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Seasonal Movements and Mortality Instances of Brown Trout (*Salmo trutta*) in a Black Hills Stream

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Abstract

Brown Trout (*Salmo trutta*), a popular game fish in the Black Hills' sport fishery, is poorly understood when it comes to seasonal movements in many Black Hills streams. We attempted to determine short and long-term movement patterns, seasonal movement changes (spawning and pre-winter), habitat preference and document mortality events across a 9-month period using radio telemetry. Twenty-five adult (227 - 421 mm) Brown Trout were surgically implanted with radio transmitters during the Summer of 2023. Movements throughout the study decreased throughout the period of sampling. Pre-spawning movements averaged 171 m in the short-term and 1,558 m over this phase. During the spawning period, movements decreased to 154 m short-term and 625 m long-term along with a further decrease post-spawn (20 m short-term, 310 m long-term). Habitat preferences during the pre-spawning (pools 23%, riffles 17%, runs 60%) and spawning season (pools 26%, riffles 12%, runs 63%) were different from those in the post-spawning season (pools 46%, riffles 5%, runs 49%), and three documented predation events occurred strictly during the post-spawning season. These findings give managers valuable insight towards seasonal movement patterns, habitat use and extent of predation on a wild Brown Trout fishery.

Keywords

Brown Trout, *Salmo trutta*, Movement, Predation

1. Introduction

Trout were introduced into the Black Hills of South Dakota in 1886 [1] [2]. Today, these fisheries supply recreation for anglers; specifically, fly anglers who seek areas where large (>400 mm TL) Brown Trout (*Salmo trutta*) reside. Management efforts have included catch-and-release regulations in conjunction with no live bait allowed to help ensure the longevity of these unique fisheries. Catch and release regulations allow an individual fish to be caught multiple times throughout their lifespan and restricting the use of live bait reduces the potential impact of "deep swallows" by fish that consume organic bait [3]. Understanding habitat preferences of target fish throughout their life stages and the potential impact of human interactions (*i.e.* catch-and-release fishing), is becoming increasingly important for best management practices [4]-[7].

The importance of wild Brown Trout and their continued survival depends on successful spawning for Black Hills stream fisheries. Spawning requires moderate flows (21 - 600 liters/second) and cold water (~12˚C) with abundant oxygen (>83%) availability over the trout redd [8] [9]. Previous studies conducted in the Black Hills have described specific areas where Brown Trout have shown preference for building redds and the approximate timing of their spawning period [10]-[15]. However, little is known about the spatial extent of their movement patterns. Except for one study, little work on spawning trout movement within the Black Hills of South Dakota has been done and that was performed on Rainbow Trout (*Oncorhynchus mykiss*) [11]. A knowledge gap still exists concerning fall spawning movement patterns. Information regarding specific movements in this stream stretch would be beneficial for long-term management practices [16]. An understanding of both the spatial and temporal characteristics regarding movements of fishes during their spawning seasons can be beneficial in their preservation. Spawning activities of fishes are a life history factor that may be impacted by stream habitat work, or other anthropogenic activities. By determining the seasonal movements of fishes, managers can more precisely determine appropriate regulations or habitat modifications to ensure fish survival and success in the environment.

Fish movements are impacted by a variety of factors, such as water discharge, temperature, photoperiod, fish size and condition, and different feeding strategies [17]-[19]. Brown Trout have shown different movements based upon genetic and phenotypic differences [8] [16] [20].

Fish survival is dependent on mortality from angling and natural causes [21]. Angling mortality is typically described as the death of an individual due to fishing activity. In the case of this study, angling mortality was limited due to the catch-and-release management restrictions for all trout and that no organic bait was permitted in the study area. Natural mortality may result from many different aspects including avian predation, mink (*Neogale vison*) predation, environmental changes, and disease. The reproductive phase of a fish's life can be a potentially stressful period; therefore, mortality from the spawning event may also impact the overall survival of fish.

Our study objectives were to identify the spawning movements of Brown Trout in a Black Hills stream section, determine the specific short and long-term movements of adult Brown Trout whilst assessing the proportion of habitat they inhabit, and determine the extent of predation on large (>300 mm TL) Brown Trout in a catch and release section of Rapid Creek. Known variability in Brown Trout movements and known site fidelity were factors in choosing the section of Rapid Creek to study. Given its importance as a sport fishery in the Black Hills, it is important to ensure that this specific population is protected, especially during the spawning season.

2. Materials and Methods

2.1. Study Area and GIS Association of Fish Locations

The study area consisted of a 3600 m stretch of Rapid Creek below Pactola Reservoir. The stream section was separated into five different segments based on physical and spatial differences. These areas were not of equal length due to differing geographical differences. Each segment was spatially segmented in ArcGIS Pro (v. 3.2.2) and given values that represent their actual start and end distance values (**Figure 1**). Specific fish locations were determined as GPS points that were associated to the centerline of Rapid Creek by digitized line features. The data compiled from this action was further segmented into 100-meter sections delineated through ArcGIS via the "split" command. This equipped each 100-meter section with a specific numerical notation, originating at the mouth of Rapid Creek. These notations were used to analyze fall spawning Brown Trout movements. Overall, these separate areas provided a broad range of habitat that allowed for relative ease when determining and assessing the overall movement patterns of Brown Trout.

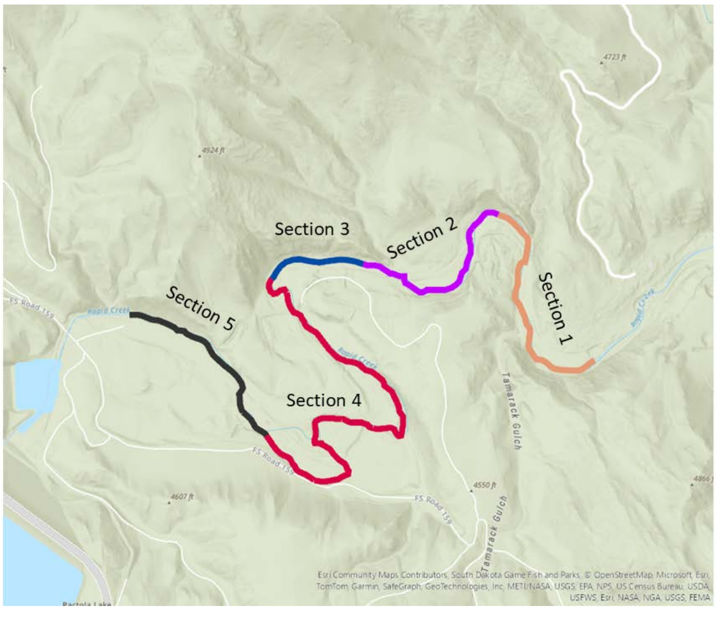

Figure 1. Map depicting relative location of the stream sections used to evaluate trout movement below Pactola Reservoir.

2.2. Implantation of Radio Transmitters

Twenty-five Brown Trout were captured along this stretch of creek using a backpack electrofishing unit (Smith Root LR-24, Vancouver, WA, USA). Immediately after their capture, they were surgically implanted with radio transmitters. The surgeries were conducted from June 21-23, 2023 as well as an additional tagging event on July 12, 2023. Throughout this process, it was ensured that the chosen fish were of the appropriate size for the transmitters. Of the 25 sampled fish, two were slightly above the 2% rule (Fish 1 = 2.33% & Fish 5 = 2.48%) (**Table 1**) [22]. During surgeries, each fish was anesthetized using tricaine methanesulfonate (MS222). The radio transmitters (Model F1570, Advanced Telemetry Systems, Isanti, MN) each weighed approximately 3.1 g and were implanted using the shielded needle technique [23]. All equipment was treated with an iodine solution to reduce possible infection. After implantation, fish were allowed to recover for approximately 15 minutes in a net pen and then released close to their original capture location.

2.3. Radio Telemetry

Tracking of implanted trout began on June 28th, 2023, and continued weekly until February 26th, 2024. This end date was chosen due to the gradual failure of the transmitters. Fish locations were identified by utilizing radio telemetry 1 - 2 times per week, during daylight hours, using a Lotek Biotracker VHF Receiver (Seattle, Washington), a three-element YAGI antenna (Advance Telemetry Systems, Isanti, Minnesota), and a Suunto Compass to determine the angle of greatest signal strength. Data were stored using Survey123 on an Android Tablet equipped with GPS capabilities. To limit the outside influence on tracked fish, we collected 1 - 2 locations at a location perpendicular to the identified fish location and the shoreline, later these positions were associated to the previously described 100 m stream sections developed through ArcGIS.

Fish were classified into guilds (mink predation, avian predation, transmitter failure, movements outside of study area, spawning behavior, unknown causes) partially based on those used by [24]. If a fish exhibited limited movement over several weeks, attempts were made to startle the individual to determine if it was still alive. In addition, on every tracking occasion and for each fish location, we visually determined and documented the general habitat where the strongest signal was identified. Locations were placed into one of three groups (*i.e.*, pool, riffle, or run) depending upon the approximate location of the individual in the stream [25]. Measurements were not taken to further define these habitat types and possibly disturb the tagged trout.

2.4. Determination of "Short-" and "Long-Distance" Movements and Temporal Analysis

Movements were separated into short- and long-distance movements based on weekly fish locations. Given the highly habitat-philopatric and residential nature of brown trout, initial short-distance movements were those that were within 100 m above or below the initial 100 m section the specific fish was originally captured.

If, or when the fish exceeded 100 m out of this range, this was considered a "long-distance" movement.

Both the pre-spawning season (June 28th through September 26th, 2023) and post-spawning season (November 28th through February 26th, 2024) lasted 90 days. These dates were determined through earlier studies within the Black Hills [10] [12]-[14]. Conversely, the spawning season (Oct. 3rd through November 22nd, 2023) lasted only 50 days. These results were determined through evidence of initial redd construction, until cessation of new redds were observed. Given the difference in length of the three "seasons", a proportion was used to ensure that any relationship was correct, and results were not skewed. Trout movement was also analyzed by separating into two categories: net and total movement. Net movement considered their ending location compared to the fish's starting location. Whereas total movement was the total of all movements (*i.e.*, summed) throughout the entire study. This total movement is an estimate of straight-line approximations as fish are likely to move laterally across the stream as well as in an upstream/downstream orientation. We also determined the average movement per day to gauge extent across each season.

2.5. Survival Assessments

Fish mortality was grouped into three categories: survived throughout the study (S), predated (P) and unknown fate (U). When transmitters were located outside of the stream, identification of potential predators were presumed (*i.e.* transmitter located in mink latrine were assumed as mink predation).

Table 1. Brown trout metrics in association to body weight, observations and presumptive fate (P = predated, S = survived, U = unknown) during radio telemetry tracking in Rapid Creek, Pennington County, South Dakota.

Fish Number	Frequency	Length (mm)	Weight (g)	Transmitter % of Body Weight	Number of Observations	Fate
1	149.432	227	133	2.33	31	P
2	149.353	257	177	1.75	41	S
3	149.311	357	493	0.63	2	U
4	149.390	421	825	0.38	37	S
5	149.483	228	125	2.48	0	U
6	149.423	336	378	0.82	20	S
7	149.382	368	517	0.60	27	S
8	149.371	405	630	0.49	40	S
9	149.412	325	372	0.83	42	S
10	149.272	278	220	1.41	40	S
11	149.442	410	670	0.46	29	P
12	149.290	510	874	0.35	24	S
13	149.472	401	701	0.44	42	S

Continued

14	149.332	362	550	0.56	28	P
15	149.453	420	816	0.38	42	S
16	149.592	393	596	0.52	41	S
17	149.643	365	550	0.56	42	S
18	149.652	378	513	0.60	38	S
19	149.554	407	711	0.44	31	S
20	149.612	350	478	0.65	42	S
21	149.664	360	474	0.65	39	S
22	149.513	378	670	0.46	37	S
23	149.563	345	441	0.70	30	S
24	149.545	390	591	0.52	38	S
25	149.502	390	630	0.49	26	S

3. Results

3.1. Movements of Brown Trout During the Summer Season

One fish was lost soon after implantation of the transmitter reducing the total number of fish to 24. During the Summer season (June 28 to September 26, 2023) 12 fish were found to have made long-distance movements with eight individuals moving over 300 m from their origin (Table 2). The other four moved less than 300 m away from their starting location. The average net movement for the pre-spawning period was approximately 171 m (SD 726) upstream as compared to the average total movement, which was 1558 m (SD 1973). Trout movement across all days of the summer season was 17.3 m.

3.2. Movements of Brown Trout During the Fall (Spawning) Season

Seven fish exhibited long-distance movement through the fall spawning period (Oct. 3 to November 22, 2023) (Table 2). Six of these seven moved distances greater than or equal to 300 m, with the greatest distance traveled being approximately 2100 m upstream. Seventeen fish did not make long-distance movements during the spawning season, three made these movements either right before or right after the determined spawning season threshold. The average net movement during this time was 154 m (SD 505) in the upstream direction, whereas the average total movement was approximately 625 m (SD 875). During the spawning season, trout movement was 12.5 m per day.

3.3. Movements of Brown Trout during the Winter Season

During the post-spawning season (November 28, 2023, to February 26, 2024), nine fish completed a long-distance movement (Table 2). Of these nine, six completed movements greater than or equal to 300 m, with the greatest distance being approximately 1100 m downstream. This long-distance movement occurred from

December 12th to December 20th with the individual fish remaining in the downstream location for the rest of the study period. The average net movement during this time was approximately 20 m (SD 284) in the downstream direction, with the average total movement being 310 m (SD 385). Movement per day was 3.44 m during the winter months.

Table 2. Average movement of Brown Trout including average net movement (ANM) and average total movement (ATM) with average movement (m) per day. Data gathered from Pactola Basin of Rapid Creek from June 2023 to February 2025.

Season	Movements		
	ANM (range)	ATM (range)	Movement (m/day)
Pre-Spawning	+171 m (0 m - +3100 m)	1558 m (0 m - 8800 m)	17.31 m
Spawning	+154 m (0 m - +2100 m)	625 m (0 m - 3300 m)	12.50 m
Post-Spawning	−20 m (0 m - −1100 m)	310 m (0 m - 1100 m)	3.44 m

3.4. Seasonal Habitat Utilization

Habitat utilization varied between seasons but especially from the Summer and Fall to Winter (Table 3). During the spawning season, Total average use for each habitat were Pool 32.9%, Riffle 10.7%, and Run 56.4%. Overall, runs were the most selected habitat in all months except January and February of 2024. During this time frame, pools (including backwater zones) were selected by few fish. Throughout the study, water flows were higher during the summer period due to downstream water demands and decreased once demands were reduced (Figure 2).

Table 3. Percentage of fish utilizing pools (P), riffles (Ri) and runs (Ru) as identified through fish locations via radio-telemetry by month.

Month	Percentage		
	P	***Ri***	***Ru***
June	25	25	50
July	31	21	48
August	16	10	74
September	19	11	70
October	24	14	62
November	28	9	63
December	44	4	51
January	52	0	48
February	56	3	42
Average	33	11	56

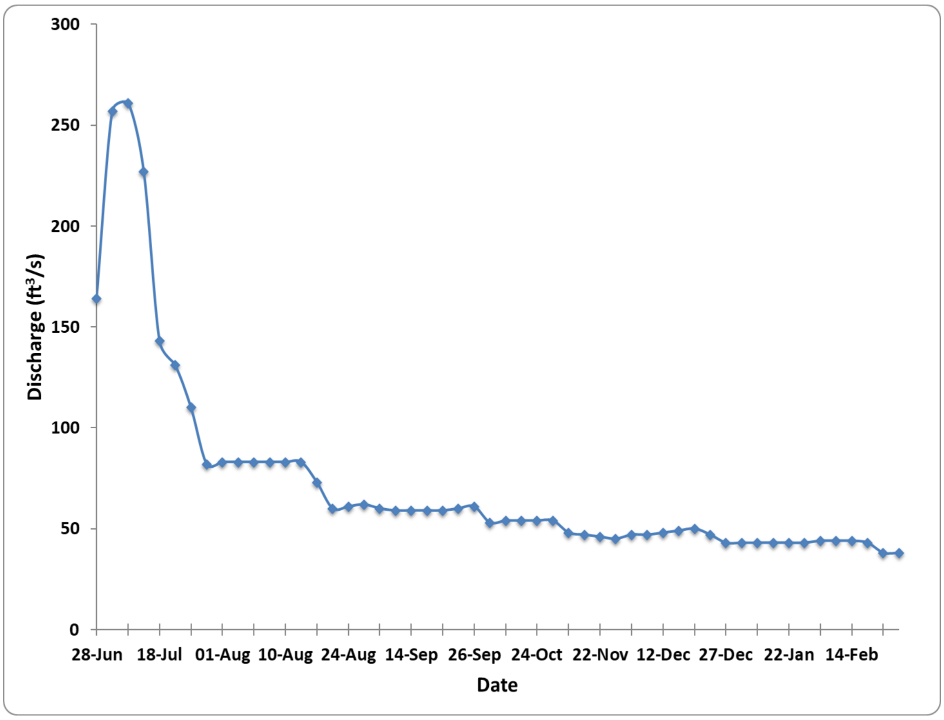

Figure 2. Discharge of U.S.G.S. water from Pactola Reservoir directly upstream of study area during the sampling period of 28 June 2023 to February 28, 2024.

3.5. Fish Mortality

Of the original 25 tagged fish, five were lost with two having an unknown fate, two losses were attributed to mink predation, and one was attributed to avian predation (Table 1). Mink predation was assumed when transmitters were found nearby the stream in a mink latrine. Avian predation was credited when the transmitter was found embedded into the top of a riverine snag assessable only by a bird of prey. This study's first "unknown" loss (#5) was assumed to have occurred immediately after transmitter implantation as it was never located after surgery. Unfortunately, this fish was one of the two, within this study to not meet the 2% rule and it is unknown if size was a factor attributing to the mortality [22]. A second fish (#3) died of unknown causes or our inability to locate may be the result of transmitter failure. Two mortalities (#14 and #11) were discovered on December 5th, 2023, with one the result of mink predation and the other was from avian predation. An additional mortality (#1) was discovered on December 12th, 2023, and was attributed to mink predation. Overall, mortality was five fish resulting in a survival rate of 80.0%.

4. Discussion

4.1. Spatial Analysis of Distance Moved for Spawning

Brown trout during this study exhibited increased movement during the spawning period. It was during the spawning period that more frequent movements occurred. Although only seven fish completed long-distance movements during the spawning period, most other individuals initiated movement immediately before or soon after this time frame. These movements could possibly be attributable to spawning migrations or may simply be due to natural variations. Average net movements and average total movements of Brown Trout decreased from the fall through the spring. The greatest movements were recorded during pre-spawn and gradually lessened throughout the spawning period before only limited movement was observed at the end of the study. This steady decrease in movement throughout the year is similar to research in Finland where Brown Trout moved 348 m pre-spawning, 208 m during the spawn, and 53 m post-spawn [8]. Conversely, others concluded that Brown Trout movements were the greatest in the fall and winter whilst fish were selecting for deeper water habitats [18]. The movement patterns of our study seem to indicate that Brown Trout are partitioning longitudinally throughout the stream course and make movements upstream to spawning locations, post spawn they then search out locations where water is deeper for overwintering. We observed this increased selection for pool habitats in a post-spawning time frame and the reduction of movement once established in the winter pool habitats. Decreased movement and an increased use of pool habitats seem to be exemplary for Brown Trout approaching winter in controlled released streams.

4.2. Outside Effects on Brown Trout Movement

Fish can take advantage or be affected by peripheral environmental stimuli [24] [25]. Stream flow has shown to be a factor in movement of Brown Trout [24] [26] [27]. Although there are seasons where Brown Trout display more limited movements (>100 m), there are other studies that found more explorative travels [28] [29]. This may be attributed towards limited food availability and searching for other resources (*i.e.* non-drift).

Stream temperature has also been a noted factor in movement of Brown Trout in a non-regulated stream [27]. Water temperature associated with season may be an impetus, along with flow, for fall movements. In this study of a regulated stream, pre-spawn movements were limited to a mean of 171 m; however, the greatest movement observed was approximately 3100 m upstream (**Table 2**). Temperatures were likely stable throughout the year due to a cold-water release from an upstream reservoir. Although the specifics for the movements seen in this study are unknown, it is entirely possible that they may have been associated with spawning, avoiding predation, or a response to some other stimuli such as flow regime; however, possible genetic and phenotypic differences cannot be discounted [16] [20].

4.3. Mortality

A total of five Brown Trout mortality events were documented during our study. Two mortalities were attributed to unknown factors, whereas three were attributed to predation and all of these occurred after the spawning period. Two of the three confirmed predation events were attributed to mink. Previous work in this stream section noted mink activity varied throughout the year but was most prevalent during early spring and late summer [18]. Our results differed in that all the mortalities attributed to predation occurred during December. In other studies, Mustelids (e.g. American Mink *Neogale vision*, and River Otter *Lontra canadensis*) and Avain (e.g. species of Mergansers *Mergus sp*., Great Blue Heron *Ardea Herodias*) have been documented as Salmonid predators [30]-[36]. Mortality in our study occurred in the late fall season. This may be due to decreasing stream complexity as ice forms, leaving fish more vulnerable [30]. Others noted that streams may be impacted to a greater extent in the fall based, because flowing water will staying open whereas lakes will freeze over thus preventing predation [34]. Jepsen and Rasmussen (2024) further stated that there might be a greater concentration of predators in streams during the initial freeze period as it would be the last water to freeze under certain conditions. Some of these factors may have contributed towards the mortality events observed in our study. The decreased complexity of the environment, decreased discharge rates, and increased lethargy of Brown Trout over the winter months may have contributed to the higher predation rate in the post-spawning season [31] [35] [36].

4.4. Seasonal Habitat Utilization

Brown Trout are "commonly found in rapids and pool-rapid transition zones" [8]. This is consistent with our findings throughout the months of October and November which have relatively small percentages regarding the use of riffle habitats. Pooling water has long been known to be utilized by trout as a thermal refuge during warm periods [37]. In this study there was a reduction in the use of runs, and especially riffles, possibly signaling a habitat preference for pools for overwintering behaviors. Others found that once ice break-up conditions were consistent in combination with high flows were Brown Trout more likely to utilize runs more and pools to a lesser extent [8]. This study, due to constraints battery life, was not able to conclude if this was consistent in Rapid Creek.

4.5. Improvements and Suggestions for Future Study

Our observations were limited to diurnal periods. Incorporating additional crepuscular or nighttime samples may indicate subtle movements we were not able to observe in our study. Increased movements of Brown Trout at night have been noted in streams [18] [38] [39]. Including nighttime locations, may ensure that long-distance movements during the day can be distinguished from normal nighttime movements. Diel movements would also provide information into these fine movement patterns.

Adherence to the 2% rule for transmitter weight to fish weight was used in all but two individuals in our study. These two fish were used due to a low population level in one section of our stream. It is unknown if this had an effect in the results of our study, but by strict obedience to this general rule would delete any potential arguments towards our results of fish size. Others have found an extended period of recouperation is needed after surgery [40] [41]. Adding additional transmitters, although at a greater cost, may have allowed for even greater interpretation of trout movement in this reach of stream.

It may also be useful to implement a smaller "long-distance" movement metric to narrow down results regarding average net and total movement results. An alternative might include more frequent monitoring (e.g. hourly) to depict subtle movement patterns. Furthermore, assessing weekly versus monthly movements instead of purely seasonal, as was done in this study, may reveal a more definite result rather than our generalized movement patterns.

Finally, flows may relate to movements in this specific stretch. To assess this, increased observations and measurements are needed than they were during this study [8]. Increased movements have been associated with higher winter flows for Brown Trout, White Suckers (*Catostomus commersonii*), and Common Carp (*Cyprinus carpio*) [17]. We did not study this potential influence of flow rates; however, fall/winter releases from Pactola Reservoir are typically lower than summer releases due to downstream demands. It may be beneficial to investigate discharge rates below Pactola Reservoir in the future to establish a baseline for normal movement and assess how flows during the spawning season may impact Brown Trout movements. This study provides an improved understanding of Brown Trout movements in this specific reach of stream, and documents mortality events.

Large brown trout are a valuable resource sought after by many anglers. Thus, it is important to know movement mechanisms and how these might indicate specific habitat needs or areas of improvement. Individual growth of these large, wild trout needs to be known by fisheries managers to sustain or increase their abundance in Pactola Basin of Rapid Creek and possibly other nearby streams. Movement studies can elucidate to managers the need to understand how changing of fauna in a stream can affect not only fishing, but overwintering areas as well. By incorporating larger samples, understanding diel changes, microhabitats and potential influences of abiotic factors (*i.e.* flow and temperature) managers can have better tools for understanding how habitat shifts or alterations may play in wild trout fisheries.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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