly significant declining trends at sites four sites, significant declining trends at five sites when evaluating over the entire periods of record. For all of the rivers over the period 1970-2007 highly significant declining trends existed at 11 sites, and significantly declining trends at 4 sites.

Magnitude of Annual Peak Discharge.—There were highly significant declining trends at seven sites, significant declining trends at two sites when evaluating the entire period of record. Over the period 1970-2007, I found highly significant declining trends at three sites, significantly declining trends at two sites.

Absolute Annual Minimum Discharge.—Absolute annual minimum discharge showed highly significant declining trends at three sites, highly significant increasing trends at four sites, significantly declining trends at three sites, and significantly increasing trends at one site. There were 8 decreasing and 10 increasing slopes in the basin for their entire periods of record.

Over the period 1970-2007, six sites changed from increasing to decreasing slopes. Over that period eight sites exhibited highly significant declining trends, and significantly declining trends at one site.

Average Monthly Discharges.—Monthly discharges changed similarly throughout the basin by season regardless of river, with only a few deviations. The majority of the 18 sites on the eight rivers experienced declines late spring, summer, and early fall months (May-October), while showing increases in monthly discharges during the other months. The station near Sidney, Montana was a clear depiction of this pattern, showing the most summer and fall months with significant declines, while the other months are experiencing increasing flows.

Timing of Discharge

Centroid of Discharge.—The center-time discharge results showed highly significant trends toward earlier runoff events at two sites 8 and 18, no sites with significant trends towards earlier runoff, and two sites with insignificant trends but trending towards earlier runoff. All nine sites showed negative trending slopes however when evaluating the entire period of record for each site.

Over the period 1970-2007, there were three sites significant trends towards earlier runoff. All but 8 sites exhibited negative slopes indicating earlier runoff events for the period 1970 to 2007.

Annual Peak Discharge.—Annual peak discharge showed the least significance in changes or trends of all of the variables evaluated. No sites showed highly significant trends, 1 site had a significant trend toward earlier annual peak discharge, and 11 sites had insignificant but negative trends for their entire periods of record. Similar results were found when evaluating the date of annual peak discharge for the more recent period 1970-2007.

Annual Baseflow Conditions.—Baseflow conditions showed highly significant trends towards earlier in the year at three sites, significant trends toward earlier in the year at two sites, and all sites but two had negative slopes toward earlier in the year over their entire periods of record.

Over the period 1970-2007, four sites exhibited highly significant trends towards an earlier onset of baseflow conditions, and five sites had significant trends towards an earlier onset of baseflow conditions.

I rejected all of the null hypotheses evaluated. There were many significant ($P<0.05$) and highly significant ($P<0.01$) trends identified for all of the variables throughout the basin. Other sites were not found significant ($P<0.10$) but trends were observed.

Discussion: Records of the total volume from the tributaries and the main stem Yellowstone River provide consistent indications that the historic magnitude and volume of discharge is declining in the Yellowstone River basin. Similar results have been documented in similar snow-dominated systems along the Rocky Mountains in North America and the Pacific Northwest.

The analyses also indicate that the declines in the YRB are prevalent basin-wide from headwaters to mouth. The regulated portions the YRB were more likely to differ from the declining trends observed in most other variables and rivers.

In addition to magnitude of discharge, the significantly altered timing of runoff found in this study in the YRB is consistent with that reported in numerous studies in the West. It has also been argued that the most important changes occurring in the hydrological cycle in the West is the declining snowpack accumulation and earlier runoff timing caused by temperature changes.

The most prevalent statistically significant trends were those indicating an earlier return of baseflow conditions. The substantial onset of earlier runoff and earlier return to baseflows in the basin reported here suggest that the free-flowing Yellowstone River and the majority of its tributaries are going to be largely affected by these changes if observed trends remain the same.

Most other studies do not investigate the causes of the observed magnitude and timing changes. Although the contributing causes of these changes in this study may be many, these confirmations in changes in streamflow magnitude and in volume are consistent with current perspectives on declining snowpack, climate change, and anthropogenic forcing (e.g., water withdrawals). The cause of the recent changes in magnitude and timing appear to coincide well with estimates of warming and prolonged droughts studied during the same period.

There are major potential implications for water users and agricultural development of declining discharges and earlier returns to baseflow. With lower discharges, especially during low flow periods, future water allocation decisions can be expected to become increasingly difficult, especially in over-allocated systems, such as the Powder River. With earlier base flow, and demand for water in the basin persisting into the fall with irrigation water users withdrawing water until they harvest crops, an earlier return to baseflow will result in more users being affected on a more frequent basis. This change toward earlier baseflows may require modified water allocation strategies, such as establishing a water use hierarchy based on beneficial use or policy changes on salvage water allocations.

These lower discharges and earlier return to baseflows also have major implications for the Yellowstone Basin's rivers. As the flows decline, the ability of rivers to tolerate pollutant loads and thermal thresholds is reduced, duration and frequency of droughts will increase in most land areas. The natural flow reductions and reductions from withdrawals will provide little protection against rising stream temperatures. Declining trends in the magnitude and earlier return to baseflow in the highly turbid, low gradient lower main stem will result in the water temperature increasing substantially. The site near Sidney, Montana, had very noticeable declines in all of the variables, especially since 1970, therefore there is concern for the native fishes and important fisheries of the lower Yellowstone River.

Alterations in the magnitude and timing of flows identified in this study can be expected to affect the ecology of the river in many ways, including altered timing of seasonal flows, increases in temperature, and less dilution abilities can make unacceptable water chemistry. Lower magnitude peak discharges and earlier timing of peak discharge could pose potential threats to species keying into them as spawning cues. Quantity and quality of in-river habitat for aquatic fauna will also be affected by the amount and timing of discharge and resulting temperature changes. Declines in magnitude of discharge and earlier timing of runoff can thus be expected to have cascading effects through not only the ecosystem for fishes and aquatic organisms but to impact water allocation decisions. Efforts to stabilize hydrographs in the face of anthropogenic factors such as irrigation withdrawals, the adjudication process, and human-induced climate change will be necessary to if the historical habitat and fauna of the Yellowstone river is to be maintained.

Conclusions on anthropogenic effects on fish: Reductions in volume of discharge, magnitude of annual peak flow, magnitude of annual minimum flow, spring, summer, and fall monthly average flows have occurred in the Yellowstone River basin, with more pronounced changes since 1970. Moreover, timing of discharge has shifted to more volume earlier in the year, and an earlier return to baseflow.

A river's hydrograph is often considered the "master variable" that most strongly influences riverine ecosystems, inclusive of physicochemical conditions such as temperature, channel geomorphology, and habitat diversity, and that in turn limits the distribution and abundance of riverine species. As such, changes in the Yellowstone River's annual hydrograph are potentially of profound concern. However, the relationship between statistically significant temporal trends in hydrological variables and the abundance and distribution of fish remains unknown and difficult to predict.

Reductions in flows would reduce the amount of aquatic habitat, potentially bringing fish into closer proximity, thereby increasing the rates of ecological interactions such as predation, competition, and transmission of disease or parasites. Reduction in flows will reduce river stage which could affect the availability of and suitability of fish habitats. For example, habitats that are at higher elevations, such as seasonally inundated side channels and floodplain habitats could be dewatered, thereby reducing the availability of important shallow, slow current velocity habitats, and reducing energy transmission between terrestrial and aquatic habitats. Reductions in flows may cause warmer water temperatures, which may have a number of influences on the fish assemblage. For example, fish distributions may shift upstream as species seek their preferred temperatures. However, although thermal regimes may shift longitudinally, other components of the ecosystem such as channel slope, riverbed substrate, position of spawning tributaries, and range fragmentation structures such as diversion dams will not, and may preclude simple shifts in the longitudinal distributions of Yellowstone River fish in response to temperature. Warmer water contains less oxygen, although rarely limiting in fluvial ecosystems, may affect fish distributions. Altered thermal regimes may change ecosystem productivity and lead to altered food webs. Reduced flow volumes will concentrate pollutants and may thereby affect fish. Perhaps most importantly, reductions in flows may increase the anthropogenic demands for water and thereby lead to further reductions in flow.

Altered timing of peak runoff will probably concomitantly alter the relationship between reproduction of fish species and hydrology. Spawning cues may be disrupted or shifted temporally, with uncertain consequences for survival of fish early life history stages. Earlier onset of baseflow could also alter the relationships between reproduction, growth, temperature, habitat, and bioenergetics under which the Yellowstone River fish assemblage evolved. Altered synchronicity between riverine ecosystem processes and fish life-history stages may result in changes in fish species distribution and abundance.

Spatial fisheries information: The data for this study was obtained from 18 United States Geological Survey Hydro-Climatic Data Network stations on the Yellowstone River and its seven major tributaries: Shields River, Boulder River, Stillwater River, Clarks Fork of the Yellowstone, Bighorn River, Tongue River, and Powder River. The station identification numbers are listed and could be spatially referenced.

BMP implications: Changes in magnitude and timing of the Yellowstone River hydrograph are probably attributable to anthropogenic climate change and water withdrawals. Therefore, societal changes that diminish the magnitude and rate of climate change will in turn reduce the magnitude and rate of change in the Yellowstone River ecosystem. Management practices that encourage conservation of the magnitude and temporal distribution of in-stream flows will minimize impacts of anthropogenic water withdrawals. Maintaining or reestablishing longitudinal connectivity may allow fish to move in response to altered thermal regimes. Managing angling pressure during periods of warm water may enhance survival of sport fishes, particularly in cold-water river reaches.

Scientific rigor: Moderate. This is a draft Master's thesis, and inference is based on statistical testing. However, the thesis has not yet been defended and approved by Mr. Watson's graduate committee.

Chapter Three: An inventory and physical observation of water use, historic and current, in the Yellowstone River Basin

Abstract: An understanding of and a system for quantification of existing water withdrawals and uses within the Yellowstone River Basin are necessary for effective water management. In this chapter I quantified all current (2008) water rights for the Yellowstone River and its tributaries, including all state permitted water rights, all federal reserved and appropriated water rights, and all other water reservations held on the rivers, 2) evaluated trends in irrigated agriculture development in the basin over the time period 1946 to 2008, 3) inventoried and quantified all known consumptive withdrawals from the Yellowstone River and its tributaries in 2006 using information from municipal, industrial, irrigation agriculture and livestock sources, and 4) conducted a physical inventory of surface withdrawals to estimate the number of main-stem surface water users. Rights to water greatly over allocate the water resources in the basin, though some rights can be considered duplicate and non-consumptive. There are large differences in the two accepted methods Montana uses to establish allowable water use for crops, creating room for large inefficiencies and waste. And the physical inventory illustrates screening issues and provides evidence of misuse. In a system that is very heavily dependent on water it is unacceptable for these issues to persist. Not only will this mismanagement fail for the resource, but it cripples Montana's ability to litigate against unfair distribution of water by other states, when their own proves to be wasteful and unchecked.

Introduction: As water demands have increased throughout the arid west in the past century, allocation and over-allocation of the limited supply have become contentious and potential sources of conflict. Nearly all water withdrawals in the west are used for human economic activity. In most localities, the limited or complete lack of actual measurement of withdrawals has led to inaccurate estimates of historic and current usage prolonging efforts to reach final adjudications.

In Montana, about 96.5% of all water withdrawals are for agriculture. Despite the importance of agriculture in accounting for withdrawals, however, discussions with the overseeing agency (the Montana Department of Natural Resources and Conservation (DNRC)) indicate that there is no uniform, formal, comprehensive approach for accurately and precisely documenting total withdrawals. There is thus no overall system for accurately holding Montana's water users accountable for their withdrawals in Montana's river basins, nor a reliable system of enforcement.

In Montana's portion of the Yellowstone River Basin, recent increases in water use demands and the need for providing instream flows for the endangered Pallid Sturgeon, other sensitive fish species, and other aquatic life has made it clear that the increasingly scarce water must be accounted for. Water shortages are anticipated to increase because of factors such as climate change, increased evapotranspiration due to increased temperatures, land use changes, and increasingly common legal disputes. In areas with little to no monitoring, supervision, or enforcement, over use conditions tend to worsen beyond that expected with naturally increasing demand and long term landscape changes. In the Yellowstone Basin, an important first step is to inventory water withdrawals from the basin.

Objectives: My objectives were to 1) inventory and quantify all current (2008) water rights for the Yellowstone River and its tributaries, including all state permitted water rights, all federal reserved and appropriated water rights, and all other water reservations held on the rivers, 2) evaluate trends in irrigated agriculture development in the basin over the time period 1946 to 2008, 3) inventory and quantify all known consumptive withdrawals from the Yellowstone River and its tributaries in 2006 using information from municipal, industrial, irrigation agriculture and livestock sources, and 4) conduct a physical inventory of surface withdrawals to estimate the number of main-stem surface water users and, the estimated amount of potentially illegal use.

Study area: The Yellowstone River Basin.

Methods: Under the state of Montana's prior appropriation doctrine ("first in time first in right"), an understanding of the five types of water rights in the state (and their seniority) is essential. The first and earliest dated rights in the basin are federally reserved and Indian reserved rights, second are the existing rights (pre July 1, 1973), third the exempt rights, fourth are new appropriation rights (post July 1, 1973), and fifth are water reservations (Montana DNRC 2008). There is, however, one category of water rights that will be mentioned numerous times in this study, *viz.,* supplemental water rights; these rights will be considered separately.

For this study, water rights data (number and water volume of permits) were extracted from the Montana DNRC website. I gathered all of the water rights and estimated the total number and volume of appropriated water based on the final cumulative list of rights present in the basin. To evaluate the total number of water rights in the basin, I separated them into 4 categories: (1) total number of water rights, (2) adjudicated and non-adjudicated, (3) surface versus groundwater sources, and (4) water rights with supplemental permits included versus rights without supplemental permits included.

I then quantified the water rights based on volume and separated the completed list into the following 6 categories for the entire basin and for each individual sub-basin: (1) total annual volume, (2) volume of adjudicated and non-adjudicated, (3) volume of consumptive and non-consumptive, (4) volume by type of use, (5) volume of groundwater versus surface water, and (6) volume of appropriated and non-appropriated reserved water rights.

Trends in irrigation water demands were based on agriculture census information for Montana and Wyoming by county within the Yellowstone River Basin. I estimated the amount of annual water use in the basin from agricultural census data for irrigated crops and livestock, and water use data from industrial and municipalities in 2006. I then used the final results of both estimates to compare the percent of estimated volume of water rights actually withdrawn annually in the basin to the amount permitted (paper water) for allocation.

The 2006 irrigated agriculture census data for the Montana and Wyoming counties (Figure 3.1) were used to estimate water use in the basin. Two estimates were developed based on different use models, and different assumptions, of the relation between the agricultural census data and actual use: (1) the Irrigation Water Requirements program and (2) Montana DNRC's allowed water use per irrigated hectare. Using the two methods, I was able to estimate the amount of water needed by the major crops that were grown in the basin based on crop needs and state allowance for the 2006 growing season.

The first method, the Irrigation Water Requirements (IWR) program, was originally created by Natural Resources Conservation Service (NRCS) Field Office Engineering Software (FOES) development team for use in the Cody, Wyoming Conservation District and in the NRCS Irrigation Guide. Second, I measured water demands for 2006 in the Yellowstone river Basin using DNRC's adjudication standard for pre-1973 water use of 160 liters per minute per hectare (lpm/ha; 17 gallons/minute/acre (gpm/acre)) to estimate allowed water use in the basin.

I computed 2006 annual water demands for the entire basin by multiplying the standard water use by the total amount of irrigated acreage to estimate the maximum potential water use. I am assuming it to be the upper end of water demand because this method does not take into account the amount of effective precipitation that supplements crop needs. It is also assumed that the users are not applying more water than the crop needs, as that would be considered waste and against Montana water laws. I estimated water demands for stock animals within the basin using county livestock census data for the period of 2003 to 2008 and DNRC's estimate of daily requirements for animal units in the basin.

To estimate the number of annual surface water withdrawal sites from the Yellowstone River and its major tributaries, and to estimate the number of undocumented (thus possibly illegal) water appropriators, I boated the Montana sections of the river and the seven major tributaries described in the study area from source to mouth and for any evidence of surface water use and recorded all potential water withdrawals (e.g., any development and equipment to aid in water withdrawals).

Results:

Water Rights Inventory

In total, there were 125,000 water rights in Montana's portion of the Yellowstone River Basin as of 2007, adding up these rights gives claimants the rights to water in access of 1.25 trillion m^3 of water annually. The main stem Yellowstone River was first in surface water withdrawals with 382.65 billion m^3 (310,217,381 ac-ft) with supplemental rights and 35.84 billion m^3 (29,053,416 ac-ft) without, followed by the Bighorn River with 573.54 billion m³ (464,979,941 ac-ft) with supplemental rights and 29.6 billion m³ (23,998,992 ac-ft) without. The same order was present with groundwater withdrawals.

Quantified existing rights, with exempt rights included, represented approximately 1.7 billion m³ of water in the basin with supplemental rights included and only 89 million m³ without supplemental rights. Quantified new appropriations in the basin accounted for nearly 19.7 million m³ (16,000 ac-ft) of water, and had little (less than 5%) surface water duplication because of supplemental water rights. Although federally reserved water rights in the basin had all been completed (ratified) in the YRB as of 2009 and the reservations are quantified, it was not possible to enumerate the amount of total water currently appropriated using the current records system.

As for 1973 reservations there was more than 1.76 billion m³ (1.42 million ac-ft) of water throughout the entire basin, the majority of it surface water. Many of these reserved water rights were largely non-consumptive held for the purpose of instream flows. These appeared as supplemental because they were listed and repeated at numerous points down the watershed. Once these supplemental water rights were removed however, there was only 70 million m³ of water to be appropriated (Table 3.6).

As for adjudicated or non-adjudicated water rights, there were more than 73, 000 pre-1973 water rights in adjudication holding claim to nearly 41 billion m³ (33.2 million ac-ft), compared to the 53,000 rights (44.2 billion m³ (35.8 million ac-ft)) that did not have to be adjudicated because they were post-1973 water rights (Figure 3.6).

Of the two main recognized sources of water withdrawal in the basin, surface water and groundwater, surface water right permits outnumbered ground water permits in the pre-adjudication era, (pre-1973), whereas groundwater source permits outnumbered surface in the more recent permits. In total, they split fairly evenly with 61,500 surface water permits and 67,700 groundwater permits, though surface water was 99 to 1 over groundwater in total volume permitted.

The major water users in the basin in order from greatest to least were fisheries 37.6%, irrigation 23.1% (15.3 billion m³), power generation 17.2%, and fish and wildlife with 11%. Consumptive water uses in the basin such as irrigation, stock, industrial, and municipal accounted for nearly 25% of the allocated water permits in the basin, approximately 21.5 billion m³ (17.4 million ac-ft) of water in 2007 not including supplemental water rights.

Trends in Irrigation Water Demands

Montana's population increased by 313% from 1890 to 1950, from 143,000 to 591,000, and then increased another 53% by the year 2000 with 902,195 residents (U.S. Census 2010).

Montana's livestock were first introduced in the late 1850's and by 2010 they outnumbered people by nearly 3 to 1 with an estimated total of 3 million.

Developments of water uses in the basin increased greatly over time. More water permits with a priority date of 1972 to 1975 were filed than there was for the first hundred years of water rights on record. Since the official start of the centralization of water rights in the state and adjudication of the Yellowstone River Basin in 1973 there was a steady amount of water permits allocated every year with a couple of extremely high years (1978, 81-82).Irrigated agriculture increased at a similar pace in both Wyoming and Montana's portions of the basin since the 1940's. The greatest increase in irrigated agriculture took place from 1956 to 1966, continued increasing into the 1980's where it peaked, diminished slightly in the early 2000, and remained fairly constant as of 2008.

Irrigated land area in the Yellowstone River Basin in both Wyoming and Montana increased from 100,000 Ha (243,000 acres) in 1946 to more than 314,000 Ha (776,000 acres) in 2006. Total irrigated land area which increased greatly from the 1940's to 2008, peaking in the 1980's at more than 450,000 Ha. As of 2008, Montana had 168,000 Ha (412,000 acres) and Wyoming had 148,000 hectares (365,000 acres) of irrigated crops in the perspective basins.

The major crops in the basin were alfalfa, barley, corn, grass, mixed hay, sugar beets, and wheat. In the upper basin region of Montana, corn was the most commonly grown crop, whereas in the lower basin it was sugar beets.

Inventory of Annual Water Use

Wyoming's YRB livestock population in 2006 was greater than Montana's by 24 percent with 1,009,436 and 814,000 livestock animals respectively. Using DNRC's water allowance for livestock in the basin, the annual water use by livestock amounted to approximately 37.5 to 75 million m^3 of water.

As a base value for water needs that year, the IWR program provided that the entire basin used at least 1.3 billion cubic meters of water in 2006, where DNRC allowed up to 15.5 billion cubic meters of water to be used. Montana's portion of water use according to the IWR was approximately 671 million m^3, at the same time DNRC allowed up to 8.2 billion m^3; Montana's lower portion of the basin accounted for 184 million m^3 of IWR's estimate and 2.25 billion m^3 of the DNRC's allowance.

Municipal water use on the main stem Yellowstone River was in four cities: Laurel, Billings, Miles City, and Glendive. The 2006 water withdrawals was the highest from 2003 to 2007, with all sites cumulatively withdrawing more than 40 million cubic meters of water. In 2006, Billings, with the largest population, consumed 34.5 million m^3, followed by Laurel at (2.7 million m^3), Miles City (1.9 million m^3) and Glendive (1.1 million m^3; Figure 3.14).

Industrial water use in the basin has occurred almost strictly on the Yellowstone River main stem rather than tributaries. In all in 2006, industries reported using 526 million m³ of water, though not all was consumptive use.

Physical Inventory

During the physical inventory, 687 water withdrawal sites were documented and locations recorded. The Yellowstone River main stem had the most withdrawal sites (317), followed by the Tongue River (144). The 687 sites were either being used at that time for water withdrawal or had evidence of recent past water withdrawal such as water pumping equipment, access to the water, and/or recent tracks from pump to river. For each site, there were from zero to five pumps present or large irrigation canals, indicating that many sites served more than one and sometimes numerous water users.

The main types of water withdrawal methods used were centrifugal pumps, turbine pumps, domestic pumps, irrigation canals without diversions, irrigation canals with partial river diversions, and irrigation canals with full river low-head diversions.

Sizes of intake pipes and headgate entrances ranged from less than 3 centimeters (approx.1 in) to 60-cm (24 in) diameter mainlines to multiple 200 cm (78 in) headgates.

Of the 687 documented water withdrawal sites, 113 were found to have screening devices present, but there were also numerous withdrawal sites clearly identified without any type of screening devices present. Identifying presence of screening devices could only be done for shallow water withdrawals, unused pumps on the banks, and the open canal irrigation methods.

Ninety-two of the 687 documented water withdrawal sites discovered during the physical inventory were not found to match with locations on the DNRC's points of use or diversion. Of these undocumented water rights there were many documented to have no evidence of that year's use, only partially established pumpsites without all components to withdrawal water and numerous small domestic water pumps with less than 10 centimeter (4 inch) diameter mainlines. There were, however, some significant pumping sites that could not be referenced to a specific right that not only were complete, but consisted of one to three pumping stations and showed evidence of recent use.

Discussion: With all water rights considered, including supplemental rights, the 1.25 trillion m³ of water, calculated using total water permit allowances, for use in the entire Yellowstone River Basin is nearly 118 times greater than the historic average annual discharge of 10.6 billion m³ from 1967-2006. Although this quantity is greatly reduced to approximately 85 billion m³ when all the supplemental water rights are removed, the amount is still nearly 8 times the estimated 10.6 billion m³ of average annual discharge historically. The water rights in the basin and in sub-basins were found to be overwhelmingly high in relation to actual supply no matter how it is calculated. Such over allocation is a common problem throughout the western states.

In the Yellowstone River Basin, over-allocation of water rights is also a problem, with the difference that much of the allocated water allocated has not yet been put to use, making it difficult to visualize exactly how soon development will occur and how soon the ensuing severe problems will develop.

Existing water rights, pre-1973 water rights, still in active adjudication account for nearly 472 billion m^3 of the total 1.25 trillion m^3 total rights (38%), and 41 billion m^3 of the 85 billion m^3 (48%) of permitted water minus supplemental rights. These rights, which are still subject to change stand to greatly alter how much water is actually appropriated and used. Only a final decree can determine the future of these rights.

In Montana in particular, supplemental rights make for very confusing estimates of total appropriation. With the same amount of water divided up by multiple uses in different locations, it is difficult to determine the exact water amount that goes to which use, thus providing opportunities for overuse, waste, and complications selling or transferring water. Thus, when evaluating water needs in the basin, the type of water rights are just as important as the date and place of use.

The hierarchy of water rights and large amounts of rights to the water already appropriated reinforces the need for proper management and a clear, unambiguous reporting strategy to be adhered to by water users. It is nearly impossible for a state to prove by clear and convincing evidence that they have the right to the water and they are not short on supply due to their own inefficiencies without accurate and defendable water data.

Inventory of Annual Water Use

The large differences in the overall allowable use using the IWR program and DNRC's acceptable amounts for water quantification for livestock and irrigation uses in the basin is of concern when comparing the differences in allocation the two methods produce

Physical Inventory

The results of the physical inventory highlighted some significant issues that deserve prompt attention. One major issue was lack of screening at most diversions. Lack of screening devices is of major concern in areas inhabited by species listed as endangered, threatened or of concern such as Pallid Sturgeon in the lower Yellowstone River. Fish losses due to entrainment into irrigation devices can be very large, numbering into the hundreds of thousands, as estimated at Intake Diversion Canal, one of the larger irrigation canals, on the Yellowstone River.

A second major issue arising from the field survey was the inability to link an actual water withdrawal use with a specific water right. About 14 percent of observed withdrawals were unable to be matched with a water right based on the withdrawal location.

Historically in the western U. S. and elsewhere, it has been a long standing procedure to solve water shortage issues by looking elsewhere to obtain more water, when more effort should instead be made to conserve and efficiently use the available water. Agricultural practices utilize the largest of all water withdrawals in the West (96.5%) and have been designated the most inefficient users of the water, thus providing massive potential to gain water by conservation measures. With water shortages becoming more common everywhere, it is ultimately in all water right users best interests to make sure it is being accurately monitored and recorded for their continued use and the use of others.

Conclusions on anthropogenic effects on fish: Yellowstone River water rights are over allocated by up to 118 times the mean annual discharge. Taken at face value, this suggests that the Yellowstone River could be severely dewatered in the future, leading to catastrophic effects on fish populations. However, given the vagaries and evolving nature of the legal and political landscape surrounding Montana water rights, the actual degree of future dewatering and effects on fishes are difficult to predict. Even so, as reviewed above, alterations of the annual hydrograph from conditions under which native fish evolved has potentially profound consequences for fish assemblages.

A physical inventory of pumps and diversion structure indicated that only 16% of 687 irrigation withdrawal structures were screened to prevent fish entrainment. Therefore, fish entrainment is probably a large source of mortality for Yellowstone River fishes. For example, prior to screening, fish entrainment at the Intake Diversion Canal included 25 native fish species, and was estimated to involve from 382,609 to 809,820 individual fish during an annual irrigation season (Hiebert et al. 2000).

Spatial fisheries information: Locations of irrigation structures were not reported in this thesis, but may be available from Trevor Watson or Dennis Scarnecchia.

BMP implications: Trevor Watson provided recommendations for improved water management to benefit water users and native fish species in the Yellowstone River Basin in Chapter 4 of his draft Master's Thesis, which I summarize and review below. These recommendations seem to be suitable as the basis for BMP development and are germane with respect to this chapter, so they are also presented here.

"The key improvements recommended in the water management system are to: 1) finalize the statewide general adjudication, 2) re-evaluate the water reservation hierarchy in the Yellowstone River Basin 3) review water policies and clarify ambiguities, 4) develop comprehensive, effective monitoring of water use statewide, and 5) Consideration of these recommendations, along with an adequate consideration for instream flows for native fishes, in Montana's new State Water Plan."

Scientific rigor: Moderate. Although this research was conducted as a Master's Degree research project, the project has not yet been reviewed and defended by the student's graduate committee.

Chapter 4: Management needs for water and native fishes in the Yellowstone River Basin: recommendations for moving forward

Abstract: Among the many western rivers dealing with water management issues, the relation between water issues and native fishes is particularly important for the Yellowstone. In this chapter, I assess, in a general way, water management needs in the Yellowstone River Basin as discerned from the results in the previous chapters and in relation to the needs of native fishes and other biota in the river and provide recommendations for improved Montana water management to benefit water users and native fish species. These recommendations are not necessarily new. Although many of them have been identified and discussed in legal journals by water law experts over the past quarter century or longer, actual progress has been slow. Some obvious, important issues remain unresolved. The key improvements recommended in the water management system are to: 1) finalize the statewide general adjudication, 2) re-evaluate the water reservation hierarchy in the Yellowstone River Basin 3) review water policies and clarify ambiguities, 4) develop comprehensive, effective monitoring of water use statewide, and 5) consideration of these recommendations, along with an adequate consideration for instream flows for native fishes, in Montana's new State Water Plan. As the Department of Natural Resource Conservation (DNRC) seeks to wisely manage Montana's water for all Montanans, present and future, Montana Fish, Wildlife and Parks, as the lead state fish and wildlife management agency whose mission and expertise are in line with native fish needs, is well positioned to assist the DNRC and the Basin Advisory Committee in this role. Their effective input into any new State Water Plan is vital for a balanced water plan insuring the economic needs of the present and future, as well as the future of the Yellowstone River and its native fauna.

Introduction: In this chapter, I identify general water management needs in the Yellowstone River Basin in relation to the needs of native fishes and other biota in the river. I also provide recommendations for improved Montana water management to benefit water users and native fish species. Emphasis here is not from the general legal perspective *per se* but from the perspective of water's role in maintaining native fishes and aquatic habitats in the Yellowstone River Basin.

As the longest river in the contiguous United States that still retains a hydrograph close to natural, the Yellowstone River remains a repository for many native species badly depleted or extirpated elsewhere in the broader Missouri River Basin (e.g. Flathead Chubs, Sturgeon Chubs, Sicklefin Chub, Western Silvery Minnow, Shovelnose Sturgeon, and Pallid Sturgeon).

Native river fishes, adapted through natural selection to rivers such as the Yellowstone, evolved under conditions of their historical flow regimes. Alterations to the historical flow regimes of rivers, is commonly implicated in the declines of stream and river-dwelling native fish populations. Changes to the hydrograph are believed to have contributed to the imperiled status of about 40% of North American freshwater and diadromous fishes. Declines in these species are associated with altered geomorphic processes that create and maintain instream habitat, altered autecological processes, and reduced summer rearing and overwintering habitat. Species that are specifically sensitive to certain aspects of the hydrograph (e.g., high discharge) would be most vulnerable to changes in those aspects. How much change and what impact specific hydrograph changes will have on specific species in particular river basins is difficult to predict because of multiple variables and drivers at play, but it is readily understood that when other systems have encountered the same types of alterations as seen in the Yellowstone, native fish communities and fisheries have suffered. It is generally accepted, as a result, that the natural flow regime is a desirable goal for recovery and restoration of impacted river systems. Natural flow regimes and higher flows not only benefit the native species adapted to these conditions, but these natural characteristics can halt, delay, and sometime prevent invasive species introduction and expansion, an increasing problem for native fishes in rivers globally.

Several factors associated with hydrograph changes (magnitude and timing) may be important for native Yellowstone River fish fauna and fisheries. Climate change in this century is projected to increase global surface temperatures 1-3°C, with significant regional variability, thereby increasing the probability of warm days, and many types of extreme weather events. In the Yellowstone Basin the natural flow regime may be difficult to achieve when multiple stakeholders are involved. Solutions that satisfy multiple objectives are neither straightforward nor easily agreed upon, but in the end decisions improving or at least stabilizing the declining water situation must be made, preferably sooner rather than later.

There is a critical need for further research to understand flow requirements for native fish species and to make species-specific recommendations for instream flows in the Yellowstone River Basin. The present study was not designed to investigate the instream flow needs for native biota. Past habitat studies suggest that several of the native species are obligatory large river fishes; although they may ascend smaller tributaries to spawn. These species include the Blue Sucker, Sicklefin Chub, Shovelnose Sturgeon, Pallid Sturgeon, and Sturgeon Chubs. To more accurately define habitat requirements during the low-flow periods of summer, studies are needed of instream flow needs for native fishes using simulations and field data and resulting in specific, science-based recommendations. The clearly projected increases in water demands, regardless of minor differences in scenarios, indicate there is a great need at this time for matching water management not only to the increasing needs of human water users but to the needs of the Yellowstone basin's native fishes and other aquatic fauna.

Recommendations: The key improvements recommended in the water management system are to: 1) finalize the statewide general adjudication, 2) re-evaluate the water reservation hierarchy in the Yellowstone River Basin 3) review water policies and clarify ambiguities, 4) develop comprehensive, effective monitoring of water use statewide, and 5) Consideration of these recommendations, along with an adequate consideration for instream flows for native fishes, in Montana’s new State Water Plan.