WARM WATER SPECIES FISH PASSAGE IN EASTERN MONTANA CULVERTS

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June 2007

prepared by
Joel E. Cahoon
Thomas McMahon
Leo Rosenthal
Matt Blank
Otto Stein

Montana State University - Bozeman

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Prepared by:

Joel Cahoon, Ph.D., P.E
Tom McMahon, Ph.D.
Leo Rosenthal, M.S.
Matt Blank, M.S.
Otto Stein, Ph.D.

Montana State University
Bozeman, Montana

Prepared for:

Montana Department of Transportation
Helena, Montana

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16. Abstract **Transportation system planners, designers and managers recognize that fish passage through culverts is a concern. However, there is much contention concerning the impact that a given culvert can have on a fishery. This is particularly true for warm water prairie fisheries. In this project, a combination of three assessment techniques were used to examine fish passage at five culvert crossings in eastern Montana. The techniques used were longitudinal distribution surveys, direct observation of fish passage in field experiments, and modeling using the FishXing program. Results show a diverse fishery with as many as 21 species in a given reach. Distributional surveys showed no difference in fish species richness and almost no difference in fish abundance between the upstream and downstream sides of culverts. Direct observation of the four most abundant species found that when all species were combined, fish passed through culverts at an equal or greater rate than through reference reaches and only one individual species, longnose dace, did not. The FishXing model tended to be conservative, even when calibrated to local hydraulics at each culvert. The strongest estimator of fish passage was to overlay the FishXing results and the field observations onto a hydrograph of the stream system to predict passage windows, or time periods where passage is predicted to not be restricted.**			
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Unit Conversion Factors

All numeric values having units are presented in SI (metric) units. The following factors can be used to convert to traditional (English) units:

1 mm = 0.03937 inch
1 cm = 0.39370 inch
1 m = 3.281 feet
1 km = 0.6214 miles
1 cms = 1 m^3/sec = 35.3198 ft^3/sec

1 inch = 25.4 mm
1 inch = 2.54 cm
1 foot = 0.3048 m
1 mile = 1.6093 km
1 ft^3/sec = 0.0283 cms

Introduction

Other Work

Culverts are a common structures used to convey water where roads intersect small streams (Baker and Votapka 1990). The large number of tributaries found in both mountain and prairie stream systems, coupled with the increasing number of road systems, can equate to thousands of culvert crossings fish populations may encounter (Coffman 2005). Concern over the implications of migratory barriers has led to considerable research and an increased emphasis on providing passage for fish species (Baker and Votapka 1990).

Studies have shown that culverts can act as upstream migration barriers to various species of fish for a host of reasons (Belford and Gould 1989; Warren and Pardew 1998; Rajput 2003; Burford 2005; Gibson et al. 2005). Hydraulic characteristics that can limit upstream movement of fish include high water velocities, large outlet drops, low water depths, lack of resting habitats both within the culvert and in the downstream plunge pool, and disorienting turbulent flows (Furniss et al. 1991). The biological repercussions of these hydraulic factors are likely different for each of the species that inhabit small streams as body type and swimming capability differ among species and fish size (Katapodis and Gervais 1991).

Historically, much of the emphasis of road culvert studies has been placed on salmonid species (Belford and Gould 1989; Harper and Quigley 2000; Kane et al. 2000; Cahoon et al. 2005). This is likely due to the economic and ecological implications of restricted fish passage to such highly migratory species. In contrast, relatively few studies have examined the effects of culvert barriers on prairie fish assemblages (Warren and Pardew 1998; Toepfer et al. 1999; Rajput 2003). However, because prairie fish evolved in low gradient systems, it may be reasonable to assume them to have lesser swimming and jumping capabilities than large-bodied, migratory salmonids. Therefore culverts may represent an even greater challenge to smaller-bodied, weaker swimming species (Katapodis 2005). While small prairie fishes may not hold the same direct economic value as salmonids, they do contribute to the overall biologic diversity of prairie aquatic ecosystems. Additionally, several species of prairie fish, including the Topeka shiner and leopard darter, are listed as ‘threatened’, thereby justifying the need for research addressing the effects of culvert crossings (Toepfer et al. 1999; Schaefer et al. 2003). More specifically, small prairie fishes comprise a considerable portion of the native species (22 out of 56) found in Montana (Montana Fish, Wildlife and Parks 2006).

Fish movement in prairie streams has been well documented. Cyprinids, which were once assumed to be relatively stationary in regards to their home ranges, have been shown to migrate for spawning purposes (Linfield 1985; Lucas 2000; Bonneau and Scarnecchia 2002), and also to move from resting to feeding habitats (Clough and Ladel 1997). Recent studies have also identified the importance of habitat connectivity at multiple scales for the conservation of small, non-salmonid stream fishes (Labbe and Fausch 2000; Fausch 2002; Dodds et al. 2004).

Upstream or downstream migration barriers could initiate the loss of species in areas that chronically dewater. Winston et al. (1991) identified the extirpation of four cyprinids as a result of dam construction on a prairie stream in Oklahoma. While there are large differences between dams and culverts, this example shows how a total barrier can result in local extirpation and a decrease in species richness above that barrier. More specifically, Rajput (2003) found significantly lower species richness as well as fish abundance upstream of low-water culvert crossings. Because seasonal dewatering is common in prairie systems, recolonization is a key factor affecting species persistence (Dodds et al. 2004). Therefore, culverts, like other landscape disturbances that prevent or impede movement, could potentially affect the rate of recolonization after local extinctions (Sheldon and Meffe 1994).

Research on passage abilities of small-bodied fish species has typically been achieved through direct observation, laboratory studies, and indirect measures such as software modeling and comparisons of upstream and downstream fish assemblages. Direct observation techniques include ‘passive’ release and recapture of marked fish (Coffman 2005; Rajput 2003; Warren and Pardew 1998) as well as ‘active’ displacement experiments (Cahoon et al. 2005). These studies provide useful information regarding the passage capabilities of multiple fish species as well as identifying the types of crossings that restrict passage. For example, Warren and Pardew (1998) used mark-recapture techniques to examine the effects of four different types of stream crossings on movement of 15 small stream fish species in Arkansas. In their study, movement was found to be an order of magnitude lower through culverts than through open box and ford crossings and natural reaches. However, mark-recapture studies are typically conducted over long periods of time, and therefore the exact conditions that either permitted or prohibited passage are not known. In addition, it is unclear whether restriction of fish passage is due to actual physical conditions at the road crossing or a lack of motivation to move upstream (Coffman 2005). Fish passage experiments using downstream displacement can be effective at overcoming the motivation question and in quantifying the conditions during time of passage. However, such experiments are limited by providing only information about passage efficiency during the relatively short time intervals, and therefore results may not be representative of culvert conditions and passage success during other times of the year (Cahoon et al. 2005).

Passage success has also been estimated from laboratory studies to define thresholds in fish swimming and jumping capabilities. These thresholds can then be compared to hydraulic conditions commonly produced by culverts to assess fish passage (Toepfer et al. 1999; Gardner 2006). For example, Toepfer et al. (1999) found that water velocities of 25 cm/s produced the greatest amount of swimming activity of leopard darters in a controlled flume. This velocity was used to determine the maximum velocity and distance these fish could travel to traverse the length of culverts. Many of the culverts found in their study area produced water velocities greater than 25 cm/s indicating that these culverts may restrict upstream passage. Limitations of laboratory-based swimming capacity tests are typically related to differences between tightly controlled environments and conditions observed in field settings (Castro-Santos 2004). For example, motivation to swim upstream in natural settings involves many different cues from physiological to chemical. In contrast, many laboratory studies use prodding and electrical stimulation to provide motivation which may not be directly comparable (Castro-Santos 2004; Gardner 2006). Additionally, laboratory flumes can have more uniform water velocities than are typical of stream crossing structures (Castro-Santos 2004).

The software model FishXing has also been widely used to estimate fish passage (Rajput 2003; Cahoon et al. 2005). The model combines hydraulic calculations based on field measurements of culvert characteristics with burst and prolonged swimming and jumping abilities from fisheries literature to estimate fish passage (Six Rivers Watershed Interactions Team 1999). Field measurements and swim speeds are input into the model via a user-friendly input screen complete with pull-down menus for many of the entries. Once the appropriate information has been entered into the model, the range of flows considered passable is calculated. The model also displays the reason for considering a culvert as a barrier. These reasons include excessive velocities, excessive leap height, insufficient water depth, and shallow plunge pool depth. Only a few studies have used this model to assess culvert passage of small prairie fishes. Rajput (2003) used FishXing to evaluate the passage status of 28 low-water culvert crossings in Arkansas. This study found that the model was congruent with direct measurement of passage success based on mark-recapture studies in 71% of the cases. Advantages of this assessment technique include the ability to assess passage status of a large number of culverts with relatively easily measured physical characteristics, and the ability to estimate hydrologic conditions where a culvert may be passable to a species of interest. However, model use is limited by the general lack of swimming capability information on many prairie fishes. Additionally, literature on field validation of this model appears to be limited. A combination of displacement experiments and FishXing modeling was used to examine fish passage through culverts for salmonid species in the Clearwater River drainage in western Montana (Cahoon et al. 2005). Cahoon et al. (2005) demonstrated a general lack of coincidence between the passibility predicted by FishXing and field observations that directly or indirectly indicated that passage of a culvert had occurred.

Differences in fish assemblage above and below barriers have also been used to examine passage restriction (Winston et al. 1991; Rajput 2003; McLaughlin et al. 2006). This approach can give a long-term perspective on effects of passage restriction. For example, Winston et al. (1991) examined fish assemblages in the North Fork Red River in Oklahoma and found 25 species in reaches above Altus Dam versus 34 species below. This study occurred 40 years after construction of the dam, and shows that barriers to migration can have long term consequences that can be observed by simply examining species composition. However, limitations to this type of assessment do exist. Longitudinal differences in fish assemblage are common in prairie stream systems (Ostrand and Wilde 2002), making it difficult to determine whether differences in assemblage above and below culverts are related to passage restriction directly or else a result of the natural longitudinal changes in species composition (Schlosser 1987).

This Study

This study documented herein used several passage assessment tools - fish distribution patterns, displacement experiments, and FishXing modeling - to examine the effects of culverts on fish passage of eastern Montana prairie fishes. Fish movement and culvert passage studies are not uncommon to Montana (Belford and Gould 1989; Schmetterling and Adams 2004; Cahoon et al. 2005). However, there have been no studies to date that specifically addressed passage capabilities of eastern Montana prairie fishes. Recent interest in prairie fish conservation has led Montana Fish, Wildlife and Parks to conduct a prairie stream inventory throughout much of eastern Montana (Montana Department of Fish, Wildlife and Parks 2003). Additionally, knowledge of fish assemblages in this region is vital for assessing potential impacts of high road densities and water quality and quantity changes associated with proposed energy development (Bureau of Land Management 2003). The proposed oil and gas development in eastern Montana includes over 24,000 km of roads which could equate to an even larger number of stream crossings (Bureau of Land Management 2003). This study will add to the knowledge base of these systems by identifying the type of structures that fish may encounter in this setting as well as how culverts affect lesser studied warm water species.

The objectives for this study were to: 1) identify and quantify the types and characteristics of stream crossings common to eastern Montana prairie streams; 2) examine the passage capabilities of common prairie fish species and the physical and hydraulic conditions that may influence their passage; and 3) examine the longitudinal distribution of prairie fish in systems with culvert crossings. Because culverts have been shown to restrict the upstream migration of many species, the general hypothesis is often that fish movement through culverts is restricted when compared to natural stream reaches (Belford and Gould 1989; Warren and Pardew 1998; Rajput 2003; Cahoon et al. 2005). A corollary is that species richness and relative abundance are reduced upstream of culverts.

Throughout this document, fish species are referred to by their common name. Table 1 identifies the formal name of each species mentioned.

Table 1. Common and formal names of fish species.

Common name	**Formal name**
Black Bullhead	*Ameiurus melas*
Blacknose Dace	*Rhinichthys atratulus*
Bluehead Chub	*Nocomis eptocephalus*
Brassy Minnow	*Hybognathus hankinsoni*
Brook Stickleback	*Culaea inconstans*
Channel Catfish	*Ictalurus punctatus*
Common Carp	*Cyprinus carpio*
Creek Chub	*Semotilus atromaculatus*)
Emerald Shiner	*Notropis atherinoides*
Fathead Minnow	*Pimephales promelas*
Flathead Chub	*Platygobio gracilis*
Goldeye	*Hiodon alosoides*
Goldfish	*Carassius auratus*
Green Sunfish	*Lepomis cyanellus*
Leopard Darter	*Percina pantherina*
Longnose Dace	*Rhinichthys cataractae*
Longnose Sucker	*Catostomas catostomas*
Longnose suckers	*Catastomas catastomas*
Mountain Sucker	*Catastomas platyrhynchus*
Northern Redbelly Dace	*Phoxinus eos*
Plains Killfish	*Fundulus zebrinus*
River Carpsucker	*Carpoides carpio*
Sand Shiner	*Notropis stramineus*
Shorthead Redhorse	*Moxostoma macrolepidotum*
Stonecat	*Noturus flavus*
Topeka Shiner	*Notropis topeka*
White Sucker	*Catastomas commersoni*

Study Area

Tributaries to the Yellowstone River near Glendive, Montana were chosen for this project. The streams chosen are generally in the lower reaches of the watershed, are species rich, and include a variety of road crossing structures. The geography of this area is typified by relatively low precipitation, and soils that have little capacity to hold water (Morris et al. 1981). As a result, hydrographs regularly show flashy responses from storm and runoff events. The culverts in the region are often sized to accommodate the flashy flows. There are generally two predictable runoff peaks: a late winter/early spring peak from lowland snowmelt, and an early summer peak from melting of the mountain snow pack. (Elser et al. 1980).

Many streams in the region were surveyed for general characteristics of interest to the project. From this larger list, Sand Creek and Clear Creek (both direct tributaries of the Yellowstone River) were chosen for intensive study. Many of the culverts surveyed for general characteristics were on streams that were dewatered for a majority of the year. One compelling reason for choosing Sand and Clear Creeks was that both streams had sufficient in-stream water throughout the year to ensure fish presence during both high and low flow periods. While there are characteristics of the intermittent stream that are absent from this study, most aspects of this study may be inferred to be relevant to the intermittent streams. This is because results from this project tend to be tied strongly to physical attributes and hydraulic conditions, not the timing of those attributes or conditions. Sand and Clear Creeks are both located in Dawson County, and flow southerly, crossing Interstate 94 before joining the Yellowstone River (Figures 1 and 2). Throughout this document, CC1a = Clear Creek Road 261 crossing #1, CC1b = Clear Creek Road 261 crossing #2, CC2 = Clear Creek I-94 crossing, CC3 = Clear Creek upper crossing, SC1 = Sand Creek Road 261 crossing and SC2 = Sand Creek I-94 crossing.

The Clear Creek crossings on Road 261 (CC1a and CC1b) are near each other, but not on a continuous channel. Clear Creek is somewhat braided at this location and the flow is split between the main channel (CC1a) and a side channel with a separate road crossing (CC1b) that has much less flow. The crossing at CC3 is a multiple barrel crossing. When multiple barrels are present at a crossing, the terms “left” and “right” are when looking in the downstream direction.

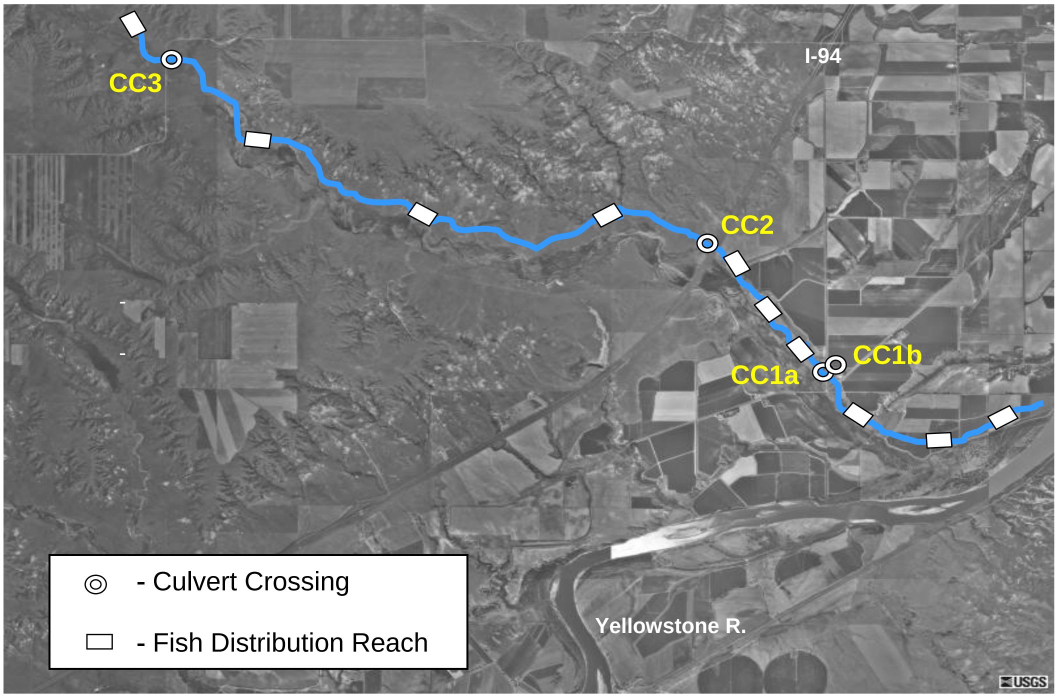


Figure 1. Aerial view of Clear Creek.

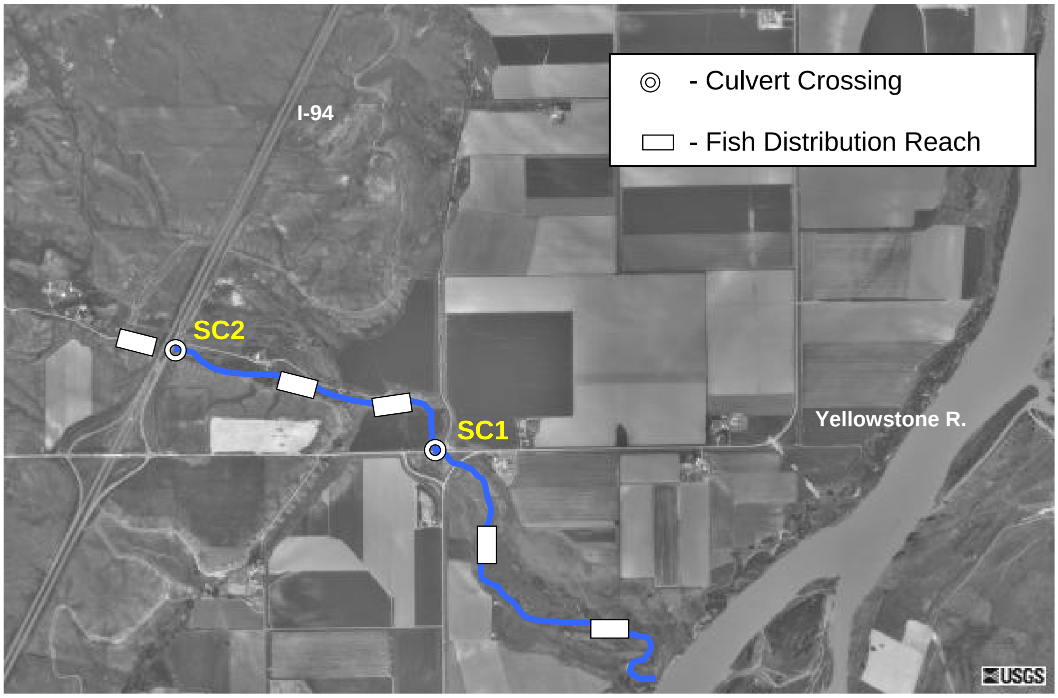


Figure 2. Aerial view of Sand Creek.

Irrigated agriculture is the predominant land use in the study area. The Glendive Unit of the Buffalo Rapids Irrigation Project controls an irrigation canal system that runs from Fallon, Montana to Glendive, Montana (Bureau of Reclamation 2007). Built between 1939 and 1941, the canal intersects all tributaries that flow southerly into the Yellowstone River in this area. Most intersections between the canals and natural streams have siphons installed and the canal has no direct interaction with the stream. In many cases, however, head-gates are installed in the canal upstream of the siphon and water is periodically released back into the natural stream either for use by downstream irrigators or to reduce flows to accommodate the capacity of the siphon. This periodic contribution of canal water to the streams can be quite large depending on water demands, and in some cases appears to have altered the channel morphology of stream reaches below the canal intersection. Additionally, the number of fish entering the system via the canal, and the effect that the irrigation water has on stream flow and chemical properties remains unknown (Morris et al. 1981). In this project we chose to take advantage of this irrigation-system-influenced hydrology to investigate fish passage at more varying water flows and for a longer duration than most natural prairie streams would facilitate.

The fish assemblage in the study area is typical of many prairie streams in southeastern Montana (Elser et al. 1980). Both Sand and Clear Creek contain rich fish assemblages, other studies have identified up to nineteen species occupying reaches in the study area (Montana Department of Fish, Wildlife and Parks 2007). Although non-native fish such as green sunfish and black bullhead are commonly found in both streams, the majority of the assemblage is comprised of native species.

Methods

Regional Culvert Survey

To identify the types of road crossing structures common to eastern Montana prairie streams, an initial survey of tributaries of the upper Musselshell River, the Little Missouri River, and the lower Yellowstone River was conducted in February 2005. This survey was led by Montana Department of Transportation personnel, and included stream crossings listed as important to agency biologists. All of the stream crossings examined were on public roads. At each crossing, measurements including height, width, length, and slope of the structure as well as the outlet drop height were taken. The structure material and amount of substrate present in the structure was noted. The approximate location of each crossing was recorded using GPS devices.

Intensive Studies on Sand and Clear Creeks

A combination of direct and indirect assessment techniques were used to examine the passage capabilities of prairie fish species at and near culverts on the downstream reaches of Sand and Clears Creeks (Figures 1 and 2). Three different techniques were used to assess fish mobility thorough five culvert crossings in the spring and summer of 2005 and 2006. The longitudinal distribution of fish at a series of sites downstream and upstream of the selected road crossings was determined. Fish passage was assessed directly at each culvert using fish displacement experiments at varying flows during the summer of 2006. Fish passage was also assessed indirectly using the FishXing model to quantify the amount of time each crossing may be passable for certain species.

Longitudinal Distribution of Fish and Habitat

Species composition and relative abundance were measured by sampling several reaches downstream and upstream of all the culverts studied in each stream. Fish sampling reaches were 300 m in length to ensure that all species were collected (Patton et al. 2000). Two to three reaches that were 300 m in length were established above and below each road crossing starting at the junction of the Yellowstone River (Figures 1 and 2). Only one reach was sampled above the uppermost culvert crossing due to property access restrictions on Clear Creek and lack of water on Sand Creek. Reach locations were chosen roughly equidistant from one another throughout the stream. Fish were captured using 6.35 mm mesh seines at each reach. Seining was conducted moving in the downstream direction, with individual hauls occurring approximately every 10 to 20 meters. Fish were placed in aerated live-wells, cataloged by species, and released. A random subset of 20 fish per species was measured for total length. Voucher samples of up to five fish per species were preserved in a 10% formalin solution, and retained for later identification. Each site was sampled during the spring (May-June) and summer (July-August) to account for temporal variation in distribution. Data from the spring and summer samplings were combined at each site to compensate for fish recruiting to the seine mesh size as summer progressed.

Habitat measurements were also recorded at each site following a protocol for eastern Montana prairie streams (see Appendix A). Variables measured included: thalweg depth, channel width, dominant substrate, water temperature, and water turbidity. Thalweg depth and dominant substrate type were recorded every 3 meters progressing downstream from the upstream-most location. Channel widths were measured at 30 meter intervals moving downstream, also starting at the upstream end of the site. Water temperature and turbidity were measured at the midpoint of each sample reach prior to entering the stream so that sediments were not disturbed.

The Spearman’s rank correlation analysis was used to examine the relationship between stream distance (from the confluence with the Yellowstone) and relative abundance of the five most common fish species collected (Quinn and Keough 2002). Relative abundance was calculated as the total number of fish collected in both spring and summer samplings for each reach. Stream distance was measured using global positioning system (GPS) waypoints measured at the center of each reach.

Species richness and relative species abundance were then compared between the upstream and downstream reaches associated with each crossing using Mann-Whitney U-tests. Species richness was calculated as the total number of species collected in each reach. To account for differences related to habitat features, habitat variables including mean thalweg depth and mean wetted width were also compared upstream and downstream of each study culvert using Mann-Whitney tests. Mean thalweg depth and mean wetted width were calculated for each reach using habitat data collected during the spring and summer.

Fish Passage Experiments

Fish passage efficiency was through culverts was examined through the use of a fish displacement experiment. Stream reaches at each study culvert were divided into treatment and reference reaches (Figure 3). The treatment reach was separated into upstream and downstream segments by the culvert, and the reference reach was similarly divided by a reach of natural stream having the same length as the culvert. These short reaches of natural stream that bisect the control segments of the stream are referred to as 'reference culverts' herein. The length of the upstream and downstream segments was generally equivalent to the length of the plunge pool. Block nets constructed of black plastic netting (6.35 mm mesh size) and supported by metal t-posts were positioned at the upstream and downstream end of the treatment and reference reaches to ensure a closed system during each trial.

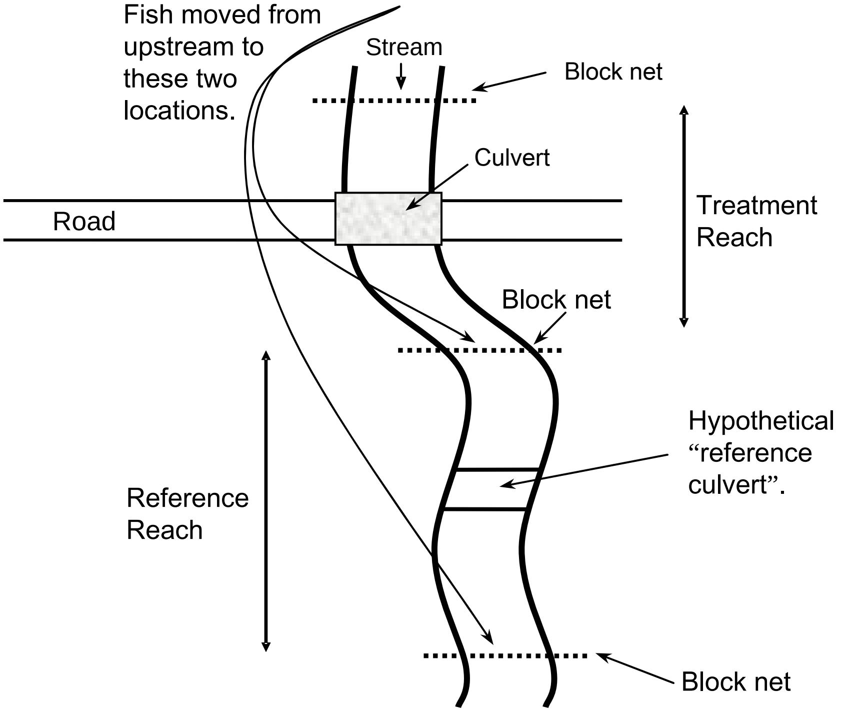


Figure 3. Fish passage experiment study design.

At the start of a trial, fish were collected upstream of the study area using 6.35-mm mesh seines. Seining was conducted by moving in the downstream direction, following similar protocols as used in the longitudinal distribution surveys. Fish were placed in an aerated live well to minimize incidental mortality. Fish were identified by species, and after at least 20 fish of each of the predominant species were collected, the fish were measured to total length and split randomly into treatment and reference groups. Each group was then marked using a specific and unique visible implant elastomer (VIE) tag. VIE tags were selected as the method of marking because the tags are adaptable to a number of species and size classes, and have been shown to have low effect on swimming capability (Northwest Marine Technology 2006). Fish as small as 20 mm in length have been successfully tagged with VIE tags (Frederick 1997), however, only fish greater than 60 mm were tagged in this study. Initial trials showed that the proximal margin of the anal fin was a suitable tag location for most species in the study. Because species, tag color, and tagging error can influence tag retention (Roberts and Angermeier 2004), an experiment was conducted to determine the retention of VIE tags. This experiment entailed marking 30 fish representing the predominant species and size classes with VIE tags. These tagged fish were then placed with a similar set of unmarked fish in an in-stream cage for 48 hours. Fish were then examined independently for tag presence by a field technician not involved with the initial tagging, and retention was determined as the proportion of fish retaining tags. In the experiment, 100% of the VIE tags were retained and the tags were identifiable.

Efforts were made to randomly select fish for reference and treatment groups during each trial so that fish length was similar between groups. Mann-Whitney U-tests were used to determine if the length of fish used in treatment groups differed from that in the reference groups. (All statistical tests herein that use a confidence level use $\alpha = 0.05$, or in traditional terminology “the 95% confidence level”.) Tests were conducted for all species combined as well as individual species. Of the fish that were marked, creek chub lengths were not significantly different in six of eight trials, but in two trials creek chub length was significantly larger for marked treatment fish than for reference fish. For all other species in all ten trials, marked fish lengths were not significantly different between treatment and reference groups for all ten trials.

The marked fish were allowed to recover in an aerated live well, and were then released just upstream of the downstream-most block net in each of the treatment and reference reaches (Figure 3). Previous studies in other settings have used the dislocation from upstream reaches as motivation for fish to swim through the reach of interest (Burford, 2005). Evidence exists in the literature that many species of warm water fish use this homing tendency to return to natal streams for spawning (Linfield 1985) and to return to resting areas after migration to and from feeding areas (Clough and Ladle 1997). Additionally, downstream displacement has been used successfully as a measure of passage efficiency in other fish passage studies (Belford and Gould 1989; Cahoon et al. 2005). Each trial was allowed to run for 48 hours.

Due to an abundance of organic material found in the streams, screens were occasionally installed upstream of each block net to reduce deposition, and the block nets were monitored and debris was removed when necessary. At the end of the 48-hour period, additional block nets were erected just upstream and just downstream of both the culvert and the reference culvert, creating four isolated reaches. Fish were then removed from each of these four segments using multiple pass seining and backpack electrofishing until no further fish were collected. Fish were examined for VIE tags, identified to species, and measured to total length. Any fish with VIE tags collected upstream of the actual or reference culvert were considered to have passed through the reach of interest. Fish captured below either of these culverts were assumed to have remained stationary. These experiments were conducted twice at each culvert, with effort made to capture local flow variation. Attempts were made to conduct a third trial during very high flow, but these trials were unsuccessful when block nets collapsed from debris accumulation.

Corresponding to each trial, the water depth and velocity were measured in both the treatment and reference culvert. Measurements were taken at five equidistant points (left bank, left-center, center, right-center, and right bank) along four equidistant transects located in each reach. These values were then averaged and compared using Mann-Whitney tests. Additionally, mean thalweg depth and mean channel width were calculated for the upstream and downstream segments for treatment and reference reaches. Thalweg depth was measured at 1.5 m intervals and wetted width was measured at 3 m intervals progressing downstream from the top of each segment. Data from the upstream and downstream segments were combined, and comparisons between treatment and reference reaches were made using Mann-Whitney statistics.

The proportion of fish that passed through reference and treatment reaches were compared using 2x2 chi-square contingency tables and an odds ratio test (Quinn and Keough 2002). The odds ratio is the proportion of fish that moved through the treatment culvert divided by the proportion of fish that moved through the reference culvert. Odds ratio values ≥ 1 suggest that fish movement through study culverts equals or exceeds that of reference culverts, and therefore no restriction in passage occurred. Odds ratio values < 1 suggest restricted passage, with less movement occurring through study culverts than through natural reaches. Odds ratios are considered statistically significant if 95% confidence intervals do not contain the value 1.0 (Quinn and Keough 2002, McLaughlin et al. 2006).

Linear regression was used to determine if any of the physical or hydraulic characteristics associated with the culverts influenced fish passage. Fish species having restricted passage as identified by the odds ratio test were used in this analysis - it makes no sense to look for factors contributing to fish immobility for species that did not appear to be hampered by the presence of the culvert. The ratio of the proportion of fish recaptured upstream of the culvert to the proportion captured downstream was used as the passage index. The passage index was then plotted against culvert slope, culvert length, and mean water velocity and examined for significant relationships ($\alpha = 0.05$).

Recapture efficiency using seines and backpack electrofishing appeared to vary in relation to in-stream habitat and turbidity. Therefore, recapture efficiency was measured in a small experiment at a subset of the study sites. To determine recapture efficiency, reaches upstream and downstream of the culvert were closed at either end using 6.35-mm block nets. Thirty fish comprised of the dominant species captured per reach were then marked with a pelvic fin clip, and placed in test segments. After 48 hours, the same method of recapture (seining and electrofishing) was used to collect the fish in each reach. Fish were counted and examined for fin clips after each pass with the seine and with the electrofisher. Recapture efficiency was calculated as the total proportion of fish recaptured after three passes of seining and three passes of electrofishing. The experiment resulted in an average recapture of 56.7% with a standard error of 6.9% in 4 trials. There was no apparent difference in recapture efficiency with respect to the side of the culvert, so the fact that not all fish are typically recaptured in any reach should not bias results based on upstream-downstream comparisons.

Modeling Using FishXing

Fish passage estimates over a range of flow conditions were made using the FishXing model. FishXing was used to model each culvert for each of the species used in the displacement experiments (creek chub, flathead chub, longnose dace, and white sucker). There is only limited information available concerning the swimming and leaping capabilities of these species. In prior studies where limited information on the species of concern was available, substitute data from a surrogate species was used (Cahoon et al. 2005). Table 2 shows these surrogate species (when needed) and the values used in the model for prolonged swimming speed and burst speed.

Table 2. Swimming capabilities and surrogate species used in the FishXing model.

Fish species modeled	**Prolonged swim speed surrogate species**	**Prolonged swim peed (cm/sec)**	**Burst speed surrogate species**	**Burst speed (cm/sec)**
White sucker	White sucker	51	Longnose sucker	182
Flathead chub	Flathead chub	44	Goldfish	137
Longnose dace	Blacknose dace	38	Goldfish	137
Creek chub	Bluehead chub	86 *	Goldfish	137

* (Gardiner 2006)

The physical and hydraulic measurements required by FishXing were collected at each culvert crossing. Measurements included culvert shape and dimensions, culvert material, corrugation dimensions, culvert entrance loss coefficient, plunge pool and tail water depth, culvert outlet elevation, culvert length, slope, and channel cross sections.

Stream gauging equipment was installed at each road crossing. TruTrack data loggers were mounted inside PVC stilling wells (Rantz et al. 1982), and set to record water height and stream temperature once per hour. Stilling wells were installed as close as possible to the culverts, and followed USGS stream gauging guidelines (Carter and Davidian 1968). Discharge was then measured at each stream crossing using a Marsh-McBirney velocity meter in conjunction with a standard top-setting rod. The USGS “six-tenths-depth” method for estimating discharge was used because the majority of study sites routinely experienced water depths between 0.3 feet and 2.5 feet (Buchanan and Somers 1969; Rantz et al. 1982). Discharge was measured a minimum of five times throughout each summer, and was measured at a variety of flows to represent the range of conditions found throughout the year. The resulting data were used to create stage-discharge relationships which produced estimated hydrographs for the duration of the study (Carter and Davidian 1968). These hydrographs were used to obtain the high and low passage flows necessary for the model.

Literature suggests that without model calibration, FishXing may not accurately predict the degree to which a culvert is difficult for fish to pass (Karle 2005, Cahoon et al. 2005). To minimize this concern, FishXing was calibrated such that the model as closely as possible predicted field measurements of water depth at the inlet and outlet of the study culverts.

Manning’s n values within the culvert and in the downstream cross section were adjusted until the predicted water depths were within 15.2 cm of field observations.

For each species, the calibrated FishXing model was used to predict passage at each culvert for flow rates over the range measured at the gauging stations. The passibility of the culvert according to FishXing over the range of flow rates observed was then superimposed over the hydrograph for the culvert to identify passage windows. These windows were expressed as the total amount of time during the study that FishXing predicted a species could pass through the culvert relative the duration of the study (late March to November 2006). These estimates could be further refined by including visual evidence of fish passage during field observations where the flow rate during the passage event was outside the range deemed passable based on FishXing results.

Linear regression was used to examine the relationship between culvert characteristics and the amount of time a culvert was estimated to be passable. The amount of time considered passable using the FishXing passage window and any additional time as observed in the displacement experiment was plotted against culvert length, slope, and outlet drop height. This analysis was conducted for each species used in the FishXing analyses.

Results

Regional Culvert Survey

Complete descriptions of the 34 stream crossings examined in February 2005 are provided in Appendix B. Of the 34 stream crossings, 15 were multiple barrel culverts, 10 were single barrel culverts, 6 were low-water fords, 2 were bridges, and 1 was a concrete box culvert crossing. Single culvert crossings consisted of mostly corrugated metal pipe (CMP) material (8 out of 10), whereas multiple culvert crossings were a mixture of CMP and structural steel plate (SSP) materials. All of the culverts found in low-water fords were constructed of CMP. There were a total of 58 individual culverts at the 34 stream crossings (because some crossings had multiple barrels). The mean culvert length was 28.9 m with a standard error of 3.4 m, however most culverts (46 of 58 or 79%) were less than 30 m in length as shown in Figure 4. Culvert slopes were relatively shallow with a mean value of 0.012 m/m and a standard error of 0.001 m/m. The mean outlet drop height was 17.2 cm with a standard error of 4.9 cm, although most culverts (41 of 58 or 71%) had no outlet drop height (0 cm).

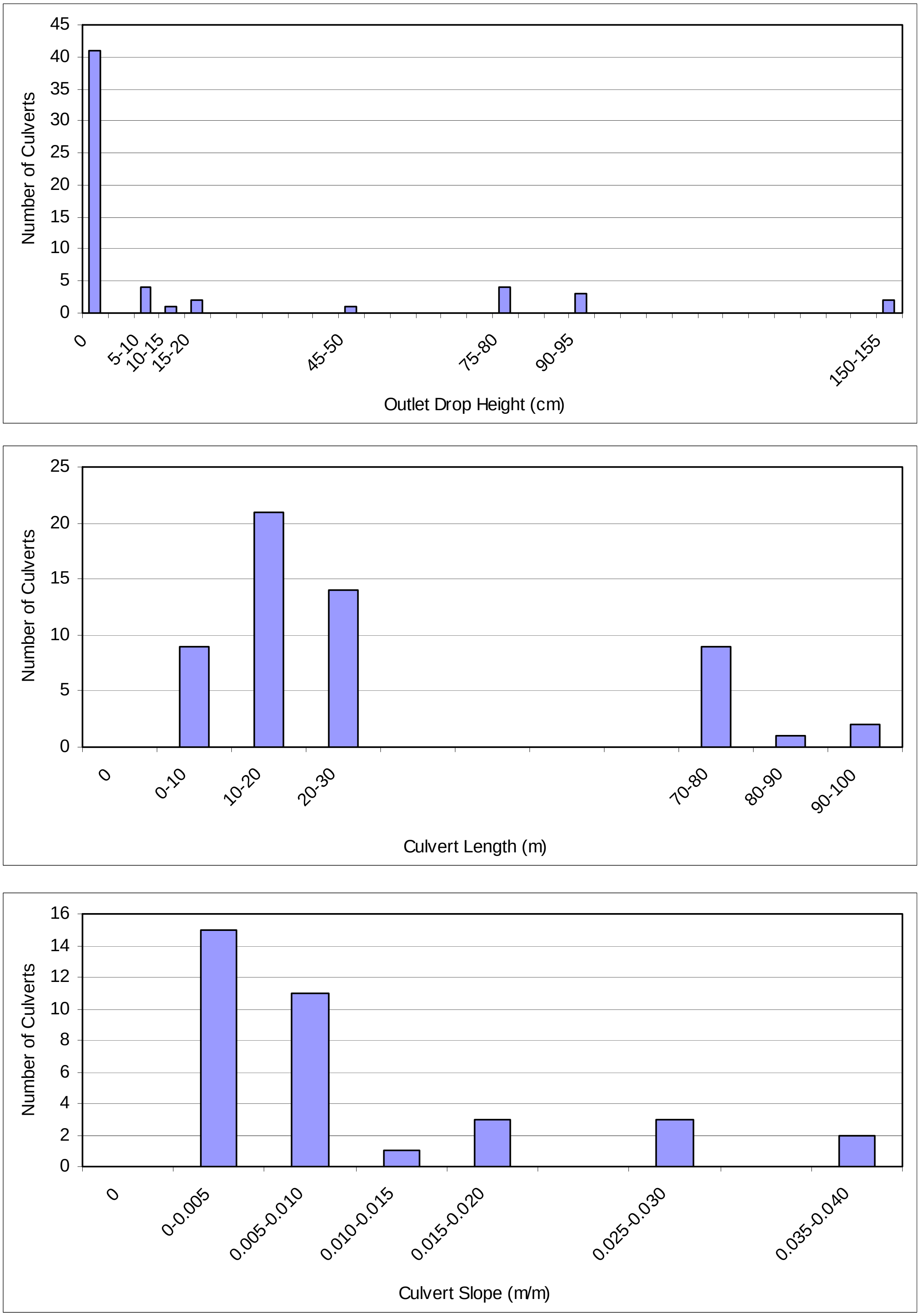


Figure 4. Data summary for the culverts included in the regional survey.

Intensive Study Culverts on Sand and Clear Creeks

The characteristics of the study sites selected for intensive analysis are shown in Table 3. Culvert length ranged from 14.0 to 70.7 m with a mean of 26.7 m and a standard error of 7.5 m. Culvert slopes ranged from 0 to 0.018 m/m with a mean of 0.011 m/m and a standard error of 0.003 m/m. Most study culverts (6 of 7) had no outlet drop (0 cm), with the only culvert having an outlet drop having only a slight drop (5.1 cm). All the study culverts had continuous flow during the irrigation season (typically May or June through August or September) and intermittent flow otherwise. All the study culverts but two were imbedded to some extent, usually with 5 to 10 cm of soil (with occasional gravel or small organic debris) above the culvert invert. This depth was variable with time and with position in the culvert. Culverts CC3 and SC1 were the exceptions with no embedment. Culvert CC2 was embedded, but had a lesser tendency to have substrate in the pipe due to hydraulic scouring.

Table 3. Characteristics of the five study culvert crossings.

Stream	**Crossing**	**Type**	**Length (m)**	**Width (m)**	**Height (m)**	**Slope (m/m)**	**Corrugation dimensions (cm x cm)**	**Outlet drop height (cm)**
Clear Creek	CC1a	SSP	19.7	3.4	2.1	0.0037	16.5 x 5.1	0.0
Clear Creek	CC1b	CMP	14.0	1.5	1.5	0.0000	7.6 x 1.3	0.0
Clear Creek	CC2	SSP	70.7	4.6	3.0	0.0055	15.2 x 5.1	5.1
Clear Creek	CC3 left	CMP	18.4	1.2	1.2	0.0166	7.6 x 1.3	0.0
Clear Creek	CC3 center	CMP	18.4	1.2	1.2	0.0159	7.6 x 1.3	0.0
Clear Creek	CC3 right	CMP	18.4	1.2	1.2	0.0185	7.6 x 1.3	0.0
Sand Creek	SC1	CMP	27.1	2.4	2.4	0.0158	8.5 x 2.5	0.0

SSP is corrugated structural steel plate, and CMP is corrugated metal pipe.

Longitudinal Distribution of Fish and Habitat

Distributional sampling reaches for Clear and Sand creeks were sampled twice during the summer of 2005 and 2006. Clear Creek contained 21 fish species in year 2006 samples with (in order of decreasing abundance) creek chub, white sucker, longnose dace, fathead minnow, brook stickleback and sand shiner being the six most common species (Figure 5). Brook stickleback were found in slightly more abundance than sand shiner; however brook stickleback were not well distributed in the system and sand shiner were, so further analysis used the four most abundant species and sand shiner. As shown in Figure 6, Sand Creek contained 10 species in year 2006 samples with (in order of decreasing abundance) flathead chub, longnose dace, creek chub, sand shiner and fathead minnow being the five most common species. Overall abundances were much lower in Sand Creek than in Clear Creek, as seen in comparisons of Figures 5 and 6. Stream length was relatively limited in Sand Creek, resulting in too few reaches above and below the stream crossings for statistical analysis. Therefore, statistical analyses were confined to Clear Creek data. Additionally, because the 2005 Clear Creek data did not include several of the reaches established in 2006, only the 2006 Clear Creek data was subjected to statistical analyses.

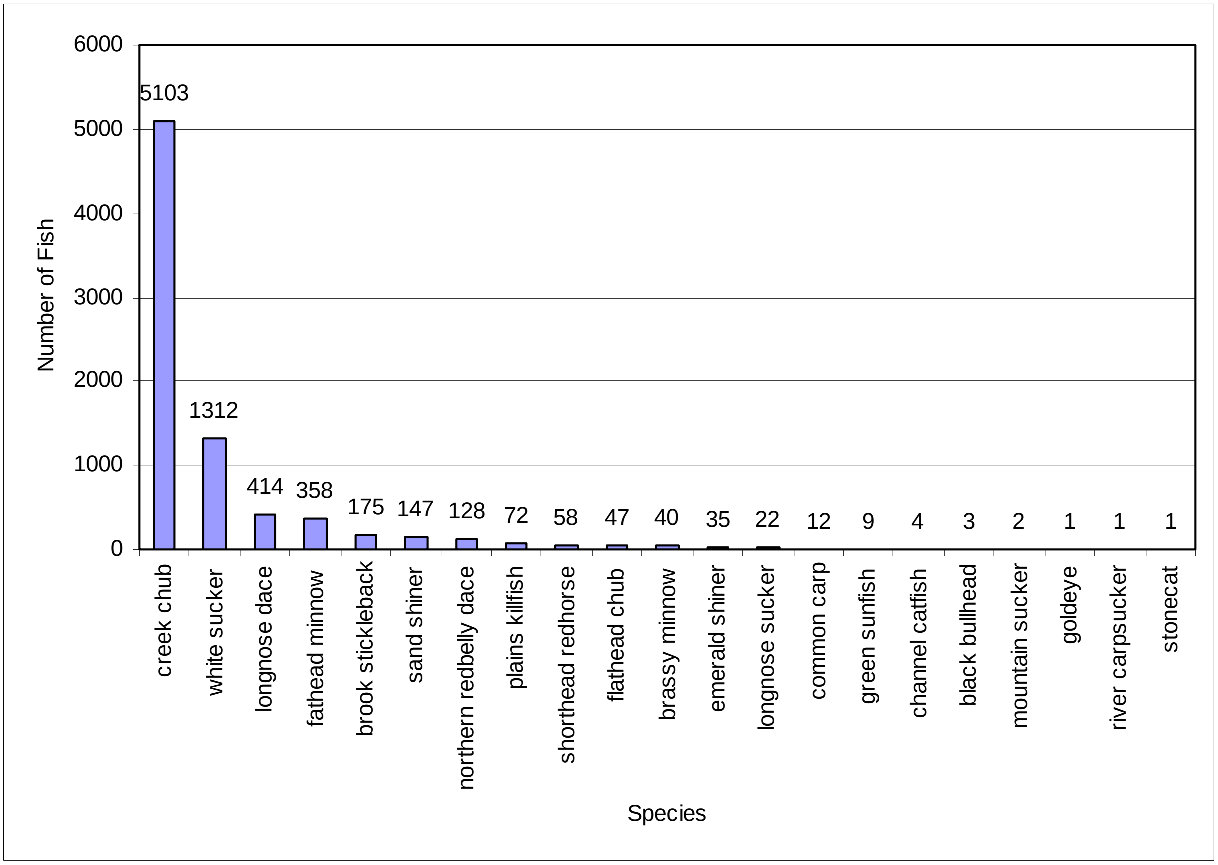


Figure 5. Species composition on Clear Creek in 2006.

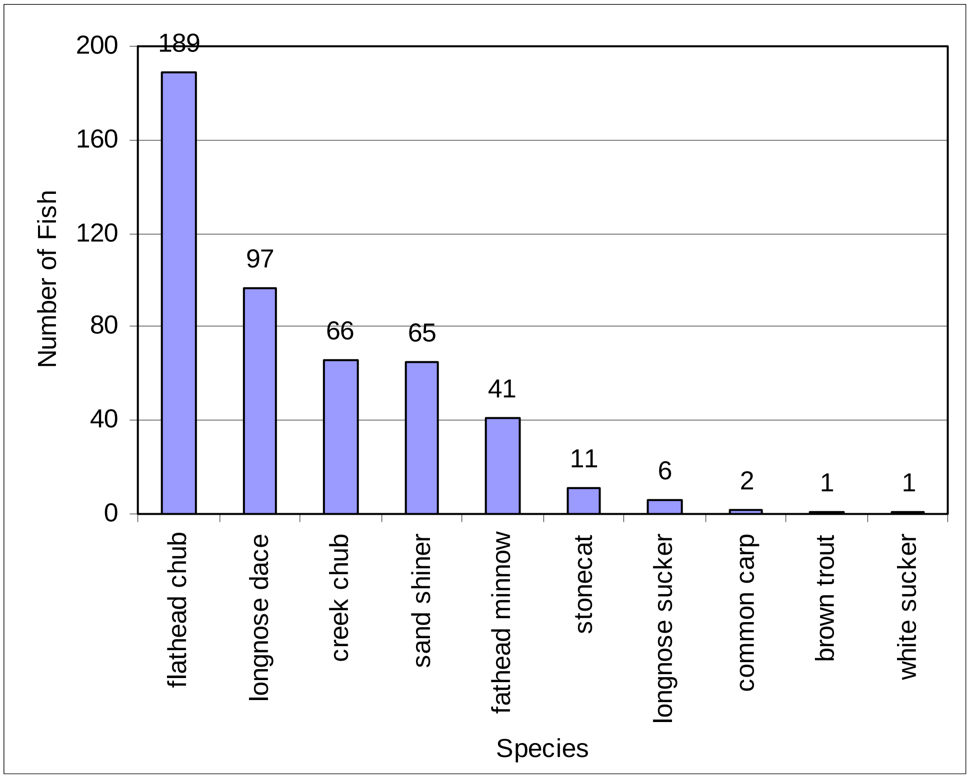


Figure 6. Species composition on Sand Creek in 2006.

In general, species richness in Clear Creek was relatively constant after an initial decline between the first and second reaches upstream from the confluence with the Yellowstone River. The most downstream reach on Clear Creek contained 18 species of fish, while the most upstream reach contained 8 species (Figure 7). However, mean species richness was similar above and below all road crossings using the Mann-Whitney test. In contrast the opposite occurred in Sand Creek where species richness upstream of the culvert was twice that detected downstream of the culvert (Figure 8).

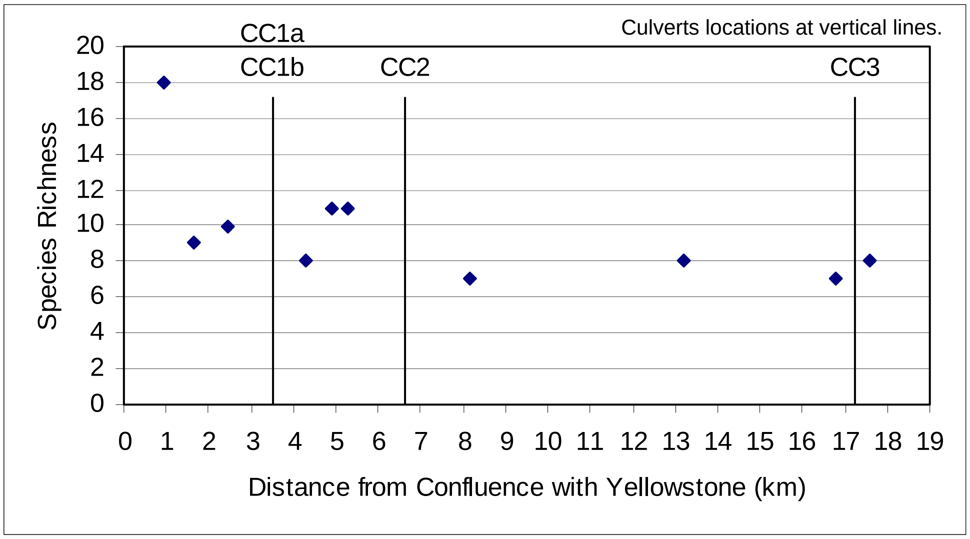


Figure 7. Species richness by distance from the confluence with the Yellowstone River for Clear Creek from May to August 2006.

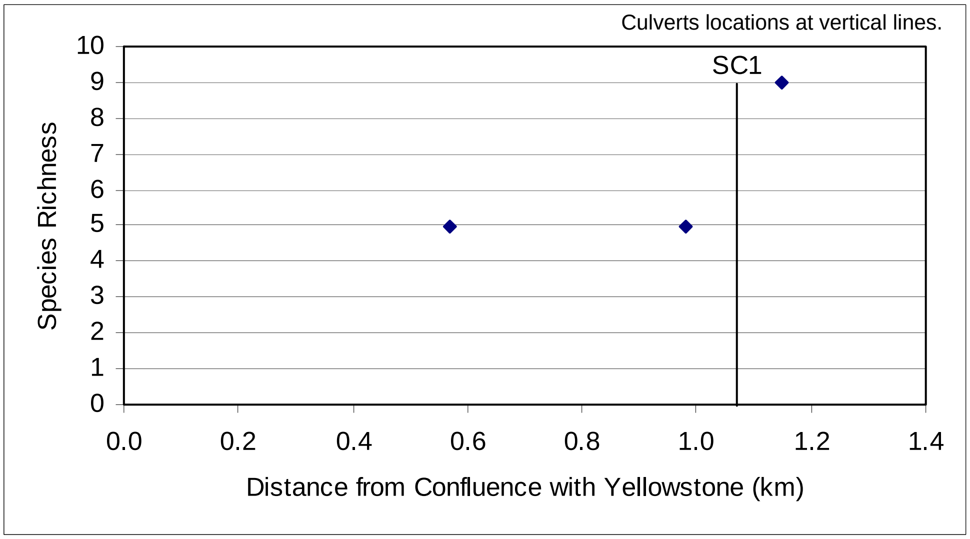


Figure 8. Species richness by distance from the confluence with the Yellowstone River for Sand Creek from May to August 2006.

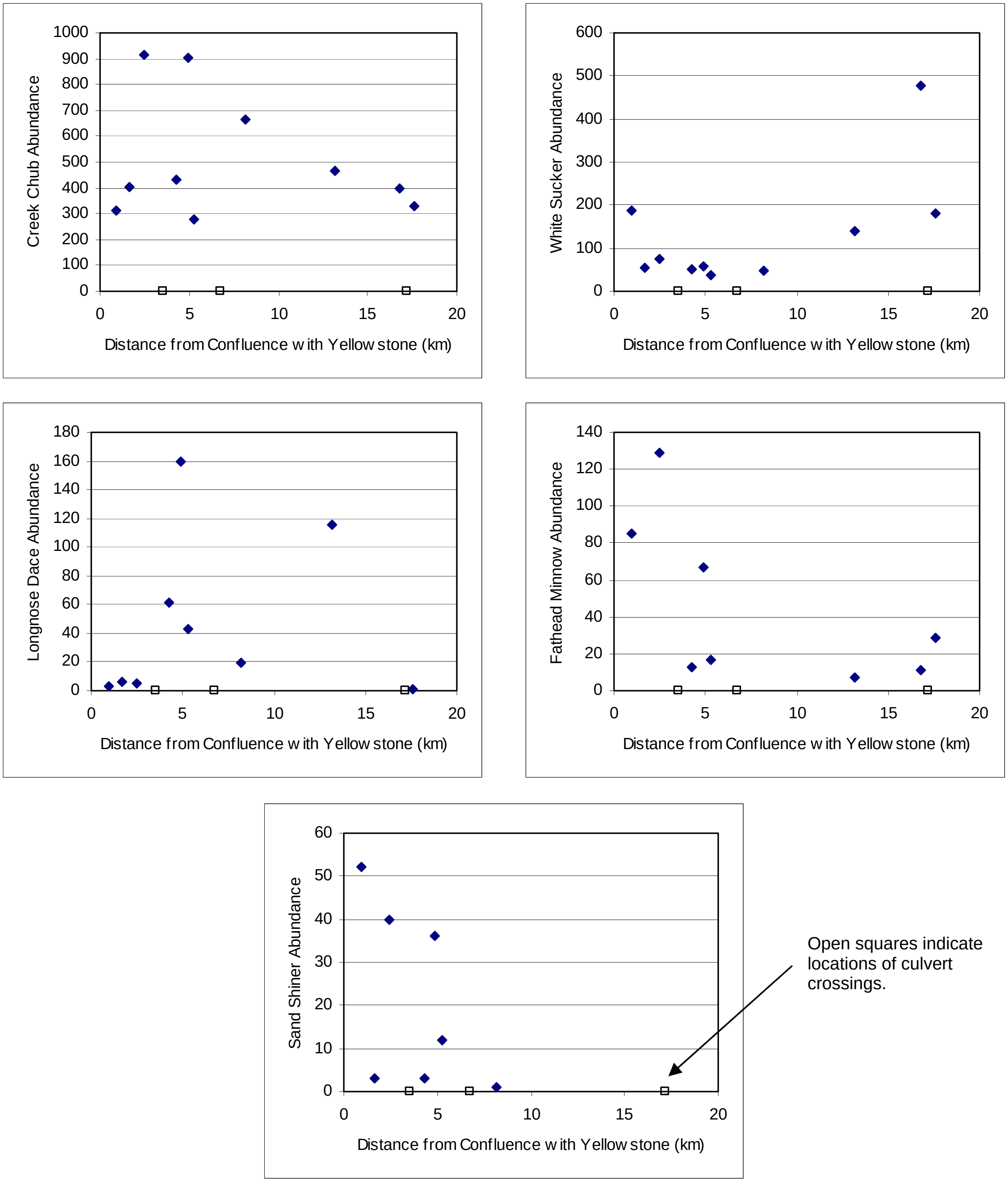
A total of 5,103 creek chubs, 358 fathead minnows, 414 longnose dace, 147 sand shiners, and 1,312 white suckers were collected in 2006 in Clear Creek. The abundance of these species relative to position in the stream system is shown in Figure 9. Creek chubs were typically the most abundant species at all sites; however white sucker were collected in similar numbers in upstream reaches. Few visual patterns in longitudinal abundance relative to culverts are evident in Figure 9. Correlation analyses showed that only the relative abundance of sand shiners was significantly correlated with distance from the confluence with the Yellowstone River, and the correlation was negative. In other words, a decreasing number of sand shiners were found as distance from the Yellowstone increased. No other of the five most abundant species showed a significant correlation between abundance and distance from the Yellowstone. While not statistically tested (due to sporadic occurrences), northern redbelly dace and brook stickleback were found mostly in the upstream reaches. In contrast, flathead chub, channel catfish, longnose sucker, river carpsucker, emerald shiner, and common carp were only found in the three to four downstream-most reaches.

The results of pairwise Mann-Whitney comparisons above and below culvert crossings on Clear Creek (Table 4) revealed that in most cases, species abundance was not significantly influenced by road crossings. No differences between upstream and downstream relative abundance were detected for creek chub or white sucker. Longnose dace abundance was significantly higher upstream of crossings CC1a and CC1b but was similar above and below other crossings, indicating that culverts did not influence fish numbers. In contrast, relative abundance was significantly lower upstream of crossing CC2 for both fathead minnow and sand shiner, suggesting that this crossing may affect fish distribution.

Table 4. Differences between upstream and downstream abundance for the five most abundant species on Clear Creek in 2006.

Species	**CC1a and CC1b**	**CC2**	**CC3**
Creek chub	no difference	no difference	no difference
White sucker	no difference	no difference	no difference
Longnose dace	**higher upstream**	no difference	no difference
Fathead minnow	no difference	**lower upstream**	no difference
Sand shiner	no difference	**lower upstream**	no difference

In-stream habitat could be described as being narrower and deeper in the lower reaches and becoming wider and shallower moving upstream. Mean thalweg depth was similar above and below crossings CC2 and CC3 using the Mann-Whitney test, but was significantly deeper below crossings CC1a and CC1b. Similarly, mean wetted width was similar above and below all stream crossings.



Open squares indicate locations of culvert crossings.

Figure 9. Relative abundance of the five most common Clear Creek fish species by distance from the confluence with the Yellowstone River in 2006.

Fish Passage Experiments

Fish displacement experiments were conducted at all five crossings at two different water flows during the 2006 field season for a total of ten trials. A total of 1,109 fish dominated by four species were marked with VIE tags. These four species included creek chub (620 fish), flathead chub (63 fish), longnose dace (164 fish), and white sucker (200 fish). Several other species of fish were marked, but because of low sample size were excluded from this analysis. Only species in which at least 20 fish were captured during the initial sampling were used in each trial. Of the ten trials, creek chub were used in nine, flathead chub were used in two, longnose dace were used in five, and white sucker were used in four trials.

Overall and as shown in Table 5, fish movement through study culverts was equal to or greater than through the natural stream reaches (termed "reference culverts") with a very significant (P = 0.001) odds ratio of 1.81. Of the four dominant species combined, 77 out of 491 (15.7 %) fish were recaptured upstream of reference culverts with an average fish length of 82.2 mm. Alternatively, 132 out of 556 (23.74 %) fish marked in treatment reaches were recaptured above study culverts with an average fish length of 92.6 mm.

When evaluated by species, passage was not significantly restricted for flathead chub and white sucker. The odds ratios for both these species were significant and greater than one. For example, with an odd ratio of 9.25, white suckers were 9.25 times as likely to move through a culvert than through a reference reach. On the other hand, longnose dace movement was significantly lower through culverts than through reference reaches, with the odds ratio indicating that longnose dace were 3.57 (or 1/0.28) times as likely to pass through reference reaches than through treatment culverts. Creek chub and flathead chub had similar passage rates through both the culverts and reference reaches.

Table 5. Results of Chi-square analysis and odds ratio tests for all fish passage experiments.

Species	**Chi-square value**	**Odds ratio**	**95% CI**	**P-value**
Creek chub	3.33	1.52	0.97 to 2.38	0.07
Flathead chub	1.49	3.00	0.49 to 18.25	0.22
Longnose dace	4.17	0.28	0.08 to 0.98	0.04
White sucker	17.82	9.25	2.94 to 29.08	<0.0001
All species	10.73	1.81	1.27 to 2.59	0.001

The passage capability of creek chub and white sucker was further examined by grouping these two species as small fish (total length ≤ 80 mm) and large fish (total length > 80 mm). Of the marked creek chub, 341 (55 %) were ≤ 80 mm, and 279 (45 %) were > 80 mm. Similarly, 87 (43.5 %) of marked white suckers were ≤ 80 mm, and 113 (56.5 %) were > 80 mm. The results of this analysis are shown in Table 6, where dashes indicate situations where the sample size was insufficient for Chi-square analysis. Fisher's Exact test was used when two or more cells had counts of five or less. Passage was not significantly restricted for creek chub or white sucker in either length classes. For both species, the larger fish passed through the culverts at a higher rate than through the reference reaches. For both species, the smaller fish passed the culverts and the reference reaches at a similar rate.

Table 6. Results of Chi-square odds ratio tests comparing the passage through reference and treatment culverts of creek chub and white sucker by length class.

Species	**Total length (mm)**	**Chi-square value**	**Odds ratio**	**95% CI**	**P-value**
Creek chub	≤ 80	0.09	1.10	0.59 to 2.05	0.76
Creek chub	> 80	4.92	2.10	1.09 to 4.05	0.03
White sucker	≤ 80	--.--	1.61	0.23 to 1.09	1.00
White sucker	> 80	18.50	18.12	3.78 to 86.91	< 0.0001

Habitat variables measured in both reference and treatment stream segments at all crossings can be found in Table 7. The CC3 habitat observations were measured when the stream was dry, so the thalweg depth and wetted width were measured as bank full depth and width respectively. Mean thalweg depth was not significantly different between treatment and reference reaches for crossings CC1a, CC1b, and CC3, however, mean thalweg depth was significantly higher in the reference reach at crossing CC2 and in the treatment reach at crossing SC1. Mean channel width did not differ significantly between treatment and reference reaches at crossing CC1a, however, mean channel width was significantly larger in treatment reaches than in reference reaches at all other crossings. Additionally, mean water depth was significantly higher in reference culverts than in treatment culverts for crossings CC1a and CC2, and significantly lower in the reference culvert than in the treatment culvert for crossing SC1. Mean water velocity did not differ significantly between treatment culverts and reference culverts at any crossing.

Table 7. Mean habitat variables measured in reference and treatment reaches for fish passage experiments.

Crossing	Reach	Segment measurements: Mean thalweg depth (cm)	Segment measurements: Mean wetted width (m)	Culvert measurements: Mean water depth (cm)	Culvert measurements: Mean water velocity (m/s)
CC1a	Reference	29.4 (0.05)	3.2 (0.5)	11.8 (0.01)*	0.12 (0.02)
	Treatment	23.6 (0.04)	2.5 (0.6)	9.2 (0.01)	0.12 (0.02)
CC1b	Reference	30.5 (0.03)	1.5 (0.08)	28.5 (0.02)	0.07 (0.01)
	Treatment	27.0 (0.03)	2.1 (0.2)*	29.9 (0.03)	0.06 (0.01)
CC2	Reference	41.9 (0.08)*	3.3 (0.3)	15.0 (0.01)*	0.09 (0.01)
	Treatment	18.3 (0.04)	5.0 (0.04)*	5.0 (0.01)	0.14 (0.02)
CC3	Reference	30.8 (0.02)	3.5 (0.5)	11.8 (0.01)	0.08 (0.01)
	Treatment	49.4 (0.04)	9.2 (0.5)*	11.1 (0.01)	0.16 (0.03)
SC1	Reference	31.9 (0.05)	2.1 (0.2)	22.4 (0.02)	0.30 (0.03)
	Treatment	57.1 (0.07)*	3.3 (0.3)*	31.9 (0.03)*	0.27 (0.04)

Standard errors are in parenthesis, and * indicates a significant difference between reference and treatment.

Because longnose dace were the only of the five most abundant species to exhibit significant culvert passage restriction, this species was further examined for relationships between passage and culvert characteristics. A passage index was created for each of the five experiments in which longnose dace were used. This passage index was calculated as the number of fish recaptured upstream of the study culvert divided by the number recaptured downstream. Index values less than 1.0 indicate restricted passage with less fish captured above than below the culvert. Index values greater than or equal to 1.0 indicate no restriction. Index values for longnose dace ranged from 0.00 to 2.00, with 3 of 5 trials showing restricted passage. No significant relationships were detected between passage index values for longnose dace and any of four culvert characteristics: culvert length, culvert slope, water velocity, or outlet drop height. Passage indices were also calculated for creek chub to contrast results from the longnose dace regressions. Passage indices for creek chub ranged from 0.00 to 5.00 with 5 of the 10 trials showing restriction of passage. Again, no significant relationships were observed between passage index values and any of the four three culvert characteristics.

Modeling Using FishXing

The FishXing model indicated that all five crossings act as partial barriers to some or all of the four predominant species examined in this study at certain flow rates. When the model predicts that a culvert is a barrier, it also indicates the hydraulic or physical reason for being a barrier. At low flow rates, barrier status was the result of insufficient water depth in all five culverts, and sometimes insufficient water depth in the plunge pool (crossings CC1a and CC2). It is possible for more than one condition to contribute to barrier status. At high flows, all five culverts were predicted to have excessive water velocity and culvert CC2 had excessive outlet drop height.

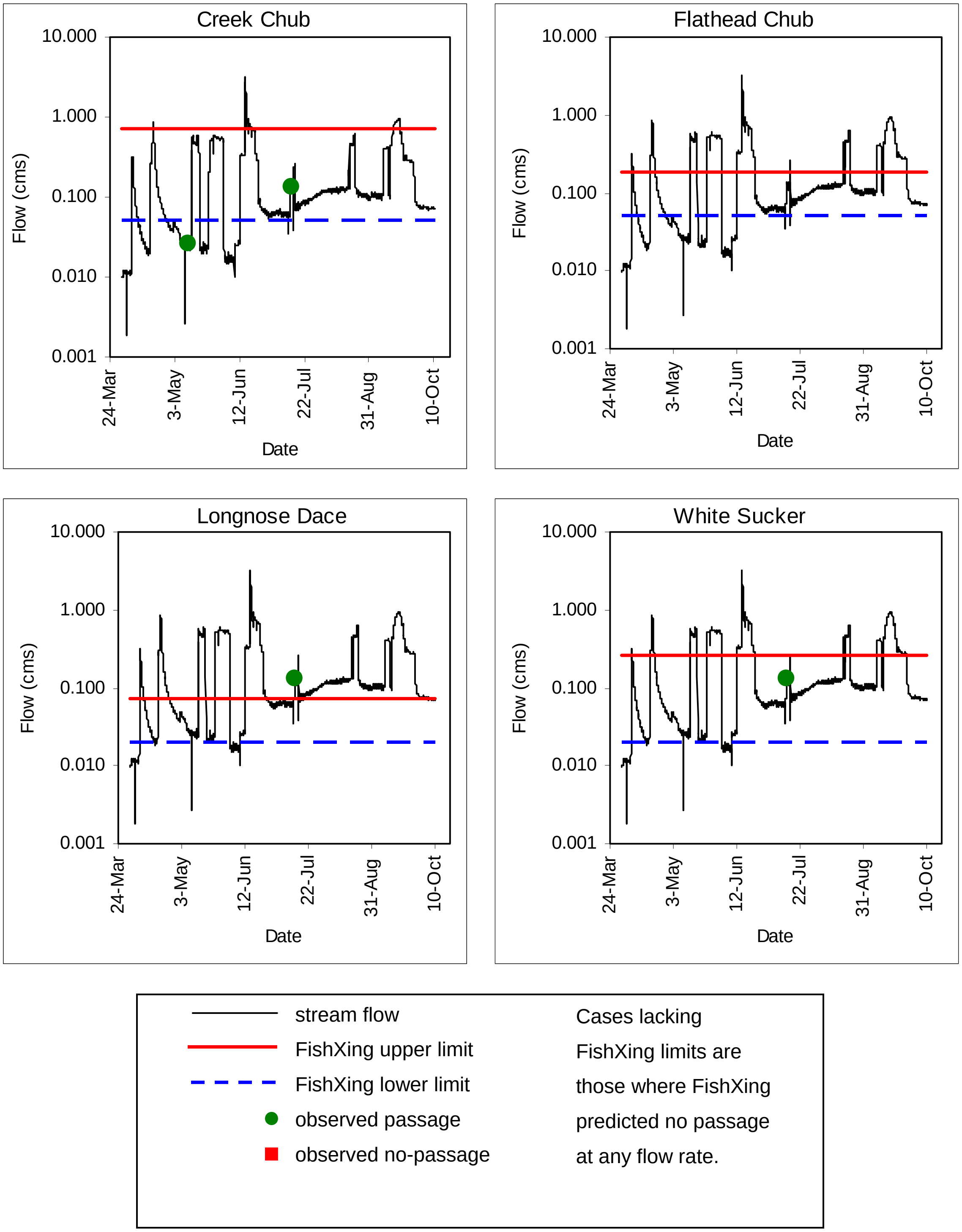
Passage windows are a convenient way to superimpose culvert hydraulics, fish capabilities, hydrology and the results of fish passage experiments into one clear picture. Figures 10 through 14 show the passage windows for each of the fish species examined at each culvert modeled and studied. A semi-logarithmic scale is used to clarify low flows. Some important features of these figures are:

1. The dashed blue horizontal line shows the lowest flow at which FishXing predicted that the culvert was not a barrier. Any flow less than this would have some sort of barrier issue according to FishXing.
2. The solid red horizontal line shows the highest flow at which FishXing predicted that the culvert was not a barrier. Any flow greater than this would have some sort of barrier issue according to FishXing.
3. The range between the two horizontal lines is the passage window. Any flow rate in this range would not have barrier issues according to FishXing.
4. The thin black line is the observed hydrograph for the culvert. Whenever the hydrograph lies within the passage window, FishXing would indicate no barrier issues.
5. Green circles indicate cases where in field experiments fish were observed to pass through a given culvert. When the green circle is in the passage window, the field experiment coincided with the FishXing results. When the green circle is outside the passage window, fish were observed to have passed through the culvert at a flow that FishXing indicated should have been a barrier.
6. Red squares indicate cases where in field experiments fish did not pass through a given culvert when included in the passage experiment. When the red square is in the

passage window, FishXing indicated that there was no barrier, but field experiments indicated restriction to passage. When the red square is outside the passage window, FishXing results coincided with field observations that the culvert was restrictive to passage.

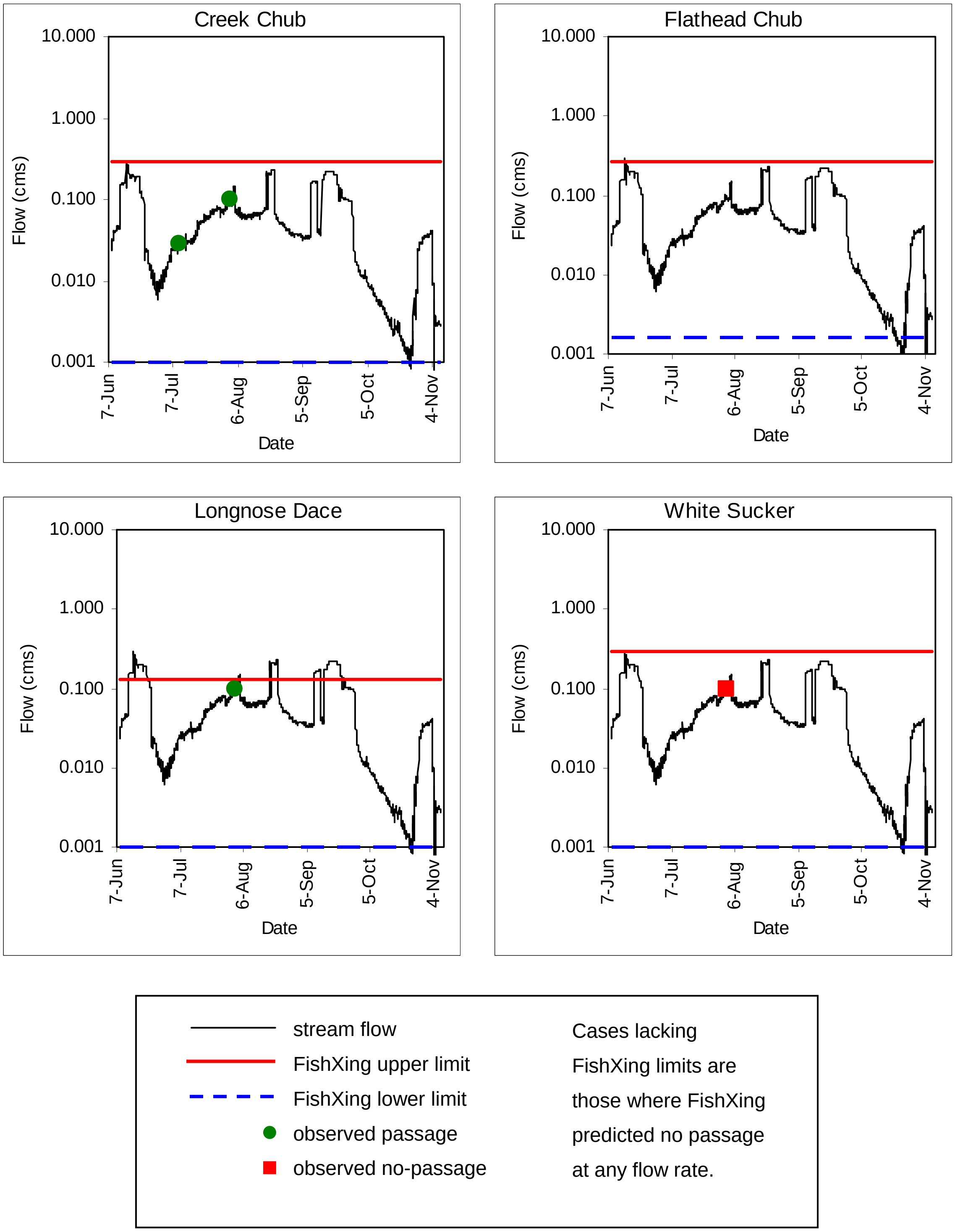
7. Some of the figures have no horizontal lines (all 4 species at CC2, and flathead chub at CC3 and SC1). In these cases FishXing predicted barrier status at all flows (no passage window).

8. The *percent of time passable* is a way of considering the passage capability of a culvert over a season, year, or other period. Table 8 shows the percent of time passable for each culvert and species over the duration of the study. The value is arrived at by dividing the total amount of time that the hydrograph lies in the passage window by the total duration of the study. Each culvert had a slightly different study duration, but in general the duration was from mid-March to late October 2006 and can be discerned from the horizontal extent of the hydrographs in Figures 10 through 14. The far right column of Table 8 shows the effect of extending the passage windows vertically in cases where field observations indicated that passage of a species at a culvert did indeed occur at a flow outside of the FishXing passage window. That is, the vertical limits of the passage window were reset to the more extreme of the FishXing results or the field experiments results. Including the field observations generates a percent of time passable that is more representative of the entire study.



Cases lacking FishXing limits are those where FishXing predicted no passage at any flow rate.

Figure 10. Passage windows for crossing CC1a.



Cases lacking FishXing limits are those where FishXing predicted no passage at any flow rate.

Figure 11. Passage windows for crossing CC1b.

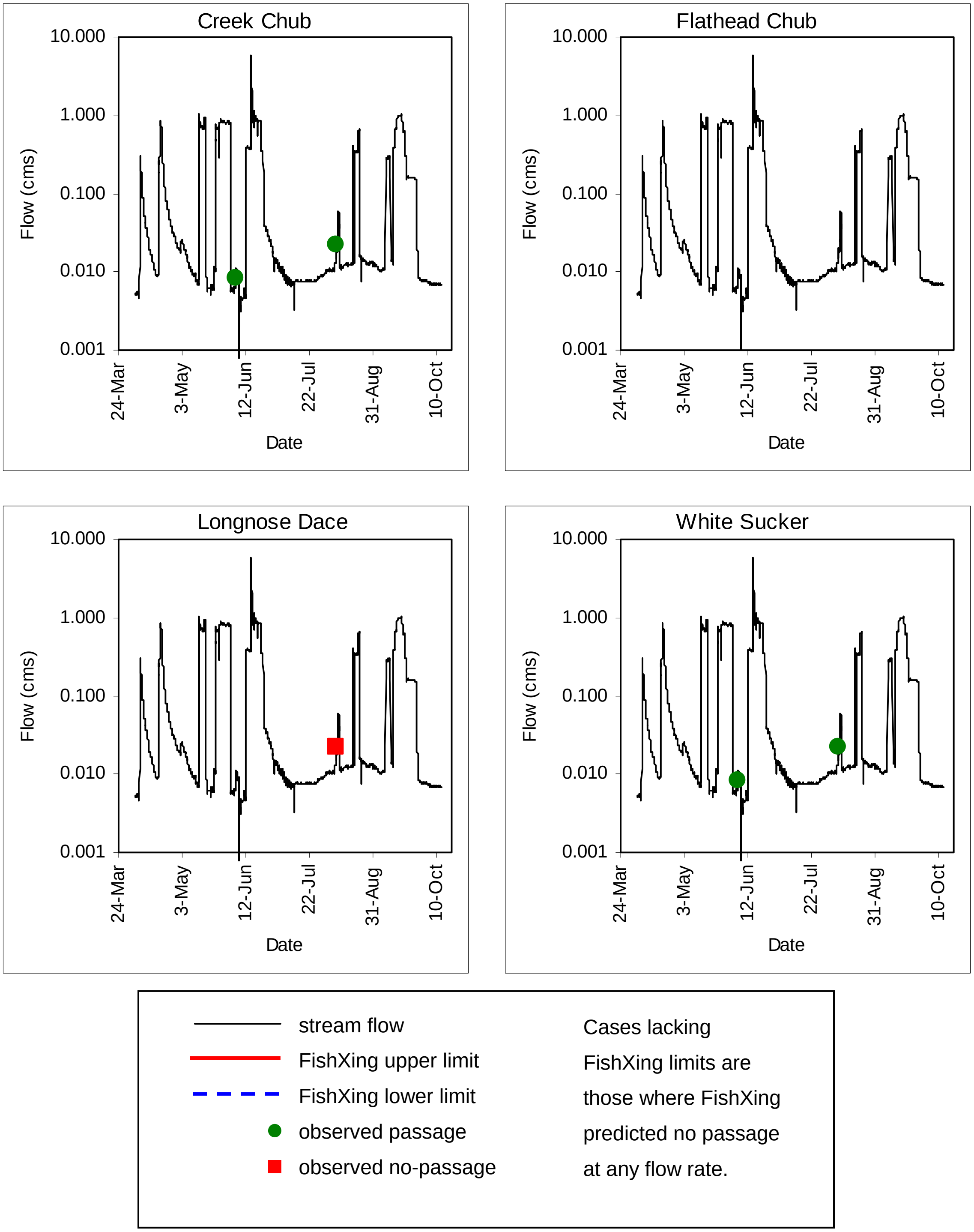


Figure 12. Passage windows for crossing CC2.

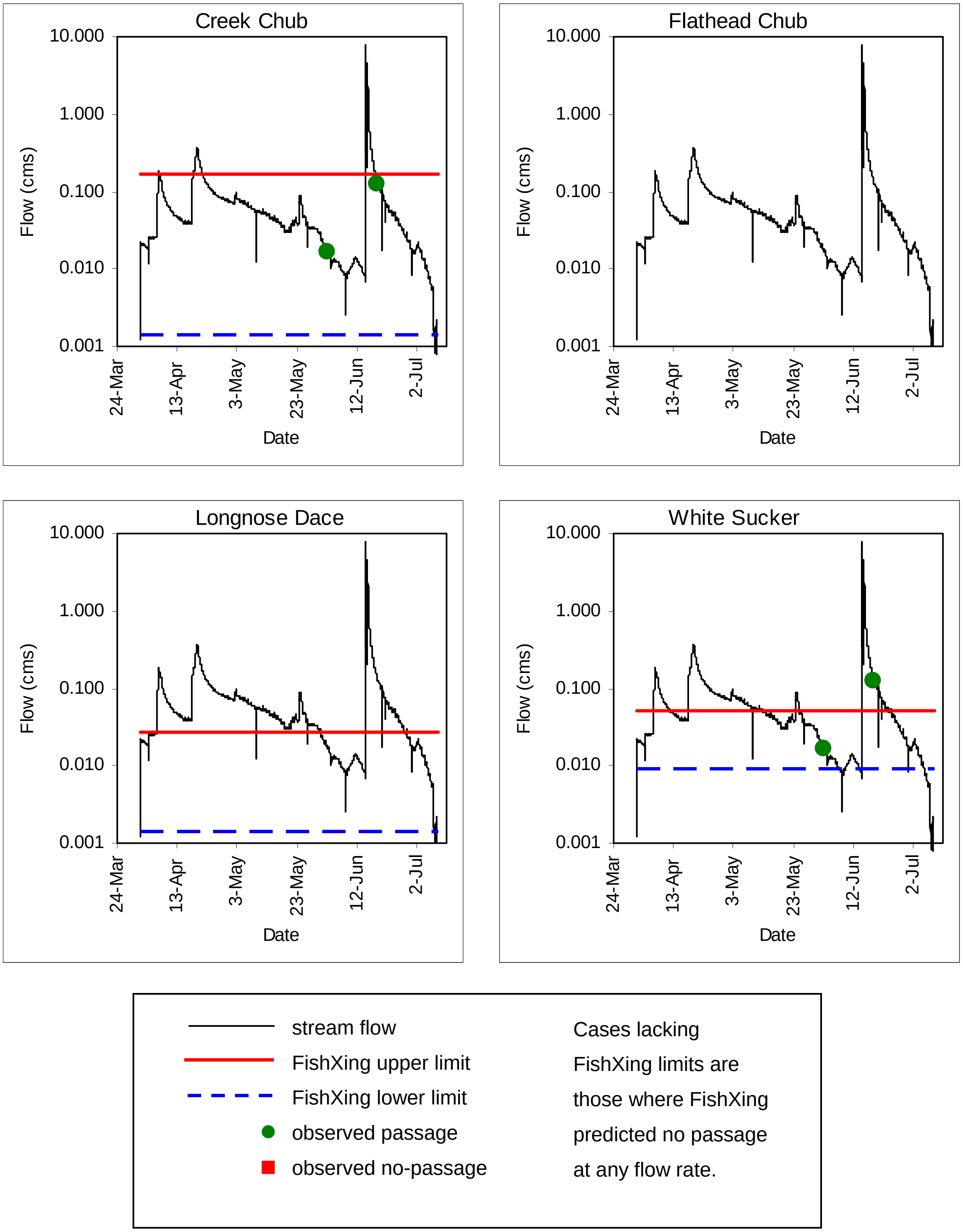


Figure 13. Passage windows for crossing CC3.

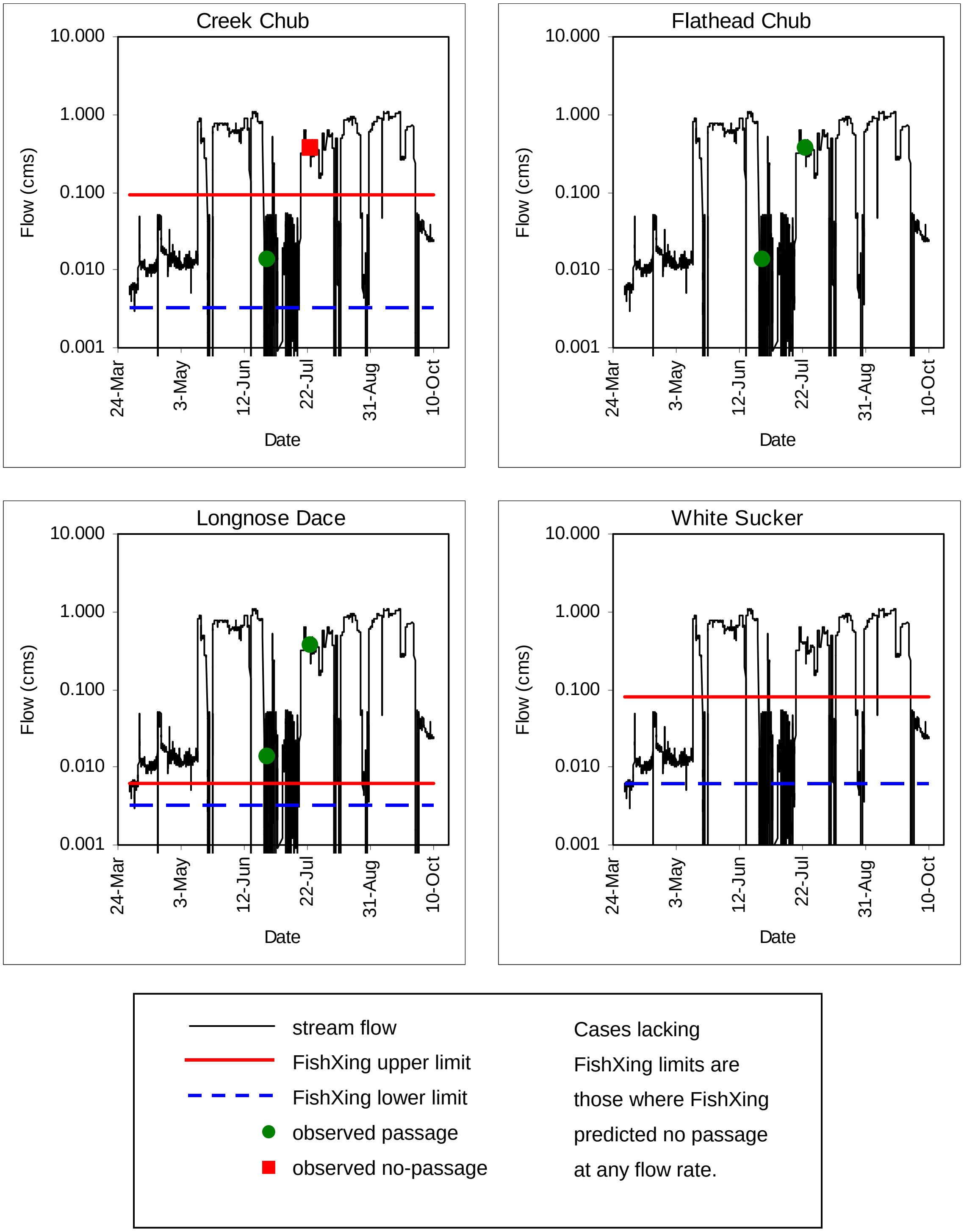


Figure 14. Passage windows for crossing SC1.

Table 8. Passage windows for each culvert crossing and all four species during the 2006 study period.

Stream crossing	Species	Percent of time passable based on FishXing	Percent of Time Passable based on FishXing and passage experiment
CC1a	Creek chub	73	73
	Flathead chub	50	-
	Longnose dace	29	**65**
	White sucker	69	69
CC1b	Creek chub	*100	*100
	Flathead chub	97	-
	Longnose dace	84	84
	White sucker	*100	*100
CC2	Creek chub	0	**35**
	Flathead chub	0	-
	Longnose dace	0	0
	White sucker	0	**35**
CC3	Creek chub	92	92
	Flathead chub	0	-
	Longnose dace	30	-
	White sucker	51	**82**
SC1	Creek chub	38	38
	Flathead chub	0	**27**
	Longnose dace	3	**48**
	White sucker	36	-

* All four values that were rounded to 100 were actually 99.97%.
\- Dashes indicate that a species was not used in the fish passage experiment at that site.

An item of note in Table 8 is that all the percent of time passable values were rounded to the nearest percent. No culvert was passable 100% of the time by either measure. The values in Table 8 that appear as 100% are actually 99.97%, where a short duration of extreme high flow exceeded either passage window used. Dashed entries in Table 8 indicate cases where a particular species was not used in the passage experiments at a particular culvert. Recall that only species of a certain abundance in the initial capture of each unique passage experiment were marked. These cases can also be noted in Figures 10 through 14 as the graphs that do not have either a green circle or a red square. Bold entries in Table 8 are cases where including field observations increased the flow range of the passage window over that predicted by FishXing.

There were 12 cases where this was possible - cases where the FishXing window was not essentially 100% of flows and the species in question was used at that culvert for a passage experiment. In 6 of those 12 cases (50% of cases), including field data increased the percent of time passable predicted by FishXing by an average of 30%.

Linear regression was used to determine if any of the measured culvert characteristics predicted the amount of time a culvert was considered passable. Outlet drop height was not tested because only one culvert had an outlet drop greater than 0.00 cm. No significant relationship was found between the percent of time passable and culvert length or culvert slope for any of the species.

Also demonstrated in Figures 10 through 14 is that all 6 of the possible combinations of FishXing results and field observations occurred in this project:

a) FishXing indicated that a passage window exists and fish are observed to pass the culvert at flows in that window,

b) FishXing indicated that a passage window exists and fish are observed to not pass the culvert at flows outside that window,

c) FishXing indicated that the culvert is not passable (no passage windows) and fish are observed to not pass the culvert during any field trials,

d) FishXing indicated that a passage window exists and fish are observed to pass the culvert at flows that are outside the window,

e) FishXing indicated that a passage window exists, but at flows within the passage window fish are observed to not pass through the culvert during field trials, and

f) FishXing indicated that the culvert is not passable (no passage windows) and fish are observed to pass the culvert during field trials.

The combinations a), b), and c) above are cases where FishXing correctly indicating passage or no passage, while cases d), e), and f) are those where FishXing did not predict field observations. The number of occurrences of each the combinations listed above are summarized in Table 9 for each species. Overall, the combination of FishXing results and field observations fell into case a), b), or c) in 11 of 23 (48%) possible events. That is, in 48% of our field trials we observed fish either passing or not passing a culvert in accordance with the FishXing results. In the other 52% of cases we observed fish passing or not passing the culvert in a manner that was not predicted by FishXing. Overall, case a) had 9 occurrences, case f) had 6 occurrences and case d) had 5 occurrences. Cases b), c), and e) occurred less frequently with one occurrence each. That is, the most common outcome was that FishXing predicted a passage window and fish were observed to pass at flows in that window in 39% of cases. The second most common occurrence was that FishXing predicted a barrier but passage was observed in field trials. The third most common occurrence was that fish passage was observed in field trials at flows outside of the window that FishXing predicted.

Table 9. Number of cases of each possible combination of FishXing passage windows and observed fish passage by species.

Species	**a) Fish observed passing at flows in FishXing window**	**b) Fish observed not passing at flows out of the FishXing window**	**c) FishXing predicted barrier and observed to be barrier**	**d) Passage observed at flows outside of FishXing window**	**e) Observed to be barrier at flows in FishXing window**	**f) FishXing predicted barrier but passage was observed**
Creek chub	6	1	0	1	0	2
Flathead chub	0	0	0	0	0	2
Longnose dace	1	0	1	3	0	0
White sucker	2	0	0	1	1	2

Discussion

A combination of three assessment techniques were used to examine fish passage at five culvert crossings in eastern Montana. The techniques individually were longitudinal distribution surveys, direct observation of fish passage in field experiments, and modeling using the FishXing program. When possible, results of different methods were overlain to provide the most comprehensive evaluation.

Results from the longitudinal distribution surveys showed as many as 18 species in a reach of Clear Creek, and as few as 5 species in a reach of Sand Creek. Species richness was highest near the confluence with the Yellowstone River on Clear Creek (18 species), dropping dramatically from there to the next upstream reach (9 species). In the upstream-most 16 km of Clear Creek, 9 sample reaches showed fairly consistent species richness ranging from a maximum of 12 species to a minimum of 6 species with an average of 9 species. Except for the difference between the most downstream reach and all the others, species richness on Clear Creek defies the trend of reduced richness with progression upstream from the mouth as reported by Schlosser (1987) and Ostrand and Wilde (2002). Sand Creek exhibited more species at the upstream-most reach (9 species) with 5 species at both reaches nearer the confluence with the Yellowstone River.

On Clear Creek, there were no significant differences in mean species richness when comparing upstream and downstream sides of the culverts. This suggests that the presence of road crossings does not affect the overall distribution of fishes throughout the watershed, and that the absence of a species in upper reaches may be the result of natural changes in assemblage. Winston et al. (1991) documented the extirpation of four prairie stream fish species upstream of the Altus Dam on the North Fork of the Red River in Oklahoma. This example describes how a total barrier to upstream fish movement can have long lasting consequences. Because no significant differences in species composition were detected above and below culverts in this study, it could be assumed that none of the culverts were acting as total barriers. Although study culverts were not acting as total barriers to upstream fish movement, one crossing did appear to influence the abundance of both fathead minnow and sand shiner. Both species had significantly lower abundances in sites upstream of crossing CC2, but were collected in further upstream sites indicating that while this crossing may be affecting their movement, individuals were able to pass at certain times.

The FishXing model predicted that none of the culverts had no barrier restriction over the entire duration of the study. However, fish distribution patterns show evidence that if these crossings affect fish movement, the impacts on the overall community is difficult to detect. Additionally, fish were often observed to pass through the culverts during experimentation in situations deemed restrictive by the FishXing model. FishXing has been considered a very conservative estimate of fish passage barriers in other studies. Sometimes this is attributed to lack of local calibration of the model, but in this study the model proved to be conservative even after local hydraulic calibration. Probably the weakest link in the modeling process is that swimming and leaping information specific to the species of fish found in the study are difficult to arrive at with high certainty.

This study revealed that many of the small-bodied, prairie fish species are able to successfully traverse road culverts in certain situations. However, the methods used in assessing the amount of passage at each crossing are not without their limitations. Comparing fish assemblages above and below road crossings can be an effective tool in examining the effects of barriers on a watershed scale. However, because prairie fish assemblages regularly display a longitudinal change in species composition, inferences about the consequences of culverts may be difficult.

Fish passage experiments using direct observation of active displacement were also successful in quantifying conditions that permitted passage for a variety of prairie fish species. These experiments were labor intensive and were limited to flow conditions that allowed efficient fish sampling (seining and electrofishing) and maintenance of block nets. Superimposing the field experiment results onto the FishXing model results provided a more effective quantification of the amount of time culverts were passable for prairie fish over FishXing model results alone.

Findings from fish displacement experiments revealed that all five study culverts were capable of passing the common fish species found in both Clear and Sand creeks. However, experiments were limited to certain flow conditions, and therefore the amount of passage during extreme high flow events remains unknown. All of the species examined in these experiments spawn in the spring and early summer (Brown 1971), therefore successful passage during these times could be considered critical for species continuity in upper reaches (Dodds et al. 2004). It should be noted, however, that even if critical passage times are during the spring and early summer, these extreme high flow events are usually flashy and short-lived, making up only a short portion of the hydrograph.

While the characteristics of the five culvert crossings examined in this study were generally representative of other crossings found in the region, extremes in outlet drop height and culvert slope that may occur in some regional culverts were not present in the study culverts. Cahoon et al. (2005) found a significant relationship between passage impedance and outlet drop height in a similar study examining the passage of small stream salmonids.

Although most species did not show significant passage restriction during experimentation, there were instances where longnose dace failed to pass study culverts. Crossing CC2 was a long culvert (270 m) that at low flow levels had a 5.1 cm outlet drop. Both creek chub and white sucker traversed this culvert successfully at this flow, but no longnose dace were able to pass. This finding supports the thought that different species and body types produce different swimming capabilities (Katapodis and Gervais 1991). The small vertical leap required by fish to pass in this instance likely was the reason for the restricted passage of longnose dace. However, because of the limited information on the leaping capabilities of these fish, the actual cause for restriction remains unknown.

Total body length did not appear to influence passage abilities for both creek chub and white sucker. Both species showed successful passage of fish in both length classes (≤ 80 mm and > 80 mm), with more fish passing culverts than reference reaches. These findings are consistent with those of Belford and Gould (1989), who found no relationship between body length and passibility for several trout species in western Montana. The authors of that study noted that this finding may have been the result of smaller fish utilizing lower velocities along the bottom and sides of the culverts. This finding was also described in a study from Alaska examining the passage of juvenile salmonids (Kane et al. 2000). These authors observed juvenile fish utilizing lower velocity zones to traverse the length of culvert crossings. Small fish in this study may have utilized the recessions between culvert corrugations to rest as they passed the culvert. The corrugation widths were typically greater than the length of the fish examined. Additionally, the small amounts of natural substrate that had washed into the culvert may have adding areas of lower water velocity for fish resting.

Engineers are charged with the design of culverts that meet all possible requirements (passage of design flows, fish passage, debris and ice flow management, adequate roadway presentation, public safety, structural integrity, maintainability, longevity, and others). While FishXing has been shown to be conservative when used to assess existing culverts, it may still be a valuable tool for designers. When used as part of a fish passage inclusive design process, the FishXing outcome of barrier status (no passage window) should never occur. That means that combinations c) and f) of Table 9 should never be encountered during design. Then, from a design standpoint, cases a) and b) are positive affirmation of the model, and case e) is negative. When examining an existing culvert, case d) is considered an indication that FishXing failed, but in design mode case d) actually represents bonus fish passage - fish passing the culvert that were not expected to do so. So, from a design standpoint, Table 9 indicates that in 10 of 16 cases where a passage window was predicted, using FishXing would have been a success. Case d) was the result in another 5 of those 16 cases, indicating that more fish than planned for would have passed through the culvert - also a success. In only 1 of the 16 cases would the *design* passage window have had field observations where passage was inhibited.

The FishXing model has been shown in this study and others to have shortcomings in predicting the barrier status of existing culverts. However, in this study and others, the model tends to have a high success rate for predicting passage. That is, if FishXing indicates fish will pass a culvert, field trials tend to corroborate. This conservativism is a hindrance to efforts to evaluate existing culverts, but is a desirable feature when incorporated into the design process.

Conclusions

The following specific conclusions can be drawn from this work. Readers are cautioned, however, in transferring these conclusions to settings having different species, hydrology, or culvert characteristics. Fish assemblages in the study area are very diverse, with reaches sampled ranging from 5 to 18 species detected. The presence of culverts did not significantly affect species richness - species richness was not significantly different in comparisons of samples taken upstream and downstream of culverts. The presence of culverts did not affect species abundance except that longnose dace were more abundant upstream of one culvert and fathead minnow and sand shiner were less abundant upstream of another culvert. Other than those two cases, fish abundance was not significantly different in comparisons of samples taken upstream and downstream of culverts. In direct observations of fish passage, fish movement overall through culverts was equal to or greater than movement through reference reaches. In direct observations of fish passage by species, only longnose dace were restricted in passage through the study culverts overall. Furthermore, in direct observations of fish passage, large creek chub and white suckers passed culverts equally as well as smaller fish of those species. Locally calibrated FishXing model predictions appear to be conservative, predicting smaller time (or flow) windows where passage is not restricted than were observed in field observations.

A more broad reaching conclusion is that the nature of the conservativism of FishXing is such that the model tends to predict passage very well, but often falls short as a predictor of passage barriers. This tendency, however, can be capitalized on in the design process. This study and others have shown that if FishXing indicates fish will pass a culvert, field trials tend to corroborate. FishXing can play a valuable role in the design of new or retrofitted culverts by superimposing predicted FishXing passage windows on the design hydrograph for a culvert that was designed traditionally, and iterating until a design is arrived at that meets all culvert design goals including fish passage.

Recommendations and Implementation

Three specific recommendations for implementation can be drawn from this project. First, the richness and abundance of the fish assemblages detected in the study streams reinforces the need to consider fish passage in the design of new stream crossings and the maintenance of existing stream crossing in settings having prairie fisheries. The observation that several species moved relatively freely throughout the systems studied should be interpreted as evidence that vigilance in protecting the mobility of these species should persist. Second, this study and others have shown that FishXing is a good indicator of passage success but not as strong an indicator of passage barriers. FishXing should still be used as a tool for assessing existing culverts, but only to separate culverts that need no further study (FishXing indicates passage) from culverts that should be subjected to more direct assessment of passage (FishXing indicates passage barrier). Third, the following basic process should be adopted for the design of culverts where fish passage is a concern.

1. Develop the annual hydrograph. This could be based on stream gauging, correlation with a gauged basin, or runoff estimates based on historic or synthetic rainfall. The hydrograph could be a static estimate using long term averages, or several hydrographs could be developed to better represent statistical variations in stream flow. Periods of no flow are certainly allowed in intermittent flow cases.
2. Determine the species that should be represented in the fish passage analysis. This may be based on economy of modeling effort. That is, multiple species may be deemed to have similar swimming abilities and mobility time periods, and could thus be represented by a single surrogate species. Or the selection of the model fish could be based on native versus non-native species, or overall abundance of certain species, or goals for reintroducing species that have been impaired. The size class should also be considered.
3. Examine the hydrograph and determine if there are critical time periods where passage is important. For example, some fish are known to have upstream mobility requirements for spawning activity that correspond to certain time periods or flow triggers.
4. Design the culvert to meet all goals other than fish passage using traditional means.
5. Take the design from step 4 and subject it to FishXing for a range of flows to identify the passage windows for each of the model fish selected in step 2.

6. Compare all of the passage windows from step 5 and create a composite window that has the highest allowable low flow and the lowest allowable high flow. This is the design window, and is also the most conservative passage window.

7. Superimpose the design window of step 6 onto the hydrograph of step 1. At this point there is some subjectivity. Does the design window cover a sufficient portion of the hydrograph? Does the design window indicate fish passage during the critical periods identified in step 3. If the design team concludes that the culvert is adequate, than the design proposed in step 4 is accepted. If not, the team should return to step 4 and alter the components of the design that are responsible for prohibiting passage according to FishXing (velocity, length, slope, outlet drop, etc.).

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Appendix A

Fish and Habitat Sampling Protocol for Prairie Streams

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Bob Bramblett
Assistant Research Professor
Montana Cooperative Fishery Research Unit
Department of Ecology
Montana State University
Bozeman, MT 59717

Fish and Habitat Sampling Protocol for Prairie Streams

Bob Bramblett

Montana Cooperative Fisheries Research Unit

January, 2003

1. ***Site location***.-Locate the sampling site using GPS for random sites, or by convenience for non-random sites. The GPS location will be the center of the reach, this is where you place the "F" flag (see Step 2). If the site is dry, shift the reach up or downstream to capture the most wetted channel possible on the parcel of land where you have permission for sampling.

2. ***Laying out the sample reach***.-Lay out a 300 m sample reach using a measuring tape and a set of 11 pin flags (labeled A-K). Follow the curves in the stream channel with the measuring tape; do not cut across curves. To avoid spooking fish, walk along the bank, not in the stream. Place a flag every 30 m. The "A" flag will be at the downstream end, the "K" flag will be at the upstream end of the reach. The "F" flag will go in the center of the reach.

3. ***Block nets***.-Place block nets (these can be old seines, 1/4" mesh) at the upstream (K flag) and downstream (A flag) ends of the sample reach if the water in the channel is continuous, deeper than 25 cm, and relatively clear. This prevents fish from leaving the sample reach.

4. ***Seining***.-Select the seine based on the size of the stream to be sampled. The seine length to be used should be approximately equal to or slightly greater than the stream width, and the seine height should be about 1.5 to 2 times greater than the depth of the stream. Dip nets can be used in very shallow, small habitats. Seining begins at the upstream end (K flag) and proceeds downstream to the A flag. Seining is performed by two people, one on each end of the seine. In pools, the seine is pulled down the stream channel, using the shore and other natural habitat features as barriers. Begin with the seine rolled up on each seine braille. The seine is typically set perpendicular to shore and hauled downstream parallel to shore. As you proceed, let out enough seine so that the seine forms a "U" shape, but not so much that the net is hard to control. Adjust the length of the seine by rolling or un-rolling net on the seine braille. The speed of seining should be fast enough to maintain the "U" shape, but not so fast

that the floats become submerged, or that the seine's lead line come way up off the bottom of the stream. If rocks or other snags are on the bottom, the seine can be lifted off the bottom for a moment to avoid the snag, or one of the netters can bring the seine around the snag to avoid it, all the while maintaining the forward progress of the seine. Similarly, areas of dense aquatic vegetation can be avoided. It is important not to stop the forward progress, because fish will swim out of the seine. It is better to avoid a snag while keeping moving than to become snagged, which will allow fish to escape. In "snaggy" waters, keep more of your seine rolled up for better control.

Proceed downstream while seining. In narrow streams, the entire channel width is spanned with the seine. In wider streams, one person walks along the shore, while the other wades through the channel. The length of each seine haul will depend on the natural features of the stream channel and shoreline, but seine hauls should not normally be more than 60 or 90 m long. Side channel bars or the end of a standing pool are good areas to haul out or "beach" the seine. Where a large bar or end of a standing pool is present both netters can simply run the net up on the shore. In streams with steep banks or lack of obvious seine beaching areas the "snap" technique can be used. At the end of the haul, the person near shore stops, while the person farthest out turns into shore, quickly, until the seine is up against the bank. The two netters then walk away from each other, taking the slack out of the seine, and keeping the seine's lead line up against the bank.

In riffles, with moderate to fast current, the "kick seine" technique can be used. The seine is held stationary in a "U" shape, while the other team member disturbs the substrate immediately upstream of the net. Then the net is quickly "snapped" out of the water by both team members using an upstream scooping motion.

Seine the entire 300 m reach, covering the linear distance at least once. If part of the 300 m is dry, just skip it. If the stream is much wider than your seine, do extra seine hauls in the large pools to cover the extra width. Sample all habitat types (shoreline, thalweg, side channels, backwaters).

After each seine haul, place fish in a bucket. If the water is warm, or you have captured many fish, place fish in a fish bag to keep them alive until seining is completed, or use an aerator. If you have to work up fish before seining is completed, release processed fish in an area that has already been seined, as far away from the area remaining to be seined as possible (or outside of the block nets). Large fish such as northern pike, common carp, white sucker, shorthead redhorse, or channel catfish, can be measured, given a small clip to the lower caudal fin and released immediately. Marking fish will prevent them from being counted more than once if they are captured again.

5. ***Processing captured fish***.-Record the species of each fish captured, and measure 20 "randomly" selected fish to the nearest millimeter, total length. If the species of fish is unknown, try to at least record it as Unknown type 1, Unknown type 2, etc. Keep track of and record the minimum and maximum length of each species.

   For each species, preserve a sub sample of at least 10 individuals per site to serve as voucher specimens. Record a small letter "v" next to the recorded length of the fish that is vouchered to allow for later validation. For *Hybognathus* spp., voucher up to 20 individuals per site. Kill the fish to be vouchered by placing them in a small bucket or 1000 ml nalgene jar with an overdose solution of MS-222. After fish processing is completed, drain the MS-222 solution and place the fish in a 1000 ml nalgene jar with a 10% solution of formalin (in clear water, if possible). For specimens longer than 150 mm, an incision should be made on the right ventral side of the abdomen after death, to allow fixative to enter the body cavity. The volume of formalin solution should be approximately equal to the twice the volume of fish tissue to be preserved, and the fish volume should be considered water when concentrations are determined. For example, if the fish take up 250 ml of the 1000 ml volume, you need about 500 ml of 10 % formalin solution (75 ml formalin and 425 ml water) in the 1000 ml nalgene jar. If necessary, use a second jar to accommodate all of the specimens. Use safety glasses and gloves when pouring formalin. Do not let the fish "cook" in the sun for a while and preserve them later, do it as soon as possible. Label all jars inside and out with Site, Site Number, Lat/Long, Date, Collectors names. Use pencil on Write-In-the-Rain or high rag paper for inside labels (just put the label right in with the fish), use a sticker label on the outside, cover it with clear (ScotchPad high performance packing tape pad 3750-P). Fish specimens should be left in formalin solution for at least 2-7 days. Fish specimens must have formalin solution soaked out before being handled extensively. Specimens should be soaked in water for at least 2 days, and water should be changed at least four times during this period. After soaking out the formalin, the fish specimens should be placed in either 70% ethanol or 40% isopropanol for long-term storage.

6. ***Habitat survey***.-Channel width, depth of water, and substrate will be measured at 11 transects perpendicular to the stream channel (located at Flags A-K), and along the thalweg in 10 thalweg intervals between transects (deepest part of channel). Stream width is measured to the nearest 0.1 m, depth is measured to the nearest cm, and substrate sizes and codes are on the data sheet. One person will be in the stream taking measurements while the other records data. Record the Latitude and Longitude (in digital degrees) of the F flag, the stream name, site number, the date, the flow status (flowing, continuous standing water, or interrupted standing water) and the names of the crew members on the data sheet. Take photographs of the site, capturing as much of the sampling reach as possible. Make sure the date feature on the camera is turned on, to allow for later identification of site photographs.

    Transects. - Start on the left bank (facing downstream) at Flag A. Measure and record the wetted width of the channel to the nearest 0.1 m. Measure and record (separated by a comma on the data sheet) five equally spaced depth and substrate measurements across the wetted stream channel:

    a. Left Bank-5 cm from the left bank;
    b. Left Center-halfway between the Center and the Left Bank;
    c. Center-center of the wetted stream;
    d. Right Center-halfway between the Center and the Right Bank;
    e. Right Bank-5 cm from the right bank

    Thalweg.-Begin by recording the depth and substrate 3 m upstream of the transect, in the deepest part of the channel (thalweg). Proceed up the thalweg to Flag B, recording depth and substrate every 3 m along the thalweg. You will record a total of 10 depths and substrates between each pair of transects. If the stream channel is dry, record a 0 for depth, and record the substrate. The last thalweg measurement point should fall on the next upstream transect. The 3 m interval can be estimated, and it is helpful if the data recorder helps to keep the person in the stream from “squeezing” or “stretching” the thalweg measurements.

Repeat this procedure until all 11 transects and 10 thalweg intervals are completed.

Gear List

- 20’, x 6’ x ¼” heavy delta seines
- 15’ x 4’ x ¼” heavy delta
- 30’ x 6’ x ¼” heavy delta (or delta) with 6’ x 6’ x 6’ bag
- Fish bags: nylon diver’s bags, ¼” mesh 18” x 30”
- Mudders – 109.00 at Ben Meadows
- Block nets, Tent stakes
- Stream Conductivity meter
- Thermometer
- Turbidity meter (LaMotte, Ben Meadows 224805, $795.00-might try the “”transparency tube” Ben Meadows 224196, $52.95)
- Waders (breathable waders are essential for this work-Cabelas has them for about $100/pair), hip boots are usually too low
- Lug sole wading boots (Cabelas)
- Habitat pole (I make habitat poles out of 1.0” OD PVC pipe. 1.5 m long including caps. Score the pipe every 10 cm with a pipe cutter, then use a Sharpie to mark rings around the pole at the scores, and label the pole 10, 20, 30, etc. 5 cm marks are made between the 10 cm rings, you can visually estimate between the 5 cm marks to get to the nearest cm. Spray or brush a Urethane finish on the pole or your marks will come off fast with sunscreen and bug dope.)
- Metric 30 m tape (Ace Hardware actually carries a tape with metric on one side)
- Measuring boards, one short 300 mm (half a 6” PVC works well for *Hybognathus* “fin flotation”, one long, ~0.5-1 m, or you can just use a meter stick for the odd big fish)

- Hand lens
- Small 1 gallon red bucket from Ace Hardware for doping fish
- 5 gallon buckets
- MS-222
- Labels and tape pads for fish samples
- 1000 ml Nalgene jars
- Formalin (buffered is great, but more expensive-I throw a Rolaids in each jar of fish to neutralize the acidity)
- Clip board
- 11 Pin flags labeled A-F

Appendix B

Data Collected in Regional Culvert Survey

Crossing	Site #	Creek Name	County	Type	Tnshp, Rnge, Sect	Latitude Longitude	Pipe Slope %	Crossing Description
1	1 2 3	East Fork Roberts	Wheatland	culvert	T10N,R16E,S34/35	N46°35.644' W109°41.024'	0-1	3 pipes; right pipe changes corrugation approx. 0.3 m from inlet
2	4	Big Coulee	Golden Valley	culvert	T6N,R21E,S29/30	N46°14.399' W109°08.150'	2	one metal pipe, squashed, mitered
3	5	Big Coulee	Golden Valley	culvert	T6N,R21E,S24/23	N46°15.366' W109°03.148'	2-4	one metal squash w/ concrete bottom, concrete apron
4	6	Big Coulee	Golden Valley	bridge	T6N,R22E,S15 SE	N46°15.816' W108°57.066'		bridge crossing, wide underneath, 1.2 m bank under
5	7 8	North Willow	Musselshell	culvert	T10N,R29/30E,S12/7	N46°38.876' W108°00.483'	4	2 metal pipes, circular; one smaller than other; small one eroding
6	9 10	North Willow	Musselshell	culvert	T11N,R29/30E	N46°40.844' W108°00.497'	2	2 metal pipes, circular; steel plate; concrete bottom 12.7 cm; concrete apron
7	11 12	North Willow	Musselshell	culvert	T11N,R29/30E	N46°40.995' W108°00.496'	3	2 metal pipes, circular
8	13	Crooked	Yellowstone	culvert	T2N,R27E,S2/3	N45°57.485' W108°20.575'	0-2	1 big metal pipe; circular; steel plate; mitered;
9	14	South Fork Crooked	Yellowstone	culvert	T2N,R27E,S3/4	N45°57.363' W108°21.822'	NA	2 pipes; metal CMP
	15							
10	16 17 18	Upper Seven Mile	Dawson	culvert	T16N,R53E,S3/24	N47°08.292' W104°56.706'	0-2	3 metal circular, spiral CMP, mitered
11	19	Upper Seven Mile	Dawson	bridge	T16N,R55ES,33	N47°05.735' W104°45.809'	NA	concrete bridge lower xing
12	20	Sand	Dawson	culvert	T15N,R55E,S30/19	N47°02.128' W104°47.747'	1-2	circular CMP
13	21 22 23	Sand	Dawson	culvert	T15N,R55E,S19	N47°02.421' W104°48.612'	0-1	3 metal squash; steel plate
14	24 25	Whoop Up	Dawson	culvert	T15N,R55E,S?	N47°00.585' W104°50.015'	0-1	2 metal squash with concrete apron; hwy xing
15	26 27 28	Clear	Dawson	culvert	T14N,R55E,S14/23	N46°57.740' W104°50.344'	0-1	3 metal squash arch with concrete apron, steel plate

Crossing	Site #	Pipe	Material	Length (m)	Diameter (m)	Currug. Width (cm)	Corrug. Depth (cm)	Outlet Drop (cm)	Field Notes
1	1	Right	CMP	10.67	1.798	15.24	3.81	0.0	~ 2.5 m BFW; no outlet drop @ frozen; intermittant flow
	2	Middle	CMP	12.19	1.219	5.72	1.27	0.0	
	3	Left	CMP	12.28	1.158	5.72	1.27	0.0	
2	4		CMP	19.81	2.89 x 1.83	7.62	2.54	12.7	~ 2.1 m BFW; H2O in pipe is 5 cm; 12.7 cm outlet drop; flow underneath pipe; lots of bank erosion, tall bank walls; erosion around pipe; rock rip-rap; large scour hole; good stream morph
3	5		CMP	25.30	2.89 x 1.83	7.62	2.54	15.2	~ 2.7 m BFW; good H2O flow; more confined than last; lots of bank erosion; good morph
4	6								~ 2.7 m BFW; natural x-ing
5	7	Right	CMP	18.29	2.225	6.35	1.27	152.4	appears to be barrier; perched 1.5 m; dry with frozen pool at outlet
	8	Left	CMP	18.59	1.829	6.35	1.27	152.4	
6	9	Right	CMP	22.25	1.753	15.24	5.08	76.2	dry with small frozen pool at outlet; dead cow in pool; 0.8 m drop due to broken conrete
	10	Left	CMP	22.56	1.600	15.24	5.08	76.2	
7	11	Right	CMP	19.20	1.524	7.62	2.54	76.2	dry with small pool; several frozen small dead carp; wide stream with 1.2 m banks; 76 cm outlet drop, talked to rancher that owns land at the end of the road and he said stream is dry except one week of the year in early spring, ran year round in '93 and flooded 4 spots over road in '92 with #3C blowing out
	12	Left	CMP	18.29	1.524	7.62	2.54	76.2	
8	13		SSP	20.42	4.267	15.24	5.08	0.0	~ est. q = 0.11 cms, ~ 3.05 m BFW; sediment in pipe; good flow with lots of water; no drop; 15 cm water depth in pipe; good fish population; private land
9	14	Right	CMP	12.50	0.762	7.62	1.27	0.0	Right pipe undercut @inlet; more flow in left; H2O in both; no drop; difference in up & downstream features; good for land use example; cattle
	15	Left	CMP	12.50	0.762	7.62	1.27	0.0	
10	16	Right	CMP	19.81	1.524	7.62	2.54	5.1	private land; no def. banks; scour pool w/ H20 below; tall banks; could be big flow
	17	Middle	CMP	19.81	1.524	7.62	2.54	5.1	
	18	Left	CMP	19.81	1.524	7.62	2.54	5.1	
11	19				0	0.00	0.00		~ 3.4 m BFW; flowing H2O; more confined; good stream morph
12	20		CMP	20.73	2.591	7.62	2.54	0.0	good flow; no outlet drop; overflow pipe up river left-no H2O; 2 roosters found
13	21	Right	SSP	73.15	3.05 x 2.13	15.24	5.08	0.0	stream moves over cable tie blocks before smooth concrete apron; left pipe has asphalt in it
	22	Middle	SSP	73.15	3.05 x 2.13	15.24	5.08	0.0	
	23	Left	SSP	73.15	3.05 x 2.13	15.24	5.08	0.0	
14	24	Right	SSP	91.44	3.51 x 2.13	15.24	5.08	0.0	no flow; substrate in pipe
	25	Left	SSP	91.44	3.51 x 2.13	15.24	5.08	0.0	
15	26	Right	SSP	20.73	3.35 x 2.13	15.24	5.08	0.0	~ 3.4 m BFW; private land; good flow; stream diverting; ~ 0.1 cms; substrate all the way through; overflow pipe100 m downstream
	27	Middle	SSP	20.73	3.35 x 2.13	15.24	5.08	0.0	
	28	Left	SSP	20.73	3.35 x 2.13	15.24	5.08	0.0	

Crossing	Site #	Creek Name	County	Type	Tnshp, Rnge, Sect	Latitude Longitude	Pipe Slope %	Crossing Description
16	29 30 31	Clear	Dawson	culvert	T14N,R54E,S11 SW	N46°58.559' W104°51.449'	0-1	3 metal squash ; steel plate
17	32 33 34	Cracker Box	Dawson	culvert	T14N,R54E,S31	N46°55.458' W104°56.108'	0-2	3 metal circular CMP, mitered
18	35 36 37	Cracker Box	Dawson	culvert	T14N,R53E,S25 and T14N,R54E,S30	N46°56.073' W104°56.471'	0-2	3 metal squash; steel plate; concrete apron; mitered; sheet pile wall
19	38	Krug	Dawson	culvert	T15N,R58E,S20/21	N47°02.214' W104°23.445'	0-2	1 metal round CMP
20	39	Krug	Dawson	culvert	T15N,R58E,S22	N47°02.147' W104°21.466'	0-1	concrete box
21	40 41 42	Beaver	Wibaux	LWF	T14N,R59E,S22	N46°56.858' W104°10.914'	NA	3 metal rusted pipes; low water ford; water under and between; concrete above and eroding. Spiral CMP
22	43 44	Beaver	Wibaux	LWF	T13N,R59E,S24/25	N46°51.614' W104°10.824'	NA	2 metal; low water ford; with concrete; left is rusted
23	45 46	Beaver	Wibaux	LWF	T12N,R60E,S6/7	N46°48.944' W104°13.027'	NA	2 metal corroding with concrete;
24	47 48	Beaver	Wibaux	LWF	T12N,R60E,S19/30	N46°46.338' W104°13.304'	NA	2 metal pipes 6' apart; low water ford; concrete and broken; rusting pipes
25	49	Beaver	Wibaux	LWF	T11N,R59E,S13	N46°42.531' W104°14.029'	NA	possibly 2; ice jams & debris; concrete broken and overtop opening
26	50	Beaver	Wibaux	LWF	T10N,R60E,S25/36	N46°35.045' W104°06.347'	NA	1 metal pipe showing; low H2O ford
27	51 52	O'Fallon	Fallon	culvert	T5N,R56E,S17	N46°11.096' W104°43.957'	0-2	2 metal circular; huge; mitered; steel plate
28	53	O'Fallon	Fallon	culvert	T3N,R56E,S8	N46°01.885' W104°47.751'	0-2	1 metal circular CMP
29	54 55	Armelles	Rosebud	culvert	T3N,R41E,S28	N45°58.696' W106°38.656'	0-2	2 pipes: 1 bigger, 1 smaller; both spiral CMP
30	56	Reservation	Rosebud	culvert	T4N,R39E,S19	N46°04.761' W106°56.353'	NA	1 pipe CMP
31	57	Reservation	Rosebud	culvert	T4N,R39E,S18 or 19	N46°05.612' W106°56.115'	0-2	1 metal pipe; steel plate
32	58	Reservation	Rosebud	culvert	T4N,R39E,S18 or 19	N46°05.851' W106°56.009'	1	1 pipe CMP
33	59	Reservation	Rosebud	culvert	T6N,R38E,S35	N46°13.733' W106°56.618'	1-2	1 pipe spiral CMP
34	60	Reservation	Rosebud	culvert	T6N,R38E,S23	N46°15.482' W106°56.093'	NA	2 pipes; Right is steel plate, Left is CMP

Crossing	Site #	Pipe	Material	Length (m)	Diameter (m)	Currug. Width (cm)	Corrug. Depth (cm)	Outlet Drop (cm)	Field Notes
16	29	Right	SSP	73.15	4.57 x 3.05	15.24	5.08	0.0	very little flow; downstream good flow; overflow pipe 30 m down; cab lets blocks below river; downstrm flow good 45 m
	30	Middle	SSP	73.15	4.57 x 3.05	15.24	5.08	0.0	
	31	Left	SSP	73.15	4.57 x 3.05	15.24	5.08	0.0	
17	32	Right	CMP	27.43	2.438	12.70	2.54	0.0	~ 3.7 m BFW; private land; rip rap present; good flow; perennial; ice in pipe; no outlet drop; L.S. has seen fish in it
	33	Middle	CMP	27.43	2.438	12.70	2.54	0.0	
	34	Left	CMP	27.43	2.438	12.70	2.54	0.0	
18	35	Right	SSP	73.15	3.35 x 2.13	15.24	5.08	91.4	good flow; huge barrier; 3 m drop; lots of good habitat below
	36	Middle	SSP	73.15	3.35 x 2.13	15.24	5.08	91.4	
	37	Left	SSP	73.15	3.35 x 2.13	15.24	5.08	91.4	
19	38		CMP	12.28	2.073	7.62	2.54	0.0	no drop; no H2O flow-ice; not real confined
20	39		Conc	82.30	3.05 x 2.74			0.0	~ 4.6 m BFW; rock rip-rap; good flow; no restriction; H2O in culvert; little H2O flow below
21	40	Right	CMP	6.10	0.457	7.62	2.54	0.0	all off hwy 7 on side roads
	41	Middle	CMP	6.10	0.457	7.62	2.54	0.0	
	42	Left	CMP	6.10	0.457	7.62	2.54	0.0	
22	43	Right	CMP	14.78	0.533	7.62	1.27	15.2	~ 4.6 m BFW; substrate in pipes; 15 cm outlet drop onto concrete;
	44	Left	CMP	14.17	0.533	7.62	1.27	0.0	
23	45	Right	CMP	7.13	0.610	7.62	1.27	0.0	~ 5 m BFW; flow below; no drop; minnow trap in outlet pool
	46	Left	CMP	7.13	0.610	7.62	1.27	0.0	
24	47	Right	CMP	7.32	0.710	7.62	1.27	0.0	~ 5 m BFW; high banks; debris in drainage; good flow
	48	Left	CMP	7.32	0.710	7.62	1.27	0.0	
25	49		CMP						no access - ice jams and debris
26	50		CMP	6.86	0.610	7.62	1.27	0.0	~ 3 m BFW; H2O over road due to pipes over road; bid river; ice w/ small flow; huge hole above;
27	51	Right	SSP	21.34	3.353	15.24	5.08	0.0	~ 3.5 m BFW; H2O flow; ice; no drop; steel pipe
	52	Left	SSP	21.34	3.353	15.24	5.08	0.0	
28	53		CMP	21.34	1.737	7.62	1.27	0.0	~ 5.3 m BFW; no drop; wide stream bed; frozen; .6 m of frozen H2O in pipe
29	54	Right	CMP	18.29	2.59 x 1.98	7.62	1.27	0.0	ice in both pipes; 3.8 m BFW; marshy w/cattails
	55	Left	CMP	18.29	1.829	7.62	1.27	0.0	
30	56		CMP	7.32	0.610	7.62	1.27	0.0	hard to say if Reservation Creek will flow H2O this year; cattle activity, no H2O
31	57		SSP	14.02	1.219	7.62	1.27	0.0	no outlet drop; no H2O; several other Xings as you move downstream
32	58		CMP	16.46	1.067	6.35	0.64	7.6	steep outlet drop (~ 1 m) w/deep scour hole; no H2O
33	59		CMP	18.59	2.743	12.70	2.54	45.7	0.4 m outlet drop w/big scour pool; H2O in scour pool and above Xing; drop probably won't be an issue when H2O level increases
34	60		SSP		1.524	7.62	2.54	0.0	no outlet drop; Left pipe has H2O (ice); several more bridges downstream before Reservation Creek meets the Yellowstone

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