



COLORADO

Department of Transportation

CDOT Office of Applied Research



Understanding How Beaver Dam Analogs Modify Habitat for Preble's Meadow Jumping Mouse: Populations and Habitat Structure

Robert A. Schorr and Terutaka Funabashi

June 2026

CDOT-2026-05

Technical Report Documentation Page

1. Report No. CDOT-2026-05	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Understanding How Beaver Dam Analogs Modify Habitat for Preble's Meadow Jumping Mouse: Populations and Habitat Structure		5. Report Date June 2026	
		6. Performing Organization Code	
7. Author(s) Robert A. Schorr and Terutaka Funabashi		8. Performing Organization Report No.	
9. Performing Organization Name and Address Colorado Natural Heritage Program Colorado State University Fort Collins, CO 80523-1475		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No.	
12. Sponsoring Agency Name and Address Colorado Department of Transportation Office of Applied Research 2829 W. Howard Place Denver, CO 80204		13. Type of Report and Period Covered	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract Preble's meadow jumping mouse (<i>Zapus hudsonius preblei</i>) is a threatened subspecies of meadow jumping mouse narrowly distributed from southeastern Wyoming to Colorado Springs, Colorado. This mouse is restricted to riparian habitats and the adjacent uplands. As riparian systems have been disrupted or impacted by incompatible land use, Preble's meadow jumping mouse populations have declined and become more isolated. One way of restoring or expanding riparian habitats is the installation of beaver dam analogs that mimic the structures built by beavers. These structures increase the water table and expand the riparian habitat components PMJM rely on. In 2021, Colorado Department of Transportation installed beaver dam analogs along East Plum and Carpenter creeks after modifications to Interstate 25 impacted Preble's meadow jumping mouse habitat. We conducted small mammal and vegetation surveys at each location immediately after analog installation in 2021, and then each year from 2023 to 2025. Preble's meadow jumping mice were found at each location each year. Captures of Preble's meadow jumping mice increased with tall vegetation cover and diverse ground cover. East Plum Creek had increasing abundances of Preble's meadow jumping mice, which corresponded to the diversity of tall vegetation and varied ground cover. Carpenter Creek had decreasing abundances of Preble's meadow jumping mice, likely because of monocultures of grasses, sedges, and rushes that increase meadow vole abundance. Although Carpenter Creek currently does not have many Preble's meadow jumping mice, we believe the beaver dam analogs will expand the available habitat over time. Beaver dam analogs can be effective riparian restoration tools; however, it is important to have any restoration tool scale with the associated floodplain and creek system. Despite stormwater flooding degrading some of the analogs, we believe beavers will take advantage of the structures and continue to dam the creeks in the vicinity. Implementation: We recommend that BDAs be used as a tool for PMJM habitat restoration, but that appropriate design match desired restoration scope and results, because the spatial, temporal, and physical scope can greatly influence the success. To offset impacts near PMJM habitat, thoroughly evaluate the size of the watershed, volume of water, and floodplain width to ensure BDAs can address the impacts.			
17. Keywords Restoration ecology, stream restoration, wildlife, flooding, habitat restoration, beaver, endangered species		18. Distribution Statement This document is available on CDOT's website: https://www.codot.gov/programs/research	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

The contents of this report reflect the views of the author(s), who is(are) responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Colorado Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Acknowledgments

We thank Brock Linder, Mica Kimmett, Margaux Hapgood, and Walter Morton from Colorado Natural Heritage Program for assistance in the field. Additionally, we appreciate assistance from CDOT and US Fish and Wildlife Service, including Kristin Salamack, Francesca Toronado, Erik Schmude, Jason Roth, and Summer Slama.

Table of Contents

Acknowledgments.....	iv
Table of Contents.....	v
List of Tables	vi
List of Figures	vii
List of Abbreviations and Acronyms	viii
Executive Summary.....	1
Chapter 1. Introduction	2
1.1. Biology and conservation of the Preble’s meadow jumping mouse.....	2
1.2. The importance of riparian habitat restoration for PMJM conservation	4
1.3. The Interstate 25 South Gap Project and habitat restoration	5
1.4. Objective: Testing efficacy of BDAs for PMJM habitat regeneration.....	5
Chapter 2. Methods.....	6
2.1. Study site.....	6
2.2. Preble’s meadow jumping mouse and vegetation sampling	8
2.2.1. Preble’s meadow jumping mouse trapping.....	8
2.2.2. Vegetation sampling	9
2.3. Statistical analysis of Preble’s meadow jumping mouse populations at vegetation	10
2.3.1. Estimating Preble’s meadow jumping mouse population parameters	10
2.3.2. Vegetation structure and composition comparisons with PMJM captures and populations	10
Chapter 3. Results.....	11
3.1. Small mammal captures.....	11
3.2. Preble’s meadow jumping mouse abundance and survival.....	12
3.3. Vegetation characteristics.....	12
3.3.1. Overstory and canopy cover	12
3.3.2. Shrub density and vertical vegetation cover	13
3.3.3. Ground cover composition	15
3.4. Habitat conditions that may support PMJM	15
Chapter 4. Discussion	16
4.1. Preble’s meadow jumping mouse captures and vegetation.....	16
4.2. Recommendations	20
Chapter 5. References	21

List of Tables

Table 1. Small mammal captures at East Plum Creek, Douglas County, 2021 – 2025.....	11
Table 2. Small mammal captures at Carpenter Creek, Greenland Open Space, Douglas County, 2021 - 2025.	12
Table 3. Percent mean vegetation density (SD) at different height classes at Carpenter Creek, Greenland Open Space, Douglas County, 2021 – 2025.	14
Table 4. Percent mean vegetation density (SD) at different heights at East Plum Creek, Douglas County, 2021 – 2025.	14

List of Figures

Figure 1. Rangewide distribution of Preble’s meadow jumping mouse from USFWS (2018).	2
Figure 2. Preble's meadow jumping mouse in Plexiglas photobox.	3
Figure 3. Preble's meadow jumping mouse habitat with dense willow and adjacent uplands.....	3
Figure 4. Locations of Colorado Department of Transportation beaver dam analogs along East Plum and Carpenter creeks, Douglas County, Colorado.	6
Figure 5. Bank impacts upstream of Interstate 25 along East Plum Creek.....	7
Figure 6. Bank impacts downstream of Interstate 25 along East Plum Creek.	7
Figure 7. Sherman live trap set along East Plum Creek, 2023.	8
Figure 8. Using a 3-m tall vertical cover board to estimate vertical vegetation density.	9
Figure 9. Mean number of overstory trees and mean percent canopy cover per plot at East Plum Creek, Douglas Creek, 2021 and 2023 – 2025. Carpenter Creek data not presented because no canopy cover or trees were encountered.	13
Figure 10. Mean shrub density (+SD) per plot at East Plum and Carpenter creeks, Douglas County, 2021 and 2023 – 2025.	13
Figure 11. Mean ground cover of forbs, grasses, rock and soil, woody debris and litter at Carpenter Creek (solid bars) and East Plum Creek (open bars) beaver dam analog sites, Douglas County, Colorado, 2021 and 2023 – 2025.	15
Figure 12. Shrub density near beaver pond at Carpenter Creek site. Note how the only shrub cover for Preble’s meadow jumping mice is along the far bank before meeting the steep slope from the upland grasslands.....	16
Figure 13. Shrub density and mesic meadow of Carpenter Creek site. Note the extent of the sedge/rush meadow in the distance.....	17
Figure 14. Shrub density and mixed ground cover at East Plum Creek site. Note the height of alders in the background, the variety of shrub heights, and mixed forbs and grasses in foreground.....	18
Figure 15. Post-flooding impacts at a beaver dam analog along East Plum Creek, Douglas County	21

List of Abbreviations and Acronyms

PMJM .. Preble's meadow jumping mouse

CDOT ... Colorado Department of Transportation

USFWS . United States Fish and Wildlife Service

BDA Beaver Dam Analog

PALS Post-assisted log structure

I25 Interstate 25

SD Standard Deviation

CI 95% confidence interval

ANOVA . Analysis of variance

Executive Summary

Preble's meadow jumping mouse (*Zapus hudsonius preblei*; PMJM) is a threatened subspecies of meadow jumping mouse, narrowly distributed from southeastern Wyoming to Colorado Springs, Colorado. This mouse is restricted to riparian habitats and the adjacent uplands. As riparian systems have been disrupted or impacted by incompatible land use, Preble's meadow jumping mouse populations have declined and become more isolated. One way of restoring or expanding riparian habitats is the installation of beaver dam analogs that mimic the structures built by beavers. These structures increase the water table and expand the riparian habitat components PMJM rely on. In 2021, Colorado Department of Transportation installed beaver dam analogs along East Plum and Carpenter creeks after modifications to Interstate 25 impacted Preble's meadow jumping mouse habitat. We conducted small mammal and vegetation surveys at each location immediately after analog installation in 2021, and then each year from 2023 to 2025. Preble's meadow jumping mice were found at each location each year. Captures of Preble's meadow jumping mice increased with tall vegetation cover and diverse ground cover. East Plum Creek had increasing abundances of Preble's meadow jumping mice, which corresponded to the diversity of tall vegetation and varied ground cover. Carpenter Creek had decreasing abundances of Preble's meadow jumping mice, likely because of monocultures of grasses, sedges, and rushes that increase meadow vole abundance. Although Carpenter Creek currently does not have many Preble's meadow jumping mice, we believe the beaver dam analogs will expand the available habitat over time. Beaver dam analogs can be effective riparian restoration tools; however, it is important to have any restoration tool scale with the associated floodplain and creek system. Despite stormwater flooding degrading some of the analogs, we believe beavers will take advantage of the structures and continue to dam the creeks in the vicinity.

Chapter 1. Introduction

1.1. Biology and conservation of the Preble's meadow jumping mouse

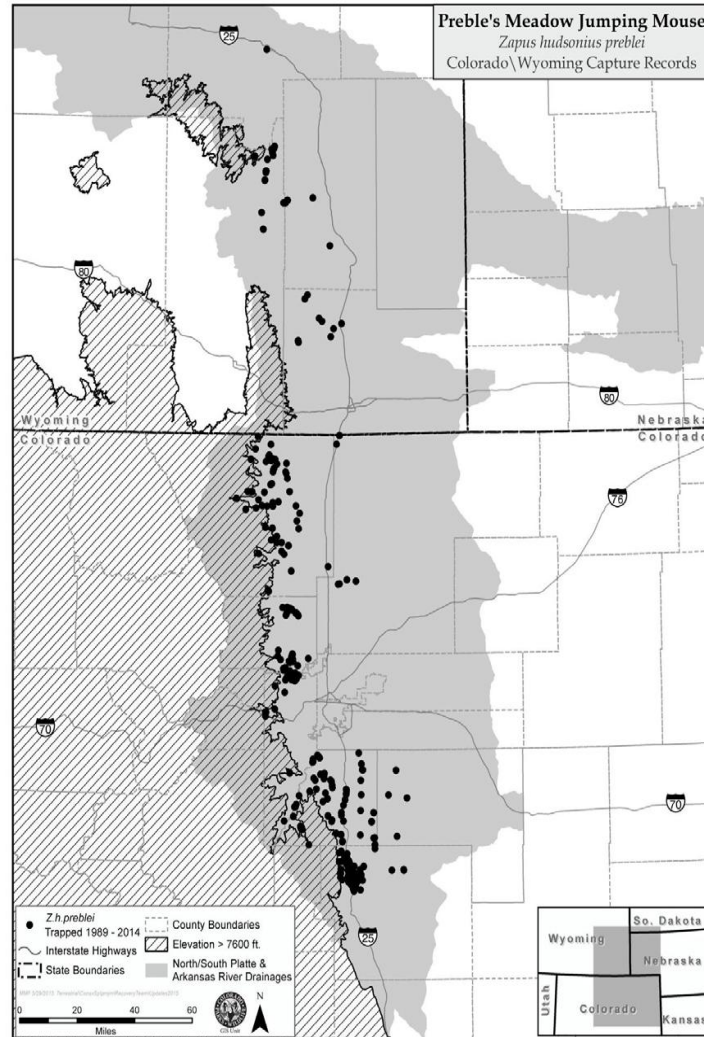


Figure 1. Rangewide distribution of Preble's meadow jumping mouse from USFWS (2018).

Preble's meadow jumping mouse (*Zapus hudsonius preblei*) is a small (<30 g) threatened subspecies of meadow jumping mouse narrowly distributed along the eastern boundary of the Front Range of Colorado from Colorado Springs to the Wyoming border (Figure 1). In Wyoming, the Preble's meadow jumping mouse (PMJM) is found in the eastern mountains and plains from the Colorado border north to approximately Douglas, Wyoming. Similar to other species of *Zapus*, PMJM have large hindfeet, long tails (usually twice the body length), and a dark, broad dorsal stripe (Figure 2). The PMJM is found in dense, riparian vegetation, typically consisting of a shrub component, such as willow (*Salix* spp.) and

lush herbaceous ground cover of grasses, forbs, rushes and sedges (Armstrong et al. 2011) (Figure 3). Individuals spend most of their time in these dense habitats but will make feeding forays into adjacent upland grasslands and shrublands (Schorr 2001, 2003) (Figure 3). Additionally, PMJM may leave the riparian habitat to build hibernation burrows and nests (Schorr 2003).



Figure 2. Preble's meadow jumping mouse in Plexiglas photobox.



Figure 3. Preble's meadow jumping mouse habitat with dense willow and adjacent uplands.

PMJM was listed as threatened by the U.S. Fish and Wildlife Service (USFWS) in 1998 because attempts to capture PMJM at historic locations failed (Ryon 1996, USFWS 2018). Riparian habitats have been decreasing along the Front Range of Colorado because of expanding urban and suburban development, intense grazing, and other habitat modifications (USFWS 2018). Recovery and delisting of PMJM requires maintaining habitat and populations across the subspecies' range (USFWS 2018).

1.2. The importance of riparian habitat restoration for PMJM conservation

The survival of PMJM is linked to the structure and composition of the riparian habitats in which they live (Schorr and Mihlbachler 2018). Thus, as these habitats are degraded and PMJM populations become isolated, both survival and recruitment of individuals will decrease (Schorr 2012). Riparian habitat restoration has the potential to connect disparate PMJM populations, increasing recruitment, population stability, and likelihood of recovery. Beavers (*Castor canadensis*) are riparian and wetland habitat engineers, introducing disturbance that alternately increases water table height, then, as dams breach, creating wet soils for generating wetland vegetation growth (Wheaton et al. 2019). Beavers' dam construction activity enhances floodplain inundation and lateral wetland connectivity, vegetation and geomorphology heterogeneity, and greatly increases biodiversity of riparian systems (Stringer and Gaywood 2016, Brazier et al. 2020). Installing low-technology structures, like Beaver Dam Analogs (BDAs) or post-assisted log structures (PALS), that mimic beaver structures, can create similar riparian hydrologic and habitat benefits. Such structures increase stream and habitat complexity and can have a broad benefit for habitat and species along creeks, including improving fish habitat, expanding riparian vegetation, storing water and sediment, improving water quality, moderating stream flows, and improving grazing habitat (Wheaton et al. 2019, Orr et al. 2024, Wohl and Inamdar 2025).

BDAs and PALS are used across the American West to restore form and function to degraded stream systems (Bouwes et al. 2016; Pollock et al. 2014). Studies have shown BDAs can create positive feedback loops similar to beaver-induced changes to a watershed (Levine and Meyer 2019, Orr et al. 2020). Where a local beaver source population exists, BDAs promote colonization of new sites and beaver occupation and maintenance of BDAs (Bouwes et al. 2016; Weber et al. 2017). There is an established history of BDAs and beaver-associated stream restoration mitigating habitat loss and degradation for aquatic and terrestrial threatened species and species of conservation concern (Davee et al. 2019).

Beaver dams alter hydrology and associated stream-floodplain processes, promoting the regeneration of riparian habitat that supports small mammal communities, including habitat for jumping mice (Frey and

Malaney 2009). Use of BDAs and PALS along Monument Creek at the U.S. Air Force Academy increased riparian vegetation cover and PMJM captures within two years after installation (Schorr et al. 2026).

1.3. The Interstate 25 South Gap Project and habitat restoration

An 18-mile-long improvement project along Interstate 25 (I25), called the I25 South Gap Project (Gap Project), was started in 2018 to include an express lane and improve pavement and infrastructure. Along this stretch of I25, both Carpenter Creek and East Plum Creek flow near, or under, the interstate. Near the Town of Larkspur, East Plum Creek flows under I25 and was impacted by the Gap Project. Similarly, within the Greenland Open Space, Carpenter Creek flows adjacent to the Gap Project and the interstate improvement project temporarily impacted habitat for PMJM. To aid in the regeneration of riparian habitat that supports PMJM, CDOT installed 11 BDAs along East Plum Creek near the Spruce Mountain Road/I25 intersection and 7 BDAs along Carpenter Creek adjacent to I25 near East Noe Road. Additionally, CDOT planted riparian vegetation to increase probability of regeneration of PMJM habitat.

1.4. Objective: Testing efficacy of BDAs for PMJM habitat regeneration

Although BDAs have been lauded for their ability to rehabilitate damaged riparian systems, there have been no formal studies demonstrating their effectiveness for restoration of PMJM habitat. CDOT's installation of BDAs along East Plum Creek and Carpenter Creek present an opportunity to assess the efficacy of using such structures to improve PMJM habitat and connect PMJM populations. Connecting PMJM populations can increase population stability by increasing habitat and the opportunity for exchange of individuals.

Chapter 2. Methods

2.1. Study site

In 2021, BDAs were installed along East Plum Creek on either side of I25 and along Carpenter Creek west of I25 (Figure 4). Both locations had components of PMJM habitat (Figures 5, 6), but directly upstream

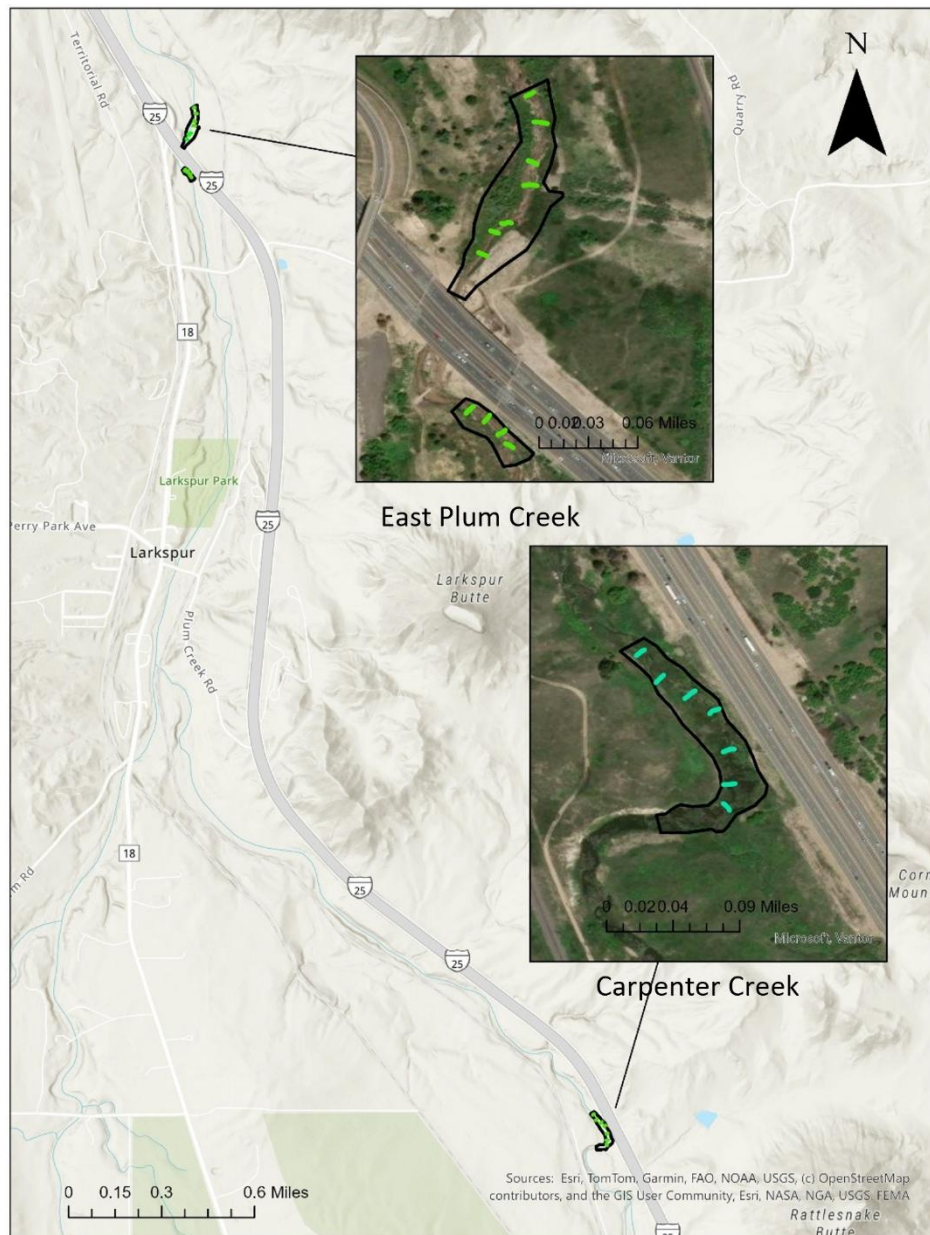


Figure 4. Locations of Colorado Department of Transportation beaver dam analogs along East Plum and Carpenter creeks, Douglas County, Colorado.

and downstream of I25, East Plum Creek had stream banks where vegetation was removed or impacted (Figures 5, 6).



Figure 5. Bank impacts upstream of Interstate 25 along East Plum Creek.



Figure 6. Bank impacts downstream of Interstate 25 along East Plum Creek.

2.2. Preble's meadow jumping mouse and vegetation sampling

2.2.1. Preble's meadow jumping mouse trapping

Sampling for PMJM was conducted using 2 Sherman live traps (Figure 7) at each point of a 65-station trapline that covered approximately 450 m. Each station was placed approximately 7 m apart within 5 m of the respective creek. Trapping transects were laid such that the beginning of the transect began upstream of the first BDA and extended past the last BDA downstream. Traps were opened and baited in the evening with a mix of crimped oats and sweet horse feed mix and a ball of polyester batting for insulation. Trapping was conducted for 4 consecutive nights each year in 2021, 2023, 2024, and 2025 for a total of 520 trapnights (trapnight = 1 trap per night). Trapping in 2021 was conducted as a preliminary evaluation of PMJM presence shortly after BDA installation. Trapping in years 2023 – 2025 were conducted as part of this project to understand the trajectory of PMJM abundance after BDA installation.

Each PMJM was weighed, sexed, and reproductive status was determined. Each individual was marked with a unique passive integrated transponder (PIT) tag. All PMJM and other small mammals were



Figure 7. Sherman live trap set along East Plum Creek, 2023.

released at the site of capture. Because each individual received a unique marker we were able to create histories of capture (capture histories) that were used to estimate abundance each year at each site.

2.2.2. Vegetation sampling

We sampled vegetation characteristics at 6 trap locations along each transect. Locations were not random but placed equally distant from each other along the entire trapping transect. In each cardinal direction, and within a 0.04-ha circular plot (James and Shugart 1970), we recorded canopy cover using a spherical densiometer ($n = 24$ per trapping transect set per year), shrub density (shrub stems > 1 m tall; $n = 24$ per trapping transect per year), and vertical vegetation density. Vertical vegetation density was measured using a 0.5 m x 3.0 m vertical cover board by estimating the amount of green vegetation obscuring each 0.5 m x 0.5 m spaces (0.0 – 0.5 m, 0.5 – 1.0 m, etc.) along the vertical cover board, from 0 to 3 m in height ($n = 24$ per trapping transect per year; Figure 8). Shrub cover is an estimate of live, woody stems that are not trees, but are more robust than forb and grass cover. We counted live, woody stems at least 1 m tall within 1 m of each cardinal transect ($n = 24$ per trapping transect per year). For tree cover, we recorded the number and diameter-at-breast height (dbh) of canopy trees with dbh > 5 cm ($n = 6$ per trapping transect set per year), and number of pieces of downed woody debris > 3 cm



Figure 8. Using a 3-m tall vertical cover board to estimate vertical vegetation density.

diameter ($n = 6$ per trapping transect per year). Also, at 13 locations (center, 3 m, 6 m, and 9 m along each cardinal direction) within the circular plot we collected measurements of percent ground cover of forb, graminoid (grasses, sedge, rush; herein called “grass”), rock and soil, moss and lichen, litter (leaves and pine needles), and woody debris (branches and bark) using a 0.1-m² sampling frame (Daubenmire 1959). Estimates of total ground cover were allowed to exceed 100% at a plot if some components overlapped ($n = 78$ samples per trapping transect per year).

2.3. Statistical analysis of Preble’s meadow jumping mouse populations at vegetation

2.3.1. Estimating Preble’s meadow jumping mouse population parameters

Because captured PMJM were marked with PIT tags, we can create a capture history that depicts the timeline of encounter during the 4 nights of trapping each year and among years. For a PMJM captured the 1st and 3rd day of a session, the capture history would be documented as “1010”. Since we know how many individuals are tagged in our area, and we can compare their capture histories, we can estimate the probability of a PMJM being captured given they are in the area. Being able to estimate this allows better understanding of the likelihood of missing individuals, which can provide a better estimate of abundance. Similarly, understanding estimates of likelihood of capture can provide more-informed estimates of survival, because we can parse out lack of detection from likelihood of mortality. We analyzed capture histories using the Robust Model in Program MARK (Kendall 2001). The Robust Model assumes that during trapping sessions (4-days long) there is closure (no births, deaths, immigration, or emigration), but between sessions (year(s) between trapping sessions) populations are open. The challenge with using any formal modeling process for estimating population parameters of rare species is that rare species are infrequently detected. Such models perform well when organisms are encountered frequently and survive long enough to be detected among sessions.

2.3.2. Vegetation structure and composition comparisons with PMJM captures and populations

We used multivariate analysis of variance to compare PMJM captures and abundances to vegetation structure and composition between sites and at a site over time. We used $\alpha < 0.15$ to suggest statistical significance, which is a lenient assessment of “significance”. We chose this level of significance simply as it may suggest biologically important relevance regardless of the minimal power of such comparisons when addressing infrequently-detected rare species.

Chapter 3. Results

3.1. Small mammal captures

Fifty PMJM were detected at both locations and those individuals were captured 79 times. Total PMJM captures represented only 6% of all small mammal captures. The most abundant small mammal captured in all years of the study was the North American deer mouse (*Peromyscus maniculatus*). North American deer mice (deer mice) were captured 547 times and represented 43% of all captures. Meadow voles (*Microtus pennsylvanicus*) were captured 434 times and represented 34% of captures. New Mexico woodrats (*Neotoma mexicana*), western harvest mice (*Reithrodontomys megalotis*), long-tailed weasels (*Mustela frenata*), and shrews (*Sorex* sp.) were encountered infrequently, representing <3% of captures (1 - 33 captures).

The East Plum Creek site had the most captures of PMJM ($p < 0.01$), and PMJM at captures increased over time (Table 1). A total of 36 individuals were captured 59 times, with few individuals captured more than twice. Deer mice increased in captures over the years, while meadow vole captures peaked in 2024. Harvest mice were abundant in 2024, but it can be difficult to distinguish young deer mice from harvest mice, so it is possible harvest mice were present throughout the study but in low numbers and periodically mistaken for young deer mice. Shrews were infrequently captured, but their capture is commonly a good indicator of PMJM habitat (unpublished data, Schorr).

Table 1. Small mammal captures at East Plum Creek, Douglas County, 2021 – 2025

Species or outcome	August 2021	June 2023	July 2024	July 2025	Total	% of captures
Preble's meadow jumping mouse (individuals)	5 (4)	10 (7)	18 (9)	26 (16)	59 (36)	10%
Deer mouse	12	95	68	117	292	48%
Meadow vole	9	11	90	24	134	22%
New Mexico woodrat	5	0	9	10	24	4%
Western harvest mouse	0	0	17	0	17	3%
Shrew	2	0	1	0	3	0%
Closed and empty trap	26	12	15	26	79	13%

There were fewer PMJM captured at the Carpenter Creek site (Table 2). The highest capture success was the year during which the BDAs were installed and number of captures declined over the study.

Meadow voles were the most abundant species at Carpenter Creek, accounting for 46% of all captures. Deer mice comprised 39% of captures, with woodrats, harvest mice, and a lone capture of a long-tailed weasel (*Mustela frenata*) making up a small portion of captures (<2%).

Table 2. Small mammal captures at Carpenter Creek, Greenland Open Space, Douglas County, 2021 - 2025.

Species or outcome	August 2021	June 2023	July 2024	July 2025	Total	% of captures
Preble's meadow jumping mouse (individuals)	10 (8)	7 (4)	1 (1)	2 (1)	20 (14)	3%
Deer mouse	61	74	65	55	255	39%
Meadow vole	62	25	106	107	300	46%
New Mexico woodrat	0	0	9	0	9	1%
Western harvest mouse	0	0	9	0	9	1%
Long-tailed weasel	1	0	0	0	1	0%
Closed and empty trap	10	14	14	20	58	9%

3.2. Preble's meadow jumping mouse abundance and survival

Because so few PMJM were captured and recapture success was not high, population parameter estimates had high estimates of variability, or the variance was inestimable. Parameter estimation is especially difficult when analysis is conducted on capture histories per location per year, reducing sample size to ≤ 16 individuals. Thus, Program MARK was unable to produce abundance estimates more reliable than the number of individuals captured.

Combining data from all years and all locations produced the most parsimonious models of capture probability, recapture probability, and survival. Capture probability, which is the probability that, given a mouse is available in the area, it is captured for the first time was 0.50 (CI: 0.40 – 0.59). Recapture probability, which is the probability that, given a mouse is available it is recaptured after being marked, was 0.30 (CI: 0.22 – 0.40). Apparent survival, which is the probability of survival but does not account for emigration, was <1% between 2021 and 2023, <1% between 2023 and 2024, and 81% between 2024 and 2025. Each year's apparent survival confidence intervals include 0 and 1.

3.3. Vegetation characteristics

3.3.1. Overstory and canopy cover

Only the East Plum Creek site had overstory species, which included thinleaf alder (*Alnus incana*), and minimal chokecherry (*Prunus virginiana*) and Ponderosa pine (*Pinus ponderosa*). There was little variability in trees and canopy cover over the years, but a clear drop in number of trees in 2024 (Figure 9). There were statistical differences in canopy cover ($p < 0.01$) and overstory (0.03) between sites, but not at a site over time.

3.3.2. Shrub density and vertical vegetation cover

Shrub density varied between sites over the years, with Carpenter Creek showing increased shrub density (Figure 10). Shrub density was significantly different between sites ($p = 0.04$) and differed over

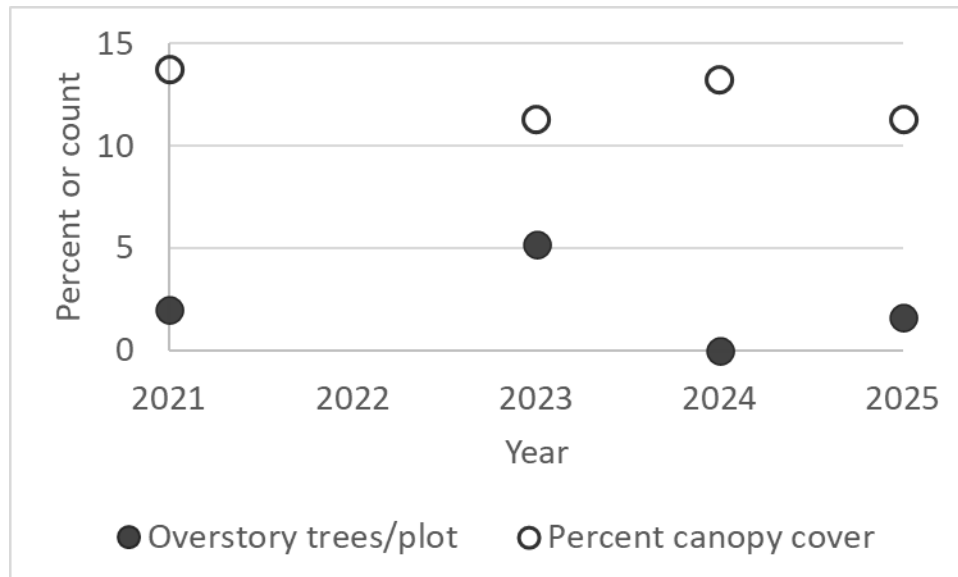


Figure 9. Mean number of overstory trees and mean percent canopy cover per plot at East Plum Creek, Douglas Creek, 2021 and 2023 – 2025. Carpenter Creek data not presented because no canopy cover or trees were encountered.

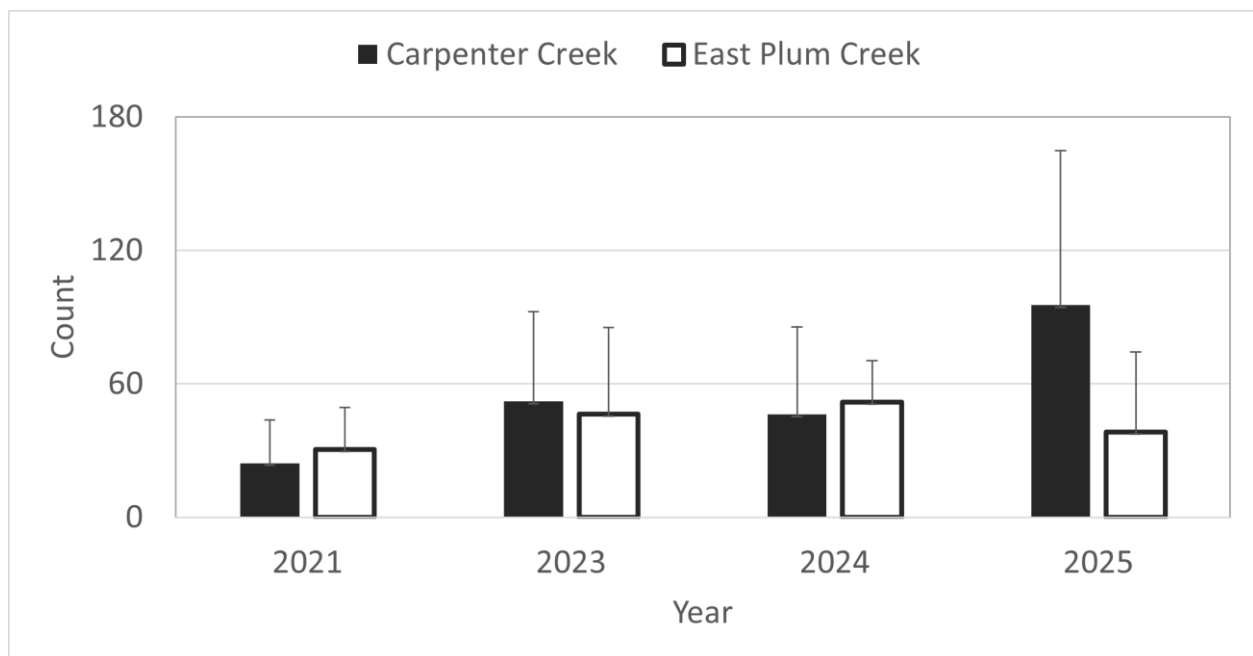


Figure 10. Mean shrub density (+SD) per plot at East Plum and Carpenter creeks, Douglas County, 2021 and 2023 – 2025.

time at Carpenter Creek ($p < 0.01$). Although East Plum Creek did not have the density of shrubs, it had taller vegetation in the form of small trees and tall willow (Tables 3, 4). Consistently, East Plum Creek had vegetation cover at heights above 2.0 m (Table 4), where Carpenter Creek only showed minimal vertical vegetation density at these heights until 2025 (Table 3). The vertical vegetation cover at Carpenter Creek is typically shorter than 1 m tall, which reflects the dominance of short shrubs, grasses and forbs at this site. Statistically, the Carpenter Creek and East Plum Creek sites differed in the following height categories: 1 – 1.5 m ($p = 0.02$), 1.5 – 2.0 m ($p = 0.01$), 2.0 – 2.5 m ($p < 0.01$), and 2.5 – 3.0 m ($p < 0.01$).

Table 3. Percent mean vegetation density (SD) at different height classes at Carpenter Creek, Greenland Open Space, Douglas County, 2021 – 2025.

Height	2021	2023	2024	2025
2.5 – 3.0 m	0 (0)	0 (0)	0 (0)	7 (15)
2.0 – 2.5 m	2 (4)	0 (0)	0 (0)	18 (26)
1.5 – 2.0 m	11 (22)	5 (11)	2 (7)	33 (37)
1.0 – 1.5 m	24 (34)	24 (33)	19 (28)	54 (44)
0.5 – 1.0 m	56 (32)	56 (39)	47 (36)	77 (36)
0.0 – 0.5 m	90 (19)	89 (19)	80 (30)	93 (17)

Table 4. Percent mean vegetation density (SD) at different heights at East Plum Creek, Douglas County, 2021 – 2025.

Height	2021	2023	2024	2025
2.5 – 3.0 m	21 (37)	11 (30)	28 (40)	17 (29)
2.0 – 2.5 m	25 (39)	14 (31)	41 (44)	24 (36)
1.5 – 2.0 m	35 (42)	21 (35)	46 (46)	33 (40)
1.0 – 1.5 m	49 (44)	41 (39)	65 (44)	44 (44)
0.5 – 1.0 m	63 (42)	58 (43)	80 (35)	62 (35)
0.0 – 0.5 m	86 (25)	89 (20)	92 (35)	90 (13)

3.3.3. Ground cover composition

Percent ground cover for many features was highly variable (Figure 11). Grass, forb, and litter cover comprised a majority of the ground cover. Forb cover ($p < 0.01$) and grass cover ($p < 0.01$) were statistically higher at Carpenter Creek, but those differences were not consistent each year. Litter cover typically was higher at East Plum Creek ($p < 0.01$), but not consistently different throughout the years. As with downed woody debris, there was more woody debris cover at East Plum Creek ($p < 0.01$). Typically, the East Plum Creek location had more rock and soil cover ($p = 0.03$). Moss and lichen cover was infrequently encountered and did not support statistical comparison.

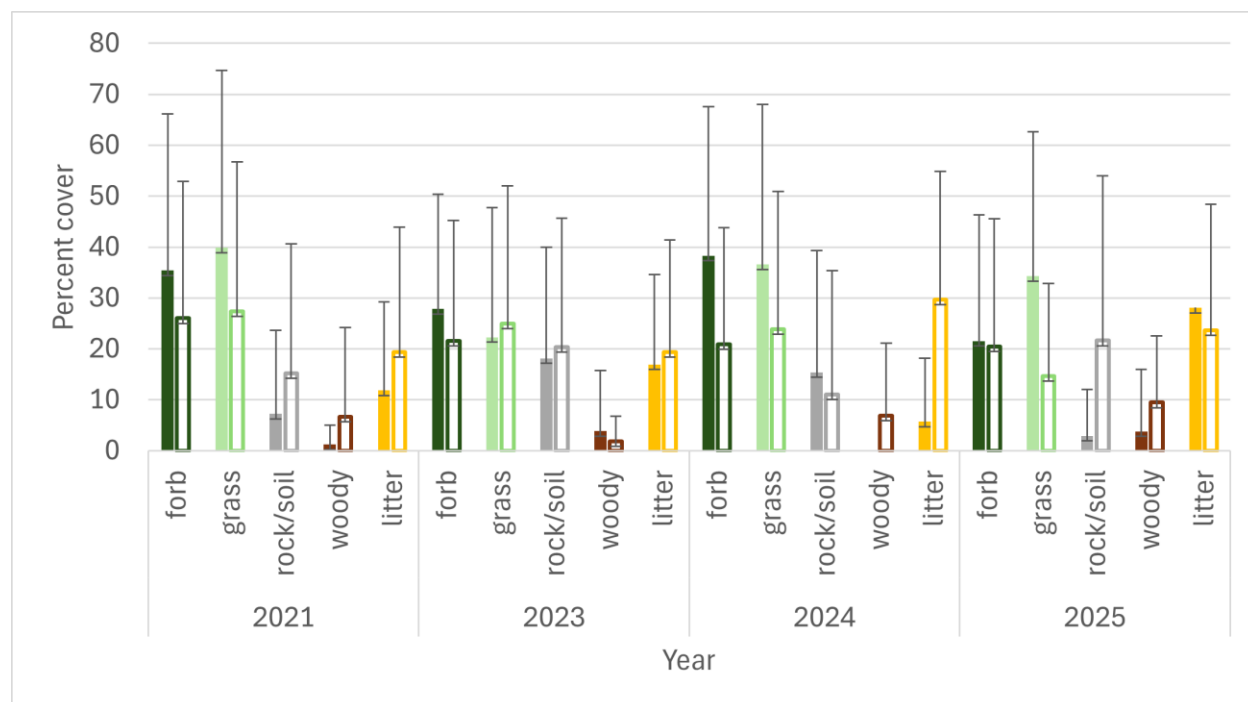


Figure 11. Mean ground cover of forbs, grasses, rock and soil, woody debris and litter at Carpenter Creek (solid bars) and East Plum Creek (open bars) beaver dam analog sites, Douglas County, Colorado, 2021 and 2023 – 2025.

3.4. Habitat conditions that may support PMJM

Captures of PMJM were higher at sites with greater woody debris ($p = 0.05$) and vertical vegetation at the highest level (2.5 – 3.0 m) ($p = 0.15$) but were lower at sites with greater shrub density ($p = 0.05$) and greater grass cover ($p = 0.05$).

Chapter 4. Discussion

4.1. Preble's meadow jumping mouse captures and vegetation

Preble's meadow jumping mice were captured at BDA restored sites along Carpenter Creek and East Plum Creek each year of the study. Captures and recaptures of PMJM did not facilitate reliable estimates of population size at either location; however, based on capture success, East Plum Creek site PMJM population increased over time, while the Carpenter Creek site PMJM population decreased since the BDA installation ($p < 0.01$ for location by time ANOVA). Interestingly, the habitat components that are typically associated with PMJM habitat were not good indicators of PMJM captures. For instance, grass cover and shrub cover are associated with increased PMJM survival (Schorr and Muhlbachler 2018), but at the Carpenter Creek BDA site captures decreased as shrub density and grass cover increased.

The Carpenter Creek BDA site may be unique because of its narrower floodplain compared to East Plum Creek site and other sites (Schorr and Muhlbachler 2018). With a narrower floodplain there is less space



Figure 12. Shrub density near beaver pond at Carpenter Creek site. Note how the only shrub cover for Preble's meadow jumping mice is along the far bank before meeting the steep slope from the upland grasslands.

to accommodate expanses of shrub and herbaceous cover seen at broader floodplains. For example, as the Carpenter Creek's BDAs were augmented by beaver, the amount of open water increased and limited shrub growth to a narrow margin around the edge of the pond (Figure 12). Comparatively, the un-dammed regions had high shrub counts, thus the high variability of shrub count measurements (Table 10). We believe the narrow nature of Carpenter Creek habitat served as a well-used movement corridor, but not as a population of resident individuals. This would explain the low capture success despite apparently conducive habitat components.

Despite lower capture numbers, Carpenter Creek site had high density of grass ground cover (Figure 13). Although grasses are associated with higher PMJM survival success, the locations where these relationships hold are not dominated by grasses, sedges, and rushes (Schorr and Muhlbachler 2018). In areas where the wet meadows along creeks are comprised of only grasses, sedges, and rushes, there were high captures of meadow voles. It is common for voles to be the primary species at inundated, graminoid-dominated wet meadows. At Carpenter Creek, meadow voles were the dominant small mammal (Table 2). Meadow voles are common co-occurring species with PMJM (Schorr 2012), but they



Figure 13. Shrub density and mesic meadow of Carpenter Creek site. Note the extent of the sedge/rush meadow in the distance.

may compete with meadow jumping mice (Boonstra and Hoyle 1986, Dueser and Porter 1986, Schorr et al. 2018).

The PMJM capture rates increased at East Plum Creek site over time. Early on, this site was difficult to traverse because of the abundance of trees and downed wood. With the establishment of the BDAs, beaver began to cull alder to supplement the BDAs, which opened the canopy and increased shrub density (2021 to 2024). The height of vegetation was consistently greater at the East Plum Creek site, and with the increased shrub density and diversity of forb and grass cover, PMJM likely had a variety of habitat resources, including feeding, cover, and breeding habitat (Figure 14). East Plum Creek had higher downed woody debris, but it is unlikely that this contributed to increasing PMJM numbers. This is simply a product of increased beaver activity at the East Plum Creek site, and the abundance of damming resources that could be harvested.

The diversity of vegetation height and ground cover may play a role in why PMJM select an area (Figure 14). Clippinger (2002) found PMJM inhabiting sites with greater plant diversity. As long as baseline



Figure 14. Shrub density and mixed ground cover at East Plum Creek site. Note the height of alders in the background, the variety of shrub heights, and mixed forbs and grasses in foreground.

needs for moisture, cover, and feeding resources are available, a greater variety of litter, bare ground, grasses, forbs, and woody debris may be key to PMJM presence. East Plum Creek and Carpenter Creek provide a contrast of a broader, diversely-vegetated system with a narrower, grass-dominated system. Studying PMJM densities and habitat structure in these different systems may elucidate specific PMJM habitat needs.

To date there have been few, if any, evaluations of the efficacy of BDAs for creating or expanding meadow jumping mouse habitat. Beaver dams can improve jumping mouse habitat (Frey and Malaney 2009), but there are no studies documenting BDA use for creating PMJM habitat. With accounts like this study, the use of BDAs will likely increase as conservation biologists work to recover PMJM. Beaver dam analogs provide a tool for connecting or expanding PMJM habitat, which should equate to increased habitat, abundance, and population resilience.

Although PMJM populations did not increase at the Carpenter Creek site, it is important to recognize that this is a narrower system and that this study did not follow populations throughout the life of the BDAs. In the natural course of a beaver dam or BDA the structure will be compromised, and water will drain from the pond. The typical lifespan for beaver dams is less than five years (Levine and Meyer 2014), and it is usually after the dam is compromised that the greatest benefit for PMJM would be realized. As the large deposition of moist soils is exposed there would be an increase in the establishment of willow and mesic forbs and grasses (Cooper et al. 2006, Levine and Meyer 2019). The beaver ponds were consistently available at the Carpenter Creek site over the years.

At the Carpenter Creek site there was limited dam building material in the form of willows, so, inevitably, as the BDAs were augmented by beaver there was a reduction in willow cover. However, it is likely that this will eventually be balanced by the recruitment of willow from beaver herbivory and after the dam is compromised (Kindschy 1989, Smith 2007), but it does highlight how many PMJM-occupied creeks have limited dam building material. As future BDAs are implemented it may be necessary to conduct follow-up cottonwood (*Populus* spp.) plantings to increase beaver access to these preferred woody materials and reduce thinning of the nearby willow shrub cover (Gallant et al. 2004, Herbison and Rood 2015). Beavers and jumping mice have shared riparian systems for centuries (Hafner et al. 1981), and beavers have temporarily altered and created the riparian and wetland systems that support jumping mice (Morrison 1992, Frey and Malaney 2009). Efforts to mimic this activity may be key to restoring PMJM habitat and recovery the subspecies.

The disconnect between high shrub density and high grass cover not corresponding with higher PMJM captures at Carpenter Creek suggests there are conditions not adequately measured by our 0.04 ha-plot sampling scale. We believe floodplain width may have been a compounding factor in allowing the shrub community to expand at Carpenter Creek compared to East Plum Creek. Future studies should incorporate Total Floodplain Width and Functional Floodplain Shrub Width at multiple locations at each restoration site. Functional Floodplain Shrub Width could be defined as portion or total distance of cross-section of floodplain width with shrubs taller than 1m.

4.2. Recommendations

Beaver dam analogs can be habitat restoration solutions for connecting and recovering PMJM habitat. Successful implementation of BDA-based riparian restoration is not always straightforward, and it is important to evaluate the host of contingencies that may, or may not, produce the desired riparian restoration outcomes (Nash et al. 2021). The pre- and post-installation monitoring of BDAs along East Plum and Carpenter creeks allow a better understanding of how streams can respond to BDAs and what PMJM-related restoration trajectories can look like. Although Carpenter Creek BDAs did not produce the immediate changes in PMJM abundance expected, there is reason to believe the restoration trajectory may change as beaver dams age. Depending on the scale of the desired restoration and size of the watershed, BDAs and other low-tech process-based restoration methods can rehabilitate PMJM habitat and recover impacted riparian habitats. However, it is important to adequately design the appropriate restoration for the habitat or system desired (Ciotti et al. 2021). We recommend that BDAs be used as a tool for PMJM habitat restoration, but that appropriate design match desired restoration scope and results, because the spatial, temporal, and physical scope can greatly influence the success (Nash et al. 2021, Wohl et al. 2015).

To offset CDOT impacts at or near PMJM habitat, we recommend thoroughly evaluating the size of the watershed, volume of water, and floodplain width to ensure BDAs, or other low-technology structures, can address the impacts. For instance, the volume and frequency of stormwater runoff that flows off hard-surface development east of the U.S. Air Force Academy has eroded streams along the Academy's eastern boundary. This has degraded or eliminated PMJM habitat. However, the scale of this problem could not be addressed by low-technology structures like BDAs or PALS. More-robust engineered structures were required and PMJM have now been documented using some streams. The BDAs along East Plum Creek periodically experienced heavy stream flows as thunderstorms regularly occur in Douglas County. Despite the structures degrading they still withheld enough water to expand the

floodplain and inundate new areas (Figure 15). Maintenance may be required to have the structures inundate and modify floodplains in the same area; however, just as beaver dams breach, BDAs will eventually fail. Ideally, any low-technology structure will be maintained by beavers that live in the system. We saw this in 2021 as beavers were building on the East Plum Creek BDAs when we checked traps in the mornings. Even if a BDA fails, it may attract beaver activity and increase natural damming that serves a broader riparian restoration goal.



Figure 15. Post-flooding impacts at a beaver dam analog along East Plum Creek, Douglas County

Chapter 5. References

Armstrong, David M., Fitzgerald, James P., and Meaney, Carron A. 2011. *Mammals of Colorado*, 2nd Ed. Denver Museum of Nature and Science and University Press of Colorado.

Boonstra, Rudy, and Hoyle, James A. 1986. "Rarity and Coexistence of a Small Hibernator, *Zapus hudsonius*, with Fluctuating Populations of *Microtus pennsylvanicus* in the Grasslands of Southern Ontario." *Journal of Animal Ecology* 55:773-784. Accessed December 1, 2025.

<https://www.jstor.org/stable/4415?seq=1>

Bouwes, Nicholaas, Weber, Nicholas, Jordan, Chris E., Saunders, W. Carl, Tattam, Ian A., Volk, Carol, Wheaton, Joseph M., and Pollock, Michael M. 2016. "Ecosystem Experiment Reveals Benefits of Natural and Simulated Beaver Dams to a Threatened Population of Steelhead (*Oncorhynchus mykiss*)." *Scientific Reports* 6:28581. Accessed December 1, 2025. <https://www.nature.com/articles/srep28581>

Brazier, Richard E., Puttock, Alan, Graham, Hugh A., Auster, Roger E., Davies, Kye H., and Brown, Chryssa M. L. 2020. "Beaver: Nature's Ecosystem Engineers." *WIREs Water* 8:e1494. Accessed December 1, 2025. <https://wires.onlinelibrary.wiley.com/doi/pdfdirect/10.1002/wat2.1494>

Cooper, David J., Dickens, Joyce, Hobbs, N. Thompson, Chirstensen, Lindsey, and Landrum, Laura. 2006. "Hydrologic, Geomorphic, and Climatic Processes Controlling Willow Establishment in a Montane System." *Hydrological Processes* 20:1845-1864. Accessed December 1, 2025. DOI:[10.1002/hyp.5965](https://doi.org/10.1002/hyp.5965)

Daubenmire, Rexford. 1959. "A Canopy-cover method of vegetational analysis." *Northwestern Science* 33:43-64.

Davee, Rachael, Gosnell, Hannah, and Charnley, Susan. 2019. *Using beaver dam analogues for fish and wildlife recovery on public and private rangelands in eastern Oregon*. U.S. Forest Service Research Paper PNW-RP-612. Accessed December 1, 2025. <https://doi.org/10.2737/PNW-RP-612>

Dueser, Raymond D., and Porter, John H. 1986. "Habitat Use by Insular Small Mammals: Relative Effects of Competition and Habitat Structure." *Ecology* 67:195-201. Accessed December 1, 2025. <https://doi.org/10.2307/1938518>

Frey, Jennifer K., and Malaney, Jason L. 2009. "Decline of the Meadow Jumping Mouse (*Zapus hudsonius luteus*) in Two Mountain Ranges in New Mexico." *Southwestern Naturalist* 54:31-44. Accessed December 1, 2025. <https://www.jstor.org/stable/40263664>

Gallant, D., Bérubé, C. H., Tremblay, E., and Vasseur, L. 2004. "An Extensive Study of the Foraging Ecology of Beavers (*Castor canadensis*) in relation to habitat quality." *Canadian Journal of Zoology* 82:922-933. Accessed December 1, 2025. <https://doi.org/10.1139/z04-067>

Hafner, David, J., Petersen, Karen E., and Yates, Terry L. 1981. "Evolutionary Relationships of Jumping Mice (Genus *Zapus*) of the Soutwestern United States. *Journal of Mammalogy* 62:501-512. Accessed December 1, 2025. <https://www.jstor.org/stable/1380398>

Herbison, Brenda, and Rood, Stewart B. 2015. "Compound Influence of River Damming and Beavers on Riparian Cottonwoods: A Comparative Study along the Lardeau and Duncan Rivers, British Columbia, Canada." *Wetlands* 35:945-954. Accessed December 1, 2025. <https://link.springer.com/article/10.1007/s13157-015-0685-8>

- James, Frances C., and Shugart, Herman, Jr. 1970. "A Quantitative Method of Habitat Description." *Audubon Field Notes* 24:727-736. Accessed December 1, 2025. <https://www.bio.fsu.edu/James/Quantitative%20Method.pdf>
- Kendall, William L. 2001. "The Robust Design for Capture-recapture Studies: Analysis Using Program MARK." Pages 357 – 360 in Field, R., Warren, R. J., Okama, H., and Sievert, P. R., editors. *Proceedings of the Second International Wildlife Management Congress*. Bethesda, Maryland. The Wildlife Society. Accessed December 1, 2025. <https://sites.warnercnr.colostate.edu/gwhite/wp-content/uploads/sites/73/2017/04/RobustDn.pdf>
- Kindschy, Robert R. 1989. "Regrowth of Willow Following Simulated Beaver Cutting." *Wildlife Society Bulletin* 17:290-294. Accessed December 1, 2025. https://www.jstor.org/stable/3782387?casa_token=nAGlOQlllaQAAAAA%3AvteyeSMBNrcDJ8zO60MWpnMXaM52qgV7vVjRzKCBHrViAqudh-SRnlW79fmDAs4-ifJ6PitfIRJkPGxLW9Nk3qPvVse340Jd6T10-GtTVMDcGcecQ&seq=1
- Levine, Rebekah, and Meyer, Grant A. 2014. "Beaver Dams and Channel Sediment Dynamics on Odell Creek, Centennial Valley, Montana, USA." *Geomorphology* 205:51-64. Accessed December 1, 2025. <https://doi.org/10.1016/j.geomorph.2013.04.035>
- Levine, Rebekah, and Meyer, Grant A. 2019. "Beaver-generated Disturbance Extends Beyond Active Dam Sites to Enhance Stream Morphodynamics and Riparian Plant Recruitment." *Scientific Reports* 9:8124. Accessed December 1, 2025. <https://www.nature.com/articles/s41598-019-44381-2>
- Morrison, Joan, L. 1992. "Persistence of the Meadow Jumping Mouse, *Zapus hudsonius luteus*, in New Mexico." *Southwestern Naturalist* 37:308-311. Accessed December 1, 2025. DOI:[10.2307/3671875](https://doi.org/10.2307/3671875)
- Orr, Matthew R., Weber, Nicholas P., Reuter, Ron J., Herzog, Skuyler P., Broughton, Heather M., and Bango, Samantha. 2024. "Multiyear Trajectories of Stream and Riparian Responses to Beaver Dam Analogs on a Low-gradient Channel Lacking Woody Riparian Vegetation." *Restoration Ecology* 32:e14223. Accessed December 1, 2025. <https://onlinelibrary.wiley.com/doi/10.1111/rec.14223>
- Pollock, Michael M., Beechie, Timothy J., Wheaton, Joseph M., Jordan, C. E., Bouwes, Nick, Weber, Nicholas, and Volk, Carol. 2014. "Using Beaver Dams to Restore Incised Stream Ecosystems." *BioScience* 64:279-290. Accessed December 1, 2025. <https://academic.oup.com/bioscience/article/64/4/279/2754168>
- Ryon, Thomas R. 1996. *Evaluation of the historic capture sites of the Preble's meadow jumping mouse in Colorado*. MS thesis, University of Colorado, Denver.
- Schorr, Robert A. 2001. *Meadow jumping mice (Zapus hudsonius preblei) on the U.S. Air Force Academy, El Paso County, Colorado*. Unpublished report to the U.S. Air Force Academy. Accessed December 1, 2025. <https://sites.warnercnr.colostate.edu/rschorr/wp-content/uploads/sites/139/2020/04/2001-AFA-PMJM-report.pdf>
- Schorr, Robert A. 2003. *Meadow jumping mice (Zapus hudsonius preblei) on the U.S. Air Force Academy, El Paso County, Colorado: populations, movement, and habitat from 2000-2002*. Unpublished report to the U.S. Air Force Academy. Accessed December 1, 2025.

<https://sites.warnercnr.colostate.edu/rschorr/wp-content/uploads/sites/139/2020/04/2003-AFA-PMJM-report.pdf>

Schorr, Robert A. 2012. "Using a Temporal Symmetry Model to Assess Population Change and Recruitment in the Preble's Meadow Jumping Mouse (*Zapus hudsonius preblei*)."
Journal of Mammalogy 93:1273-1282. Accessed December 1, 2025. <https://sites.warnercnr.colostate.edu/rschorr/wp-content/uploads/sites/139/2020/02/2012-Schorr-PMJM-lambda.pdf>

Schorr, Robert A., and Mihlbachler, Brian S. 2018. "Understanding Habitat Quality for Preble's Meadow Jumping Mouse: How Survival Responds to Vegetation Structure and Composition."
Journal of Fish and Wildlife Management 9:545-553. Accessed December 1, 2025.
<https://sites.warnercnr.colostate.edu/rschorr/wp-content/uploads/sites/139/2024/04/2018-Schorr-and-Mihlbachler-Understanding-Habitat-Quality-for-Prebles-Meadow-Jumping-Mouse-How-Survival-Responds-to-Vegetation-Structure-and-Composition.pdf>

Schorr, Robert A., Mihlbachler, Brian S., Grunau, Lee, and Gilb, Roy. 2026. *Conservation and Management Plan for Preble's meadow jumping mouse on the U.S. Air Force Academy*. Department of Defense, Colorado Natural Heritage Program, U.S. Fish and Wildlife Service. Accessed December 1, 2025.

Stringer, Andrew P., and Gaywood, Martin J. 2016. "The Impacts of Beavers *Castor* spp. on Biodiversity and the Ecological Basis for their Reintroduction to Scotland, UK." *Mammal Review* 46:270-283. Accessed December 1, 2025. <https://onlinelibrary.wiley.com/doi/full/10.1111/mam.12068>

Smith, J. Dungan. 2007. "Beaver, Willow Shrubs, and Floods." Pages 603 – 672 in Johnson, E. A., and Miyanishi, K., editors. *Plant Disturbance Ecology: The Process and Response*, Elsevier Academic Press, Burlington, Massachusetts. Accessed December 1, 2025. <https://doi.org/10.1016/B978-012088778-1/50021-2>

(USFWS) U.S. Fish and Wildlife Service. 2018. *Preble's Meadow Jumping Mouse Recovery Plan*, Colorado. Region 6, Lakewood, Colorado. Accessed December 1, 2025.
https://ecos.fws.gov/docs/recovery_plan/Final_Draftpreblesrecoveryplan_10032018_signed.pdf

Weber, Nicholas, Bouwes, Nicolaas, Pollock, Michael M., Wheaton, Joseph M., Wathen, Gus, Wirtz, Jacob, and Jordan, Chris E. 2017. "Alteration of Stream Temperature by Natural and Artificial Beaver Dams." *PLOS One* 12:e0176313. Accessed December 1, 2025.
<https://doi.org/10.1371/journal.pone.0176313>

Wheaton, Joe M., Bennett, Stephen N., Bouwes, Nicolaas, Maestes, Jeremy D., and Shahverdian, Scott M. 2019. *Low-tech Process-based Restoration of Riverscapes: Design Manual*. Utah State University Restoration Consortium. Logan, UT. Accessed December 1, 2025.
<https://lowtechpbr.restoration.usu.edu/manual/>

Wohl, Ellen, and Inamdar, Shreeram. 2025. "Beaver Versus Human: The Big Differences in Small Dams." *Wiley Interdisciplinary Reviews: Water* 12:e70019. Accessed December 1, 2025.
<https://wires.onlinelibrary.wiley.com/doi/10.1002/wat2.70019>