

# Brown Trout Spawn Timing, Redd Locations, and Stream Characteristics in Spearfish Creek within Spearfish, South Dakota, USA

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## Abstract

This study documented brown trout (*Salmo trutta*) spawning locations, redd construction timing, and associated environmental variables in an 850-m long mainstem section and a 400-m long diversion channel of Spearfish Creek within the city limits of Spearfish, South Dakota, USA in 2019. The first redds were observed on October 15, with no new redds observed after November 12. Redd construction peaked during the first week of November, when 23 redds were observed in the mainstem section and 50 in the diversion channel. Substrate size was significantly smaller, water temperatures significantly higher, and water velocities significantly greater in redd versus non-redd locations in both the mainstem reach and the diversion channel ( $P < 0.05$ ). Six significant redd hotspots were observed in the diversion channel. Hotspots were associated with a small ( $0.1^{\circ}\text{C}$ ), but significant, increase in water temperature from the rest of the channel locations. This is the first study to document redd locations in Spearfish Creek and will provide a baseline to evaluate future spawning activity, particularly as it may be affected by likely future anthropogenic changes potentially affecting the stream environment.

## Keywords

Brown Trout, *Salmo trutta*, Spawning, Redds, Black Hills, South Dakota

## 1. Introduction

Brown trout (*Salmo trutta*) are an important recreational fish species and are also considered to be an indicator of aquatic ecosystem health [1]. In the Black

Hills of South Dakota (USA), brown trout are not native and were introduced in 1890 [2]. They quickly became naturalized, with naturally-reproducing and self-sustaining populations in nearly all of the 1287 km of Black Hills streams where appropriate habitat is present [3] [4] [5].

Brown trout spawning characteristics vary regionally [6]. In the Black Hills, spawning typically occurs over four weeks, beginning in mid-to-late October [7] [8] [9] [10]. As with other salmonids, brown trout create redds, which are gravel pit nests for egg deposition [11]. Redd location is predicated on stream characteristics, including morphology, substrates, and water velocity [12]. Brown trout prefer faster-moving water over coarse gravel in shallower stream reaches [7] [13]. Redd data has been used to assess trout populations [14] [15] [16] [17] [18]. The location and number of redds within a stream may also be useful to assess the environmental impacts of changes in water flows or temperatures [19].

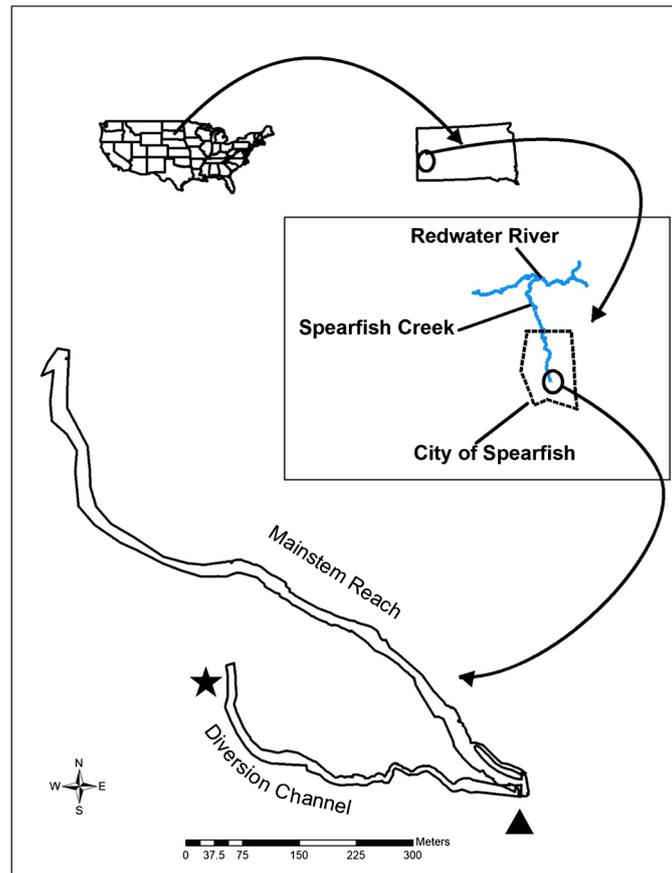
Spearfish Creek drains a major portion of the Northern Black Hills and contains a large brown trout population in a reach running through the city of Spearfish [20]. Human population growth is rapidly increasing in the Spearfish metro area [21], creating potential water demands that may impact Spearfish Creek. In addition, changes to commercial and agricultural operations, such as increased discharges from the D.C. Booth Historic National Fish Hatchery [22] [23], may also influence the hydrologic characteristics of the creek, and, in-turn, brown trout reproduction and recruitment.

Only two studies have examined brown trout redd locations and numbers in three Black Hills streams. Ketelsen *et al.* [9] provided cursory data for two locations in the central Black Hills, and [10] obtained redd data for a small prairie stream adjacent to the Black Hills. No redd information from Spearfish Creek is currently available. In addition, there is no documentation concerning the environmental factors potentially influencing the spawning site selection of brown trout anywhere in the Black Hills. Thus, the objective of this study was to document the abundance and spatial distribution of brown trout redds, and identify redd environmental characteristics, in both a mainstem reach and diversion channel of Spearfish Creek within the city of Spearfish, South Dakota.

## 2. Methods

### 2.1. Study Area

This study occurred in a mainstem reach and diversion channel of Spearfish Creek within the city of Spearfish in Lawrence County, South Dakota, USA. The mainstem reach site was approximately 850 m long. It began at the Spearfish City Hydropower Plant and ended at a low head dam located just downstream from the playground by the main city park parking lot (latitude, longitude = 44°28'48.60"N, -103°51'22.99"W, **Figure 1**). The diversion channel in its entirety is approximately 400 m long. It originates from the downstream side of the hydropower plant, flows through the Spearfish City Campground, and terminates at the D.C. Booth Historic National Fish Hatchery. It is the primary water supply



**Figure 1.** Study site map showing mainstem and diversion channel. Hydropower plant location is marked with a triangle and the DC Booth Historic National Fish Hatchery is marked with a star.

for the hatchery.

## 2.2. Redd Identification and Location

Sampling began on October 15, 2019. Observations occurred weekly until the construction of new redds had largely ceased and there was no observation of spawning fish, as described by [24]. The final sampling date was November 12, 2019. Redd identification followed the techniques described previously [9] [10] [24]. However, because redds varied greatly in size and creek conditions varied from week-to-week due to variability in hydropower plant discharges, redd identification was more loosely defined as the presence of a clear pit and overturned substrate that formed a mound and/or a clear tail (Figure 2) [25]. Redd locations were recorded using a Global Positioning System unit (Trimble, Sunnyvale, California, USA). Spearfish has a continental, temperate climate, and average daily ambient air temperatures at the start and end of the study were 4°C and -5°C, respectively.

## 2.3. Environmental Data Collection

Environmental data, including stream width, water depth, velocity, temperature,



**Figure 2.** Photo of typical redd with gravel and rocks devoid of sediment in comparison to the surrounding stream bed.

substrate size, and the presence or absence of cover directly over the redd, was recorded at each redd location. Water velocity and depth were measured with a flow meter (OTT MF Pro, HydroMet USA, Loveland, Colorado, USA). Substrate size was measured with a gravelometer (WildCo, Forestry Suppliers, Jackson, Mississippi, USA). If the substrate was too large for the gravelometer to measure, it was assigned a value of 300 for data analysis. The presence or absence of cover (bridge, shrub, or tree) directly above the sampling location was also recorded. Stream width was measured bank to bank to the nearest 15 cm.

The week after the last redds were constructed, environmental data was collected in random, non-redd locations. Sampling locations were determined from a random points map, generated with ArcMap software (ArcGIS Desktop v. 10.7.1, Environmental Systems Research Institute, Redlands, California, USA).

#### **2.4. Data Analysis**

Redd locations were spatially analyzed using a time-space implementation of the Getis-Ord  $GI^*$  statistic (Emerging Hotspot Analysis, ArcMap v. 10.7.1, Environmental Systems Research Institute, Redlands, California, USA). Redd locations from November 5, 2019 were used for the emerging hotspot analysis, due to redd deterioration on the final sampling date. T-tests were conducted to compare environmental data collected at the hotspot and non-hotspot locations in the diversion channel. T-tests were also used to compare environmental data at redd and non-redd locations, and redd locations between the mainstem reach and the diversion channel ( $P < 0.05$ ).

### **3. Results**

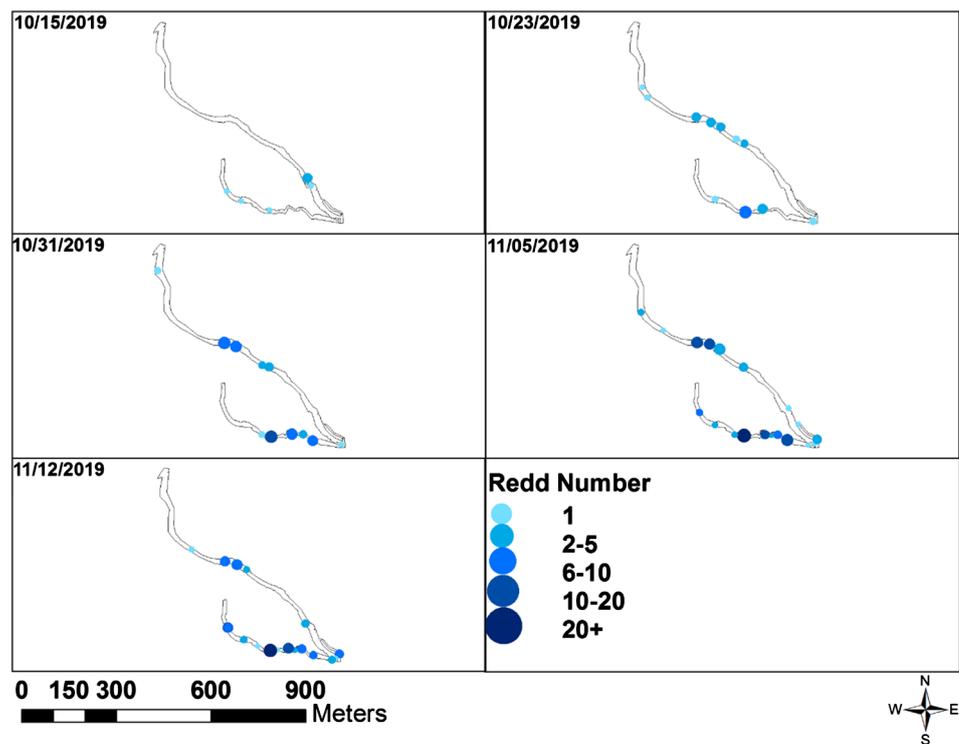
A total of 105 redds in both locations were observed over the five-week study period (**Table 1**). Peak spawning activity was observed on October 31, when 48

new redds were observed. The smaller diversion channel had nearly three times the number of redds compared to the larger mainstem reach (**Figure 3**). Six significant hotspots were identified in the diversion channel (**Figure 4**). Water temperature was the only variable significantly different between the hotspot and non-hotspot locations in the diversion channel, although the difference was only 0.1°C (**Table 2**). Substrate size, overhead cover, stream width, stream depth, and water velocity were not significantly different between hotspot and non-hotspot locations.

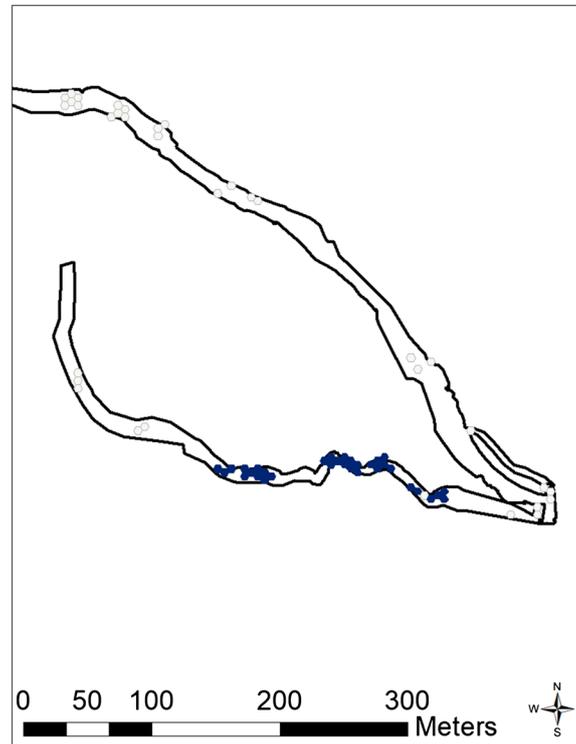
Compared to non-redd locations, redd locations in the mainstem reach were in significantly shallower water with significantly higher velocities in significantly smaller substrate, with significantly more overhead cover (**Table 3**). In the diversion channel, overhead cover was not significantly different between redd and non-redd locations, but substrate size, stream width, stream depth, and water

**Table 1.** Number of redds in a mainstem and diversion channel of Spearfish Creek, South Dakota USA from October 15 through November 12, 2019.

Date	Mainstem	Diversion	Total
10/15/2019	3	3	6
10/23/2019	12	13	25
10/31/2019	23	50	73
11/05/2019	31	74	105
11/12/2019	29	76	105



**Figure 3.** Weekly redd location and number.



**Figure 4.** Emerging hotspot analysis (Getis-Ord Gi Statistic) showing six hotspots for redd construction in a mainstem and diversion channel of Spearfish Creek, South Dakota, USA from October 15 to November 5, 2019.

**Table 2.** Mean (SE) substrate size, cover (0 = absent, 1 = present), water temperature, width, depth, and velocity at redd locations and non-redd environmental characteristics for hotspot (n = 65) and non-hotspot (n = 9) redd locations in a diversion channel of Spearfish Creek, South Dakota, USA.

	Hotspot	Non-hotspot	P
Substrate size (mm)	27 (1)	25 (3)	0.607
Cover (0 or 1)	0.4 (0.1)	0.1 (0.1)	0.067
Temperature (°C)	5.0 (0.0) z*	4.9 (0.0) y*	0.011
Width (m)	5.1 (0.2)	4.4 (0.4)	0.258
Depth (m)	0.3 (0.0)	0.3 (0.0)	0.764
Velocity (m <sup>3</sup> /s)	0.3 (0.0)	0.3 (0.0)	0.459

\*Means in a row followed by a different letter are significantly different ( $P < 0.05$ ).

velocity were significantly different. With the results from the diversion channel and mainstem reach combined, redds were in locations with significantly smaller substrate, greater stream width, and higher water velocities.

In comparison to redd locations in the mainstem reach, redds in the diversion channel were in significantly slower water velocities in significantly narrower locations (**Table 4**). In addition, water temperatures in the diversion channel were significantly higher and substrate sizes were significantly smaller.

**Table 3.** Mean (SE) substrate size, cover (0 = absent, 1 = present), width, depth, and velocity at redd locations and non-redd locations in the mainstem channel, diversion channel and overall in Spearfish Creek, South Dakota, USA.

		Redd	Non-redd	P
Mainstem	Substrate size (mm)	36 (3) z*	61 (7) y*	0.029
	Cover (0 or 1)	0.6 (0.1) z*	0.4 (0.1) y*	0.041
	Width (m)	9.5 (0.6)	10.3 (0.5)	0.376
	Depth (m)	0.2 (0.0) z*	0.3 (0.0) y*	0.031
	Velocity (m <sup>3</sup> /s)	0.34 (0.02) z*	0.26 (0.02) y*	0.021
Diversion	Substrate size (mm)	27 (1) z*	52 (11) y*	0.024
	Cover (0 or 1)	0.4 (0.1)	0.5 (0.1)	0.191
	Width (m)	5.0 (0.2) z*	4.1 (0.2) y*	0.001
	Depth (m)	0.3 (0.0) z*	0.2 (0.0) y*	0.000
	Velocity (m <sup>3</sup> /s)	0.27 (0.01) z*	0.15 (0.02) y*	0.000
Overall	Substrate size (mm)	29 (2)	57 (6)	0.000
	Cover (0 or 1)	0.5 (0.1)	0.4 (0.0)	0.754
	Width (m)	6.4 (0.3) z*	7.6 (0.4) y*	0.016
	Depth (m)	0.3 (0.0)	0.3 (0.0)	0.786
	Velocity (m <sup>3</sup> /s)	0.29 (0.01) z*	0.21 (0.01) y*	0.000

\*Means in a row followed by a different letter are significantly different ( $P < 0.05$ ).

**Table 4.** Mean (SE) substrate size, cover (0 = absent, 1 = present), water temperature, width, depth, and velocity at redd locations in the mainstem reach and the diversion channel in Spearfish Creek, South Dakota, USA.

	Mainstem	Diversion	P
Substrate size (mm)	55 (5) z*	36 (6) y*	0.038
Cover (0 or 1)	0.4 (0.1)	0.5 (0.0)	0.849
Temperature (°C)	3.1 (0.2) z*	3.8 (0.1) y*	0.000
Width (m)	10.1 (0.4) z*	4.6 (0.1) y*	0.000
Depth (m)	0.3 (0.2)	0.3 (0.0)	0.061
Velocity (m <sup>3</sup> /s)	0.28 (0.02) z*	0.21 (0.01) y*	0.000

\*Means in a row followed by a different letter are significantly different ( $P < 0.05$ ).

## 4. Discussion

### 4.1. Redd Timing

The results of this study indicate that the timing of Spearfish Creek brown trout redd construction is similar to that reported elsewhere in the Black Hills region [9] [10] and in Canada [26]. However, the timing is earlier than brown trout in their native range. Rubin *et al.* [27] found anadromous brown trout spawning in Sweden began in late November and extended through December. Alp *et al.* [28] reported a similar starting period with spawning going through January in Turkey. Latitude, altitude, photoperiod, and water temperature have all been corre-

lated with spawning times, with earlier and shorter spawning seasons associated with colder water temperatures, more variable water temperatures, and variable flows [25] [29] [30].

#### 4.2. Redd Density

The 84 redds/km observed in this study are within the range of densities reported for other locations. In three other stream reaches in the Black Hills, approximately six redds/km were recorded in a section of Crow Creek [10], 43 redds/km in a reach of Box Elder Creek [9], and 106 redds/km in a reach of Rapid Creek [9]. The number of redds in Spearfish Creek, Box Elder Creek, and Rapid Creek are greater than that reported in locations outside of the Black Hills and outside of the USA. Gortázar *et al.* [6] found 36 redds/km in the river Castril, Granada, Spain. Zimmer and Power [26] observed about 10 redds/km in the Credit River, Ontario, Canada, and [31] reported about 73 redds/km in a narrow tributary of the River Don, Aberdeenshire, north-east Scotland. Only Crow Creek has a lower redd density, which may be because it is a heavily sedimented stream running through cattle grazing land [9] [10].

#### 4.3. Superimposition/Spawning Behavior

Redd superimposition is when a female trout uses a previously excavated redd location. Although this was not observed in Spearfish Creek, it was not explicitly measured. However, redds were constructed in very close proximity to one another, especially in the identified hotspots. Similarly, no redd superimposition in Crow Creek just outside the Black Hills was reported [10], but significant redd clustering was observed in one of the three creek sections examined in Black Hills where both brown and brook trout (*Salvelinus fontinalis*) reside [9]. Redd superimposition has been frequently observed between salmonids elsewhere and may be due to reasons other than spawning habitat availability [6] [10] [32]. Gortázar *et al.* [6] suggested that female brown trout may use previously altered creek substrates to select specific spawning sites. Site selection is also likely due in part to brown trout homing behavior [33].

#### 4.4. Redd Relationship to Environment

This study supported the well documented relationship between substrate size, stream width, water depth, and water velocity to trout spawning habitat [6] [9] [12] [26]. Water temperature is also widely believed to be a significant factor in salmonid habitat and spawn timing [6] [9] [12] [26], although [6] did not consider water temperature to be that important in brown trout redd location. In this study, emerging hotspot analysis isolated temperature as the only difference between redd sites in the hotspot and redd sites not located in the hotspot in the diversion channel. The 0.1 °C temperature difference, though statistically significant, may not be biologically significant. However, water temperature could be further investigated in its influence on the spatial distribution of redds in the

Black Hills.

#### 4.5. Study Limitations

This study was limited to only 1.25 km of only one stream in the Black Hills of South Dakota. Thus, the results of this study may not be applicable beyond this localized brown trout population. In addition, although the redd observers were well-trained, they were relatively inexperienced in redd identification which may have affected results. Lastly, identification of a redd does not necessarily indicate the presence of eggs or successful reproduction. Thus, this survey may not be indicative of actual spawning success in Spearfish Creek, nor of recruitment of progeny into the established brown trout population.

#### 4.6. Management Implications

Redd numbers can be good indicators of fish population size [14] [15] [16] [17] [18] [34], making redd surveys a relatively inexpensive alternative to the more costly electrofishing for population monitoring typically used [14] [15] [16] [17] [18]. Monitoring of redd locations can also help assess changes in stream environmental conditions [19]. This initial redd survey can be used as a baseline to document the potential changes in spawning habitat and reproductive success of brown trout in this section of Spearfish Creek due to inevitable anthropomorphic changes in the associated watershed [25] [29] [30] [35]. Additional research would greatly assist in determining which environmental variables are most important for successful redd construction, as well as the potential location of future habitat improvement projects.

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#### Conflicts of Interest

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

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