INFLUENCE OF MINK PREDATION ON BROWN TROUT SURVIVAL AND SIZE-STRUCTURE IN RAPID CREEK, SOUTH DAKOTA

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Wildlife and Fisheries Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the Department of Natural Resource Management.

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ABSTRACT

INFLUENCE OF MINK PREDATION ON BROWN TROUT SURVIVAL AND SIZE-STRUCTURE IN RAPID CREEK, SOUTH DAKOTA

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I compared movement, home range, habitat selection, and mortality among radio-tagged Brown Trout (*Salmo trutta*) at an American Mink (*Neovison vison*)-removal site, improved habitat site, and an undisturbed stream site in Rapid Creek, South Dakota. I observed high, post-surgery (> 26 days) survival rate (90%) of radio tagged Brown Trout. Average gross movement of Brown Trout was greater at the improved habitat site (127 m) compared to the mink removal (31 m) site, while average home range size (i.e., stream distance) among all three sites was not significantly different indicating strong site fidelity (125 to 200 m). Brown Trout movements were greatest in the Fall-Winter when fish selected deeper water habitats (pools and runs). No apparent mink predation occurred in the mink removal site, whereas 22% (7 of 32) of fish fates were attributed to apparent mink predation at other sites.

I assessed mean weekly mink activity, along with the abundance and apparent survival of Brown Trout before (29 weeks) and after (36 weeks) predator block management efforts were implemented at the mink removal site. Mean weekly mink activity decreased in the improved habitat (-43%) and mink removal (-55%) sites after predator block management was initiated, while there was no significant decrease in

mink activity at the undisturbed site. After mink removals were implemented, I observed substantially higher abundance and apparent survival of Brown Trout at the mink removal site compared to the improved habitat site, and substantially higher apparent survival in the mink removal site compared to the undisturbed stream site. There was essentially no change in Brown Trout abundance at the undisturbed site.

Mink activity varied with time of year and was greatest during early Spring and late Summer, coinciding with the breeding season and juvenile dispersal period, respectively. Using radio telemetry, I evaluated the movements of mink at the improved habitat and undisturbed sites. I observed similar patterns in mink movement at the improved habitat (gross movement; 775 m) and undisturbed sites (665 m); however, home range size indicated stronger site fidelity in the improved habitat area (1,987 m) compared to the undisturbed site (4,510 m). I found that localized, mink removal efforts reduced mink activity and thus their predation on Brown Trout, resulting in lower gross movement, and greater trout abundance and apparent survival. The removal of two, adult mink from the mink removal site may have eliminated territorial boundaries and allowed mink from the improved habitat site (3.6 km upstream) to expand their home range further downstream explaining the unexpected decrease in mean weekly mink activity at that site. Smaller average home range distance in the improved habitat area allowed mink to concentrate their movements, which may be a result of the additional overwater structure that mink use to hunt prey.

CHAPTER 1

INTRODUCTION

There are 15 recognized subspecies of American Mink (*Neovison vison*) distributed throughout northern North America and they are typically found inhabiting riparian areas, lake shorelines, and coastal marshes (Eagle and Whitman 1987; Trani and Chapman 2007). Since their introduction to Europe for fur farming, American Mink have become well established (Bonesi and Macdonald 2004a; Cuthbert 1973) and their expansion has caused conservation concerns related to competition with and predation of native species, leading to substantial reductions or local extinctions (MaCdonald and Harrington 2003; Melero et al. 2008; Previtali et al. 1998). Mink are versatile, wetland-dependent species, able to adapt their feeding habits and habitat use based on prey availability owing to their generalist diet (Bonesi and Macdonald 2004a; Gerell 1967) that consists of small mammals, birds, amphibians, crayfish, and fish (Ben-David et al. 1997; Burgess and Bider 1980; Cuthbert 1979; Erlinge 1969). This adaptability combined with their effective search-and-pursuit hunting strategy (Dunstone 1978) can lead to negative impacts on local vertebrate species (aquatic, avian, and terrestrial).

While American Mink are opportunistic predators, fish typically comprise an appreciable proportion of the small mustelids forage base. Using mink fecal analysis, Cuthbert (1979) observed diets consisting of mammals, birds, and fish, with 67% of the scats containing fish remains (47% of which were salmonid). Similar diet items were observed by Erlinge (1969), with 60% containing fish. This high predation on fish is also observed directly through studies on salmonid movement using radio telemetry (Davis et al. 2016; Lindstrom and Hubert 2004) and by comparing salmonid mortality rates during periods with and without the presence of mink (Heggenes and Borgstrom 1988). In North America, Brown Trout (*Salmo trutta*) provide important sport fishing opportunities and are one of the most expansively introduced fish species (Fuller et al. 1999). Native to Europe, northern Africa, and western Asia, Brown Trout were first brought to the United States from Germany in 1883 (Courtenay et al. 1984; Mather 1889) and subsequently introduced into streams in the Black Hills of western South Dakota in 1890 (Barnes 2007; Miller 2014).

The Black Hills contain approximately 1300 km of streams including about 400 km of fishable, spring-fed trout streams along Spearfish Creek, Rapid Creek, Whitewood Creek, Spring Creek, and Crow Creek (Miller 2014), with suitable habitat allowing Brook Trout (*Salvelinus fontinalis*), Rainbow Trout (*Oncorhynchus mykiss*), and Brown Trout to thrive. Pactola Reservoir is positioned on Rapid Creek approximately 20 km West of Rapid City, South Dakota and produces cold-water hypolimnetic discharge, resulting in a productive and popular catch-and-release tailwater trout fishery throughout most of the year. Supplemental stockings in the Black Hills management area are implemented in stream reaches where environmental conditions reduce the opportunity for self-sustaining trout populations (Miller 2014). However, the tailwater fishery on Rapid Creek boasts healthy, naturalized populations of Brook Trout and Brown Trout, so the most biologically justified management strategies are catch-and-release regulations and manipulations of biotic and abiotic.

Annual population surveys on Rapid Creek in the Black Hills of South Dakota revealed that the abundance of adult Brown Trout (≥ 200 mm total length) biomass had declined by approximately 70% in the mid-to-late-2000's (Carreiro and Wilhite 2007). This became a concern for area managers due to the popularity of this stream as both a "class 1" fishery (Galinat et al. 2014) at the tailwater section below Pactola Reservoir dam and a local fishery for residents of Rapid City. During this period, the region was experiencing a protracted drought (2002-2005) resulting in below average annual discharge in Rapid Creek, potentially reducing carrying capacity for Brown Trout. While the drought period was associated with low trout biomass, it did not fully explain the population decline of adult Brown Trout in Rapid Creek (James et al. 2010). Thus, other impacting factors were proposed, such as nuisance algal species and fish emigration. Reports of nuisance blooms of *Didymosphenia geminata* coincided with drought conditions, leading fisheries managers to suspect this may have contributed to the decline of Brown Trout. Research investigating these hypotheses indicated that *D. geminata* alters invertebrate communities. However, a diet study evaluating gut fullness, growth, and condition of fish revealed that food availability was not a limiting factor for Brown Trout, and juvenile Brown Trout abundance increased in this section of the creek (James and Chipps 2010).

Subsequently, in 2010 and 2011, Davis et al. (2016) performed a radio telemetry study on Brown Trout in Rapid Creek below Pactola Reservoir where they observed 31.6% (18 of 57) of fish mortality was associated with apparent American Mink predation, with 80% of those fish being less than 300 mm. An additional inference from this research was that high discharge over time resulted in altered stream hydrology and degraded in-stream habitat, leading to the hypothesis that a lack of stream complexity could be a potential limiting factor. In response to this hypothesis, habitat restoration efforts began in the Winter of 2015-2016 on a 760-meter section of Rapid Creek directly below the dam on Pactola Reservoir to increase stream complexity through the addition of large woody debris, in-stream boulder placement, bank reinforcement, and dredging out embanked pools. In-stream habitat manipulation is often used to improve populations of stream-dwelling salmonids (Whiteway et al. 2010), which is linked to increases in trout biomass, abundance, and survival (Baldigo et al. 2008; Binns 2004). Riley and Fausch (1995) observed an increase in abundance and biomass of age-2 and older trout in six northern Colorado streams following habitat enhancement, while Solazzi et al. (2000) observed an increase in salmonid abundance following the increase of winter habitat in two coastal Oregon streams.

However, while habitat improvements are imperative for the recovery or sustainment of fish populations, they may not eliminate exposure to piscivorous terrestrial and avian predators. Burgess and Bider (1980) observed an increased biomass of trout and Crayfish (*Cambarus bartoni*) after improving overhead cover and pool habitat through the addition of boulders, woody debris, and small dams. This coincided with an increase in mink activity. Scat analysis, however, revealed that it was likely associated with the increased biomass of Crayfish. However, the improved habitat section on Rapid Creek lacks a vulnerable secondary aquatic prey species (e.g. Crayfish), which may promote higher mink predation on local salmonids.

Understanding the movements and mortality sources of stream fishes is important for evaluating and managing fish populations. In particular, interpreting movements of salmonids provides inference into their life history strategies (Soloman and Templeton 1976), spawning migrations (Rustadbakken et al. 2004), and habitat use (Young 1995). Many studies have focused on movements of Brown Trout in lotic systems (Bunnell Jr. et al. 1998; Burrell et al. 2000; James et al. 2007), often providing insight on the effects of abiotic factors such as discharge (Bunt et al. 1999), water temperature (Garrett and Bennett 1995), and photoperiod (Clapp et al. 1990). Additionally, individual characteristics, such as fish size (Meyers et al. 1992) and feeding strategy (Bachman 1984), are known to influence Brown Trout movement. With so many variables related to a fish's movement, it is important to have a general understanding of their behavioral responses to varying conditions.

In this study, I monitor and compare Brown Trout movements (gross movements and home ranges), habitat selection, and mortality sources using radio telemetry methods (Enders et al. 2007) among three sections of Rapid Creek that include the in-stream improved habitat area, a predator-block management area where mink were actively trapped and removed, and a undisturbed stream section. Improving the physical habitat characteristic in a stream by dredging pools and reinforcing banks, along with adding boulders, large woody debris, and coarse substrate makes it possible to improve salmonid population densities, survival, and recruitment through increasing depth and flow conditions (Brittain et al. 1993; Burgess and Bider 1980; House and Boehne 1985;

NÄSlund 1989), improving overhead cover (Boussu 1954; Eklov et al. 1999), and enhancing spawning substrate (Palm et al. 2007; Pulg et al. 2013).

A second objective of this study was to compare the seasonal distribution of mink activity among the three study sections of Rapid Creek before and after mink removals occurred. Mink activity generally increases during two distinct time periods: the breeding season in the Spring and juvenile dispersal period in the Fall (Bonesi and Macdonald 2004b; Burgess and Bider 1980). In addition to evaluating mink distribution before and after removal, I used a before-after-control-impact (BACI) experimental design to monitor changes in Brown Trout abundance and apparent survival among the three study areas. Heggenes and Borgstrom (1988) observed higher rates of fish mortality during periods of mink presence and concluded that stream sites with a lack of a secondary prey may result in mink predation reducing fish abundance.

The third and final objective of my study was to capture and surgically implant radio transmitters into mink in the improved habitat and undisturbed stream areas to compare movement patterns and home range distances between the two stream sections. My telemetry efforts provide understanding of this wetland-dependent carnivore, including the amount of stream area covered within home ranges, the potential impact their predation might have on the Brown Trout population, and if effective management strategies can/should be implemented.

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CHAPTER 2

INFLUENCE OF HABITAT AND PREDATION ON BROWN TROUT (SALMO TRUTTA) MOVEMENT AND HOME RANGE

Abstract

We compared movement, home range, habitat selection, and mortality among radio-tagged Brown Trout (*Salmo trutta*) at an American Mink (*Neovison vison*)-removal site, improved habitat site, and an undisturbed stream site in Rapid Creek, South Dakota. We observed high post-surgery survival rates with 90% (43 of 48) of our radio tagged Brown Trout surviving longer than three weeks (>26 days), with 49% (21 of 43) surviving their respective six-month census periods. While we did not identify any significant differences in average gross Brown Trout movement among the study sites, there was a substantially large effect size between the improved habitat (127 m) and mink removal (31 m) sites. Brown Trout movements were highest in the Fall-Winter and we recorded fish selecting for deeper water habitats (pools and runs) more often during these colder seasons. There was no evidence of home range differences among the study areas; however, small average home ranges (125 to 200 m) indicate strong site fidelity. We did not observe any radio tagged Brown Trout mortality associated with mink predation at the site where predator block management was implemented, but we did observe 22% (7 of 32) of fish fate attributed to apparent mink predation at the other sites, combined. As a result, we found that localized, mink removal efforts reduce the threat of mink

predation on Brown Trout, which results in lower average gross movements when compared to the improved habitat and undisturbed stream sites.

Introduction

In-stream habitat improvements are known to enhance survival and abundance of salmonid populations (Whiteway et al. 2010). Rock dams, boulder placement, and large woody debris enhancement improves the amount of overhead cover available by increasing water depth and physical structures, which improves salmonid biomass and survival by lowering predation risk and mortality (Boussu 1954; Eklov et al. 1999; Lonzarich and Quinn 1995). Additionally, the addition or restoration of spawning substrate may increase recruitment of salmonids (Palm et al. 2007; Pulg et al. 2013).

While an important tool for managing fish populations, habitat improvement may not eliminate exposure to avian and(or) terrestrial predators. After improving overhead cover and pool habitat through the addition of boulders, woody debris, and small dams, Burgess and Bider (1980) observed an increase in trout and Crayfish (*Cambarus bartoni*) biomass. Additional surveys and scat analysis revealed that American Mink (*Neovison vison*) activity increased in the improved habitat area compared to an undisturbed stream site and was attributed to increased crayfish biomass. However, in stream reaches without a vulnerable secondary aquatic prey species (e.g. Crayfish), the increase in salmonid biomass may promote increased mink activity and, potentially, predation.

American Mink are efficient fish predators (Dunstone 1978). The generalist feeding behavior of mink allows them to adapt to changes in habitat conditions and prey availability (Bonesi and Macdonald 2004) that can lead to local reductions in fish populations (MaCdonald and Harrington 2003; Previtali et al. 1998). While mink are opportunistic predators (Medina 1997), fish make up an appreciable component of their diet. An analysis of 722 mink scats by Cuthbert (1979) revealed fish, mammalian, and avian diet components, with 67% of the scats containing fish remains (47% of which were salmonid). Similar diet items were discovered in an analysis of 122 mink scats by Erlinge (1969), with 60% containing fish, where they observed that fish prey dominated mink diets in winter. This supports the discovery made by Gerell (1967) that over a five-year period the occurrence of fish in mink diets exhibited seasonal fluctuations with a substantially higher proportion of fish prey in winter.

The decline in adult Brown Trout (> 200 mm TL) biomass in Rapid Creek, South Dakota lead to investigations of the population status. James and Chipps (2010) identified a change in the invertebrate community due to the establishment of nuisance *Didymosphenia geminata*, but an evaluation of feeding and growth revealed that food availability was not a limiting factor for Brown Trout. From this, James (2011) hypothesized that the hypolimnetic release of water from the Pactola Reservoir kept Rapid Creek warm enough in the winter months to prevent the formation of solid or frazil ice conditions, leaving fish vulnerable to mink predation throughout the year. Additionally, Lindstrom and Hubert (2004) observed 8% Cutthroat (*Oncorhynchus clarki*) and 28% Brook Trout (*Salvelinus fontinalis*) mortality associated with mink predation while evaluating fish movements via biotelemetry in a western Wyoming watershed, and speculated that the lack of complete ice cover may enhance mink predation on salmonids. An evaluation of Brown Trout movement using radio telemetry in Rapid Creek found that 32% (18 of 57) of radio tagged fish mortality was attributed to American Mink predation (Davis et al. 2016).

The objective of this study was to compare Brown Trout movement, habitat selection, and mortality among three sections of Rapid Creek, that include an in-stream improved habitat area, a predator-block management area where mink were actively trapped and removed, and an undisturbed stream area. We evaluate sources of mortality of radio tagged Brown Trout and hypothesize that localized mink removal will result in increased survival and abundance of Brown Trout

Methods

Study Area

We selected three, 500 m sections of Rapid Creek below Pactola Reservoir to monitor movement and mortality of adult Brown Trout (Table 2.1). The farthest upstream study site (hereafter, improved habitat) is approximately 20 km West of Rapid City, sitting just below the basin of Pactola Reservoir, and underwent habitat improvement efforts in the Winter of 2015-2016 by dredging pools, reinforcing stream banks, and adding boulders and large woody debris. Approximately 3.6 km downstream from the improved habitat site, near Placerville, South Dakota, we established a predator block management site (hereafter, mink removal) by actively trapping and removing mink. A third site (hereafter, undisturbed) was located approximately 16.1 km downstream from the mink removal site near the town of Hisega, South Dakota (Table 2.1).

Fish Collection and Tagging

We collected adult Brown Trout (> 200 mm total length, TL) in Rapid Creek using backpack electrofishing (Smith Root LR-24, Vancouver, Washington, USA) and censused movement patterns from 21 November 2017 to 26 March 2019. Fish used for radio tracking were collected and tagged during two tagging events (Fall 2017, n = 24; Summer 2018, n = 24). Adult Brown Trout collected during each time period were placed into in-stream holding cages for processing. Individual Brown Trout (mean size = 319 mm, 334 g; transmitter < 2% body weight) were selected one at a time from the holding cages and anesthetized using CO_2 (0.3 ml acetic acid + 1.6 g baking soda/L). Once anesthetized, we measure total length (mm) and weight (g), then placed fish supine in a foam restraining block to restrict movement during surgery. Water containing anesthetic solution was circulated through the mouth and over the gills to maintain anesthesia. Using disinfected surgical tools and aseptic methods, we performed the shielded needle technique (Ross and Kleiner 1982) to surgically implant fish with radio transmitters (Advanced Telemetry Systems, Isanti, Minnesota, USA; model 1570F, 13x24x6 mm, 3.1 g, 30 pulses per minute, 257-day battery life; frequency range = 148.341 to 151.205 MHz). Each fish also had a passive integrated transponder (PIT) tag (Oregon RFID, Portland, Oregon, USA; 12x2.12 mm, 0.1 g, HDX PIT) injected (UID Multi PIT Tag Injector, Lake Villa, Illinois, USA) into its body cavity as a means of secondary identification in the event of tag expulsion or predation.

We tagged a total of 24 Brown Trout (n = 8 per site) in Fall 2017 (late November). Mean total length of fish was 302 mm (range = 233-390 mm) and mean weight was 280 g (range = 132-554 g) for a mean tag weight-to-body weight burden of 1.32%. In Summer 2018, we collected and tagged 24 Brown Trout (July-September). Mean total length of fish was 335 mm (range = 255-410 mm) and mean weight was 388 g (range = 146-618 g) for a mean tag-to-body weight burden of 0.90% (Table 2.2). Using surgically implanted transmitters that weigh less than 2% of fish body weight, we assumed the radio transmitters had minimal to no effect on general Brown Trout characteristics of growth, survival, or swimming performance (Adams et al. 1998; Bridger and Booth 2010; Jepsen et al. 2008; Zale et al. 2005) and that Brown Trout used in these studies adequately represent the Rapid Creek population. We tracked radio tagged Brown Trout for the duration of the telemetry period or until a predation event or transmitter loss occurred.

Tracking and Determining Fates

We used a Biotracker VHF Receiver (Lotek, Seattle, Washington, USA) with a three-pronged foldable antenna to record weekly locations for each radio tagged Brown Trout. We tracked fish for a maximum of 176 days, owing to the life expectancy of transmitter batteries (~257 days). This eliminated any telemetry results being assigned an unknown fate due to battery failure. We did not analyze telemetry data during the first week of each tracking period to provide fish time to resume normal behaviors. However, we still tracked and located fish to monitor immediate post-surgery survival and movements. During each subsequent weekly tracking event, we recorded data for each fish that included: a GPS point of the fish's location, date, precipitation, terrestrial predator sightings or signs, and stream habitat type the fish used. We classified stream habitat type as pool, riffle, or run (McMahon et al. 1996). To record these variables for each fish, we used a Bluetooth GPS (Bad Elf GNSS Surveyor) connected to a tablet (Samsung Galaxy Tab A 10.1") with the Survey123 application installed for recording information. We uploaded the data to the ArcGIS Maps platform after every tracking event, checked fish locations on ArcGIS for accuracy, and manually adjusted them as needed. These data points provided information necessary to quantify fish movement and stream habitat selection.

Once per month, after tracking data were collected, we confirmed if fish were alive with their transmitter still intact by walking along the bank or within the stream until a movement up or down from their previous location was observed, confirming their viability. If we discovered that a fish was no longer in the stream or not moving, we attempted to determine a fishes' fate by locating the transmitter and evaluating potential sources of mortality. We assigned an apparent fate to each transmitter found as one of the following: alive, mink predation, avian predation, unknown, or expelled. An "alive" classification was associated with individuals that survived the entire six-month tracking census. Transmitters located in or near a mink latrine, found near the creek with tooth marks, or tracked to a den were listed as "mink predation". "Avian predation" was assigned to transmitters that were discovered in nests (e.g., Bald Eagle [*Haliaeetus* *leucocephalus*]), under trees, or inside of avian predators (e.g., Great Blue Heron [*Ardea herodias*]) that flushed during investigations. "Unknown" fates were assigned to transmitters that either failed or were out of range and never located. Finally, a classification of "expelled" was assigned to fish that successfully survived surgery and were tracked several times before finding their radio transmitter in the water. Subsequent surveys revealed that these fish were alive with surgery scars or sutures still visible and confirmed via their PIT tag.

Measuring Movement Distances

Using ArcGIS Maps and a distance measuring tool, we measured distances between locations chronologically starting with the initial tracking event. Data derived from fish tracking included gross movement and home range size for each fish. Gross movement of each fish represented the distance (m) that a fish moved either upstream or downstream from its previous location every ~1 week. Home range was calculated by measuring the distance between the most upstream point and the most downstream point that a fish was located (Young 1994; Höjesjö et al. 2007; Ertel et al. 2017). Additionally, we calculated gross movement and home range distances as an average of seasonal patterns.

Seasons were categorized as Winter-Spring (10 January 2018 to 16 May 2018; day 49 to 175), Summer-Fall (25 July 2018 to 31 October 2018; day 245 to 336), or Fall-Winter (1 November 2018 to 9 January 2019; day 337 to 413). Movement data were collected from Brown Trout during two tagging events: a census period lasting from 21

November 2017 to 16 May 2018 (n = 24 fish) and a census period lasting from 25 July to 27 February 2019 (n = 24 fish). We combined the two telemetry periods to include all 48 radio tagged Brown Trout for a single census period lasting from 21 November 2017 to 27 February 2019.

Data Analysis

Gross Movement, Home Range, and Habitat Selection

To begin, we removed five radio tagged Brown Trout from analysis due to small sample sizes (< 5 movements recorded), we removed observations outside telemetry census period (10 January 2019 to 27 February 2019), which eliminated an additional radio tagged Brown Trout, and we removed dates with seasonal overlap (21 November 2017 to 9 January 2018). The final data set used for movement analysis containing 42 radio tagged fish with movements monitored from 10 January 2018 to 9 January 2019. Seasonal ranges were set as 10 January 2018 to 16 May 2018 (day 49 to 175) for Winter-Spring, 25 July 2018 to 31 October 2018 (day 245 to 336) for Summer-Fall, and 1 November 2018 to 9 January 2019 (day 337 to 413) for Fall-Winter (Figure 2.1; Figure 2.2).

Using this data set, we performed a one-way analysis of variance (ANOVA) test to compare fish length among study areas; correlation analysis was used to evaluate the relationship between mean movement and fish length (Bunnell Jr. et al. 1998). Mean gross movement of Brown Trout was compared using a mixed model analysis of variance test with location (site) as a main effect, time (season) as a covariate, and individual fish as a random effect. We compared differences among LS Means using a Tukey-Kramer pairwise comparison for unequal sample sizes (Cody and Smith 2006). Lastly, we used one-way ANOVA to evaluate the effects of location on home range size and a t-test to compare home range distances of fish between the first tagging event (21 November 2017 to 16 May 2018; Fall-Spring) and second tagging event (25 July 2018 to 27 February 2019; Summer-Winter) at each study site.

Habitat selection by Brown Trout was classified into one of three categories defined as pool, riffle, or run habitat. We compared habitat selection by Brown Trout among study areas (improved habitat, mink removal, and undisturbed stream) and seasons (Fall-Winter, Summer-Fall, and Winter-Spring) using a Pearson's Chi-square test.

Results

Gross Movement

A total of 734 fish locations were collected from 42 radio tagged Brown Trout from 10 January 2018 to 9 January 2019. Mean total length of fish varied among the improved habitat (347 mm; 410 g), predator block management (327 mm; 376 g), and undisturbed areas (282 mm; 219 g; ANOVA, $F_{2, 45} = 9.99$; $P < 0.001$). Mean size of Brown Trout in the undisturbed reach (282 mm; 219 g) was significantly lower than fish at the improved habitat (347 mm; 410 g) or mink removal (327 mm; 376 g) sites (Tukey's HSD test, $P<0.05$). However, we found no relationship between mean gross movement and fish total length ($r = 0.05$; $P= 0.73$).

Average gross movement of Brown Trout varied by season and location (interaction effect, $F_{4, 724} = 3.71$, P = 0.005). Differences in LS Means, showed that Brown Trout movement was greater for fish at the improved habitat site (111 m) compared to fish at the mink removal site (30 m; t = 3.08, P = 0.006; Table 2.3). Brown Trout movement was similar among fish in the improved habitat site (111 m) and undisturbed stream site (61 m), and among fish at the undisturbed stream site (61 m) and the mink removal site (30 m; P > 0.2). On a seasonal basis, Brown Trout movement was greater during Fall-Winter (146 m) than Summer-Fall (67 m) periods (differences in LS means, t = 2.55, P = 0.03) but similar during other seasons (P > 0.2; Table 2.3).

Home Range

Of the 42 radio tagged Brown Trout we used for analysis, the average home range size of these fish was 165 m, with 34 of them (81%) exhibiting home ranges less than 250 m (half of our study area distance). Mean home range size of tagged Brown Trout was similar among the improved habitat (178 m, n = 11), predator block management (200 m, n = 16), and undisturbed area (125 m, n = 15; $F_{2, 39} = 0.61$; P = 0.55; Table 2.4). Additionally, we observed substantially smaller mean home range distances during the Fall-Spring (126 m, n = 22; 21 November 2017 to 16 May 2018) telemetry study period compared to the Summer-Winter (213 m, n = 20, 25 July to 27 February 2019) period (t = -1.5, P = 0.14). Within the Fall-Spring telemetry period, mean fish home ranges were 106 m (n = 6) in the improved habitat site, 188 m (n = 8) in predator block management site, and 78 m (n = 8) in the undisturbed stream site, which were all lower than Summer-

Winter period mean home ranges of 265 m (n = 5) in improved habitat site, 265 m (n = 8) in predator block management site, and 179 m (n = 7) in undisturbed stream site. Home range distances were further analyzed using a t-test to compare between the first and second telemetry studies at each site. Welch's two-sample t-tests indicate that there was no statistically significant difference when comparing between time periods at each study site for the improved habitat ($t = -0.99$; $P = 0.38$), predator block management ($t = -0.26$; $P = 0.8$), or undisturbed area ($t = -1.21$; $P = 0.27$).

Habitat Use

We recorded a total of 734 habitat locations (pool, riffle, or run) by 42 radio tagged Brown Trout and categorized them by study area and season. Pearson's Chi-Squared test ($\alpha = 0.05$) revealed a significant association between Brown Trout habitat use and season ($X^2 = 20.60$; df = 4; $P < 0.001$; Table 2.5). Brown Trout displayed a strong association with pools during the Fall-Winter (18.72%), riffles in the Summer-Fall (17.21%), and runs in the Fall-Winter (16.08%) and Winter-Spring (26.25%). Similarly, telemetry observations revealed that pools (46%) and runs (30%) were dominant habitats selected by trout in the Winter-Spring (Figure 2.3). Fish had higher selection for pools and less selection of runs as seasonal temperatures increased in the Summer-Fall (47.74% and 20.58%, respectively) followed by the spawning season in the Fall-Winter (60.87% and 17.39%, respectively; Figure 2.3).

We observed a significant association between Brown Trout habitat selection and study location ($X^2 = 216.19$; df = 4; $P < 0.001$). Observed locations of Brown Trout were associated with pools in the improved habitat and mink removal sites, whereas fish in the undisturbed site selected for riffle (Table 2.6). Pool habitat was selected substantially more in the predator block management (68%) and improved habitat (60%) areas when compared to the undisturbed stream (18%; Figure 2.4). Brown Trout in the undisturbed stream tended to select riffle habitat (55%), whereas trout in the improved habitat site rarely used riffle habitat (5%).

Fate and Predation

We tracked and determined the fates for 48 radio tagged Brown Trout from 21 November 2017 to 9 January 2019 (Table 2.7) and discovered that half (24 of 48) of the fish survived through their entire respective telemetry census periods. Of Brown Trout that did not survive, 25% (12 of 48) of their fates were attributed to lost fish (n = 10) or expelled tags (n = 2). These events are likely attributed to avian predators or, less likely, extremely long fish movements taking transmitters out of range, illegal angler harvest, or premature battery failure. The other 25% of fish fates were confirmed mortalities related to American Mink (n = 7) or avian predation (n = 5). All radio tagged fish killed by mink were outside of our mink removal area, with four in the improved habitat section and three in the undisturbed area. We confirmed avian predation in all three study areas, with the predator block management experiencing three events and the other two sites having one each. Many of the lost transmitters were likely due to avian predation, but we were unable to definitively confirm via telemetry. Bald Eagles were present throughout the research period and we began to see substantial increases in Great Blue Heron presence and activity during the Spring. We confirmed one radio tagged fish taken by a Heron on 4 April and four others taken by Bald Eagles on 15 March, 22 August, and 21 and 29 November. We personally observed a substantial increase in avian activity in the Spring, which coincided with high numbers of lost radio transmitters between 21 March and 9 May 2018 (one lost in the improved habitat, one lost in the predator block management, and two lost in the undisturbed stream). While we were unable to officially confirm the cause of disappearance, we speculate that avian predation is the most likely source.

During the Fall-Spring radio telemetry period we discovered that 33.3% (8 of 24) of radio tagged fish were confirmed dead, with 25% of the study fish (6 of the 8 confirmed mortalities) dying as a result of mink predation (Table 2.7; Appendix A.1). We recovered four radio transmitters from mink latrines; one transmitter was recovered on the bank with tooth imprints on the antenna and transmitter casing. Two transmitters were confirmed in mink latrines, but unable to be recovered due to location. Additionally, 8.3% (2 of 24) were lost to confirmed avian predation; one transmitter was tracked to a Bald Eagle nest and could not be recovered, while another was confirmed to be inside of a Great Blue Heron after flushing the bird multiple times while tracking the radio signal. An additional five radio tagged fish were lost to unknown sources, which were likely avian predation, long-range fish movements, illegal angler harvest, or premature battery failure.

During the Summer-Winter radio telemetry period we documented fewer predation-related mortalities compared to the Fall-Spring period. Only 16.7% (4 of 24) of radio tagged fish experienced confirmed mortality events, and only one fish linked to mink predation (4.2% of total; Table 2.7; Appendix A.3). The other three mortalities (12.5%) were apparent losses to Bald Eagle predation. An additional five radio transmitters were lost to unknown sources, including two fish lost after surgery and never tracked, that were likely associated with avian predation, long distance movements, illegal harvest, or premature battery failure. Finally, there were two incidences of finding radio transmitters in the water. Unknown fate was assigned to these fish until they were subsequently re-captured during electrofishing surveys and confirmed via surgery scars and PIT tags, meaning the radio transmitters were expelled.

Discussion

The focus of adding large woody debris and boulders, along with dredging and reinforcing banks in the Basin section of Rapid Creek was to provide cover, slow water refuge, deeper pools, and stabilized banks. The improved steam characteristics that result from enhancing these habitat conditions have been found to increase salmonid abundance and biomass (Binns 2004; Whiteway et al. 2010). NÄSlund (1989) discovered that Brown Trout densities increased substantially in stream sections following the addition of boulder dams (which increased the mean depth of thalweg, percentage of pool area, and wetted area) and the addition of deflectors (which concentrated stream flow and decreased the wetted area). During evaluation of Brown Trout populations in southern Swedish streams, Eklov et al. (1999) found a positive relationship between fish size and the amount of cover, vegetation, and coarse substrate. Additionally, while monitoring the addition and restoration of coarse substrate in a southern German river to provide more suitable spawning grounds, Pulg et al. (2013) observed an increased number of young-of-the-year Brown Trout, indicating that population recruitment will likely increase after the improvement of coarse substrate. It is well known that habitat improvements benefit the population dynamics of a fishery; in turn, we used radio telemetry to investigate how these improvements affected individual movement, habitat use, and survival when compared to a mink removal area and an undisturbed area.

Radio telemetry is an effective and widely accepted method to evaluate the behavior and survival of fish within their natural environment, with the effects of surgically implanted radio transmitters having minimal effects on the general behavior of salmonid growth, survival, and swimming performance (Adams et al. 1998; Bridger and Booth 2010; Jepsen et al. 2008; Zale et al. 2005). We observed high post-surgery survival rates with ~90% (43 of 48) of our radio tagged Brown Trout surviving longer than three weeks after surgery (> 26 days), and ~50% (21 of those 43) surviving > 176 days. The average gross movement of Brown Trout in our study showed a large effect size (Cohen's D of 0.58) between fish in the mink removal area (30 m) and the improved habitat area (110m), indicating a substantial difference between the two treatments. One explanation for higher mean gross movement in the improved habitat area was provided by Riley and Fausch (1995). They discovered low recapture rates of marked trout after habitat improvements took place and speculate that high emigration rates were due to the pressures of intraspecific competition resulting from increased local trout abundance due to the habitat improvements. Additionally, Burgess and Bider (1980) observed a 52.5%

increase of American Mink activity in the area surrounding an improved habitat section. Although scat studies revealed that those mink did not respond to increases of trout biomass, their presence may influence Brown Trout movement patterns.

Our analysis of home range distances reveal no statistically significant differences between the improved habitat (178 m), mink removal (200 m), or undisturbed stream area (125 m) sites. The small home ranges reveal a strong site fidelity and relatively sedentary behavior, which is typical of Brown Trout inhabiting lotic waters (Garrett and Bennett 1995; Young 1999). While trout in all three study areas exhibited strong site fidelity, the results do not support our hypothesis that habitat improvements would result in significantly less movement and a smaller home range.

Studies by Höjesjö et al. (2007) and Sundström et al. (2004) found that dominant individuals generally exhibit more movement through exploratory and aggressive behavior in comparison to subordinate fish. After comparing mean fish lengths and weights between Brown Trout in the improved habitat area (347 mm; 410 g) and mink removal area (327 mm; 372 g), we saw no significant difference in physical characteristics. While the fish in the site with higher movement were larger on average, our correlation analysis revealed no relationship ($r = 0.05$) between fish size and movement. Young (1994) identified strong site fidelity among radio tagged Brown Trout in two south-central Wyoming streams, with large Brown Trout moving greater distances than small fish. This may be due to roving behavior in search of more beneficial feeding/resting locations. Diet studies have shown an ontogenetic shift in Brown Trout prey from insect-foraging behavior to piscivory around 300-400 mm (Grey 2001; Jensen et al. 2012), which is likely due to the observation made by Elliott and Hurley (2000) that a single prey fish item provides three times more energy gain than insects for Brown Trout. This may be one explanation for why movement in the improved habitat area is greater than the mink removal area, because 67% of our radio tagged fish in the in the improved habitat area were over 350 mm, while only 22% were over 350 mm in the mink removal area.

To further investigate potential reasons for significant differences in movement, we evaluated stream habitat selection by fish and discovered a strong association with pools in mink removal area and riffles in the improved habitat area (Figure 2.4). Brown Trout in the mink removal area were found in pool (68%) and riffle (17%) habitat types more frequently than fish in the improved habitat section (60.1% and 4.6%, respectively), but they used runs (15% compared to 35%) substantially less. Deep water (pool and run) habitat selection by Brown Trout in the improved habitat area was observed 95% of the time, compared to 83% in the mink removal area. The selection of deep-water habitat by Brown Trout follows similarly to findings by Bunt et al. (1999), who observed that pools were selected 75-80% of the time and runs were selected 20-25%. We also observed a change in habitat selection by Brown Trout during the colder season, where they would select for deeper habitats (pools and runs). Pool and run selection comprised 68.3% in the Summer-Fall, and increased to 78.3% during Fall-Winter, and remained at 77% during Winter-Spring. Heggenes and Gunnar Dokk (2001) observed a similar shift toward slow-flowing glide mesohabitats during the Winter by Brown Trout and Atlantic Salmon (*Salmo salar*). The shift observed by our radio tagged adult Brown Trout is likely due to the selection of runs and riffles during the Fall spawning period, followed by a return to the deeper habitats that adult fish tend to prefer (Baran et al. 1997).

Young (1994) observed strong site fidelity among radio tagged Brown Trout in two south-central Wyoming streams and speculated that tracking efforts likely do not influence their mobility or telemetry results due to the numerous avian and terrestrial predators the fish encounter. This brings up another point; we observed a high rate (25%) of radio tagged fish mortality associated with predation. Avian predators were prevalent in our study areas during the Spring, Summer, and Fall, with Eagles remaining in the area through the Winter, and were responsible for the loss of 5 (10%) Brown Trout. However, up to 10 fish (~21%) may have been lost to avian predators but were unconfirmed due to lost signal. Lost signals likely resulted from avian predators capturing radio tagged Brown Trout and taking them beyond the reach of our receiver. The reliability of the transmitter batteries, along with our ability to identify long-range movements of fish that remained in the stream and other, local predation events – strengthen this hypothesis. Mink are the other predatory threat to salmonids in our study area. They are adaptable and opportunistic hunters that forage on fish, birds, mammals, amphibians, crustaceans, insects, and any other vulnerable prey items available (Burgess and Bider 1980; Maran et al. 1998; Medina 1997). However, fish comprise a major component of the food habits of mink scat, making up a large proportion of the total diet, especially in lotic waters (Cuthbert 1979, 67%; Erlinge 1969, 60%). Outside of the mink removal area, mink predation accounted for the fates of 7 of 32 fish (22%) with a majority of predation occurring during the Winter-Spring. These findings are supported by a previous investigation by Davis et al. (2016) that evaluated the movements of Brown Trout along a similar stretch of Rapid Creek below Pactola reservoir during which they discovered that 18 of 57 (31.6%) radio tagged fish succumbed to apparent mink predation.

Finally, in the mink removal area, we did not document any radio tagged Brown Trout mortality associated with mink predation, compared to 25% and 19% mortality due to mink in the improved habitat area and undisturbed area, respectively. Continual lethal trapping is likely the cause for the absence of mink predation within the mink removal area. However, the combined use of deep water and overhead cover in the improved habitat site is likely the reason for less avian predation (one confirmed and an additional one suspected; n = 2) when compared to the predator block management (three confirmed and an additional one suspected; n = 4) and undisturbed stream (one confirmed and three suspected; n = 4) sites (Lonzarich and Quinn 1995). The increased terrestrial predation within the improved habitat area when compared to our undisturbed stream section may be a result of the large woody debris enhancement. We speculate that, since mink are overhead predators, it aided in hunting success. We also observed mink tracks at the areas where woody debris was secured and buried along the banks. This likely provided small interstitial spaces and tunnels that mink use for hunting and latrines for eating, resting, and avoiding predators. While habitat improvements are beneficial to Brown Trout, they may also be beneficial to the wetland-dependent American Mink that are present. Burgess and Bider (1980) discovered that habitat improvement increased the biomass of salmonids and Crayfish (*Cambarus bartoni*).

However, they observed increased mink activity in the area surrounding the habitat improvement area. An evaluation of mink scat revealed that Crayfish was an abundant forage source and the increased biomass was likely the result of increased mink presence in the area, while the salmonids did not appear to be exploited. A lack of a secondary aquatic prey in our habitat improvement section in Rapid Creek likely resulted in mink exploiting the salmonid population within the area.

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Figures and Tables

Table 2.1. Location and description of three study areas that include improved habitat, mink removal, or undisturbed stream.

Site Description	Location	Elevation (m)	Treatment Length (m)	Average Stream Width (m)	Mean Adult Brown Trout Abundance (>200 mm TL)[1]
Improved Habitat (Basin)	44°04'35"N 103°28'53"W	1347	500	11.1	217
Mink Removal (Placerville)	44°04'38"N 103°26'03"W	1335	500	10.4	74
Undisturbed Site (Hisega)	44°03'14"W 103°24'23"W	1233	500	9.2	174

[1]Mean population estimates compiled from three 500 m, single-pass electrofishing surveys during the June, July, and August of 2017.

Table 2. 2. Length, weight, and transmitter attributes for Brown Trout implanted with radio tags in Rapid Creek, South Dakota. Two tagging periods occurred at each site during the census period (November 2017 to January of 2019). Standard error is denoted in parentheses.

			Length (mm)		Weight (g)		Transmitter/Body Weight (g)		Surgery Time (s)	
Tagging Period	Study Treatments	N	Average	Range	Average	Range	Average	Range	Average	Range
November 2017	Improved Habitat	8	323 (18)	248-390	329 (46)	160-554	0.011 (0.002)	0.006-0.019	367 (60)	183-630
	Mink Removal	8	309 (14)	233-362	310 (38)	132-429	0.012 (0.002)	0.007-0.024	323 (29)	241-478
	Undisturbed	8	273 (13)	252-362	199 (29)	151-399	0.017 (0.001)	0.008-0.025	241 (20)	158-328
	Average		302 (10)	233-390	280 (24)	132-554	0.013 (0.001)	0.006-0.024	310 (25)	158-630
July-Sept 2018	Improved Habitat	8	370 (12)	328-410	491 (32)	379-618	0.007 (0.0004)	0.005-0.008	204 (26)	150-375
	Mink Removal	8	344 (12)	305-392	435 (40)	292-615	0.008 (0.001)	0.005-0.011	258 (20)	189-345
	Undisturbed	8	291 (13)	255-362	238 (32)	146-412	0.015 (0.002)	0.008-0.021	277 (26)	165-360
	Average		335 (10)	255-410	388 (30)	416-618	0.009 (0.001)	0.005-0.021	246 (15)	150-375

Table 2.3. Mean gross movement (m) of radio-tagged Brown Trout in each study area. Standard error denoted in parentheses and superscripts represent significant differences among treatments ($P<0.05$).

	Average Gross Movement Distance (m)			
Treatment	Fall-Winter	Summer-Fall	Winter-Spring	Total
Improved Habitat	254 (178)	147 (85)	13 (3)	111 (49)^{a}
Mink Removal	34 (7)	39 (8)	20 (4)	30 (4)^{b}
Undisturbed Site	258 (149)	36 (11)	16 (2)	61 (24)^{ab}
Total	146 (60)	67 (23)	17 (2)	

Table 2.4. Home range distance (m) of radio-tagged Brown Trout in each study area by season and combined for the entire research period. Standard error denoted in parentheses.

	Home Range Distances (m)		
Treatment	Fall-Spring	Summer-Winter	Total
Improved Habitat	106 (36)	265 (157)	179 (74)
Mink Removal	188 (75)	211 (55)	200 (45)
Undisturbed Site	78 (6)	179 (83)	125 (40)

Table 2.5. Seasonal habitat selection by radio-tagged Brown Trout in Rapid Creek, SD 2017-2019. Values represent frequency counts of observed fish locations that were pooled from three study reaches (improved habitat, mink removal and undisturbed site).

	Observed Values		
Habitat	Fall-Winter	Summer-Fall	Winter-Spring
Pool	98	116	153
Riffle	35	77	76
Run	28	50	102

Table 2.6. Site-specific habitat selection of radio-tagged Brown Trout in Rapid Creek, SD. Values represent frequency counts of observed fish locations that were pooled across seasons.

	Observed Values		
Habitat	Improved Habitat	Mink Removal	Undisturbed Site
Pool	119	207	41
Riffle	9	51	128
Run	70	46	64

Table 2.7. Fate table revealing mortality sources of radio tagged Brown Trout during telemetry studies in Fall-Spring and Summer-Winter, along with the fate summary for the entire research period from 21 November 2017 to 27 February 2019.

Fate	Fall-Spring Fate Table				Summer-Winter Fate Table				Research Total Fate Table			
	Improved Habitat	Mink Removal	Undisturbed Site	Total	Improved Habitat	Mink Removal	Undisturbed Site	Total	Improved Habitat	Mink Removal	Undisturbed Site	Total
Total Fish	8	8	8	24	8	8	8	24	16	16	16	48
Alive	3	4	4	11	4	7	2	13	7	11	6	24
Mink	4	0	2	6	0	0	1	1	4	0	3	7
Avian	0	2	0	2	1	1	1	3	1	3	1	5
Lost	1	2	2	5	2	0	3	5	3	2	5	10
Expelled	0	0	0	0	1	0	1	2	1	0	1	2
Total Mortality	0.5	0.25	0.25	0.333	0.125	0.125	0.25	0.167	0.313	0.188	0.25	0.25
Mink Predation	0.5	0	0.25	0.25	0	0	0.125	0.042	0.25	0	0.188	0.146

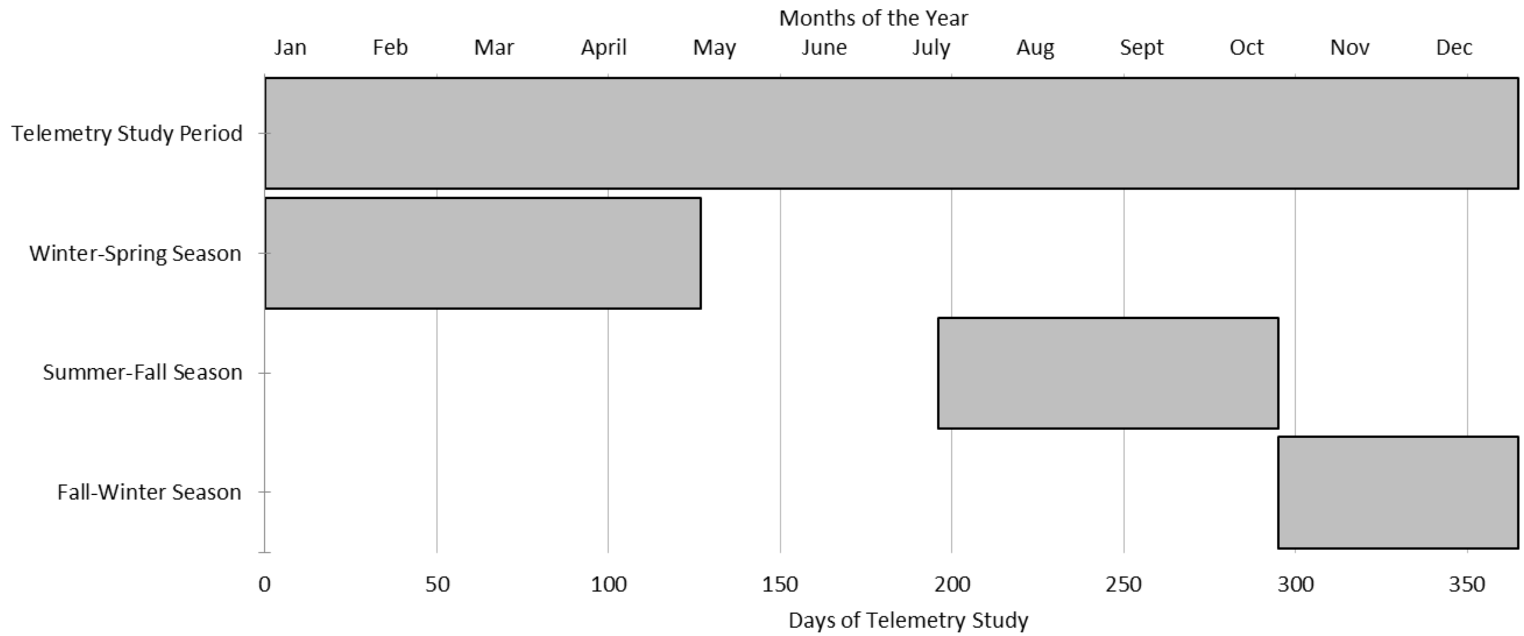

Figure 2.1. Breakdown of seasonal categories used for radio telemetry analysis with 10th of January 2018 to 16th of May 2018 (day 49 to 175) as the Winter-Spring season, the 25th of July 2018 to 31st of October 2018 (day 245 to 336) as Summer-Fall, and the 1st of November 2018 to the 9th of January 2019 (day 337 to 413) as Fall-Winter.

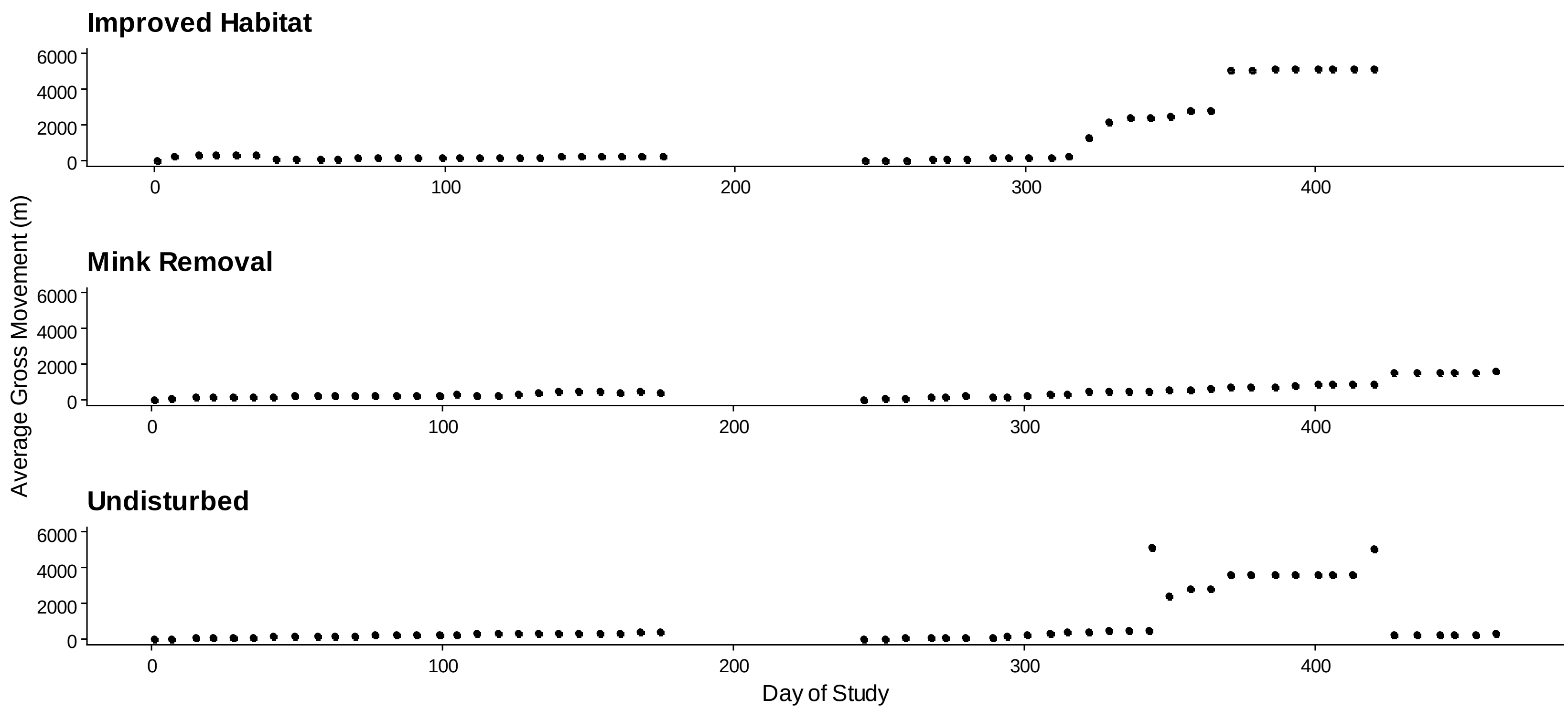

Figure 2.2. Average gross movement by day of study starting with the 10th of January 2018 to 16th of May 2018 (day 49 to 175) as the Winter-Spring season, the 25th of July 2018 to 31st of October 2018 (day 245 to 336) as Summer-Fall, and the 1st of November 2018 to the 9th of January 2019 (day 337 to 413) as Fall-Winter.

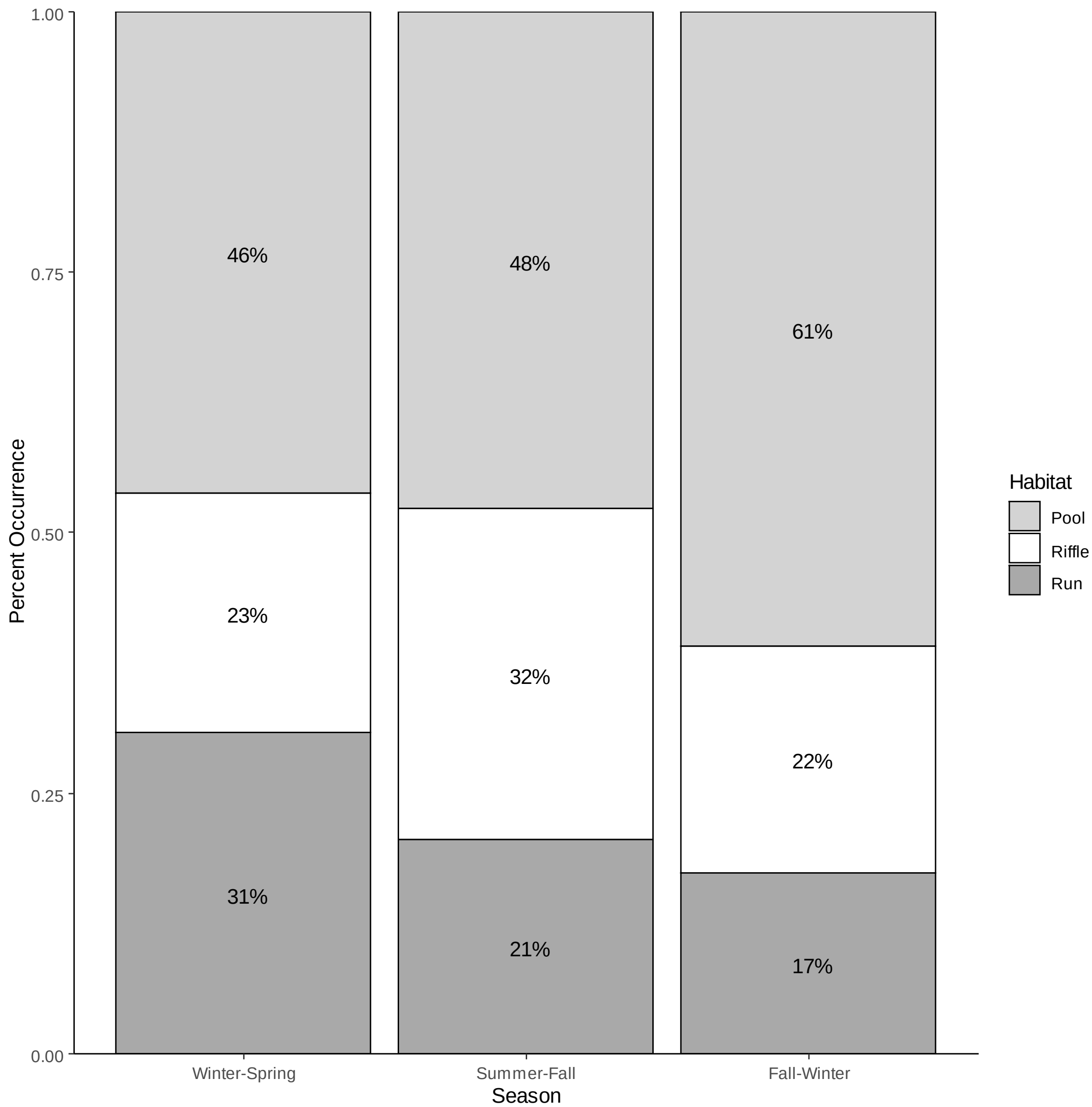

Figure 2.3. Proportion of habitat selection by season for radio tagged Brown Trout in Rapid Creek during the Winter-Spring (n = 331), Summer-Fall (n = 243), and Fall-Winter (n = 161) from the 10th of January 2018 to the 9th of January 2019.

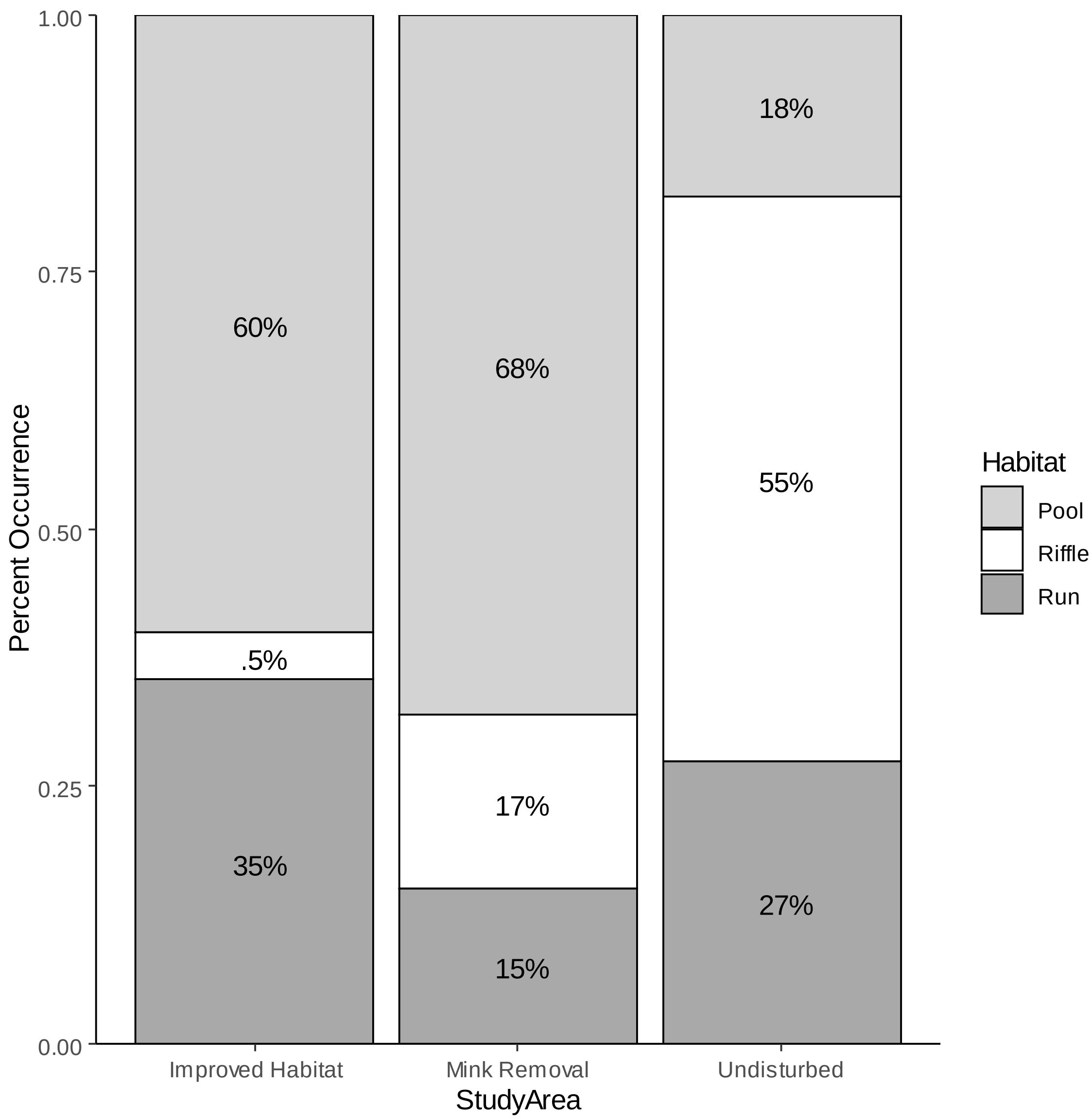

Figure 2.4. Proportion of habitat selection by radio tagged Brown Trout in the improved habitat (n = 198), mink removal (n = 304), and undisturbed site (n = 233) from the 10th of January 2018 to the 9th of January 2019.

CHAPTER 3

EVALUATING THE EFFECTS OF AMERICAN MINK REMOVALS ON BROWN TROUT POPULATIONS AND SEASONAL DISTRIBUTION OF MINK ACTIVITY

Abstract

We assessed mean weekly activity and seasonal distribution of American Mink activity (*Neovison vison*) along with the abundance and apparent survival of Brown Trout (*Salmo trutta*) at three sections of Rapid Creek, South Dakota before (29 weeks) and after (36 weeks) mink removal efforts were implemented at a predator block management site. Mean weekly mink activity significantly decreased in the improved habitat site (by 43%) and the mink removal site (by 55%) after predator block management was initiated, while there was no significant decrease at the undisturbed stream site (by 28%) between the two time periods. Additionally, after mink removals were implemented, we observed a substantial increase in abundance and apparent survival estimates of Brown Trout at the mink removal site when compared to the improved habitat site. Apparent survival also increased at the mink removal site when compared to the undisturbed stream site; however, there was essentially no change in abundance. We observed two time periods when the seasonal mink activity increased: early Spring and late Summer. These increases coincided with mink breeding season and juvenile dispersal periods. It was unexpected to observe a significant decrease in mean weekly mink activity at the improved habitat site after mink removals took place, but we speculate that the removal of two mink from the mink removal site (3.6 km downstream) may have eliminated

territorial boundaries and allowed mink from the improved habitat site to expand their home ranges farther downstream. It also appears that by implementing predator block management efforts in one section of creek, we were able to increase apparent survival and, to an extent, abundance of Brown Trout.

Introduction

American Mink (*Neovison vison*) are versatile, wetland-dependent mammals, able to adapt their habitat use in response to prey availability due to their generalist diet (Bonesi and Macdonald 2004a; Gerell 1967) consisting of small mammals, birds, amphibians, crayfish, and fish (Ben-David et al. 1997; Burgess and Bider 1980; Cuthbert 1979; Erlinge 1969). This adaptability combined with their efficient search-and-pursuit hunting strategies (Dunstone 1978) can impact local vertebrate species (terrestrial, avian, and aquatic) through predation and interspecific competition (MaCdonald and Harrington 2003; Previtali et al. 1998). American Mink are considered an invasive species throughout Europe since their initial introductions for fur farming (Bonesi and Macdonald 2004a; Cuthbert 1973) and their successful establishment has caused conservation concerns related to predation and competition with local wildlife (Melero et al. 2008).

While mink are opportunistic predators, fish typically comprise a predominant source of their forage base. This has been observed through diet analysis of mink scats by Cuthbert (1979) and Erlinge (1969) where 67% and 60% of diets consisted of fish, respectively. During a mark-recapture evaluation of juvenile Atlantic Salmon and Brown Trout, Heggenes and Borgstrom (1988) observed greater mortality during periods of mink presence along the stream. Mink predation is also directly observed during evaluations of salmonid movements via radio telemetry (Krimmer et al. 2011; Lindstrom and Hubert 2004). During an evaluation of Brown Trout movement in Rapid Creek, South Dakota, 32% of radio tagged fish were attributed to apparent mink predation (Davis et al. 2016).

In this study we compare the mean weekly activity and seasonal distribution of American Mink among three sections of Rapid Creek before and after mink removals occur. Our study included a mink removal site, and two unimpacted stream sites; one of which underwent habitat improvements in the Winter of 2015-2016, and the other was an unaltered, undisturbed site. We hypothesize that the distribution of seasonal mink activity is significantly lower in the mink removal area after the implementation of predator block management. Additionally, using a before-after-control-impact (hereafter, BACI) design, we hypothesize that Brown Trout abundance and apparent survival will increase at the predator-removal site, compared to other locations. Due to the piscivorous tendencies of wetland-dependent mink (Cuthbert 1979; Erlinge 1969), we hypothesize that removing them from one study area will result in an increased estimate of Brown Trout abundance and apparent survival when compared to our improved habitat and undisturbed site (Heggenes and Borgstrom 1988). In summary, after predator block management is implemented in the mink removal site, we anticipate seeing a decline in the seasonal distribution of mink activity along with an increase in Brown Trout abundance and apparent survival compared to our other study areas.

Methods

Study Area

We selected three, 500 m sections of Rapid Creek below Pactola Reservoir to monitor movement and mortality of adult Brown Trout. Pactola Reservoir is approximately 20 km West of Rapid City, South Dakota, and our farthest upstream study site (hereafter, improved habitat) was located approximately 0.85 km downstream of Pactola dam. This stretch of stream underwent habitat improvement efforts in the Winter of 2015-2016 by dredging pools, reinforcing stream banks, and adding boulders and large woody debris. Approximately 3.6 km downstream from the improved habitat site, Near Placerville, South Dakota, we established an impact site (hereafter, mink removal) where predator block management efforts were accomplished by actively trapping and removing mink. Our final site was located approximately 16.1 km downstream from the mink removal site, near the town of Hisega, South Dakota and contained similar habitat features as the mink removal site (hereafter, undisturbed). Using two control stream sites with different habitat features in our BACI design, we explored how mink removal influenced mink activity and Brown Trout survival and abundance in Rapid Creek.

Mink Raft Design

Detection of American Mink was accomplished using floating rafts with a clay/sand tracking medium (Reynolds et al. 2004). Our raft design consisted of a sheet of polystyrene (for buoyancy) secured in between plywood boards with eyebolts on each of the four corners. The floating platform approximately 1.2 x 0.6 x 0.06 m was suspended in the creek by connecting the eyebolts to riparian trees or stakes via steel cable wire. We cut a rectangular hole in the middle of the floating platform to hold a 28 x 20 x 10 cm basket (Sterilite Small White Ultra Basket) consisting of a layer of clay/sand mixture on top of floral foam (Floracraft Wet Foam Bricks). The bottom of the basket was submerged below the floating raft, allowing the floral foam to absorb water. The ambient moisture provided by the floral foam prevented the tracking medium from drying out, without flooding the surface and washing away the tracks. To protect the tracking medium from the elements, we fitted a small enclosure (40 x 25 x 15 cm) with a retractable lid over the center of the raft. This enclosure protected the tracking medium from rain, and also provided a dark, overwater structure that may entice their use. Imprints left in the tracking medium were impressionable enough to differentiate them among the mammalian species that used the raft (e.g. mink vs racoon).

Mink Removal, Distribution, and Activity

Six floating rafts were deployed in all three 500 m study reaches from 21 April 2017 until 26 March 2019. Mink removals began in the mink removal section on 21 December 2017 and continued until 26 March 2019. Eight, two-door Havahart live traps (Havahart, Inc., Lilitz, PA; model #1030-B) were placed along riparian areas within our 500 m removal section until 4 April 2018 when we switched to lethal conibears (Bridger Bodygrippers, Minnesota Trapline Products, Inc., Pennock, MN; model size #110). Boxes and floating rafts (4 of each) designed specifically to hold conibears were deployed near riparian areas for the remainder of the study period. Information was not collected in the mink removal site or undisturbed site for the six weeks of 10 January 2018 to 21 February

2018 as rafts were inaccessible due to ice formation. Additionally, information during the 17 weeks from 11 April to 3 August 2018 was lost due to a hardware malfunction on the device where our data were stored. We have omitted these two time periods from analyses.

We conducted raft visits on the same day each week, barring weather setbacks, for the duration of the study to record presence or absence of mink tracks, make any necessary raft repairs, and wipe clean and reapply the tacking medium as needed. We recorded mink activity at a raft with a "1" if tracks were present and a "0" if tracks were absent. At each study area, we summed the number of visited rafts per week (range = 0 if no tracks detected to 6 if all rafts contain tracks) to develop cumulative seasonal distributions of mink activity through time. These allow us to estimate general distribution and activity patterns of mink in our three study areas (Burgess and Bider 1980; Reynolds et al. 2004). We monitored changes in activity patterns at each site by comparing mean tracks per week before and after removals using a paired two-sample t-test. Additionally, we used Cohen's D for two-sample t-tests to determine the effect size difference between the two time periods. The general interpretation guidelines for Cohen's D follow that results around 0.1 are "small" in magnitude, those around 0.3 are "medium", and those around 0.5 are "large" (Durkin 1999; Cohen 1988).

Fish Sampling and Mark-Recapture

Brown Trout, Rainbow Trout (*Oncorhynchus mykiss*), Brook Trout (*Salvelinus fontinalis*), and Lake Trout (*S. namaycush*) were collected at all three study areas using three backpack electrofishing units (Smith Root LR-24, Vancouver, Washington, USA) and then placed in holding cages within the stream. These open-population sampling events took place three times in the Summer of 2017 (June-August) and three times in the Summer of 2018 (August-September) for six total surveys over two years. Captured fish were measured for total length (TL, mm), weighted (g), and given a unique individual marking (fish ≥120 mm TL) by injecting a passive integrated transponder (PIT) tag (Oregon RFID, Portland, Oregon, USA; 12x2.12 mm, 0.1 g, HDX PIT) into their abdominal cavity. During each subsequent survey, captured fish were measured (TL, mm), weighed (g), and scanned (Avid Power Tracker VII, Norco, California, USA) for a PIT tag. Unmarked Brown Trout collected in subsequent surveys were marked by injecting them with a PIT tag and fish containing PIT tags were recorded as recaptured and identified by their PIT tag number (Table 3.2).

Estimates of Fish Survival and Abundance

All Brown Trout used for analysis were captured and measured at least once during the sampling events. Individual capture histories were developed for each Brown Trout by recording a “1” if the fish was observed during a sampling event and a “0” if not. Using these capture histories, we estimated Brown Trout apparent survival using open-population Cormack-Jolly-Seber methods (Cormack 1989; log-linear model) to account for variable capture probabilities related to fish behavior following capture (Ogle 2016a; Ogle 2016b). We estimated apparent survival for two size classes of fish (< 300 mm TL or ≥ 300 mm TL) based on length frequency histograms and findings by Davis et al. (2016)

indicating that 80% of apparent mink predation occurred on fish less than 300 mm total length. Apparent survival estimates were calculated for the two size classes of fish within the improved habitat, mink removal, and undisturbed sites before (Summer 2017) and after (Summer 2018) mink removals were implemented at the mink removal site.

Brown Trout were sampled three times before (Summer 2017) and three times after (Summer 2018) mink removals to evaluated changes in relative abundance. Capture frequencies of Brown Trout were categorized into six 50-mm size classes ranging between >150 mm to <350 mm total length (Table 3.5). Mean capture frequencies for each size class category were determined for the improved habitat, mink removal, and undisturbed stream section before and after mink removals were implemented.

Using the before-after-control-impact design (BACIP; Smith 2002), we determined differences in apparent survival for each size class when comparing the mink removal site to the improved habitat site and undisturbed site before and after predator block management began using the equation:

$$D_{ik} = \mu + \eta_i + \varepsilon_{ik}$$

where μ is the mean difference between control and impact, η_i is the change in difference at site $_i$ from before to after, and ε_{ik} is the error associated with the differences. To test the impact of mink removal, we use a paired two-sample t-test to compare the mean difference between the sites during the two time periods. Furthermore, Cohen's D for two-sample t-tests was used to determine the effect size difference between the means of each group (Cohen 1988).

Results

Mink Removal, Distribution, and Activity

Floating rafts were monitored for 29 weeks before mink removals began on 21 December 2017 and for 36 weeks after. Two mink were successfully removed from the mink removal section on 8 August 2018 and 11 September 2018. We observed a decline in mink activity as evidenced by decreased presence of tracks at our rafts across all study areas after mink removals began (Table 3.1). Mean weekly activity (rafts with tracks) declined in the improved habitat area by 43% from 2.3 (SE = 0.4) to 1.3 (SE = 0.3), in the mink removal area by 55% from 2.6 (SE = 0.3) to 1.2 (SE = 0.3), and in the undisturbed stream area by 28% from 0.9 (SE = 0.3) to 0.7 (SE = 0.3). We observed significant declines in mean weekly activity at the improved habitat site (df = 63; t = -2.16; p = 0.04) and mink removal site (df = 63; t = -3.13; p = 0.003) following mink removals. However, mink activity at the undisturbed site was similar before and after mink removal (df = 63; t = -0.68; p = 0.5). Cohen's D revealed a large effect size after mink removals took place at the improved habitat (0.53) and mink removal (0.78) sites, while there was essentially no effect at the undisturbed (0.17) site.

Seasonal mink activity at the improved habitat and undisturbed stream sites remained low from the initial deployment of mink rafts on 21 April 2017 until an increase during mid July 2017 (Figure 3.1; Figure 3.2), which may be associated with periods of juvenile dispersal from den sites (Bonesi and Macdonald 2004b; Burgess and Bider 1980). However, mink activity in the mink removal site revealed a relatively constant trend until mink trapping began in December 2017. This decreased activity was observed at all three study sites and lasted until April 2018. This is likely a response to the presence of our traps (we also deployed live traps in December 2017 at the improved habitat and undisturbed stream sites for mink telemetry efforts; Chapter 4) and the formation of stationary ice cover along the riparian areas during January through March 2018. The rapid increase of mink activity following this period was likely due the beginning of the mating season (Gerell 1970; Zschille et al. 2009) along with ice coming off the creek. Following this, all three study areas experienced a protracted reduction in mink activity from August 2018 until December 2018. During this time period, we removed two mink from the mink removal area and inserted radio transmitters (Chapter 4) into three mink (one did not survive) in the habitat removal site and one mink in the undisturbed stream site.

Brown Trout Abundance and Apparent Survival

Mean apparent survival of Brown Trout decreased in the improved habitat (-0.19) and undisturbed stream (-0.15) sites after mink removals took place, whereas mean apparent survival increased at the mink removal site (0.29; Table 3.4). A paired two-sample t-test revealed no difference (df = 1; t = -1.07; P = 0.48) in change of mean apparent survival when comparing the improved habitat site and mink removal site. However, Brown Trout apparent survival decreased by 19% in the improved habitat site and increased by 29% in the mink removal site. We further evaluated this difference using Cohen's D for effect size, which revealed a substantially large effect size (1.45) between the two estimates of apparent Brown Trout Survival. Additionally, a paired two-sample t-test revealed no significant difference (df = 1; t = -5.18; P = 0.12) in changes of mean apparent survival when comparing the undisturbed stream site to the mink removal site. While apparent survival in the mink removal site was not statistically different from the undisturbed site, mean apparent survival decreased by 15% in the undisturbed stie and increased by 29% in the mink removal site. Using Cohen's D for effect size, we observed a large effect (1.22) between the two means of average apparent survival.

Mean capture frequency of Brown Trout decreased at the improved habitat (-23 fish per length class), mink removal (-8), and undisturbed stream (-28) sites during the period after mink removals were implemented (Table 3.5). A paired two-sample t-test revealed a significant decrease (df = 5; T = 2.02; P = 0.08) in capture frequencies when comparing between the improved habitat and mink removal site. No difference was observed when comparing between the undisturbed section and mink removal section (df = 5; T = 2.02; P = 0.19). Comparisons across fish size classes, revealed that fish <150 mm increased in abundance following mink removal at the improved habitat and mink removal sections (Table 3.5).

While localized reduction of mink may affect trout survival and movement, particularly among smaller, more vulnerable fish (<250 mm), an increase in the size-structure of Brown Trout following mink removal was not apparent in this study. Rather, from 2017 to 2018, we observed a significant change in the size distribution of Brown Trout at the improved habitat (df=20, $\chi 2$ =143.3, P<0.0001), mink removal (df=13, $\chi 2$ =158.7, P<0.0001) and undisturbed site (df=12, $\chi 2$ =228.7, P<0.0001) indicating reduced abundance of fish between ~175-250 mm in 2018 (Figures 3.3 to 3.5). Low abundance of trout between 175-250 mm was observed at all sites in 2018 and could be related to changes in year-class strength, environmental conditions, and(or) other factors affecting Brown Trout survival in Rapid Creek.

Discussion

We found that mink removal efforts in Rapid Creek significantly reduced mink activity, while coincidentally we observed an increase in abundance and apparent survival estimates in the mink removal area when compared to controls. The purpose of performing mink removals in one study area and comparing it to two others was to monitor the responses of mink behavior and Brown Trout population trends in the hopes of understanding what type of an influence mink presence has on the abundance and apparent survival of Brown Trout. Heggenes and Borgstrom (1988) observed higher rates of fish mortality during periods of mink presence and concluded that the lack of a secondary prey source at stream sites may result in mink playing a major factor in decreasing fish abundance. After predator block management was implemented, we observed a decrease in mean weekly mink activity by 43% at the improved habitat site, 55% at the mink removal site, and 22% at the undisturbed site.

The decrease at the mink removal site was likely attributed to removing two mink from the area. However, the decrease at the improved habitat site was unexpected. One possible explanation is the proximity of the sites to each other; they were approximately 3.6 km apart. Gerell (1970) suggested that two factors influence the distribution of mink activity: food availability and territorial boundaries. While home range size is sexually dimorphic and fluctuates to account for seasonal and behavioral changes, mean home range size can range from 1.7 to 15.4 km of stream distance outside of the mating season (Zschille et al. 2012). There is potential that by reducing the presence of mink in the mink removal site, mink from the improved habitat area were able to disperse farther.

When evaluating seasonal distribution of mink activity, we observed increased activity beginning in April, which was likely a result of the beginning of the mating season (Gerell 1970; Zschille et al. 2009) and receding ice providing unobstructed access to riparian water edges. Additionally, we observed a protracted reduction in mink activity from August 2018 until December 2018. However, we expected to see an increase in mink activity related to juvenile dispersals from den sites around August and September (Bonesi and Macdonald 2004b; Burgess and Bider 1980). The cause of this may be related to the removal of two mink from the mink removal area along with the live captures of three mink (one did not survive) in the improved habitat site and one mink in the undisturbed stream site for radio telemetry (Chapter 4). All of these captures happened during August and September 2018 and may have altered mink behavior and subsequently influenced the seasonal distribution of mink activity in our study sites.

The mean change in Brown Trout apparent survival decreased substantially at the improved habitat site and undisturbed stream sites when comparing the periods before and after predator block management was implemented. Survival decreased by 19% and 15% at these two sites, respectively, while it increased at the mink removal site by 29%. The large effect size produced after comparing the changes at both of these sites to the mink removal site reveals a strong case that mink removals benefit the survival of Brown Trout. Observing increased apparent survival in the study area where mink were removed was consistent with results from Heggenes and Borgstrom (1988), where they discovered higher salmonid mortality rates during periods of mink presence. In addition to this, we also saw a less drastic change in abundance. While mean capture frequencies at all sites decreased after mink removals were implemented, we saw substantially higher decreases at the improved habitat (-23 fish per length class) and undisturbed stream (-28) sites than we did at the mink removal (-8) site.

The use of predator block management (i.e., mink removal), while associated with increased survival of fish < 300 mm, may have limited application in improving Brown Trout size structure compared to other management options such as habitat improvement. The availability of deep water (i.e., pools) and in-stream cover can play an important role in both increasing fish productivity and reducing predation on trout by mammalian and avian piscivores (Tabor and Wurtsbaugh 1991; Anders et al 2005).

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Figures and Tables

Table 3.1. Total and average mink activity at each study site based on the presence of fresh, mink tracks (i.e., frequency count) on floating rafts before and after mink removal. Standard error denoted in parentheses.

Period	Weeks	Improved Habitat	Mink Removal	Undisturbed
Before	29	68	75	27
	Average/Week	2.3 (0.3)	2.6 (0.3)	0.9 (0.3)
After	36	48	42	24
	Average/Week	1.3 (0.3)	1.2 (0.3)	0.7 (0.3)
	Net Decline (%)	-43*	-53*	-22

*Statistically significant decreases ($P<0.05$).

Table 3.2. Number of marked and recaptured Brown Trout surveyed during each sampling date before and after mink removals took place in the mink removal area.

Period	Sampling Date	Habitat Improvement		Mink Removal		Undisturbed Site	
		Mark	Recap	Mark	Recap	Mark	Recap
Before	6/28/17	371	15*	127	1*	237	3*
	7/25/17	117	51	42	19	185	117
	8/24/17	92	76	63	20	114	227
	Total	580	142	232	40	536	347
After	8/15/18	39	30	10	2	84	55
	9/5/18	43	58	44	9	153	112
	9/25/18	24	49	41	26	59	91
	Total	106	137	95	37	296	258

*Recaptures in sampling event 1 were from a previous study (Davis et al. 2016).

Table 3.3. Number of PIT-tagged Brown Trout collected in each study area before and after mink removals took place.

Period	BNT Size	Improved Habitat	Mink Removal	Undisturbed Site
Before	<300	252	200	514
After	<300	49	96	407
	Total	298	296	921
Before	≥300	333	19	24
After	≥300	123	13	9
	Total	456	32	33

Table 3.4. Before-after-control-impact table comparing estimates of apparent survival at the mink removal site with the improved habitat site and undisturbed stream site before and after mink removals are implemented. Standard error denoted in parenthesis.

Location	BNT Size (mm)	Before	After	Difference
Improved Habitat	<300	0.46 (0.37)	0.11 (0.07)	-0.35
	>300	0.68 (0.09)	0.65 (0.08)	-0.03
	Mean			-0.19
Undisturbed Site	<300	0.82 (0.04)	0.88 (0.12)	0.06
	>300	0.68 (0.34)	0.33 (0.27)	-0.35
	Mean			-0.12
Mink Removal	<300	0.34 (0.1)	0.92 (0.45)	0.58
	>300	1 (0.56)	1 (0)	0
	Mean			0.29

Table 3.5. Before-after-control-impact table comparing average capture frequencies from three, 500 m, single-pass surveys during the summers before and after mink removals were implemented. Standard error denoted in parentheses.

Location	Size	Before	After	Difference
Improved Habitat	<150	10 (4)	28 (2)	18
	150-199	20 (3)	8 (0)	-12
	200-249	51 (37)	2 (0)	-48
	250-299	41 (28)	3 (1)	-38
	300-349	28 (6)	14 (4)	-14
	>350	94 (1)	50 (7)	-44
	Mean			-23
Undisturbed	<150	139 (70)	117 (32)	-22
	150-199	66 (4)	34 (9)	-33
	200-249	130 (16)	37 (2)	-93
	250-299	49 (7)	35 (8)	-14
	300-349	7 (1)	3 (0)	-3
	>350	4 (1)	0 (0)	-4
	Mean			-28
Mink Removal	<150	49 (30)	66 (23)	17
	150-199	13 (4)	9 (2)	-4
	200-249	26 (11)	5 (1)	-21
	250-299	38 (8)	2 (1)	-36
	300-349	4 (2)	3 (1)	-1
	>350	5 (1)	4 (2)	-1
	Mean			-8

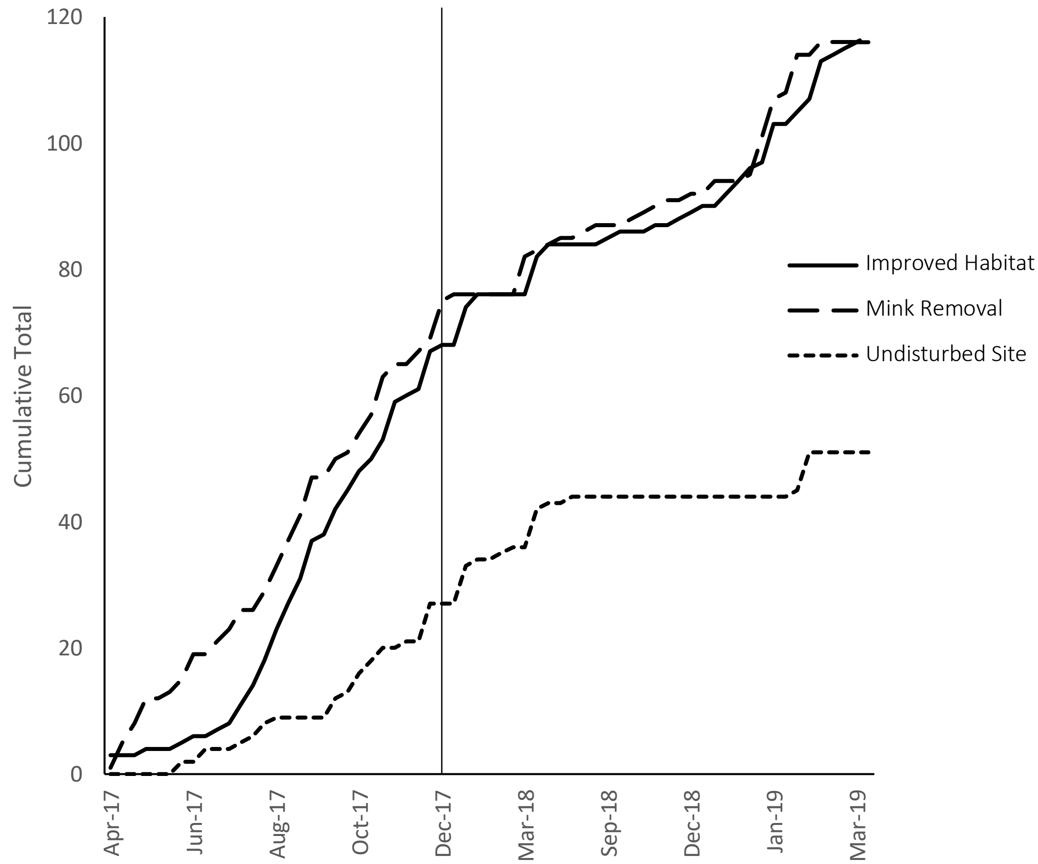

Figure 3.1. Cumulative mink activity within the improved habitat, mink removal, and undisturbed stream sites in Rapid Creek, South Dakota from April 2017 to March 2019. Solid verticle line represents when mink trapping began.

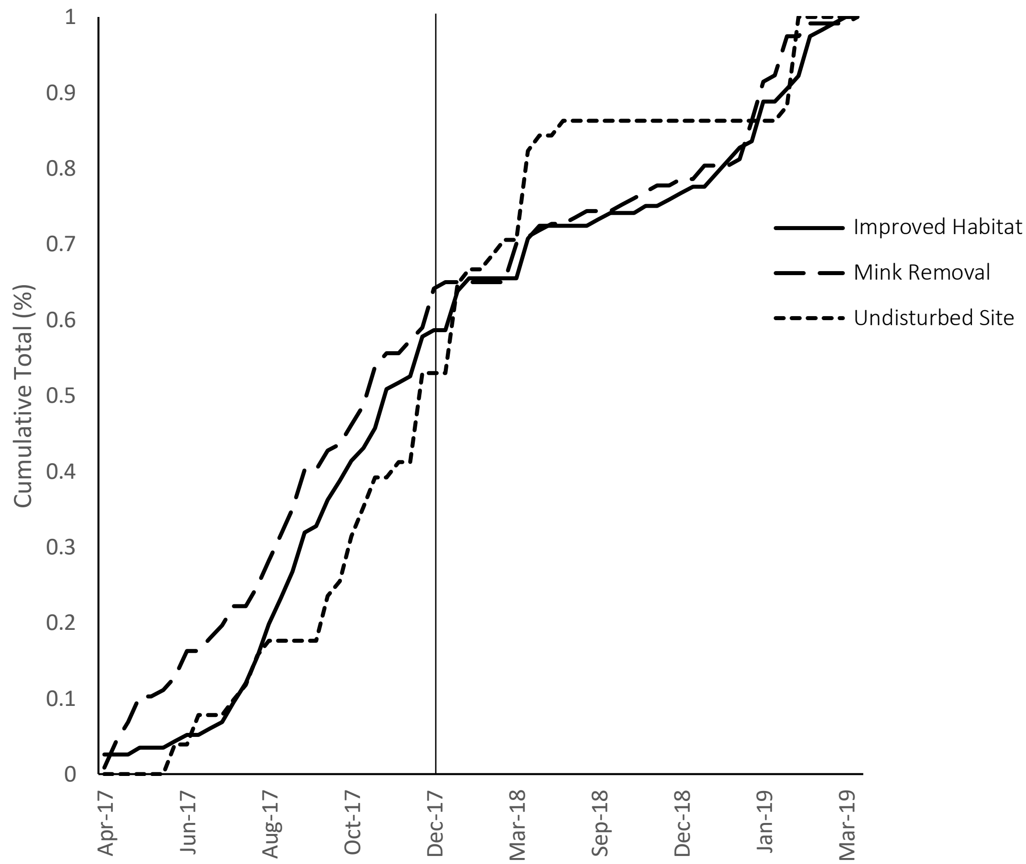

Figure 3.2. Cumulative percentage of mink activity within the improved habitat, mink removal, and undisturbed stream sites in Rapid Creek, South Dakota. Solid verticle line represents when mink trapping began.

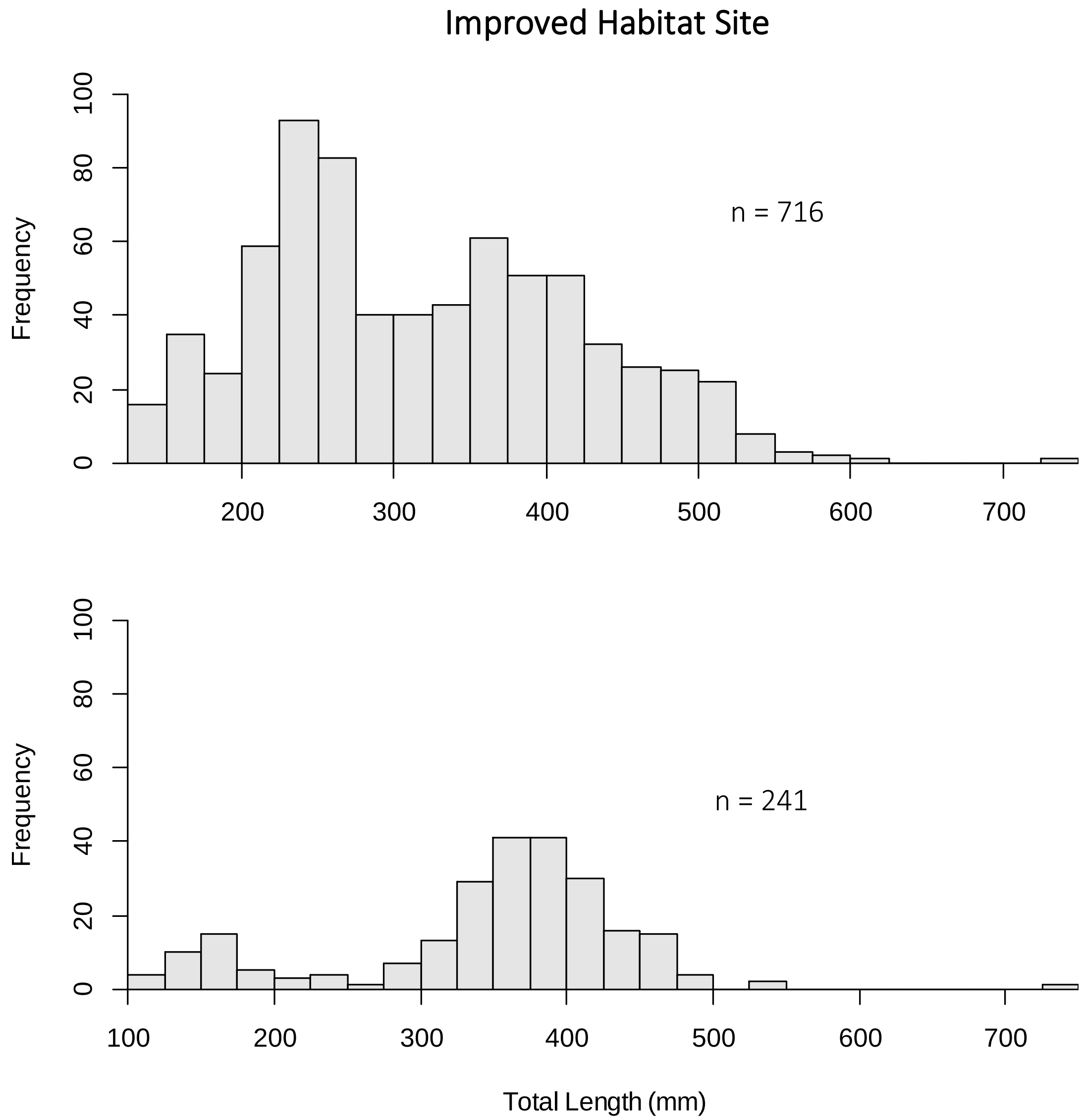

Figure 3.3. Length frequency distribution of PIT-tagged Brown Trout at the improved habitat site of Rapid Creek, SD before (upper panel, 2017) and after (lower panel, 2018) removing mink at the Mink removal site.

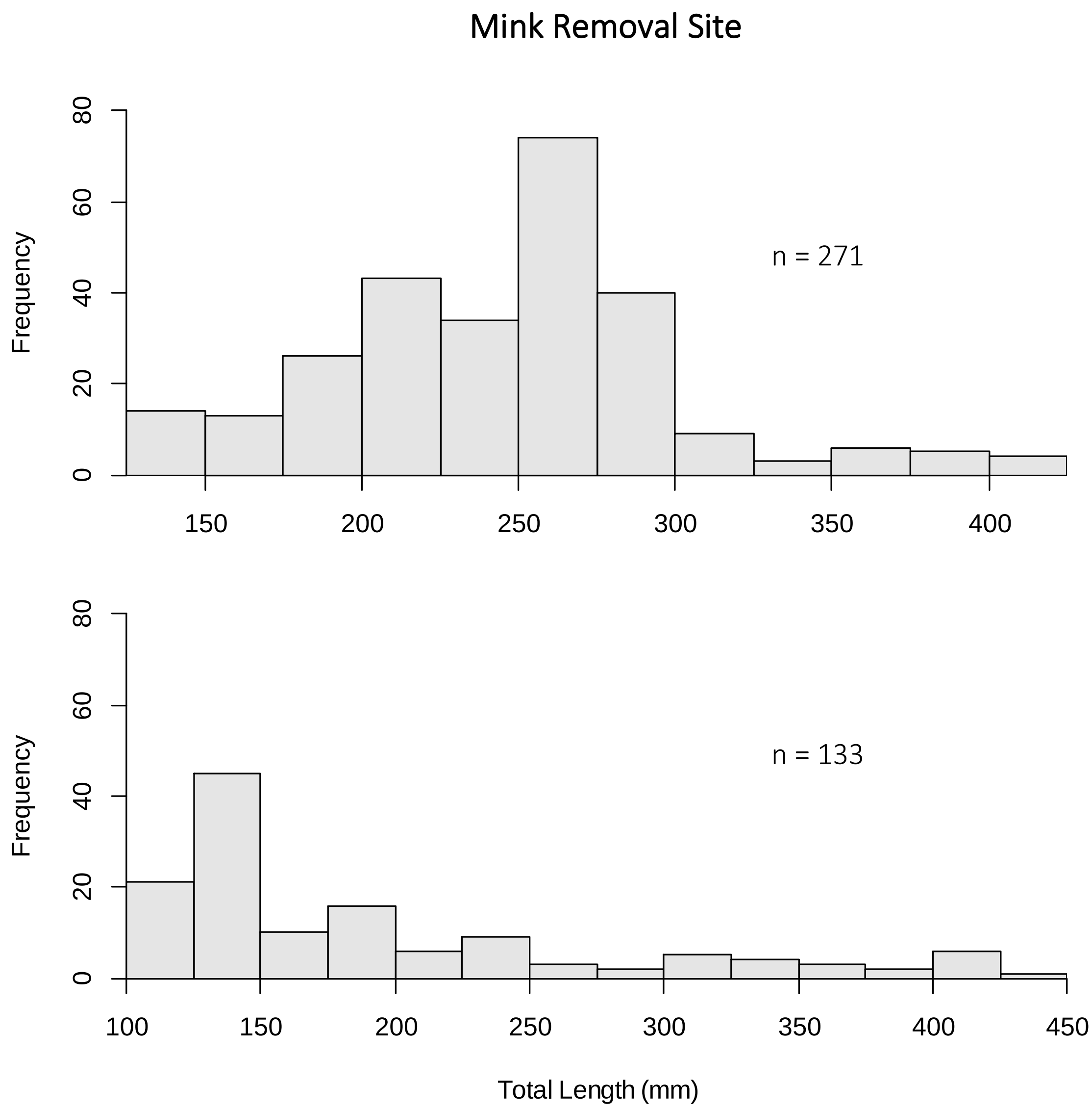

Figure 3.4. Length frequency distribution of PIT-tagged Brown Trout at the mink removal site of Rapid Creek, SD before (upper panel, 2017) and after (lower panel, 2018) removing mink at the Mink removal site.

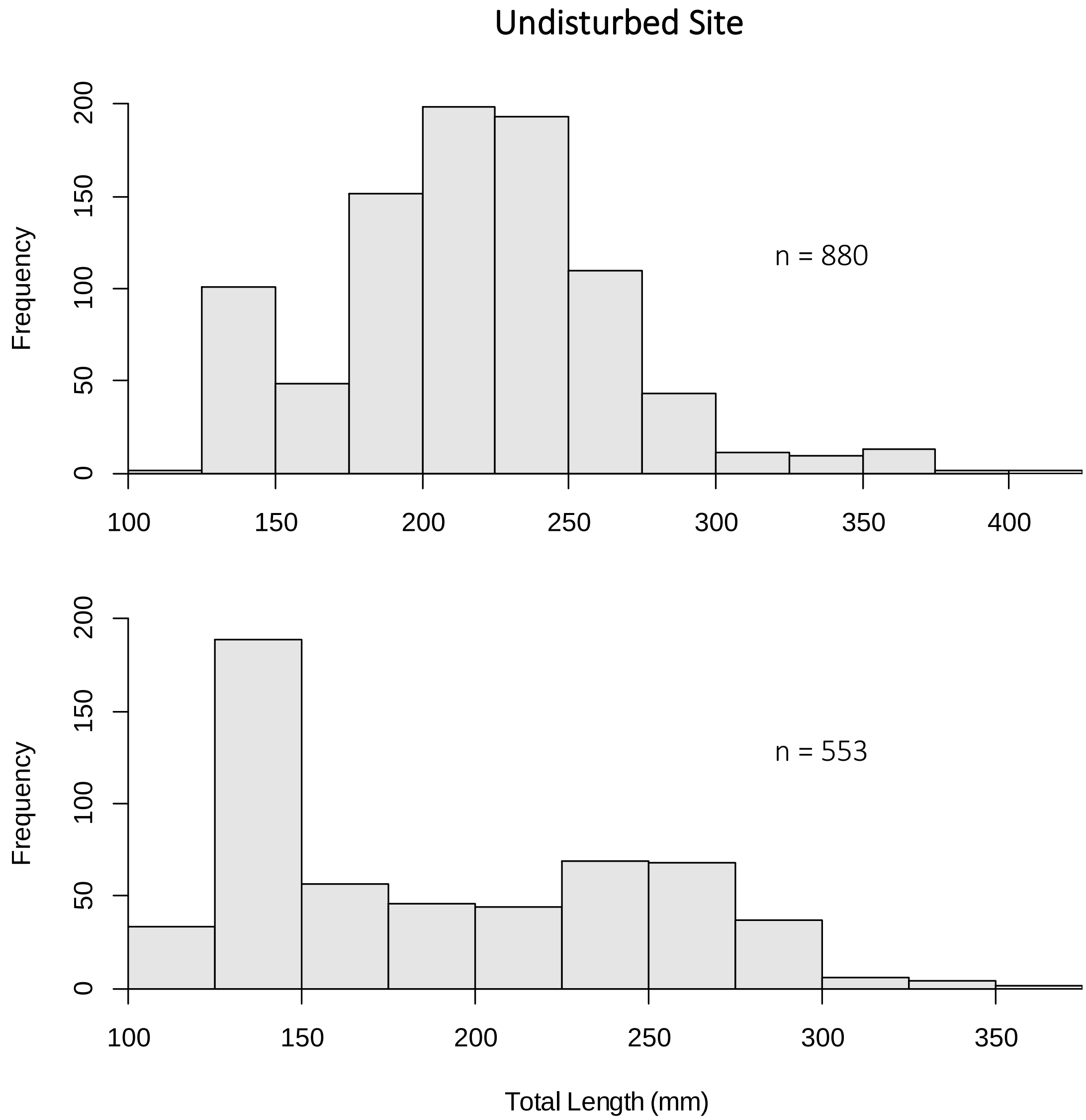

Figure 3.5. Length frequency distribution of PIT-tagged Brown Trout at the undisturbed site of Rapid Creek, SD before (upper panel, 2017) and after (lower panel, 2018) removing mink at the Mink removal site.

CHAPTER 4

COMPARING AMERICAN MINK (NEVISON VISON) MOVEMENTS AND HOME RANGE DISTANCES BETWEEN AN IMPROVED HABITAT AND UNDISTURBED AREA USING SURGICALLY IMPLANTED RADIO TRANSMITTERS

Abstract

Using biotelemetry, we evaluated the movements of American Mink (*Neovison vison*) in two areas of Rapid Creek, South Dakota where little is known about this local species' behaviors and home range sizes. One section of Rapid Creek selected underwent recent (Winter of 2015-2016) instream habitat improvements, while the other was an undisturbed section of stream used as a control. Between March and August 2018, we successfully captured and surgically implanted radio transmitters into the peritoneal cavity of two mink at each study area. Average gross movement was used to measure the total amount of distance a mink traveled from the beginning to the end of our study and revealed similar movement patterns between the two study areas. However, when analyzing home range distances along the waterway, we discovered that mink exhibited a higher site fidelity in the improved habitat site (1987.2 m) compared to the undisturbed site (4510.25 m). The instream habitat improvements that were implemented to benefit the salmonid populations in Rapid Creek also appeared to benefit the local mink by decreasing their home range sizes, while maintaining their movement patterns. The addition of large woody debris along the riparian areas and placement of instream

boulders provide overwater structures and slower moving water where fish congregate, which create opportunities for mink predation on trout.

Introduction

Movement patterns and home range distances of American Mink (*Neovison vison*) in the Black Hills of South Dakota are unknown, but their predation on salmonids is apparent from recent radio telemetry studies (Davis et al. 2016). Fish makeup an appreciable component of mink diets, having been detected in 60% of scats collected by Erlinge (1969) from a Southern Sweden river and 67% (47% of which were salmonid) of scats by Cuthbert (1979) from Scottish rivers. Fish become an increasingly important diet item in the Winter as their vulnerability increases due to colder water temperatures and the decreased availability of various other prey species (Gerell 1967), such as the migration of avian species or dormancy of small mammals during this time. A result of higher proportions of fish, as opposed to mammals, found in mink diets is smaller home range distances (Salo et al. 2010). Thus, mink have been observed occupying more concentrated home rages during the Winter, which is likely a result of the seasonally fluctuating prey availability forcing them to focus on fish in the colder months (Gerell 1970). In general, however, habitats with low prey abundance may force mink to expand their home range distances in search of adequate resources (Salo et al. 2010). Movement patterns and home range distances of mink are also influenced by territorial ranges and life history strategies.

Male and female mink exhibit intrasexual territoriality, where there exists spatial overlap between the two sexes, but territorial competition within the sexes as they defend their territories for access to mates and forage resources (Zabala et al. 2007). Intrasexual competition is largely influenced by sexually dimorphic characteristics due to varying body sizes. Males are larger than females and it has been hypothesized that males focus their energy into growth to favor sexual selection, whereas the smaller females require less energy for daily maintenance and can invest a greater proportion of acquired energy into the breeding season and rearing offspring (Birks and Dunstone 1985; Moors 1980). As a result, males target larger prey than females which allows two mink of opposite sexes to potentially cohabitate (McDonald 2002; Yamaguchi and Macdonald 2003). These sexually dimorphic characteristics also influence mink movements during the breeding season in which females tend to maintain a consistent home range, while transient males roam in search of a mate (Gerell 1970; Yamaguchi and Macdonald 2003). Additionally, increased seasonal distribution of mink activity has also been observed during the juvenile dispersal period in the Fall (Burgess and Bider 1980; Gerell 1970).

Prey availability, territorial boundaries, and seasonally changing life history strategies all influence movement patterns and home range distances of mink. However, one additional factor to consider is the availability of riparian habitat. Mink use efficient search-and-pursuit hunting strategies to maximize prey locations and minimize capture effort (Dunstone 1978), and the presence of in-stream woody debris and boulders increases over-water structures along riparian areas that mink use to search and dive-chase after aquatic prey (Dunstone and O'Connor 1979). The presence of large woody debris also provides small interstitial spaces that mink use for resting and avoiding predators. Benefits of high-quality riparian habitat extend beyond mink, to the aquatic species they heavily rely on for forage. Burgess and Bider (1980) found that in-stream habitat improvements increased salmonid and Crayfish (*Cambarus bartoni*) biomass, which in-turn promoted greater use of the area by mink.

During an evaluation of Brown Trout movements, Davis et al. (2016) discovered 32% (18 of 57) of radio tagged fish mortality was attributed to apparent mink predation along Rapid Creek in the Black Hills of South Dakota. With relatively little else known about mink in these areas, we set out to evaluate the movement patterns and home range distances of these mink using biotelemetry methods. Two reaches of Rapid Creek where mink were previously documented set the site of our investigations: a improved habitat area and an undisturbed area. While the improved habitats were meant to improve the abundance and survival of salmonid populations, we hypothesized that the addition of large woody debris in the riparian areas and instream boulder placements also benefited the search-and-pursuit hunting strategies of American Mink (Dunstone 1978). Our telemetry efforts will help to understand the semiaquatic carnivorous predator, including the amount of stream section within their home ranges, the potential impact their predation might exert on salmonid populations, and if management strategies should be implemented.

Methods

Study Area

We selected two 500 m sections of Rapid Creek in the Black Hills of South Dakota to capture and implant radio transmitters into American Mink and a third site where we actively removed mink from the area. These sites were selected based on previous observations of mink predation on Brown Trout (Davis et al. 2016). The first study site (hereafter, Improved habitat) is below the Stilling Basin of Pactola Reservoir, approximately 20 km West of Rapid City, South Dakota. This section of stream underwent in-stream habitat improvements during the Winter of 2015-2016. Approximately 3.6 km downstream, near the town of Placerville, South Dakota, we established a second site (hereafter, Mink removal) where predator block management efforts were implemented to remove mink. Lastly, we established a third site (hereafter, undisturbed stream) approximately 16.1 km downstream from the mink removal site, near the town of Hisega, South Dakota. We monitored American Mink movements and home ranges at the improved habitat site and undisturbed stream site via radio telemetry. Furthermore, at the western edge of Rapid City's limits on Rapid Creek, Cleghorn Springs Fish Hatchery performed lethal mink removals from their facility and provided us with additional body measurements.

Trapping

Eight, two-door Havahart live traps (Havahart, Inc., Lilitz, PA; model #1030-B) were labeled, weighed, and deployed in the improved habitat and undisturbed areas from 31 January 2018 until 26 March 2019. We secured live traps in riparian zones on floating mink rafts (Reynolds et al. 2004) or in trap boxes, both of which provide shelter from the elements. Lethal conibears (Bridger Bodygrippers, Minnesota Trapline Products, Inc., Pennock, MN; model size #110) were placed in floating rafts or box traps and secured along the riparian zone in the predator block management area from 21 December 2017 until 26 March 2019. Size #110 conibears are also used by the staff at Cleghorn Springs Fish Hatchery to perform predator removals. Live traps and conibears were baited with either mink trapping bait (Caven's Coon and Mink Bait, Minnesota Trapline Products, Inc., Pennock, MN), fish, beaver, rabbit, or mice. We occasionally alternated between scent lures of mink gland and shellfish oil (Caven's Mink Master and Minnesota Brand Shellfish Oil, Minnesota Trapline Products, Inc., Pennock, MN) near the traps to attract mink. Live traps were checked daily and only active during periods where overnight temperatures were predicted to remain above -7°C (approximately 20°F), while conibears were set regardless of temperature and checked daily in accordance with South Dakota trapping regulations.

Surgery

We transport captured mink to an enclosed trailer for surgery and begun by subtracting the total weight of the live trap containing the mink by the previously recorded trap weight to determine approximate mink weight for administering the appropriate levels of anesthetic (combination of Ketamine and Xylazine) for chemical immobilization (Appendix B.5). We determined the amount of drug to administer using the equation (Kreeger 2012):

$$Volume\ of\ Drug\ Administered\ (mL) = \frac{Body\ Weight\ (kg) * Dosage\ (\frac{mg}{kg})}{Concentration\ (\frac{mg}{mL})}$$

We opened one side of the live trap and inserted a wood block with handle to crowd the mink towards the back of the live trap, allowing us to inject the anesthetic (3-cc syringe with 20 gauge by ½ inch needle) intramuscularly into one of the hind legs to immobilize the animal. Once mink were immobilized and showed complete muscular relaxation, they were removed, and data collection and surgical practices were initiated. The anesthetized mink were re-weighed to determine if the appropriate amount of anesthetic was administered and to calculate appropriate levels of post-surgical antibiotic (Baytril) and long-acting pain reliever (Buprenorphine) needed. Sex, age, length from the nose to the base of the tail, and body girth behind the forelegs were measured for each mink captured (Table 4.1)

All instruments and other surgical equipment used to perform surgery were sterilized via autoclaving or low-temperature gas sterilization. Sterilized surgical packs included forceps, needle holders, hemostats, towel clamps, gauze, and a scalpel. Additional items in the surgical pack included gloves, razorblades, and sutures, along with a sealed, gas sterilized radio transmitter (Advanced Telemetry Systems M1230, Isanti Minnesota, USA; 70x25x18 mm; 23 g).

Prior to surgery, sedated mink were positioned supine on a towel on a surgical table. Nylon ropes were tied to all four of the animal’s limbs and loosely anchored to the eyebolts at the corners of the surgical table, providing unobstructed access to the abdomen. An area near the ventral midline on the abdomen was shaved to the epidermis and disinfected with chlorhexidine scrub and isopropanol. Eye drops (ReNu MultiPlus Lubricating and Rewetting Drops) were administered to prevent the animal's eyes from drying out and vitals (internal body temperature, heart rate, and respiratory rate) were measured.

An incision (approximately 25 mm) was made directly posterior of the umbilicus, exposing the abdominal muscles. Another incision was made along the linea alba (a fibrous structure running down the midline of the abdominal muscles where bleeding was minimal) exposing the peritoneal cavity. The radio transmitter was then inserted into the opening and arranged so it was oriented parallel to the abdominal walls. The peritoneum and muscles were sewn closed using a simple interrupted suture at least every 5 mm. The dermis was sewn together using a simple interrupted suture every 5 mm with the first, last, and a middle suture being anchored to the muscular layer underneath. Upon completion of surgery, the animal was subcutaneously injected with buprenorphine (long-acting pain reliever) and intramuscularly injected with Baytril (long-lasting antibiotic). A light layer of skin glue and aluminum spray bandage (AluSpray Aerosol Bandage) was applied to improve the strength and durability of the sutures. These surgical procedures were adapted from Eagle et al. (1984) and Zschille et al. (2007) for surgical implantation in a remote field site and approved by South Dakota State University's IACUC after performing practical surgeries on three farmed mink (17-054A).

Recovery and Release

After surgery, mink were placed in a large, steel live trap (Havahart 1-door Professional Style Live Animal Cage, 61 x 61 x 41 cm) with water and wet cat food (Friskies) and kept in our enclosed surgery trailer for undisturbed recovery. Recovery time required one night of holding (range = 20-22 hours) before the animal began exhibiting signs of full functionality and no irritation to suture. Mink were released back into the wild at the site of capture and tracked via radio telemetry.

Condition, Movement, and Home Range

We determined relative body condition using the equation,

$$K = \frac{W}{aL^n}$$

where W is mink weight (g), L is the mink length (cm) from the nose to the base of the tail, and *a* and *n* are regression coefficients (Kruuk and Conroy 1991; Le Cren 1951; Sidorovich et al. 1999).

After the mink were released, we used a Biotracker VHF Receiver (Lotek, Seattle, Washington, USA) with a three-pronged foldable antenna to obtain mink locations every day for the first week to monitor animal behavior, movement, and survival during the post-surgical period and then every other day for the remaining duration of the study. Since mink from our study areas occupied a stream system, we measured movement as a linear distance along the waterway (Haan and Halbrook 2015; Zschille et al. 2012). Using ArcGIS Maps, we started with the initial release point and measured movement in chronological order; upstream and downstream movements from a previous location were assigned positive and negative values, respectively. These data provide us net movement, gross movement, and home range distances for each individual mink (Table 4.2).

Net movement represents the sum of all positive (upstream) and negative (downstream) movements to determine the distance (m) a mink displaced from the start to the end of the telemetry period. Total gross movement was measured as the distance (m) a mink moved during the telemetry period by summing the absolute value of each movement from the beginning to the end of the study for each radio tagged mink's movements. From total gross movement, we determined the average gross distance moved between each recorded location. Additionally, home range was measured as the total waterway distance used between the farthest upstream and downstream locations recorded for each mink. Finally, using radio telemetry tracking methods, we evaluated factors associated with mink mortality. Because radio transmitters were programmed to emit a mortality signal (a rapid sequence of beeps) when an animal was stationary for more than four hours, it provide a means to locate and investigate mortality-related causes.

Results

Mink Captures and Condition

During the trapping period lasting 31 January 2018 until 26 March 2019, we live captured three mink in the improved habitat site and two mink in the undisturbed stream site, while removing two mink in the mink removal site. We obtained measurements on four additional mink from Cleghorn Springs Fish Hatchery while they were performing predator removals from their facility during the Winter-Summer of 2018 (Table 4.1). All mink were captured during either the juvenile dispersal period (n = 6) from August-September 2018 (Gerell 1970; Yamaguchi and Macdonald 2003) or the mating season (n = 5) from March-April 2018 (Enders 1952; Zschille et al. 2009). Mink removals using lethal conibear traps occurred on 8 August and 11 September 2018 in the mink removal site, while removals from Cleghorn Springs Fish hatchery occurred on the 21, 27, and 30 March and 27 April 2018. All live captured mink were females and occurred on 4, 9, and 10 August 2018 in the improved habitat area and on 18 March and 8 August 2018 in the undisturbed area.

All seven mink captured from our study areas were female, while the fish hatchery provided three males and one female. The mean average size of male mink was substantially larger (1397 g with SE = 123.91; 47.33 cm with SE = 1.43) than for female (612 g with SE = 143.26; 32.25 cm with SE = 0.97). However, we observed an unusual size difference between the hatchery female (936 g; 36 cm) and the average of our study area females (565.71 g with SE = 29.59; 31.71 cm with SE = 0.42). We estimate body condition for each individual mink using the equation,

$$K = \frac{W}{aL^n}$$

and solved using regression coefficients for *a* (male = 0.0252; female = 0.0524) and *n* (male = 2.8833; female = 2.6594) from Sidorovich et al. (1999). Female mink had a higher average body condition (1.13, n = 8) compared to males (0.82, n = 3; Table 4.1).

Mink Telemetry

Three mink from the improved habitat site and two mink from the undisturbed stream site were surgically implanted with radio transmitters. Mean surgery time was approximately 32 minutes (range = 24 to 50 minutes) with an average recovery time, before release of approximately 21 hours (range = 19.5 to 22 hours). In the improved habitat area, one mink never fully recuperated from surgery and died after approximately 45 hours of recovery time. We captured the first mink on 18 March 2018 and released it the following day after a successful surgical radio transmitter implantation. We were able to track this mink for 21 days until a mortality signal began emitting. We found her cached with puncture wounds on the base of the skull and upper back. Necropsy revealed the skull had been crushed and the width of the canines was approximate to that of a Mountain Lion (*Puma concolor*). We deployed a trail cam at the cache site and captured a photograph of a Mountain Lion returning to the area.

Three additional mink were captured and successfully released: two in the improved habitat area on 4 and 10 August 2018 and one in the undisturbed area on 8 August 2018. We tracked each of these three mink for 9-10 days before the signal was no longer within range of our receiver. Aerial telemetry using a fixed wing plane five weeks after the first signal was lost revealed that the mink in our undisturbed stream site had migrated approximately 11.3 km downstream from its last known location and was emitting a mortality signal. Interference from housing developments and powerlines prevented us from pinpointing the exact location of the signal and recovering the mink to determine the cause of death. We were unable to locate the other two lost mink from the improved habitat area using either ground or aerial telemetry.

Movement and Home Range

For movement and home range analysis, we monitored two mink in the improved habitat area and two mink in the undisturbed area (Table 4.2). From the beginning to the end of our telemetry period, average net movement of mink in the improved habitat area was 1.1 km downstream from their initial location, whereas mink in the undisturbed area traveled 3.9 km upstream from their initial location. Gross movement varied substantially due to differentiating study durations, so we developed an average gross movement per location for each mink. Average gross movement was similar for mink in the improved habitat area (0.8 km) and the undisturbed area (0.7 km). However, an analysis of home range distance along the waterway revealed that the average home range for mink in the improved habitat area (1.9 km) was substantially smaller than in the undisturbed area (4.5 km). While average gross movement measurements remained similar between the two study areas, net movement and home range distances revealed that mink in the improved habitat area had a higher site fidelity and lower roving behavior than those in the undisturbed area.

Discussion

Our comparison of female American Mink average gross movements were similar between the improved habitat site and undisturbed stream site. However, average home range distance in the improved habitat area was approximately 60% less than in the undisturbed area. This high site fidelity in the improved habitat area allowed mink to concentrate movements within a shorter length of waterway, which allowed them to become more familiar with the distribution of resources as well as lowering the risk of predation (Zschille et al. 2012). Unfortunately, three of our mink captures occurred during the juvenile dispersal period and the other mink was killed by a mountain lion after only 21 days of tracking. So, our home range estimates are based on a small number of locations before the animals were lost or killed, but they are consistent with home range distances from other studies of American Mink. The average female mink home range distances observed in the improved habitat and undisturbed areas contain 1.9 km (SE = 0.5) and 4.5 km (SE = 0.4) of stream length, respectively. Our results were similar to findings by Zschille et al. (2012) who reviewed studies evaluating mean home range sizes of mink in Europe and the United States of America. They discovered that female mink using lotic systems exhibit home range sizes from 0.4 km to 4.9 km. However, movement patterns and home ranges can vary with season. Using radio telemetry, Gerell (1970) observed a tendency for mink to occupy more concentrated home ranges during the Winter and concluded that there are two factors that influence the distribution of mink activity: food availability and territorial boundaries. The concentrated home ranges in Winter may be due to their diets shifting to a more predominant source of fish in the Winter and Spring as they take advantage of the low water temperatures and decreased availability of other prey species that increase fish vulnerability to mink (Gerell 1967).

The generalist diet of mink make it a versatile, wetland-dependent species, able to adapt to different types of habitat in response to prey abundance (Bonesi and Macdonald 2004a; Gerell 1967). This adaptability combined with search-and-pursuit hunting strategy (Dunstone 1978) means that habitat availability and suitable prey base likely influence mink movement patterns and home range distances. Burgess and Bider (1980) found that habitat improvements increased salmonid and Crayfish biomass, which in-turn promoted greater use of the area by mink. While the introduction of large woody debris and instream boulders in the improved habitat area were implemented to increase the abundance and survival of salmonids, these additions also increased over-water structures within the creek and along the riparian areas that mink use to search and dive-chase after aquatic prey (Dunstone and O'Connor 1979). These habitat improvements also provide small interstitial spaces that mink use for resting and avoiding predators.

Bonesi and Macdonald (2004b) stated that there is a disproportionate increase in mink captures during two time periods: the breeding season and when juvenile mink are present. This likely explains why all of our mink captures (live and lethal) occurred during either the mating season (n = 5) from March-April 2018 (Enders 1952; Zschille et al. 2009) or the juvenile dispersal period (n = 6) from August-September 2018 (Gerell 1970; Yamaguchi and Macdonald 2003). Of these 11 captured mink, average male body size (n = 3; 1397 g; 47.33 cm) was substantially larger than female body size (n = 8; 612 g; 32.25 cm). This is typical when comparing between the sexes of American Mink, as they exhibit a noticeable sexual dimorphism in body sizes (Zabala et al. 2007; Zschille et al. 2009). Males can grow to be two times the size of females due to inter-sexual competition or intra-sexual selection, which typically results in larger home range distances and increased movements of males (Thom et al. 2004).

However, one questionable observation is the substantially larger body size of the female captured at Cleghorn Springs Fish Hatchery (936 g; 36 cm; April 2018) compared to the average females in our study areas (565.71 g, SE = 29.59; 31.71 cm; SE = 0.42; August-September 2018). The most likely explanation is that the females captured in the Fall were sub-adult sized juveniles and lowered the populations average body size, while the hatchery female captured in the Spring was a sexually mature adult (Enders 1952). Yet, when we compare the female study mink captured in March (700 g; 30.5 cm) to the hatchery female in April (936 g; 36 cm) we still observe substantially different body size measurements. Damgaard et al. (1998) found that growth rates of mink kits are affected by dietary protein levels, and lower levels of dietary protein results in lower body weights. Thus, an additional explanation for intra-sexual body size differences may be the accessibility to a prey base of concentrated fish in unprotected outdoor raceways at the hatchery, providing a forage opportunity unlike that observed in the wild.

Of the four mink used for telemetry, one was killed by a Mountain Lion after 21 days while the three others were tracked for 9-10 days until their signal was lost. The lost mink were all captured at the beginning of August 2018 when kit dispersals are taking place (Yamaguchi and Macdonald 2003). Aerial telemetry discovered that one of the missing mink had migrated 11.3 km downstream from its last known location. Unfortunately, we were unable to find the other two missing mink. It is not likely that the mink were removed by trappers, since the trapping season in South Dakota (1 December until 31 January) did not coincide with our tracking efforts. Gerell (1970) stated that the largest-scale mink movements start at the beginning of July when juveniles disperse and observed males traveling 21 km and 45 km. This leads us to believe that the distance juveniles dispersed was beyond the signal range of our ground and aerial telemetry.

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Figures and Tables

Table 4.1. Captures, body measurements, condition, and fates for mink telemetry efforts in the improved habitat and undisturbed areas, and for mink removals in the mink removal and hatchery areas. Standard error is denoted in parenthesis.

Location	Date	Frequency	Sex	Weight (g)	Nose to Base (cm)	Girth (cm)	Condition	Fate
Improved Habitat	8/10/2018	148.141	Female	600	33.5	14	1.01	Lost
	8/4/2018	148.023	Female	520	32	10.5	0.99	Lost
	8/9/2018	148.041	Female	460	31	10	0.95	Dead
Undisturbed Site	8/8/2018	148.123	Female	510	30.5	11.5	1.10	Dead
	3/18/2018	148.201	Female	700	30.5	13	1.51	Dead
Mink Removal	8/8/2018	-	Female	600	32.5	14.5	1.09	Conibear
	9/11/2018	-	Female	570	32	12.5	1.08	Conibear
Hatchery	4/27/2018	-	Female	936	36	18.5	1.30	Conibear
			Average	612 (143.26)	32.25 (0.65)	13.06 (0.96)	1.13 (0.07)	
Hatchery	3/21/2018	-	Male	1644	48	27	0.93	Conibear
	3/27/2018	-	Male	1256	46	23	0.80	Conibear
	3/30/2018	-	Male	1291	48	22.5	0.73	Conibear
			Average	1397 (123.91)	47.33 (0.67)	24.17 (1.42)	0.82 (0.06)	

Table 4.2. Movement and home range distances for radio tagged mink in the improved habitat and undisturbed areas. Standard error denoted in parenthesis.

Location	Date	Frequency	Locations	Net Movement (m)	Gross Movement (m)	Stream Home Range (m)
Improved Habitat	8/10/2018	148.141	10	-1940.19	10454.39	2481.1
	8/4/2018	148.023	9	-298.7	4539.3	1493.3
			Average	-1119.45 (820.75)	7496.85 (2957.55)	1987.2 (493.9)
Undisturbed Site	8/8/2018	148.123	10	3973.5	6360.1	4150
	3/18/2018	148.201	17	3895.42	11796.02	4870.5
			Average	3934.46 (39.04)	9078.06 (2717.96)	4510.25 (360.25)

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

My research was beneficial in understanding the influence American Mink have on stream-dwelling Brown Trout in Rapid Creek, South Dakota. I evaluated movement and mortality of Brown Trout in three stream sections using biotelemetry, while also monitoring the response of fish abundance and survival to predator block management (i.e., mink removal). Additionally, I captured mink and tracked their movements to understand their distribution and home range size. High water levels during both Summer fish survey periods made sampling more difficult than usual; however, all three sites were equally impacted by these conditions.

My investigation supported earlier observations that mink predation on radio-tagged Brown Trout in Rapid Creek ranged between 20-25%. I found that localized trout abundance and apparent survival increased following mink removal compared to other stream sections. These results were especially evident when comparing the improved habitat section to the mink removal section.

I observed substantially smaller home range size for mink at the improved habitat section compared to the undisturbed stream site, supporting the notion that manipulation of stream habitat may benefit mink. The addition of large woody debris, for example, provides the overwater structures mink use to search and detect fish, while potentially providing cover from predators and(or) den habitat. Brown Trout in my study used deep, slow moving sections (run and pool) of the stream during Winter and Spring when they appear to be more susceptible to mink predation. Moreover, reduced availability of alternative prey in Winter-Spring may cause mink to reduce their home range and target fish.

The improved habitat section below Pactola Reservoir did not completely freeze during winter, owing to stable flows and warmer water temperatures. However, ice cover did not appear to be a factor inhibiting mink from preying on fish. Although ice covered the entire surface area of creek at the undisturbed site, I also observed mink predation at this site. Two of our radio tags were found in a corridor underneath the ice. I suspect that either: 1) after the ice formation, water levels dropped and provided interstitial spaces for mink to continue targeting fish, or 2) mink continued to use the riparian areas as snow melted and ice formed, developing cavern systems allowing them to continue preying on fish.

Among my study areas, the improved habitat site had substantially higher numbers of large, adult fish, likely owing to better habitat conditions. Two of the three sections of Rapid Creek have catch-and-release regulations, while the third (i.e., undisturbed site) provides limited access for fishing due to steep hillsides and dense vegetation (willows, *Salix* sp.). In the catch-and-release areas, fishing mortality is essentially eliminated and hooking mortality associated with fly fishing is low. Thus, in the absence of fishing mortality, it is likely that mink predation may be compensatory. If true, then losses of Brown Trout to mink predation may not constitute an additive component of mortality at a scale large enough to improve density-dependent growth and size-structure of Brown Trout in Rapid Creek, despite detectable increases in local abundance of Brown Trout associated with mink removal.

Studies where habitat improvements have been implemented generally report increased density of salmonids, which has been shown to increase emigration rate. This could explain why I observed greater gross movement by Brown Trout in the improved habitat site, compared to the mink removal and undisturbed stream sites.

Brown Trout in my study areas use deeper and slower moving sections (run and pool) of stream during the Winter and Spring seasons, while also moving significantly more. These periods of time also appear to be when stream-dwelling fish are most susceptible to mink predation. The lack of avian and terrestrial prey species along with increased vulnerability of fish due to lower water temperatures cause mink to condense their home ranges and target fish. Additionally, the improved habitat section of creek below Pactola Reservoir did not completely freeze over due to hypolimnetic discharge of consistently flowing water temperatures. However, ice cover did not appear to be a factor inhibiting mink from preying on fish.

Ice covered the entire surface area of creek at the mink removal and undisturbed stream sections, but we still observed mink predation in the undisturbed site where predator block management was not implemented. During this time, we also observed trappers targeting mink in the improved habitat section of the creek during the December-January trapping season in South Dakota. Personal communications with trappers reveal that there is not a very high success rate, but I speculate that the presences of lethal traps along the riparian areas may obstruct the habitats mink use to hunt fish, negatively influence their predatory successes during this time.

Using biotelemetry, we observed substantially smaller home range distances of American Mink in the improved habitat section compared to an undisturbed stream site, which further substantiates my hypothesis that the addition of stream structures benefits mink. I postulate that the addition of large woody debris provides the overwater structures mink use to search-and-pursue fish, while additionally providing small interstitial spaces as cover from predators and dens to consume prey and raise young. Unfortunately, three of our mink captures occurred during the juvenile dispersal period and the other mink was killed by a mountain lion after only 21 days of tracking. So, our home range estimates are based on a small number of locations before the animals were lost or killed, but they are consistent with home range distances from other studies of American Mink. Overall, mink removals would likely benefit fish populations by reducing terrestrial predation potential resulting in increases to fish abundance and survival.

In summary, we are able to conclude that the removal of American Mink benefitted Brown Trout population abundance and apparent survival. While habitat improvements have been shown to result in higher fish densities, they also promote increased fish movement due to the high-density populations competing for a limited resource, which increases exposure to predators. Observed mink predation on Brown Trout is apparent in our study sites; however, the effect may be negligible, if not beneficial, due to the catch-and-release regulations. High density fish populations often exhibit bottlenecking due to intraspecific competition, and natural reductions of fish due to predation likely lead to higher growth potential. The introduced habitat structures also provide American Mink shelter and overwater structures that aid in predation success of fish, which lead to substantially smaller home range distances when compared to our undisturbed stream site.

While I do not believe that American Mink have a substantial impact on the population dynamics of salmonids in Rapid Creek, there may be potential for them to negatively influence trout populations under the right conditions. Factors that reduce the carrying capacity of trout, such as drought (i.e. water availability) or changes in forage availability, could lead to declines in fish abundance through either mortality or emigration. During low water years, in particular, trout may be more vulnerable to mink and avian predation, leading to more substantial predation and thus declines in the trout population that may take long periods to recover. To fill in gaps related to mink and avian predation on Brown Trout, fecal analysis of mink and avian predators (e.g., DNA) could be used to evaluate their diet, as well as their distribution and abundance.

Future efforts to improve the size-structure of Brown Trout below Pactola Reservoir would probably be better served by focusing on habitat improvement rather than predator block management. The size distribution of trout observed at the improved habitat site included relatively high numbers of fish between 300-500 mm that were infrequent (or even absent) at the mink removal and undisturbed sites.

APPENDIX

Appendix A.1. Brown Trout characteristic data for the radio telemetry study from Fall of 2017 to Spring of 2018.

Season	Study Area	Frequency	Length (mm)	Weight (g)	Fate	Surgery Time (s)	Tag/Body Weight (g)	Habitat Use			Habitat Proportion		
								Pool	Riffle	Run	Pool	Riffle	Run
Fall-Spring	Basin	149.021	350	424	Alive	326	0.00731	14	0	12	0.54	0.00	0.46
Fall-Spring	Basin	149.092	248	179	Mink	318	0.01732	3	1	13	0.18	0.06	0.76
Fall-Spring	Basin	149.151	311	288	Mink	246	0.01076	11	1	4	0.69	0.06	0.25
Fall-Spring	Basin	149.180	320	299	Alive	183	0.01037	23	1	2	0.88	0.04	0.08
Fall-Spring	Basin	149.212	350	365	Unknown	330	0.00849	5	1	12	0.28	0.06	0.67
Fall-Spring	Basin	149.243	365	366	Mink	274	0.00847	2	0	0	1.00	0.00	0.00
Fall-Spring	Basin	149.262	253	160	Alive	630	0.01938	24	2	0	0.92	0.08	0.00
Fall-Spring	Basin	149.290	390	554	Mink	630	0.00560	2	0	4	0.33	0.00	0.67
Fall-Spring	Placerville	148.431	335	429	Alive	260	0.00723	11	3	8	0.50	0.14	0.36
Fall-Spring	Placerville	148.452	343	410	Alive	478	0.00756	7	5	14	0.27	0.19	0.54
Fall-Spring	Placerville	148.491	362	409	Unknown	410	0.00758	20	5	0	0.80	0.20	0.00
Fall-Spring	Placerville	148.522	233	132	Alive	280	0.02348	3	22	1	0.12	0.85	0.04
Fall-Spring	Placerville	148.621	295	263	Avian	241	0.01179	19	0	0	1.00	0.00	0.00
Fall-Spring	Placerville	148.800	305	300	Alive	340	0.01033	25	1	0	0.96	0.04	0.00
Fall-Spring	Placerville	148.922	284	199	Unknown	279	0.01558	20	0	0	1.00	0.00	0.00
Fall-Spring	Placerville	148.982	316	338	Avian	293	0.00917	4	3	9	0.25	0.19	0.56
Fall-Spring	Hisega	148.341	255	191	Unknown	301	0.01623	1	10	13	0.04	0.42	0.54
Fall-Spring	Hisega	148.360	263	194	Alive	217	0.01598	9	11	6	0.35	0.42	0.23
Fall-Spring	Hisega	148.542	252	156	Unknown	328	0.01987	1	10	10	0.05	0.48	0.48
Fall-Spring	Hisega	148.573	260	153	Alive	212	0.02026	1	6	14	0.05	0.29	0.67
Fall-Spring	Hisega	148.592	254	151	Mink	268	0.02053	5	3	9	0.29	0.18	0.53
Fall-Spring	Hisega	148.681	260	174	Alive	210	0.01782	8	3	15	0.31	0.12	0.58
Fall-Spring	Hisega	148.740	362	399	Mink	235	0.00777	8	3	7	0.44	0.17	0.39
Fall-Spring	Hisega	148.859	280	174	Alive	158	0.01782	1	8	13	0.05	0.36	0.59

Appendix A.2. Movement data for radio tagged Brown Trout during the telemetry study from Fall of 2017 to Spring of 2018.

Season	Study Area	Frequency	Locations	Days	First-to-Last (m)	Net Movement (m)	Gross Movement (m)	Gross/Day (m)	Goss/Week (m)	Home Range (m)
Fall-Spring	Basin	149.021	26	176	-26.1	-28.96	148.06	0.841	5.695	49.6
Fall-Spring	Basin	149.092	17	112	-142.5	-138.5	211.3	1.887	12.429	18.4
Fall-Spring	Basin	149.151	16	112	-40	-41.91	110.35	0.985	6.897	39.8
Fall-Spring	Basin	149.180	26	176	166.4	171.64	397.68	2.260	15.295	238
Fall-Spring	Basin	149.212	18	119	172.5	175.48	345.28	2.902	19.182	105.1
Fall-Spring	Basin	149.243	2	7	-11.4	-11.4	11.4	1.629	5.700	7.22
Fall-Spring	Basin	149.262	26	176	-175.3	-166.27	286.93	1.630	11.036	183.6
Fall-Spring	Basin	149.290	6	35	-1886.9	-1886.4	1975.8	56.451	329.300	44.7
Fall-Spring	Placerville	148.431	22	155	956.8	955.53	970.41	6.261	44.110	682.6
Fall-Spring	Placerville	148.452	26	176	-107	-106.63	757.17	4.302	29.122	252.3
Fall-Spring	Placerville	148.491	25	169	222	228.58	769.36	4.552	30.774	253.4
Fall-Spring	Placerville	148.522	26	176	102.2	124.27	326.25	1.854	12.548	121.9
Fall-Spring	Placerville	148.621	19	126	10.3	11.07	213.81	1.697	11.253	55.8
Fall-Spring	Placerville	148.800	26	176	7.85	3.44	166.32	0.945	6.397	28.4
Fall-Spring	Placerville	148.922	20	133	10.4	10.5	150.02	1.128	7.501	22.4
Fall-Spring	Placerville	148.982	16	113	197.7	204.97	567.27	5.020	35.454	106.9
Fall-Spring	Hisega	148.341	24	161	112.4	111.5	313.16	1.945	13.048	56.5
Fall-Spring	Hisega	148.360	26	176	101.8	96.65	367.99	2.091	14.153	109.9
Fall-Spring	Hisega	148.542	21	154	20.9	14.88	290.82	1.888	13.849	64.8
Fall-Spring	Hisega	148.573	21	140	88.2	85.53	472.31	3.374	22.491	83.1
Fall-Spring	Hisega	148.592	17	112	-3.97	-0.51	324.29	2.895	19.076	90.5
Fall-Spring	Hisega	148.681	26	176	10.4	26.86	381.22	2.166	14.662	76.8
Fall-Spring	Hisega	148.740	18	119	44.4	44.75	422.35	3.549	23.464	81.9
Fall-Spring	Hisega	148.859	22	147	5.87	2.32	252.46	1.717	11.475	61.6

Appendix A.3. Brown Trout characteristic data for the radio telemetry study from Summer of 2018 to Winter of 2019.

								Habitat Usage			Habitat Percentage		
Season	Study Area	Frequency	Length (mm)	Weight (g)	Fate	Surgery Time (s)	Tag/Body Weight (g)	Pool	Riffle	Run	Pool	Riffle	Run
Summer-Winter	Basin	150.020	408	611	Expelled	375	0.00507	0	0	9	0.00	0.00	1.00
Summer-Winter	Basin	150.080	341	410	Alive	200	0.00756	25	0	1	0.96	0.00	0.04
Summer-Winter	Basin	150.182	377	474	Alive	150	0.00654	20	0	6	0.77	0.00	0.23
Summer-Winter	Basin	150.221	410	538	Alive	200	0.00576	1	2	23	0.04	0.08	0.88
Summer-Winter	Basin	150.260	350	471	Avian	182	0.00658	2	0	2	0.50	0.00	0.50
Summer-Winter	Basin	150.360	328	379	Alive	182	0.00818	14	6	6	0.54	0.23	0.23
Summer-Winter	Basin	150.710	408	618	Unknown	150	0.00502	0	0	2	0.00	0.00	1.00
Summer-Winter	Basin	150.132	340	430	Unknown	189	0.00721	NA	NA	NA	0.00	0.00	0.00
Summer-Winter	Hisega	150.312	362	412	Unknown	338	0.00752	16	7	2	0.64	0.28	0.08
Summer-Winter	Hisega	150.810	255	146	Mink	265	0.02123	0	10	0	0.00	1.00	0.00
Summer-Winter	Hisega	150.910	265	172	Expelled	285	0.01802	0	10	1	0.00	0.91	0.09
Summer-Winter	Hisega	150.981	290	237	Alive	360	0.01308	2	23	1	0.08	0.88	0.04
Summer-Winter	Hisega	151.021	260	179	Alive	165	0.01732	0	21	5	0.00	0.81	0.19
Summer-Winter	Hisega	151.151	321	338	Avian	205	0.00917	0	15	3	0.00	0.83	0.17
Summer-Winter	Hisega	151.205	286	211	Unknown	240	0.01469	2	3	0	0.40	0.60	0.00
Summer-Winter	Hisega	151.099	286	211	Unknown	360	0.01469	NA	NA	NA	0.00	0.00	0.00
Summer-Winter	Placerville	150.408	346	407	Alive	345	0.00762	15	5	6	0.58	0.19	0.23
Summer-Winter	Placerville	150.450	305	292	Alive	225	0.01062	19	5	2	0.73	0.19	0.08
Summer-Winter	Placerville	150.490	307	332	Alive	230	0.00934	24	1	1	0.92	0.04	0.04
Summer-Winter	Placerville	150.550	365	520	Alive	320	0.00596	24	0	2	0.92	0.00	0.08
Summer-Winter	Placerville	150.600	385	615	Alive	270	0.00504	26	0	0	1.00	0.00	0.00
Summer-Winter	Placerville	150.650	392	550	Alive	189	0.00564	12	6	8	0.46	0.23	0.31
Summer-Winter	Placerville	150.752	323	406	Avian	202	0.00764	8	1	2	0.73	0.09	0.18
Summer-Winter	Placerville	150.860	331	358	Alive	285	0.00866	7	1	18	0.27	0.04	0.69

* Fishes 150.132 and 151.099 were not found after surgeries; likely attributed to avian predation or transmitter failure.

Appendix A.4. Movement data for radio tagged Brown Trout during the telemetry study from Summer 2018 to Winter 2019.

Season	Study Area	Frequency	Locations	Days	First-to-Last (m)	Net Movement (m)	Gross Movement (m)	Gross/Day (m)	Goss/Week (m)	Home Range (m)
Summer-Winter	Basin	150.020	9	63	35.2	34.77	52.27	0.830	5.808	38.0
Summer-Winter	Basin	150.080	26	175	21.6	24.17	231.85	1.325	8.917	44.6
Summer-Winter	Basin	150.182	26	175	-150.6	-142.35	2722.23	15.556	104.701	1350.4
Summer-Winter	Basin	150.221	26	175	-30.5	-26.7	629.16	3.595	24.198	196.7
Summer-Winter	Basin	150.260	4	23	4.87	6.79	16.39	0.713	4.098	9.4
Summer-Winter	Basin	150.360	26	175	-854.6	-727.53	17121.97	97.840	658.537	8767.5
Summer-Winter	Basin	150.710	2	8	6.2	6.2	6.2	0.775	3.100	12.4
Summer-Winter	Basin	150.132	-	-	-	-	-	-	-	-
Summer-Winter	Hisega	150.312	25	168	-582.9	-593.89	783.37	4.663	31.335	625.0
Summer-Winter	Hisega	150.810	10	70	-22.1	-21.29	121.83	1.740	12.183	60.5
Summer-Winter	Hisega	150.910	11	77	-3.7	-3.22	67.24	0.873	6.113	20.0
Summer-Winter	Hisega	150.981	26	173	119.5	-97.2	279.78	1.617	10.761	138.1
Summer-Winter	Hisega	151.021	26	175	103.8	128.41	9950.51	56.860	382.712	4762.9
Summer-Winter	Hisega	151.151	18	119	71.3	64.9	533.3	4.482	29.628	105.7
Summer-Winter	Hisega	151.205	5	26	-620.7	-614.36	650.64	25.025	130.128	640.5
Summer-Winter	Hisega	151.099	-	-	-	-	-	-	-	-
Summer-Winter	Placerville	150.408	26	175	597.2	601.48	940.96	5.377	36.191	696.2
Summer-Winter	Placerville	150.450	26	175	132.9	141.66	746.18	4.264	28.699	243.2
Summer-Winter	Placerville	150.490	26	175	134.5	135.48	506.02	2.892	19.462	122.1
Summer-Winter	Placerville	150.550	26	175	249.6	255.95	1791.71	10.238	68.912	373.7
Summer-Winter	Placerville	150.600	26	175	-4.12	-13.65	373.85	2.136	14.379	110.3
Summer-Winter	Placerville	150.650	26	175	104.6	122.03	415.65	2.375	15.987	70.3
Summer-Winter	Placerville	150.752	11	68	107.6	112	394.86	5.807	35.896	134.7
Summer-Winter	Placerville	150.860	26	173	202.6	204.01	1565.69	9.050	60.219	508.7

* Fishes 150.132 and 151.099 were not found after surgeries; likely attributed to avian predation or transmitter failure.

Appendix B.1. Concentrations and dosages of drugs used for chemical immobilization (Ketamine and Xylazine), long-lasting antibiotic (Baytril), and long-acting pain reliever (Buprenorphine) along with amounts to be administered based on animal weight.

	Ketamine	Xylazine	Baytril	Buprenorphine SR
Concentration (mg/mL)	100	10	22.7	1
Dose mg/kg	40	1	20	0.1
Weight	mL (IM)	mL (SC)	mL (IM)	mL (SC)
0.5	0.20	0.05	0.44	0.05
0.75	0.30	0.08	0.66	0.08
1	0.40	0.10	0.88	0.10
1.25	0.50	0.13	1.10	0.13
1.5	0.60	0.15	1.32	0.15
1.75	0.70	0.18	1.54	0.18
2	0.80	0.20	1.76	0.20
2.25	0.90	0.23	1.98	0.23
2.5	1.00	0.25	2.20	0.25
2.75	1.10	0.28	2.42	0.28
3	1.20	0.30	2.64	0.30
3.25	1.30	0.33	2.86	0.33
3.5	1.40	0.35	3.08	0.35

* Intramuscular injection denoted with IM and subcutaneous injection denoted with SC.