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Bull Trout Passage at Beaver Dams in Two Montana Streams

Running footer: Trout Passage at Beaver Dams

1 Table, 3 Figures, Supplementary Materials: 1 Table, 1 Figure, available online only

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Abstract

Beaver (*Castor canadensis*) translocation and mimicry is an increasingly popular set of tools for process-based restoration of degraded streams. Previous studies indicate that spring-spawning salmonid fishes can pass beaver dams in higher proportions than fall-spawning species. Thus, restoration or mimicry of beavers in streams containing threatened, fall-spawning bull trout (*Salvelinus confluentus*) is of concern to many biologists. We evaluated bull trout passage at beaver dams in two Montana streams: Meadow Creek (East Fork Bitterroot River drainage) in summer 2020 and Morrison Creek (Middle Fork Flathead River drainage) from 1997 to 2011. In Meadow Creek, 16% of PIT-tagged bull trout which entered a large beaver dam complex were detected upstream of some dams, but no fish moved through the entire 1 km complex. The redds in Morison Creek occurred below beaver dams in higher proportion than if random spawning-site selection had occurred. Redds were found above some beaver dams during all 9 years dams were present. These results suggest that beaver dams can affect the movement of bull trout and that passage depends on the characteristics of individual dams and reach geomorphology, though our methods cannot distinguish between inhibition of fish movement and selection of beaver-created habitats by fish due to the limited data we had on spawning habitat. Therefore, we suggest future beaver restoration in streams with bull trout be carefully monitored and conducted in an adaptive framework. Comparing spawning-site selection and fish movement in streams with and without beavers may provide additional information.

Keywords: Ecosystem engineer, fish passage, redds, threatened species, charr

Introduction

Beaver (*Castor* spp.) dams have profound impacts on stream habitats (Westbrook et al. 2011, Levine and Meyer 2019) including increasing late-season water flow (Nyssen et al. 2011, Majerova et al. 2015), increasing resiliency to wildfires (Fairfax and Whittle 2020), and creating habitat for native co-occurring species (Cook 1940, Rosell et al. 2005). Simultaneously, in some systems they can interfere with infrastructure (Albert and Trimble 2000) and provide habitat that can be beneficial for non-native fishes (Gibson et al. 2015). Historical removal of beavers from across North America, and a growing recognition of the benefits they provide, has led to a dramatic upswing in the use of beaver restoration and mimicry to restore degraded ecosystems (McKinstry and Anderson 2002, Pilliod et al. 2018, Wheaton et al. 2019). Beaver dam analogs (BDAs) are being widely deployed to aggrade streams and improve habitat for beaver recolonization in systems where beaver extirpation has occurred (Pollock et al 2014, Pilliod et al. 2018). Most salmonids in North America and Europe co-evolved with beavers, and beaver dams have many direct, positive impacts on salmonids including creation of high-quality habitat for adults and juveniles (Cook 1940, White and Rahel 2008), providing thermal refuge during warm summer months (Weber et al. 2017), and providing anchor-ice-free winter refuges (Jakober et al. 1998, Lindstrom and Hubert 2004). However, beaver dams are known to impede salmonid movement under some circumstances (DuPont et al. 2007, Lokteff et al. 2013), and the extent to which this occurs, especially during spawning migration, is of particular interest to fish biologists (Kemp et al. 2012). If beaver dams impede salmonid movement during critical life-history periods, special consideration may be needed for streams with threatened salmonids for which short-term recruitment is just as critical as long-term habitat restoration.

Several previous studies have examined salmonid passage at beaver dams. In northern Utah, native Bonneville Cutthroat Trout (*Oncorhynchus clarkii utah*) passed beaver dams more effectively than non-native Brown Trout (*Salmo trutta*) or Brook Trout (*Salvelinus fontinalis*) (Lokteff et al. 2013). Adult and juvenile steelhead (*O. mykiss*) were unhindered by beaver dams and BDAs in northeastern Oregon (Bouwes et al. 2016), and native Arctic Grayling (*Thymallus arcticus*) in southwestern Montana passed beaver dams successfully on 88% of their attempts (Cutting et al. 2018). However, Cutthroat Trout, steelhead, and Arctic Grayling all spawn in the spring when streamflow is near its yearly maximum in the Western US, and thus passage at channel-spanning structures is most probable. Indeed, studies of fall-spawning Atlantic Salmon (*Salmo salar*) have found occasional-to-frequent blockage of upstream movement by beaver dams in New Brunswick (Mitchell and Cunjack 2007) and Nova Scotia where passage varied predictably with total autumn precipitation (Taylor et al. 2010). Similarly, redd counts of Sea Trout (*S. trutta trutta*) in Lithuania were greater in 500 m reaches below large beaver dams than above, whereas in streams with only smaller River Trout (*S. trutta fario*), redds were distributed almost evenly above and below smaller, less intact dams (Kesminas et al. 2013). In a series of passage experiments in a northern California creek, juvenile Coho Salmon (*O. kisutch*) passed two BDAs in high proportions during two out of three experiments but low proportions in the third (Pollock et al. 2022). A related study found passage of juvenile Coho Salmon at BDAs in northern California to vary seasonally with streamflow levels (O'Keefe 2021).

Bull trout (*Salvelinus confluentus*) are coldwater specialists and fall spawners that have been listed as a threatened species under the Endangered Species Act in the United States since 1998 (USFWS 1998). Primary causes of decline are habitat degradation, invasive species, warming water temperatures, and stream fragmentation due to dams, diversions, and dewatering (Rieman and McIntyre 1993, Nelson et al. 2002, Al-Chokhachy et al. 2016). Bull trout abundances have substantially declined throughout their range and, in western Montana, most river basins that once contained large-bodied migratory individuals now contain only isolated, headwater-resident populations (MBTSG 1995). Within Montana drainages, only the upper Flathead and upper Kootenai River basins still contain relatively abundant populations of migratory bull trout (Kovach et al. 2018). Due to these range-wide declines, further fragmentation of bull trout populations by channel-spanning structures such as beaver dams is of great concern. To help determine if process-based restoration utilizing beaver translocation or mimicry is viable for usage in streams with bull trout, we examined bull trout passage at natural beaver dams in tributaries to the East Fork Bitterroot River and Middle Fork Flathead River.

Methods

Study Area

Meadow Creek is a third-order tributary of the East Fork Bitterroot River in the Sapphire Mountains of western Montana (Figure 1) with an estimated average baseflow at the project area near 0.1 $m^3 \cdot s^{-1}$ with average peak flows estimated at about 0.71 $m^3 \cdot s^{-1}$ (McCarthy et al. 2016). A large beaver dam complex approximately 1 km long is located at stream km 6.4 (45°52′00.1″N, 113°48′09.9″W, with stream kms measured from the confluence with the East Fork of the Bitterroot River). Morrison Creek is a third-order tributary to the Middle Fork Flathead River (Figure 1) with an estimated average baseflow of 0.71 $m^3 \cdot s^{-1}$ and average peak flow greater than 8.5 $m^3 \cdot s^{-1}$ (McCarthy et al. 2016).

Both creeks contain stable bull trout populations with a proportion of the population expressing a fluvial (Meadow Creek) or adfluvial (Morrison Creek) life history, necessitating they migrate 10s to 100s of kilometers to their spawning habitat in these systems (MTBSG 1995, MBTRT

2000). Resident bull trout also exist in both creeks. Migration to upstream spawning grounds typically takes place in June–August, with variations in exact timing by year, sub-basin, and fish size (Rieman and McIntyre 1995, Swanberg 1997, Paragamian and Walters 2011).

Meadow Creek PIT Tag Study

On 21 July 2020, we installed a battery-powered, submersible passive integrated transponder (PIT) tag antenna system (Biomark©, Boise, ID) on the upstream and downstream ends of the Meadow Creek beaver dam complex (Figure 1). We placed rocks around the antennas to force PIT-tagged trout to swim close enough to the antenna to be recorded. In the three days following installation, we captured 49 bull trout via backpack electrofishing (LR-24 Backpack Shocker, SmithRoot©, Vancouver, WA) in and above the beaver dam complex. We implanted 37 individuals larger than 100 mm with a 12 mm, uniquely coded PIT tag (Biomark© Model HDX12) and released fish immediately below the downstream antenna. Antenna batteries were replaced bi-weekly to ensure continuous antenna operation until they were removed on 01 October. We chose start and end dates based on a telemetry study in nearby Skalkaho Creek that found the vast majority of upstream bull trout spawning runs occurred between late July and September (Clancy 2017).

At study completion, we surveyed the entire beaver dam complex with a mobile PIT tag antenna (Biomark© BP Plus Portable Antenna) which recorded the location and tag number of all detected fish as we waded through the water in a similar manner to electrofishing. At that time, we also censused beaver dams in the complex by recording the locations, condition, crest heights, and jump heights following the Hafen et al. (2020) beaver dam rapid assessment method. We calculated a pool depth-to-jump height ratio (i.e., ratio = pool depth/jump height; hereafter pool-to-jump ratio) for each dam (Stuart 1964, Kondratieff and Myrick 2006). Aerial imagery was acquired with a drone (DJI, Shenzhen, China) and we used this imagery to delineate dam crests in ArcGIS Pro (ESRI, Redlands CA, USA).

Morrison Creek Redd Counts

Standardized bull trout redd counts have occurred in the Middle Fork Flathead River tributaries since 1979 and serve as an index of bull trout abundance in the watershed (Shepard and Graham 1982). In most years, trained redd surveyors walk Morrison Creek (typically upstream to down) for 13.8 km. Stream kilometer 16.9 (48°12′53.8″N, 113°17′31.8″W) to 3.1 (48°06′55.7″N, 113°16′53.7″W), with kms measured from confluence with the Middle Fork of the Flathead River) were surveyed most years. During "basin-wide survey" years a longer reach was surveyed, from stream kilometer 20.1 (48°13′12.0″N, 113°16′29.5″W) to 3.1 (17.0 km total). Using archived 1997 to 2011 field notes, we converted recorded pace counts of each redd and beaver dam location to approximate stream kilometer; we used year-specific pace-to-kilometer conversions by dividing total paces in a given year by the known kilometers surveyed. We were able to convert 11 years in this way. Beavers were trapped out of Morrison Creek in 2010 due to concerns regarding trout passage and several dams were breached in the study area.

To determine if redd locations were randomly distributed below beaver dams, we randomly drew the same number of locations as redds present for that year from a number line representing 1-m stream increments of the survey reach (Supplementary Figure S1 available online only). For both real redds and randomly selected locations, we calculated the distance downstream from a beaver dam, which were negative if upstream of all dams. We then compared the distribution of real redds and random locations across all years using two Kolmogorov-Smirnov tests to determine if the real redd locations were randomly distributed. The first test was for random distribution with respect to distance downstream from a dam. The second test was for random distribution with respect to stream meters along our survey reach. We ran two-sided Kolmogorov-Smirnov tests with α set at 0.05 to test the null hypothesis that both samples were drawn from the same distribution (Conover 1972). All analyses were conducted in the program R (R Core Team 2022).

Results

Meadow Creek PIT Tag Study

The mean length of the 37 tagged fish was 155.5 ± 49.3 mm (mean ± standard deviation), and 6 fish were larger than 200 mm (Figure 2). We detected 18 (48.6%) of the bull trout at the downstream antenna (Figure 2). Within 8 days of tagging (by 29 July 2020), 9 fish had passed the lower PIT tag antenna. The remaining 9 fish were detected at a relatively steady rate over the next two weeks with the final new detection occurring on 13 August. No fish were detected at the lower antenna between 14 September and when it was removed on 01 October. Of the six > 200 mm fish tagged, 4 (66.7%) were detected at the lower antenna while 14 of the 31 (45.2%) fish under 200 mm were detected there (Figure 2). No fish were detected at the upstream antenna.

Three fish with lengths of 117, 107, and 131 mm were detected with the mobile PIT antenna on 01 October. Two of these fish were detected above several secondary dams (maximum jump height of 0.5 m, Figure 1: fish #1 and #2) and the other fish was detected just above the first primary dam (jump height 0.5 m, Figure 1: fish # 3). The mean pool-to-jump ratio of these dams was 1.40 ± 0.91 (±1 SD) with a range of 0.5 to 2.5 (Supplemental Table S1 available online only).

We recorded 35 beaver dams along the 1 km study reach of Meadow Creek (Supplemental Table S1). Of these dams, 3 (8.6%) were primary dams creating a pond with a beaver lodge or food cache, 27 (77.1%) were intact secondary dams, and 5 (14.3%) were blown out or breached. Crest and jump heights of primary dams were 1.20 ± 0.17 m (mean ± SD) and 0.82 ± 0.30 m, respectively. Secondary dams had crest heights of 0.74 ± 0.28 m with jump heights of 0.38 ± 0.27 m. The maximum observed jump height was 1.1 m. Along the lateral margins of all 3 primary dams, we identified side channels with lower jump heights than the primary dam crest, which may have served as alternative routes for upstream fish movement (Figure 1, see side channels).

Morrison Creek Redd Counts

Of the 11 years we analyzed (1997, 1998, 2002–2005, 2007–2011), only in 1998 and 2011 (2011 was the year after beavers were trapped) were no beaver dams recorded within the Morrison Creek study area (Figure 3). During this time period, the monitoring reach averaged 28.7 ± 12.7 redds (±1 SD). In every year except 1998, the majority of bull trout redds were located in the lower half of the study area, below stream kilometer 9.3 (48°9′3.4992″N, 113°15′35.46″W). During the 9 years with beaver dams, multiple redds were found that required fish to pass two or more dams, except in 2003 and 2004. In those 2 years, there was a single redd that would require multiple dam passage and they had the lowest redd counts of the dataset (10 and 14 respectively; Figure 3, Table 1). In 6 of the 9 years with beaver dams, the majority of redds were downstream of all beaver dams (i.e., not above any dam; Table 1). No redds were recorded above the upper-most dam in 7 of the 9 years with dams (Figure 3, Table 1). Across all years, while an average of 14% of the survey reach was half a kilometer or less below a beaver dam, 39% of redds were half a kilometer or less below a dam. A Kolmogorov-Smirnov (K-S) test on the distance downstream from a dam showed that observed redds were not drawn from the same distribution as the random locations ($D = 0.16$, $P = 0.0013$). A second K-S test comparing stream meter locations revealed that the observed redds were not randomly located within the stream (D = 0.28, $P < 0.0001$).

Discussion

Given that no bull trout passed all dams in Meadow Creek and redd locations in Morrison Creek were more likely than random to be immediately downstream of dams, we surmise that beaver dams affect the movement and spawning locations of bull trout. We are unable to determine if this is a result of impairment of upstream migration or selection of downstream habitats. For example, in 2011 after beaver dams were breached in Morrison Creek, bull trout still spawned at high densities within the same reaches that were previously below beaver dams even though they were newly passable (Figure 3). Differentiating between blockage and selection is further complicated by the fact that bull trout prefer redd locations with active hyporheic exchange (Baxter and Hauer 2000), and beaver dam complexes increase the magnitude and extent of groundwater-surface water interactions (Westbrook et al. 2006, Weber et al. 2017).

Our results are similar to a report from northern British Columbia that found bull trout redds both above and below beaver dams up to 1.5 m in height on three different creeks; passage at those dams, like at the ones reported here, appeared to vary yearly and seasonally based on flow conditions and dam morphology (Bustard 2017). Only a well-designed experiment in combination with laboratory studies could determine if bull trout are impaired from upstream migration or are selecting downstream habitats created by dams in the form of pools, hyporheic flow paths, or spawning gravels. It is likely that both impairment and selection occur simultaneously, similar to the manner in which beaver dams both create suitable rearing habitat for bull trout (Jakober et al. 1998) while delaying or halting downstream migrations of adults in low-flow conditions (DuPont et al. 2007).

Laboratory studies found that a pool-to-jump ratio of approximately 0.8 is ideal for salmon and trout (Stuart 1964). Our case study generally corroborates this number for bull trout, with passage detected at dams with pool-to-jump ratios between 0.5 and 2.5 (Supplementary Table S1). Specific estimates of optimal pool-to-jump ratios or maximum jump heights of bull trout have not been calculated, to our knowledge. Two primary dams in Meadow Creek did not have any passage detected. Their observed pool-to-jump ratios were 0.27 and 0.29, much lower than other dams we observed passage at, or the 0.8 optimal estimate. This indicates they would likely be difficult for bull trout to pass. Side channels along both of these primary dams provided smaller jump heights (minimum of 0.23 m and 0.15 m) but similar pool-to-jump ratios (0.20 and 0.35). Laboratory studies of closely related Brook Trout jumping mechanics indicate pool-to-jump ratios are much less important for fish larger than 200 mm attempting short jumps of < 20 cm (Kondratieff and Myrick 2006). Several studies have also observed salmonids swimming directly through or around (via small rivulets) beaver dams (Lokteff et al. 2013, Cutting et al. 2018, Pollock et al. 2022). It is likely that bull trout in both Meadow and Morrison Creeks would need to go over or through some beaver dams to create the observed recapture histories and redd locations found in this study.

The exact timing of bull trout migration and spawning varies by location, year, and fish size (Rieman and McIntyre 1993, 1995; Swanberg 1997). Bull trout in the East Fork Bitterroot River typically spawn in September (Jakober et al. 1998, Nyce 2011) but have been observed spawning as early as the end of August (Mike Jakober, US Forest Service, personal communication). Within Meadow Creek, a tributary to the East Fork, 80% of the bull trout detections at the lower antenna occurred prior to 17 August, a pattern similar to fish in nearby Skalkaho Creek (Clancy 2017). Bull trout in other Montana rivers have been observed making spawning movements from

May through September, with long-distance migratory fish moving earlier than resident fish (Fraley and Shepard 1989, Swanberg 1997, Paragamian and Walters 2011). Differences in movement timing, life histories, annual stream hydrology, and floodplain connectivity (e.g., overflow and side channels) could lead to varying passage rates at beaver dams for bull trout across individual dams, streams, and years.

Further research on bull trout passage at beaver dams is necessary. It is possible placement of the upstream PIT tag antenna closer to the halfway point of the Meadow Creek beaver complex would be better for detecting fish that had passed lower dams but remained within the complex for spawning, overwintering, or both. We have several lines of evidence for spawning activities taking place within the beaver dam complex. Yearly redd counts conducted within our study reach by the US Forest Service indicate some passage of beaver dams by migratory bull trout in recent years (Mike Jakober, US Forest Service, personal communication). During electrofishing, we captured one potentially fluvial fish (migrant from the East Fork Bitterroot) that was 347 mm total length from within the beaver complex. During our mobile PIT tag detection efforts in October 2020, we observed several large-bodied bull trout in the 300–400 mm range behind the two upstream-most primary dams that were not observed during our initial electrofishing in July 2020. However, the complexity of multiple channel braids within the beaver dam complex and our limited number of PIT tag antennas prevented us from using a mid-complex antenna approach. Detection of fish within the complex was likely underreported by the mobile PIT tag antenna because it is not ideal for use in streams as large and deep as beaver-influenced Meadow Creek. Future studies using this mobile antenna method could consider combining it with electrofishing to enhance recapture probabilities.

Based on the two case-studies we highlighted in tributaries to the East Fork Bitterroot and Middle Fork Flathead Rivers, we suggest beaver restoration and mimicry within bull trout streams be implemented in an adaptive framework with frequent monitoring. Restoration efforts should endeavor to reconnect the stream with its floodplain (i.e., be built so as to create flooding or side channels around the dam), not only to maximize the restoration benefits (Burchsted et al. 2010, Pollock et al. 2014), but to also create multiple passage routes for fish species (Lokteff et al. 2013, Bouwes et al. 2016, Cutting et al. 2018). If maximizing the stream length available to spawning bull trout is the top management concern, we recommend seasonal notching of beaver dams that have jump heights greater than 0.6 m, pool-to-jump ratios less than 0.8, and no side channel routes (Bustard 2017). This will promote increased passage (Taylor et al. 2010) while maintaining benefits for juvenile growth and development during the following spring and summer (White and Rahel 2008, Bouwes et al. 2016).

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Figure Captions

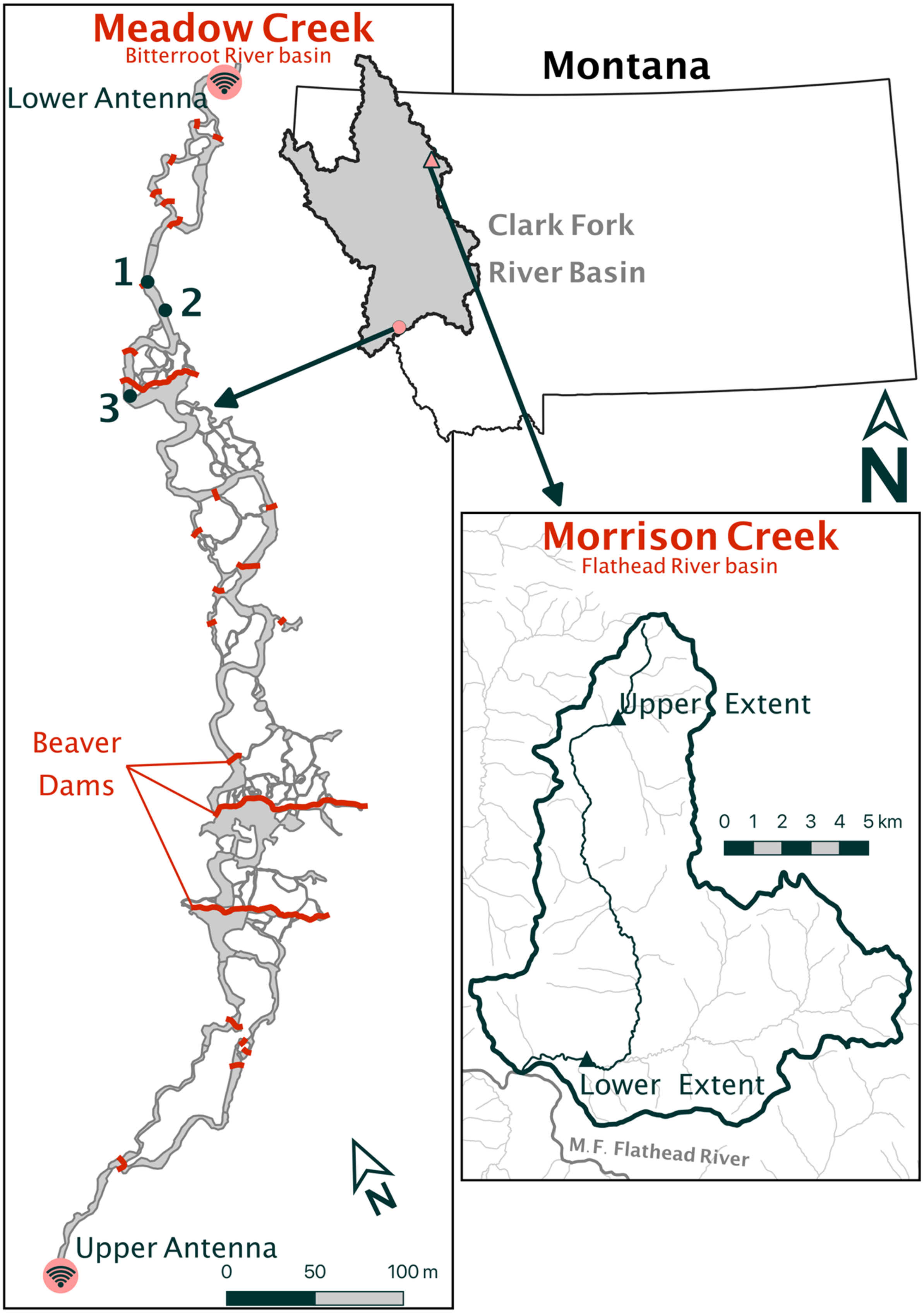
Meadow Creek
Bitterroot River basin
Lower Antenna
1
2
3
Beaver
Dams
Upper Antenna
0
50
100 m
N
Montana
Clark Fork
River Basin
N
Morrison Creek
Flathead River basin
Upper Extent
0 1 2 3 4 5 km
Lower Extent
M.F. Flathead River

Figure 1. Study sites within the Clark Fork River basin. The left side displays locations of the beaver dams, PIT tag antennas, and fish detected with the mobile PIT tag reader (numbers 1–3 correspond to fish descriptions in results section) at Meadow Creek, East Fork Bitterroot River, MT. Right side displays the redd survey extents within Morrison Creek, Middle Fork Flathead River, MT.

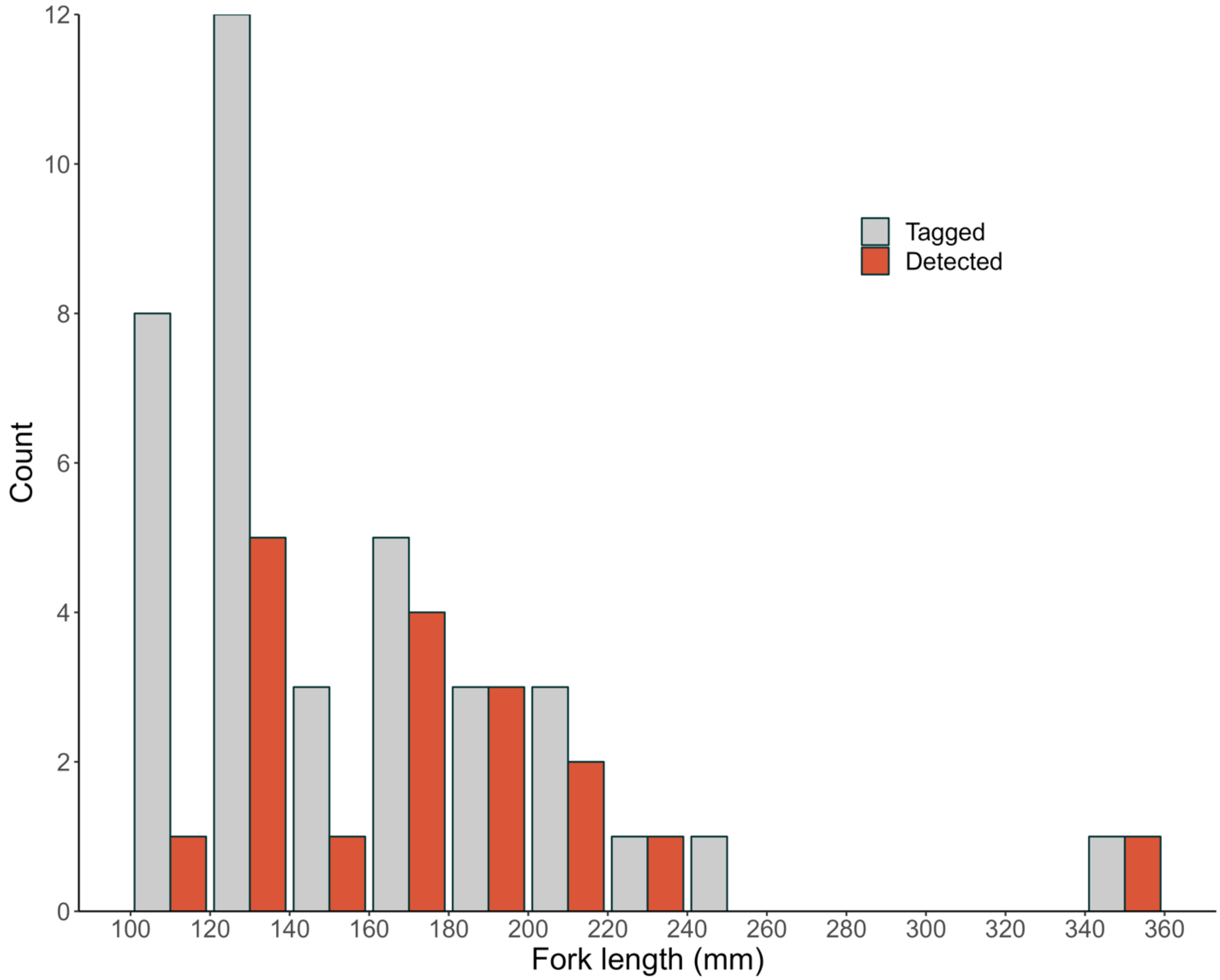

Figure 2. Length distribution of bull trout caught, PIT tagged, and released below the lower antenna in grey along with those detected by the lower antenna in red.

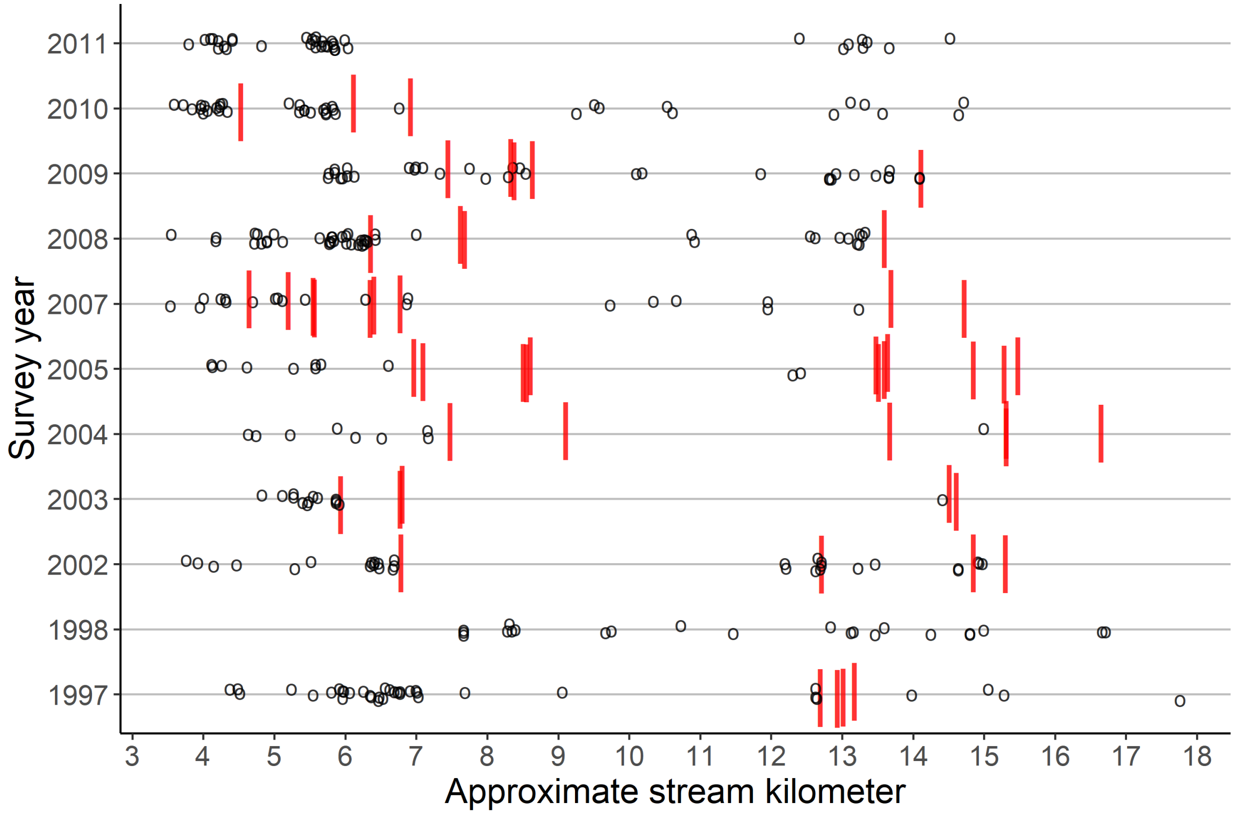

Figure 3. Morrison Creek redd counts (streamflow is from right to left on the x-axis), Flathead River basin, Montana, 1997–2011. Years included are those in which pace counts could be converted to stream kilometers. Red lines indicate locations of beaver dams and circles indicate bull trout redds. Stream kilometers proceed upstream. Both redds and dams are offset on the vertical axis by a small amount to enhance visibility of features in close proximity.

Tables

TABLE 1. Location of bull trout redds in proximity to beaver dams during each of the 1997–2011 redd count surveys in Morrison Creek, Middle Fork Flathead River basin. Numbers in parentheses refer to yearly proportion. "Immediately below dam" refers to redds 0.5 kilometers below beaver dams. Number of redds above km 9.3 (stream kilometer 9.3) is provided as an index of the spread of redds.

Year	Beaver dams*	Number of redds					
		Reach proportion immediately below dam	Immediately below dam	Above all dams	Below all dams	Above km 9.3	Total
2011	0	0	0	No dams	No dams	9 (0.23)	39
2010	3	0.11	16 (0.37)	12 (0.28)	17 (0.40)	11 (0.26)	43
2009	5	0.13	13 (0.38)	0	14 (0.41)	14 (0.41)	34
2008	4	0.11	18 (0.39)	0	31 (0.67)	12 (0.26)	46
2007	9	0.27	11 (0.52)	0	7 (0.33)	6 (0.29)	21

2005	12	0.22	1 (0.07)	0	13 (0.87)	2 (0.13)	15
2004	6	0.18	4 (0.40)	0	9 (0.90)	1 (0.10)	10
2003	5	0.10	9 (0.64)	0	13 (0.93)	1 (0.07)	14
2002	4	0.14	19 (0.61)	0	17 (0.55)	14 (0.45)	31
1998	0	0	0	No dams	No dams	16 (0.70)	23
1997	4	0.06	4 (0.10)	4 (0.10)	36 (0.9)	8 (0.20)	40

*Beaver dams were recorded both individually and as a complex and the number of dams each year should be viewed as an index.

Supplementary Materials
Bull Trout Passage at Beaver Dams in Two Montana Streams

J. Marshall Wolf, Niall G. Clancy, and Leo R. Rosenthal

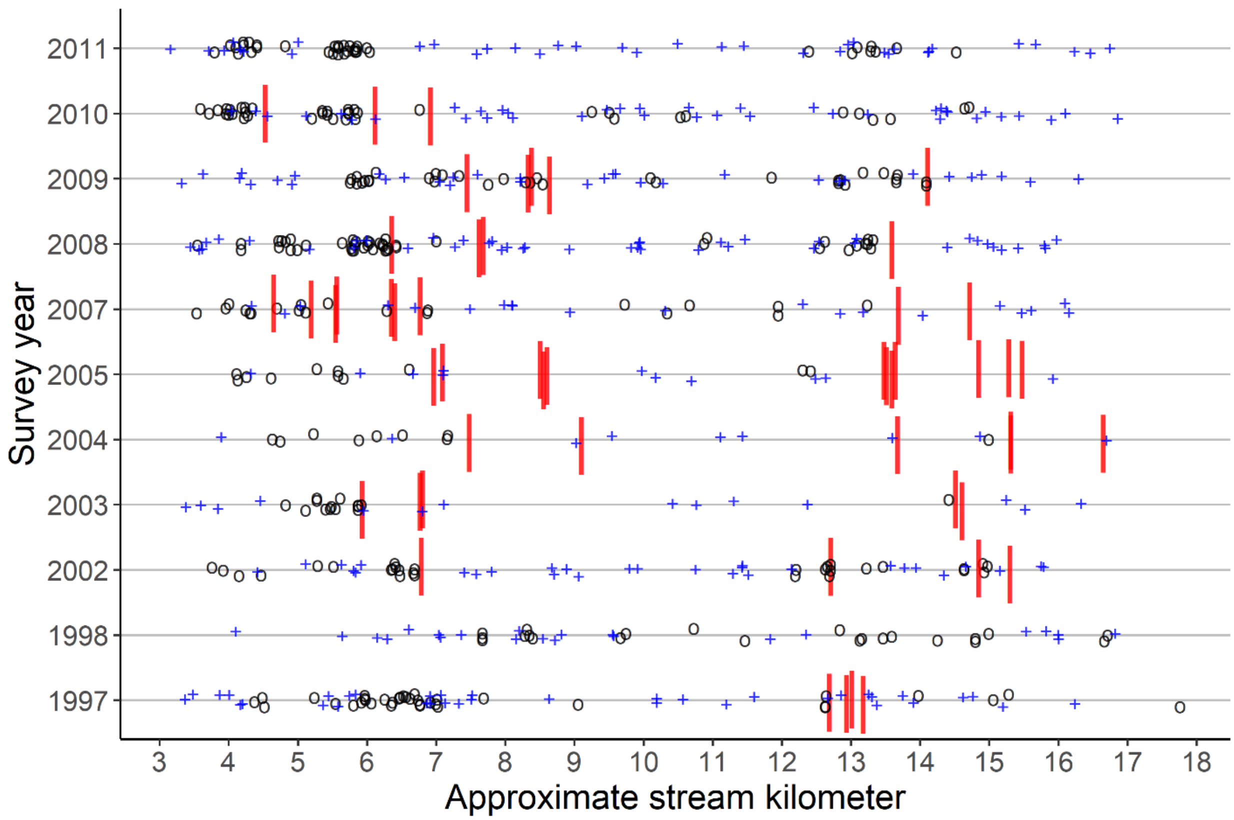

Figure S1. Morrison Creek redd counts (streamflow is from right to left on the x-axis), Flathead River basin, Montana, 1997–2011. Red lines indicate locations of beaver dams, circles indicate actual bull trout redds, and blue crosses represent randomly generated points. Years included are those in which beaver dams were recorded and pace counts could be converted to stream kilometers. Stream kilometers proceed upstream. Both redds and dams are offset on the vertical axis by a small amount to enhance visibility of features in close proximity.

TABLE S1. Survey of all beaver dams in Meadow Creek in summer 2020. Heights and lengths are in meters. Jump height is the crest height above the downstream pool. P-J ratio is the ratio of the pool depth to the jump height. N/A means not applicable.

Dam number	Dam type	Dam height	Jump height	P-J ratio	Crest length	Condition
1	secondary	0.6	0.4	0.50	3.1	intact
2	secondary	1.45	1.3	0.50	3.2	intact
3	secondary	0.75	0.4	0.88	3.8	intact
4	secondary	0.95	0.25	2.80	2.25	intact
5	secondary	0.9	0.5	0.80	4.0	intact
6	secondary	0.8	0.4	1.00	6	breached
7	secondary	0.7	0.2	2.50	5	breached
8	secondary	0.85	0.25	2.40	5	intact
9	secondary	0.3	0.3	0.00	2.25	blown out
10	primary	1.1	0.5	1.20	31.5	intact
11	secondary	n/a	n/a	n/a	n/a	blown out
12	secondary	1.1	0.55	1.00	5	intact
13	secondary	0.6	0.4	0.50	3.3	intact
14	secondary	0.75	0.63	0.19	3.35	intact
15	secondary	0.8	0.5	0.60	12	intact
16	secondary	n/a	n/a	n/a	n/a	blown out
17	secondary	0.95	0	n/a	1.25	intact
18	secondary	n/a	n/a	n/a	n/a	blown out
19	secondary	1.05	0.65	0.62	2.4	intact
20	secondary	0.73	0.5	0.46	1.3	intact
21	secondary	n/a	n/a	n/a	n/a	blown out
22	secondary	0.71	0.55	0.29	1.95	intact
23	secondary	0.71	0	n/a	1.15	intact
24	secondary	0.45	0	n/a	0.6	intact
25	secondary	0.45	0	n/a	1.1	intact
26	secondary	0.31	0.25	0.24	0.3	intact
27	secondary	0.6	0.35	0.71	.5	intact
28	secondary	1.4	0.75	0.87	10.6	intact
29	primary	1.4	1.1	0.27	89	intact
30	primary	1.1	0.85	0.29	87	intact
31	secondary	0.5	0.3	0.67	6	intact
32	secondary	0.4	0.24	0.67	5	intact
33	secondary	0.55	0.37	0.49	1.9	intact
34	secondary	0.75	0.4	0.88	0.45	intact
35	secondary	0.5	0.12	3.17	7.9	breached