

RELATIONS AMONG ARCTIC GRAYLING, NONNATIVE SALMONIDS, AND  
ABIOTIC CONDITIONS IN THE BIG HOLE RIVER, MONTANA

by

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DEDICATION

To Madison, Canyon, and Ryan – Among my many motivations to complete this project was the hope to give you a better life.

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## ABSTRACT

Arctic Grayling *Thymallus arcticus* in Montana have experienced declines in abundance and distribution over the last century, which contributed to the species being designated as a Species of Concern and petitioned for protection under the Endangered Species Act. Conservation of Arctic Grayling in the Big Hole River watershed was based on presumed environmental influences. Interactions with nonnative species, increasing stream water temperatures, drought, and habitat alterations are suggested to influence Arctic Grayling abundances, although sparse quantitative information exists to support these hypotheses. My objective was to evaluate the influence of these biotic and abiotic factors on Arctic Grayling abundances using data collected in the Big Hole River drainage from 1983 through 2015. Arctic Grayling and nonnative salmonids were sampled at 32 sites, stream temperature data were collected at 33 sites, stream discharge data were collected at 21 sites, and habitat data were collected at 441 sites. Ordinary least squares and quantile ( $\tau = 0.90$ ) regression analyses were used to evaluate the relationships among Arctic Grayling catch per unit effort (CPUE), nonnative salmonids CPUE, stream temperature, stream discharge, and habitat condition. The strongest univariate relationship was a positive correlation between the CPUE of Arctic Grayling  $\geq$  age 1 and Brook Trout *Salvelinus fontinalis* CPUE ( $r = 0.55$ ,  $N = 77$ ), which was contrary to the *a priori* predicted relationship. Multivariate analyses suggested that high water temperatures and low discharges during drought conditions have the greatest limiting influences on the CPUE of Arctic Grayling  $\geq$  age 1; Brown Trout CPUE, low water temperatures, and high maximum discharges were suggested as having the greatest limiting influences on age-0 Arctic Grayling CPUE. My findings support current management to increase discharge during drought conditions and further explore relationships between Arctic Grayling CPUE, habitat conditions, and Brown Trout CPUE.

## 1. INTRODUCTION

In North America, Arctic Grayling *Thymallus arcticus* were historically distributed throughout Alaska and northern Canada west of the Hudson Bay; two disjunct southern populations were also present within the upper Missouri River Basin and Michigan (Figure 1; Vincent 1962; Northcote 1995). In Michigan, Arctic Grayling inhabited the major watersheds north of the Rifle and White rivers in the southern peninsula and the Otter River in the northern peninsula (Nuhfer 1992). Currently, populations in Alaska and Canada are widespread, but many have experienced declines in abundance and distribution in recent years (MacPherson et al. 2012). Arctic Grayling in the Missouri River Basin have been reduced to five isolated populations in Montana that occupy less than 5% of the historical range (Kaya 1992a; FWP and USFWS 2006; Peterson and Ardren 2009), and the species was extirpated from Michigan in the 1930s (Vincent 1962; Kaya 1992b).

Interactions with nonnative species, increasing water temperatures, drought and habitat alterations have been hypothesized to limit Arctic Grayling populations (Murphy and Koski 1989; Jorgenson and Joyce 1994; ASRD 2005; Corell 2006; FWP and USFWS 2006; MacPherson et al. 2012; Hackshaw et al. 2014). Previous research evaluated the influence of related biotic or abiotic factors on Arctic Grayling (Hubert et al. 1985; Liknes and Gould 1987; Skaar 1989; Shepard and Oswald 1989; McMichael 1990; Lohr et al. 1996; Byorth and Magee 1998; Hackshaw et al. 2014). Whereas these studies have expanded on the knowledge of Arctic Grayling ecology, evaluating biotic and abiotic factors concurrently is important to understand the factors that influence variation in

population abundance (Power et al. 1988), particularly because management actions for Arctic Grayling typically influence, either directly or indirectly, those biotic and abiotic conditions. For example, management actions that improved riparian habitat and mitigated drought conditions for Arctic Grayling in upper Big Hole Watershed, MT were hypothesized to contribute to an increase in the catch per unit effort (CPUE [fish/km]) of sympatric nonnative salmonid species in 10 sampling reaches (A. McCullough, Montana Fish, Wildlife and Parks, unpublished data).

In Montana, Arctic Grayling are a Species of Concern (FWP 2013) and have been considered for protection under the Endangered Species Act since 1982 (FWP 2013; USOFR 2014). Declines in the abundance and distribution of the Big Hole River population were initially observed in the early 1980s (Kaya 1992b), which initiated an ongoing collaborative conservation effort among state and federal agencies, universities, non-governmental organizations, and private landowners (FWP 2013). Conservation management for the Big Hole River population has been predicated on the hypothesized negative influences of nonnative salmonid species interactions (e.g., competition, predation, or both), increased stream temperature, reduced stream discharge, and degraded habitat on Arctic Grayling abundance (Kaya 1990, 1992b; FWP and USFWS 2006). Conservation actions during the late 1990s consisted primarily of measures to increase stream discharge (i.e., stock-water tanks and incentive programs to reduce irrigation withdrawals) and improve the condition of stream and riparian habitats. In 2006, the Candidate Conservation Agreement with Assurances for Fluvial Arctic Grayling in the Upper Big Hole River (CCAA) program was established to facilitate

conservation actions on non-federal property (FWP and USFWS 2006). The CCAA program was permitted by the U.S. Fish and Wildlife Service through 2026. Currently, 30 participating landowners have enrolled about 61,000 ha in the CCAA program (USOFR 1999; FWP and USFWS 2006). The number of management actions implemented and resources allocated to support conservation efforts have increased considerably through the CCAA program (i.e., an estimated 400 projects and US \$6 million from 2006 through 2014; Montana Fish, Wildlife & Parks, unpublished data). Specifically, minimum discharge targets (July through October) were established at five locations on the Big Hole River (i.e., 0.57 cubic meters per second [CMS] at Miner Lakes Road; 1.13 CMS at Little Lake Creek Road; 1.70 CMS at Highway 43 near Wisdom, MT; 2.83 CMS at Mudd Creek Bridge; and 4.81 CMS at Dickie Bridge; FWP and USFWS 2006); properties owners enrolled in the CCAA program are required to reduce irrigation withdrawals in accordance with property-specific water conservation agreements when discharge levels in the Big Hole River decline below minimum targets. Property owners enrolled in the CCAA program are also required to manage riparian habitats sustainably as defined by the Natural Resources Conservation Service (NRCS) riparian assessment method (NRCS 2004; FWP and USFWS 2006). Additionally, a watershed-wide drought management plan encourages landowners, including those not enrolled in the CCAA program, to reduce irrigation withdrawals when discharge levels decline below targets that were established at five locations on the Big Hole River (Wisdom, MT, Dickie Bridge, Maiden Rock Fishing Access Site, Notch Bottom Fishing Access Site, and confluence with the Jefferson River; BHWC 2014) —a complete

description of the drought management plan is available from the Big Hole Watershed Committee.

The direct and relative benefits of the conservation actions outlined above for Arctic Grayling and sympatric nonnative salmonid species remain unclear. For example, do conservation actions that increase stream discharge during drought conditions relate to an increase in Arctic Grayling abundance? And, if so, do conservation actions that increase stream discharge relate to a greater increase in Arctic Grayling abundance than conservation actions that improve the condition of stream and riparian habitats? A better understanding of the relationships among Arctic Grayling, nonnative salmonids, and abiotic conditions will inform managers about the efficacy of CCAA conservation actions for increasing Arctic Grayling abundance—a primary goal of the CCAA program (FWP and USFWS 2006). Thus, the objective of this study was to evaluate the relationships among Arctic Grayling CPUE, nonnative salmonid CPUE, stream temperature, stream discharge, and condition of stream and riparian habitat using empirical data that were collected from 1983 through 2015. This study marks the first time that over three decades of data collected in the Big Hole River basin have been synthesized and analyzed to inform Arctic Grayling conservation management. Although inference from this study used inductive reasoning that was derived from observational data, the data were collected at large temporal and spatial scales that are not common in other studies on Arctic Grayling.

## 2. STUDY AREA

The Big Hole River originates in the Beaverhead Mountains in southwest Montana and flows 250 km without major impoundments before converging with the Beaverhead River to form the Jefferson River (DNRC 1979). Data used in this study were collected from the Big Hole River and its tributaries between Dickie Bridge (river km 119) and Saginaw Bridge (river km 241; Figure 2). The Big Hole River in the study area is characterized by low gradient (0.08% – 0.37%), low to moderate sinuosity (1.1 – 1.9), and substrate that is dominated by sand, gravel, and cobble (OEA 1995). Stream planform is predominately meandering riffle-pool sequences within a single or anabranching channels. The highest elevation town in the study area, Jackson, MT, is located at 1,973 m above sea level (Figure 2). The fish assemblage consists of Arctic Grayling, Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi*, Brook Trout, Brown Trout *Salmo trutta*, Rainbow Trout *Oncorhynchus mykiss*, Mountain Whitefish *Prosopium williamsoni*, Burbot *Lota lota*, White Sucker *Catostomus commersonii*, Longnose Sucker *Catostomus catostomus*, Mountain Sucker *Catostomus platyrhynchus*, Longnose Dace *Rhinichthys cataractae*, and Mottled Sculpin *Cottus bairdi* (Oswald 2000).

Predominant land-use practices in the study area facilitate agricultural production. Traditional cattle ranches dominate the landscape, with the largest town inhabiting about 100 people (Wisdom; Figure 2; USCB 2015). Beaverhead County contains about 80% of the study area and produces the most beef cattle among counties in Montana and ranks fifth for beef cattle production among counties in the USA (USDA 2014). Additionally,

about 1,000 water rights allow for the seasonal diversion of surface water from streams to irrigate hay fields or provide water for livestock (FWP and USFWS 2006). Native riparian (e.g., *Salix* spp., *Carex* spp., and *Juncus* spp.) and upland (e.g., *Artemisia* spp.) plants dominate the vegetative assemblage, but agricultural land use frequently promotes nonnative grasses (e.g., *Poaceae* spp. and *Phleum* spp.) and forbs (e.g., *Brassica* spp., *Trifolium* spp., and *Taraxacum* spp.; OEA 1995).

### 3. METHODS

#### Arctic Grayling and Nonnative Salmonid Abundance

Abundance was estimated or CPUE data (fish/km) were collected for Arctic Grayling and nonnative salmonids (i.e., Brook Trout, Brown Trout, and Rainbow Trout) from 12 Big Hole River reaches (87 km; 71% of the Big Hole River in the study area was sampled) and 20 tributary reaches (72 km) from 1983 through 2015 (Figure 2; Appendix A). Abundance was estimated infrequently and was generally of poor precision because the number of recaptures was low. Thus, CPUE data were calculated as the total number of fish sampled during the first sampling pass divided by the length (km) of the sampling reach. Sampled stream reaches varied from 0.3 to 18.8 km (mean = 4.9 km) in length and generally targeted the Big Hole River or the lower portion of its tributaries. Data were not collected from all stream reaches in all years, and only Arctic Grayling were sampled (i.e., nonnative salmonids were not sampled) during 83 of the 263 sampling events (Appendix A). Fish CPUE data were assumed to be independent within and among years because the Big Hole River watershed is an open system and fish migrate in response to environmental conditions.

Fish were sampled from late-August through early-November using boat-mounted (Coffelt Mark XXII-M, Leach, or West rectifying unit on a Crawdad® or drift boat) or backpack (Smith-Root, Inc.; models 12-B or LR-24) electrofishing equipment and measured for length (mm; TL) and weight (g). Sampling occurred in water temperatures <18.5°C. Arctic Grayling of all age classes were sampled (probably age 0 [ $\leq$  150 mm]

through age 5; Kaya 1990; Montana Fish, Wildlife & Parks unpublished data). However, minimum lengths were regularly established for measuring nonnative salmonid species to complete sampling events more expeditiously; thus, nonnative salmonid CPUE data were truncated to only include individuals  $\geq 254$  mm, which was the greatest minimum length established for nonnative salmonids during sampling events.

### Stream Temperature

Stream temperature data were collected using Onset® HOBO® Temp or Water Temp Pro loggers at 33 sites from 1992 through 2015, but data were not collected from all sites in all years (Figure 2; Appendix A). Data loggers recorded information at 30- to 60-minute intervals and typically operated from 1 May through 30 September. Loggers were contained in polyvinyl chloride housings and secured to a rock, bridge, or the base of a willow (*Salix* spp.).

### Stream Discharge

Stream discharge data were collected seasonally (April through October) at nine Big Hole River sites and 12 tributary sites from 1988 through 2015 (Figure 2; Appendix A). Data were not collected at all sites in all years. Continuous water-stage height measurements were recorded (AquaRod®, TruTrack® WT-HR series, Design Analysis®, or Sutron® instruments) and calibrated to stream discharge that was measured from 5 to 10 times annually throughout the hydrograph (e.g., ascending limb, peak, descending limb, base flow; USGS 1982). Discharge measurements ( $\text{m}^3/\text{s}$ ) were

estimated using depth (m), width (m), and current velocity (m/s) measurements from a minimum of 20 locations along a transect perpendicular to the stream flow (USGS 1982). Typically, current velocity was measured at a depth of 0.6 times the total water depth using Marsh-McBirney® Flo-Mate 2000 flowmeter. A rating curve was developed by relating discharge measurements to water-stage height measurements to estimate stream discharge for the monitoring period.

### Stream and Riparian Habitat Condition

The NRCS riparian assessment method (NRCS 2004) was used to quantitatively evaluate the condition of stream and riparian habitats from 2005 through 2015 (FWP and USFWS 2006; Appendix A). The attributes of the riparian area (e.g., vegetative and flood plain characteristics) and morphological processes of a stream (e.g., erosion and deposition characteristics) were visually assessed and scored using ten criteria to produce a unit-less value that characterized the condition of stream and riparian habitat—a higher score reflected better habitat condition. A complete description of the methodology is available from the NRCS (NRCS 2004). The total riparian assessment score can be partitioned into three subcategory scores (i.e., geomorphic, vegetative, and functional). Assessment reaches typically coincided with land-use boundaries (i.e., livestock pasture or hay field fence line).

### Data Analysis

Arctic Grayling CPUE (fish/km) data were partitioned into two demographics (i.e.,  $\geq$  age 1 and age 0) and were truncated to only include values greater than zero for analyses—CPUE values of zero were removed to specifically evaluate relationships with biotic and abiotic conditions where Arctic Grayling occur. Nonnative salmonid CPUE data were standardized to fish  $\geq 254$  mm in length and partitioned by species (i.e., Brook Trout, Brown Trout, and Rainbow Trout). Stream discharge can influence the efficacy of CPUE estimates by affecting variability in capture efficiency among sampling events (Bohlin et al. 1989; Hubert and Fabrizio 2007). Median discharges (mean among sample years) were significantly different among the monitoring sites (ANOVA:  $F_{12, 74} = 6.33$ ,  $P < 0.001$ ); each significantly different ( $P \leq 0.10$ ) pairwise comparison (Tukey Honest Significant Differences test) included median discharges from the Dickie Bridge or Mudd Creek Bridge monitoring sites, which were the highest median discharges among monitoring sites. Median discharge at the monitoring site near Wisdom, MT was the highest without a significant difference from the sites with a lower median discharge; thus, was selected as the upper limit for stream discharge to control for variation in capture efficiency in fish sampling reaches. Watershed area regulates discharge characteristics (Rosgen 1996) and was used to extrapolate the upper stream discharge limit to fish sampling reaches without discharge data; thus, CPUE data for all species were truncated to include sampling reaches with a watershed area  $\leq 157,052$  ha (the watershed area at the Wisdom, MT monitoring site) to minimize the variation in capture efficiency among fish sampling events. As a result, Big Hole River sampling sites

downstream from Wisdom, MT were excluded from analyses, which removed 60 sampling events from the dataset ( $N = 203$ ).

Total years sampled varied among fish sampling reaches (mean = 9 years, minimum = 2, maximum = 25). Trends in Arctic Grayling relative abundance were evaluated for stream reaches with a long-term data set (i.e., > 12 years) and at least two CPUE estimates greater than zero (i.e., “McDowell” reach of the Big Hole River, Steel Creek, Swamp Creek, Fishtrap Creek, LaMarche Creek, and Deep Creek). For these stream reaches, long-term trend was evaluated using data from all available years, and trend since the inception of the CCAA program was evaluate using data from 2006 through 2015. Trends of  $\geq$  age-1 and age-0 Arctic Grayling relative abundances were evaluated using ordinary least squares (OLS) regression to relate CPUE estimates to sample year.

Stream water temperature data were summarized as the median, CV ( $100 \cdot SD / \text{mean}$ ), and total hours greater than or equal to established temperature thresholds for Arctic Grayling in the Big Hole Watershed (21°C, FWP and USFWS 2006; 23°C, BHCW 2014; 25°C, Lohr et al. 1996; FWP and USFWS 2006) and the upper temperature preference threshold for European Grayling *Thymallus thymallus* (18°C, Coutant 1977). Temperature summaries used data that were collected from 1 June through 30 September.

Stream discharge data were summarized as total days less than or equal to a minimum stream discharge target, maximum discharge, and median discharge. Maximum and median discharges were also standardized by the watershed area to

characterize the discharge metrics relative to stream channel size (e.g., cross-sectional area, width, mean depth; Rosgen 1996; Brockman et al. 2012). Minimum discharge targets during drought conditions were established using the wetted perimeter method (i.e., lower inflection point; Leathe and Nelson 1989) at five monitoring sites on the Big Hole River to guide water conservation activities for the CCAA program (i.e., 0.57 cubic meters per second [CMS] at Miner Lakes Road; 1.13 CMS at Little Lake Creek Road; 1.70 CMS at Highway 43 near Wisdom, MT; 2.83 CMS at Mudd Creek Bridge; and 4.81 CMS at Dickie Bridge; FWP and USFWS 2006); the minimum discharge target at other monitoring sites was predicted as a function of watershed area using information from the five Big Hole River sites (Minimum discharge target [CMS] =  $3.26 + 0.0003663 \cdot \text{watershed area [ha]}$ ;  $F_{1,3} = 52.57$ ,  $P = 0.005$ ,  $r = 0.97$ ). Discharge summaries used data that were collected from the date maximum discharge occurred through 30 September for total days less than or equal to a stream discharge target, 1 May through 26 July for maximum discharge variables, and 1 May through 31 October for median discharge variables.

Riparian assessment data were summarized as the total score and total score for each subcategory (i.e., geomorphic, vegetative, and functional). Riparian assessment scores were weight-averaged as a function of the total distance surveyed when more than one reach was assessed within a fish sampling reach to correspond with fish CPUE data for analysis. For example, if riparian assessment data were collected from two reaches within a 3-km fish sampling reach—a total score of 60 in a 1-km reach and a total score

of 75 in a 2-km reach—, the total score that was related to fish CPUE was 70 (i.e.,  $(1 \text{ km}/3 \text{ km} \cdot 60) + (2 \text{ km}/3 \text{ km} \cdot 75) = 70$ ).

Arctic Grayling, nonnative salmonid, and abiotic data collected within the same reach and year were matched for analyses (Appendix A); however, incomplete observations (i.e., one or more data summary to be used in the analysis was missing) were omitted. Univariate relationships between Arctic Grayling CPUE and an explanatory variable were evaluated using regression modelling methods. Associative and wedge-shaped patterns were observed in the data, suggesting that different functional relationships existed (e.g., correlative or limiting). Ordinary least squares regression was used to estimate the central tendency (Stats Package, Program R version 3.2), and quantile regression ( $\tau = 0.90$ ) was used to estimate the upper limit of the response variable as a function of the explanatory variable (Quantreg Package, Program R version 3.2; Terrell et al. 1996). Relatively similar OLS and quantile regression slopes implied a constant error distribution and a correlative relationship, whereas dissimilar regression slopes implied systemic non-constant error distribution (i.e., increasing or decreasing spread as a function of the explanatory variable) and a limiting relationship (Terrell et al. 1996). Linear and exponential relationships were evaluated with OLS and quantile regression. Exponential growth or decay was evaluated using the model structure  $y = N \cdot \exp(c \cdot x)$ , where  $y$  = response variable;  $N$  = estimated y-intercept;  $c$  = estimated rate of change;  $x$  = explanatory variable. Univariate models were constructed to evaluate Arctic Grayling CPUE as a function of nonnative salmonid CPUE, stream temperature, stream discharge, and riparian habitat condition. Significance level ( $\alpha = 0.10$ ) was not corrected

for the multiple correlation analyses (e.g., Bonferroni correction) to error in favor of false positive significant relationships (McDonald 2014); although multivariate analyses provided additional support for the correlations, further investigating will be needed to determine cause and effect.

The relative influence of multiple explanatory variables on Arctic Grayling CPUE was evaluated using an information-theoretic approach (Burnham and Anderson 2002). Akaike's information criterion corrected for a small sample size ( $AIC_c$ ) was used to rank the amount of support by the data for a set of candidate models (MuMIn Package, Program R version 3.2; Akaike 1974; Hurvich and Tsai 1989). Sets of candidate models consisted of a global model and all nested models. The top-ranked model was considered the best model and the amount of support for subsequently ranked models was evaluated using a  $\Delta AIC_c$  score:  $< 2$  was strongly supported; 2-7 was moderately supported; and  $> 7$  was poorly supported (Burnham and Anderson 2002). Only explanatory variables with a significant ( $P \leq 0.10$ ) univariate relationship to the corresponding response variable were eligible to be included in the global models; however, stream and riparian habitat condition data were excluded because those data were matched with Arctic Grayling CPUE data infrequently and reduced the number of complete observations available for multivariate analyses. The final suite of explanatory variables for each global model was selected by evaluating the potential biological influences of highly correlated explanatory variables ( $r \geq 0.50$ ) that had a significant univariate relationship with the response variable and were from the same category (e.g., nonnative salmonid CPUE, stream temperature, or stream discharge). For example, total hours  $\geq 18^\circ\text{C}$ ,  $21^\circ\text{C}$ ,  $23^\circ\text{C}$ ,  $25^\circ\text{C}$

were each significantly related to the CPUE of Arctic Grayling  $\geq$  age 1 and highly correlated; thus, only total hours  $\geq 18^{\circ}\text{C}$  was retained for the global model because the temperature metrics represented similar environmental conditions, and  $18^{\circ}\text{C}$  was the only temperature threshold that did not contain zero hours. In contrast, Brown Trout CPUE and Rainbow Trout CPUE were each significantly related to age-0 Arctic Grayling CPUE and highly correlated ( $F_{1,62} = 121.1$ ,  $P < 0.001$ ,  $r = 0.81$ ), but both variables were retained for the global model because each species potentially influences age-0 Arctic Grayling differently. Global models were constructed to allow for exponential growth or decay,  $y = N \cdot \exp(c_1 \cdot x_1 + \dots + c_i \cdot x_i)$ .

#### 4. RESULTS

Catch per unit effort of Arctic Grayling  $\geq$  age 1 was highest in tributaries near the downstream boundary of the study area (Figure 3), and age-0 Arctic Grayling CPUE was highest in tributaries near the middle of the study area (Figure 4). Nonnative salmonid CPUE was dominated by Brook Trout (Figure 5), but Brown Trout and Rainbow Trout CPUE were higher than Brook Trout CPUE in Deep Creek, the lowest tributary sampled in the study area (Figures 6 and 7). Catch-per-unit-effort of age-0 Arctic Grayling was weakly correlated with CPUE of  $\geq$  age-1 Arctic Grayling ( $t_{99} = 4.725$ ,  $P = 0.089$ ,  $r = 0.17$ ). Catch per unit effort of Arctic Grayling  $\geq$  age 1 was positively related to Brook Trout CPUE (Figure 8 and Table 1), and age-0 Arctic Grayling CPUE was negatively related to Brown Trout and Rainbow Trout CPUE (Figure 9 and Table 2).

Water temperature was highly variable in the Big Hole River and lowest in relatively high-gradient tributaries near the downstream boundary of the study area (Figure 10). Median water temperature and total hours  $\geq 18^{\circ}\text{C}$ ,  $21^{\circ}\text{C}$ ,  $23^{\circ}\text{C}$ , and  $25^{\circ}\text{C}$  each had a significant univariate relationship with Arctic Grayling  $\geq$  age 1 CPUE and age-0 CPUE (Figures 11 and 12; Tables 1 and 2); however, autocorrelation among these explanatory variables was high (Figures 11 and 12). Interestingly, median water temperature and total hours  $\geq 18^{\circ}\text{C}$ ,  $21^{\circ}\text{C}$ ,  $23^{\circ}\text{C}$ , and  $25^{\circ}\text{C}$  were each negatively related to the CPUE of Arctic Grayling  $\geq$  age 1 (Figure 11 and Table 1), but positively related to age-0 Arctic Grayling CPUE (Figure 12 and Table 2). The CPUE of Arctic Grayling  $\geq$  age 1 was also limited as the temperature threshold increased (Figure 11). For example,

CPUE of Arctic Grayling  $\geq$  age 1 did not exceed 5 fish/km if total hours  $\geq 18^{\circ}\text{C}$  exceeded 721, total hours  $\geq 21^{\circ}\text{C}$  exceeded 167, total hours  $\geq 23^{\circ}\text{C}$  exceeded 31, or total hours  $\geq 25^{\circ}\text{C}$  exceeded zero (Figure 11).

Stream discharge was highest and most variable in the Big Hole River (Figure 13), and total days less than or equal to minimum discharge target was greatest in Rock Creek (Figure 14). Maximum and median discharge, which were highly correlated, were negatively related to both Arctic Grayling CPUE metrics (Figures 15 and 16; Tables 1 and 2); CPUE did not exceed 5 fish/km when maximum discharge exceeded  $42 \text{ m}^3/\text{s}$  ( $\geq$  age 1) or  $26 \text{ m}^3/\text{s}$  (age 0) or when median discharge exceeded  $7.0 \text{ m}^3/\text{s}$  ( $\geq$  age 1) or  $1.7 \text{ m}^3/\text{s}$  (age 0; Figures 15 and 16). Additionally, the CPUE of Arctic Grayling  $\geq$  age 1 was negatively related to total days  $\leq$  discharge target, but positively related to median discharge/watershed area (Figure 15 and Table 1); the CPUE of Arctic Grayling  $\geq$  age 1 did not exceed 5 fish/km when the total days  $\leq$  discharge target exceeded 18 days.

Total riparian assessment score was highly correlated with each subcategory score ( $r > 0.81$ ; Figures 17 and 18). The geomorphic subcategory was positively related to the CPUE of Arctic Grayling  $\geq$  age 1 (Figure 17 and Table 1). Riparian assessment scores were not related to age-0 Arctic Grayling CPUE (Figure 18 and Table 2).

Arctic Grayling CPUE was either static or declining; declining trends were observed in the “McDowell” reach ( $\geq$  age-1 Arctic Grayling:  $t_{24} = -4.749$ ,  $P < 0.001$ ; age-0 Arctic Grayling:  $t_{24} = -2.934$ ,  $P = 0.007$ ), Deep Creek ( $\geq$  age-1 Arctic Grayling:  $t_{23} = -1.820$ ,  $P < 0.083$ ), and Fishtrap Creek (age-0 Arctic Grayling:  $t_8 = -2.573$ ,  $P = 0.037$ ). Arctic Grayling CPUE from 2006 through 2015 were static, increasing, or declining;

increasing trends occurred in Swamp Creek ( $\geq$  age-1 Arctic Grayling:  $t_8 = 2.312$ ,  $P = 0.054$ ; age-0 Arctic Grayling:  $t_8 = 2.291$ ,  $P = 0.056$ ) and Deep Creek ( $\geq$  age-1 Arctic Grayling:  $t_8 = 0.5471$ ,  $P = 0.017$ ), and decreasing trends occurred in Steel Creek (age-0 Arctic Grayling:  $t_8 = -2.272$ ,  $P = 0.053$ ) and LaMarche Creek ( $\geq$  age-1 Arctic Grayling:  $t_8 = -2.149$ ,  $P = 0.075$ ; age-0 Arctic Grayling:  $t_8 = -2.678$ ,  $P = 0.037$ ).

A global model was constructed to evaluate the relative influence of biotic and abiotic factors on CPUE of Arctic Grayling  $\geq$  age 1. Brook Trout was the only significantly related nonnative salmonid CPUE and was retained for the global model ( $F_{1, 76} = 33.5$ ,  $P < 0.001$ ,  $r = 0.55$ ). Total hours  $\geq 18^\circ\text{C}$  was highly correlated with median temperature ( $F_{1, 51} = 319.7$ ,  $P < 0.001$ ,  $r = 0.93$ ) and the total hours  $\geq 21^\circ\text{C}$  ( $F_{1, 51} = 205.2$ ,  $P < 0.001$ ,  $r = 0.89$ ),  $23^\circ\text{C}$  ( $F_{1, 51} = 49.9$ ,  $P < 0.001$ ,  $r = 0.70$ ), and  $25^\circ\text{C}$  ( $F_{1, 51} = 18.2$ ,  $P < 0.001$ ,  $r = 0.51$ ); thus, total hours  $\geq 18^\circ\text{C}$  was the only water temperature variable retained for the global model. Maximum discharge was highly correlated with median discharge ( $F_{1, 37} = 38.1$ ,  $P < 0.001$ ,  $r = 0.71$ ), and total days  $\leq$  discharge target was highly correlated with median discharge/watershed area ( $F_{1, 37} = 59.0$ ,  $P < 0.001$ ,  $r = 0.78$ ); therefore, maximum discharge and total days  $\leq$  discharge target were retained for the global model. The following multivariate global model was used to evaluate the relative influence of biotic and abiotic factors on CPUE of Arctic Grayling  $\geq$  age 1: Arctic Grayling  $\geq$  age 1 CPUE =  $N \cdot \exp(c_1 \cdot \text{Brook Trout CPUE} + c_2 \cdot \text{total hours} \geq 18^\circ\text{C} + c_3 \cdot \text{maximum discharge} + c_4 \cdot \text{total days} \leq \text{discharge target})$ . Model selection results strongly supported the top two models that included total hours  $\geq 18^\circ\text{C}$ , total days  $\leq$  discharge target, and maximum discharge ( $\Delta\text{AIC}_c = 0$ ; Table 3); and total hours  $\geq 18^\circ\text{C}$

and total days  $\leq$  discharge target ( $\Delta\text{AIC}_c = 1.07$ ; Table 3). However, an additional seven models were moderately supported ( $\Delta\text{AIC}_c \leq 5.65$ ) resulting in model selection uncertainty. The combined weight of models that included each explanatory variable was calculated to provide supplemental information about their relative influence: total hours  $\geq 18^\circ\text{C}$  ( $w_i = 0.96$ ); total days  $\leq$  discharge target ( $w_i = 0.77$ ); maximum discharge ( $w_i = 0.49$ ); and Brook Trout CPUE ( $w_i = 0.28$ ). Thus, model selection results and the combined model weight values suggested that total hours  $\geq 18^\circ\text{C}$  and total days  $\leq$  discharge target were most supported by these data for having the greatest relative influence on CPUE of Arctic Grayling  $\geq$  age 1 (Table 3).

A global model was also constructed to evaluate the relative influence of biotic and abiotic factors on age-0 Arctic Grayling CPUE. Brown Trout and Rainbow Trout CPUEs were highly correlated ( $F_{1,65} = 127.1$ ,  $P < 0.001$ ,  $r = 0.81$ ), but have the potential to interact with age-0 Arctic Grayling differently; thus, both nonnative salmonid species were retained for the global model. Total hours  $\geq 18^\circ\text{C}$  was highly correlated with median temperature ( $F_{1,45} = 151.1$ ,  $P < 0.001$ ,  $r = 0.88$ ) and total hours  $\geq 21^\circ\text{C}$  ( $F_{1,45} = 172.9$ ,  $P < 0.001$ ,  $r = 0.89$ ),  $23^\circ\text{C}$  ( $F_{1,45} = 52.3$ ,  $P < 0.001$ ,  $r = 0.73$ ), and  $25^\circ\text{C}$  ( $F_{1,45} = 20.5$ ,  $P < 0.001$ ,  $r = 0.56$ ); thus, total hours  $\geq 18^\circ\text{C}$  was the only water temperature variable retained for the global model. Maximum discharge, which was highly correlated with median discharge ( $F_{1,36} = 32.5$ ,  $P < 0.001$ ,  $r = 0.69$ ), was the only discharge variable retained for the global model. The following multivariate global model was used to evaluate the relative influence of biotic and abiotic factors on age-0 Arctic Grayling CPUE: age-0 Arctic Grayling CPUE =  $N \cdot \exp(c_1 \cdot \text{Brown Trout CPUE} + c_2 \cdot \text{Rainbow Trout}$

CPUE +  $c_3 \cdot \text{total hours} \geq 18^\circ\text{C}$  +  $c_4 \cdot \text{maximum discharge}$ ). The top model included Brown Trout CPUE, total hours  $\geq 18^\circ\text{C}$ , and maximum discharge ( $w_i = 0.68$ ); the addition of Rainbow Trout CPUE in the second-ranked model ( $\Delta\text{AIC}_c = 2.11$ ) was not supported because model deviance was reduced by an amount similar to the  $\text{AIC}_c$  penalty (+2 units) for including an additional parameter (Arnold 2010), thus providing stronger support for the top model (Table 4). The combined weight of models that included Brown Trout CPUE ( $w_i = 0.95$ ), total hours  $\geq 18^\circ\text{C}$  ( $w_i = 0.95$ ), or maximum discharge ( $w_i = 0.99$ ) was similar. Thus, Brown Trout CPUE, total hours  $\geq 18^\circ\text{C}$ , and maximum discharge were most supported by these data for having the greatest relative influence on age-0 Arctic Grayling CPUE (Table 4).

Select relationships between abiotic variables were evaluated to better understand the efficacy of management actions, specifically those that may influence stream water temperature. The influence of stream discharge (Poole and Berman 2001) or habitat condition (Seavy et al. 2009) on water temperature was evaluated using OLS regression. Total days  $\leq$  discharge target was positively correlated with total hours  $\geq 18^\circ\text{C}$  ( $t_{66} = 2.27$ ,  $P = 0.027$ ,  $r = 0.15$ ), and total riparian assessment score was negatively correlated with total hours  $\geq 18^\circ\text{C}$  ( $t_{34} = -1.85$ ,  $P = 0.073$ ,  $r = -0.30$ ).

Additional relationships beyond the scope of the objective stated in the introduction were also explored to further inform Arctic Grayling management. The influence of stream temperature, stream discharge, and the condition of stream and riparian habitat on nonnative salmonid CPUE was evaluated to understand the benefit of management actions more comprehensively (Appendix B). Additionally, the drivers of

Arctic Grayling distribution were evaluated by relating nonnative species CPUE, stream temperature, stream discharge, and the condition of stream and riparian habitat to Arctic Grayling occurrence (Appendix C).

## 5. DISCUSSION

This study evaluated how biotic and abiotic metrics relate to Arctic Grayling relative abundance using data that were collected over three decades in the Big Hole River watershed, MT. Data exploration is a powerful approach for better understanding the factors that influence Arctic Grayling and is useful in informing conservation actions. Long-term trends in Arctic Grayling relative abundance were either static or declining, but in some cases, were stabilized or increasing since the CCAA program began in 2006. Conservation actions implemented through the CCAA program may have contributed to improving trends in Arctic Grayling relative abundance and were generally supported by the results of this study. However, monitoring and research needs were identified to fill information gaps and improve Arctic Grayling management.

The influence of nonnative salmonids on Arctic Grayling was species-specific. Brook Trout CPUE had a strong positive correlation with CPUE of Arctic Grayling  $\geq$  age 1, which was contrary to the *a priori* hypothesized relationship. Brook Trout and Arctic Grayling  $\geq$  age 1 CPUE were similarly influenced by temperature and discharge metrics (Appendix B); thus, the abiotic conditions likely contributed to covariation for both species. The combined evidence from this study and previous studies (McMichael 1990; Byorth and Magee 1998) suggests that Arctic Grayling and Brook Trout occupy slightly different ecological niches and can coexist. In contrast, Brown Trout and Rainbow Trout CPUE were negatively related to age-0 Arctic Grayling CPUE. Brown Trout were a common factor to most extirpated Arctic Grayling populations in Montana (Missouri, Sun, Dearborn, Smith, Gallatin, lower Madison, Jefferson, Beaverhead, and Gibbon

rivers; Vincent 1962; Kaya 1990). The results of this study support the hypothesis that Brown Trout have a negative effect on Arctic Grayling populations, but the underlying mechanism remains unknown. Predation is probable given the piscivorous nature of adult Brown Trout (Klemetsen et al. 2003) and relatively high susceptibility of Arctic Grayling to predation during early life-stages (Kaya 1992a). However, the negative relationship may also be driven by differing habitat requirements between the two species; for example, increasing stream water temperatures was suggested as regulating concurrent expanses in Brown Trout distribution and contractions in Bull Trout *Salvelinus confluentus* distribution (Al-Chokhachy et al. 2016) that may otherwise appear to be the result of interspecific interactions.

Several studies, including this study, support the long-standing hypotheses that water temperature and drought are limiting factors for Arctic Grayling (especially for populations at the southern extent of their range). In this study, thermal constraints on Arctic Grayling relative abundance were apparent across four temperature thresholds. For example, the upper limit (i.e., 90<sup>th</sup> quantile) of CPUE for Arctic Grayling  $\geq$  age 1 was estimated to be 103% higher in a stream that had water temperature higher than 18°C for 10 hours than a stream with 500 hours. Furthermore, stream water temperatures in the study area regularly exceeded the upper incipient lethal temperature (temperature that is survived by at least 50% of the test population for longer than one week) for age-1 Arctic Grayling that was derived in a lab setting using F<sub>1</sub> progeny from the Big Hole River population (25°C; Lohr et al. 1996). Thermal criteria for adult Arctic Grayling were established from populations in Alaska and an upper suitability threshold of 20°C was

identified (Hubert et al. 1985); however, populations in Montana are known to exist in warmer thermal regimes (USOFR 2014). Finally, the survival rate of European Grayling  $\geq$  age 1 was negatively related to mean water temperature  $\geq 19^{\circ}\text{C}$  (Charles et al. 2006). Similar negative relationships between water temperature and fish abundance have been observed for other coldwater salmonid species, such as Bull Trout (Al-Chokhachy et al. 2016) and Redband Rainbow Trout *Oncorhynchus mykiss gairdneri* (Zoellick 2004).

Conversely, age-0 Arctic Grayling CPUE was positively related to water temperature metrics (albeit these relationships had more variation than relationships between CPUE of Arctic Grayling  $\geq$  age 1 and water temperature), thus corroborating previous observations that juvenile Arctic Grayling have a higher temperature tolerance than adults (USOFR 2014). The instantaneous growth rate of age-0 Arctic Grayling is positively related to water temperature (Deegan et al. 1999; Luecke and MacKinnon 2008), which likely contributes to the positive relationship between water temperature and age-0 Arctic Grayling CPUE observed in this study. An increased growth rate of juvenile salmonids has been positively linked to survival (Zabel and Achord 2004) and can be advantageous for competitive interactions with conspecifics and allospecifics (Gardiner and Geddes 1980).

Maintaining adequate discharge levels during drought conditions is an important consideration for Arctic Grayling conservation. In this study, decreasing discharge during drought conditions had a strong limiting relationship with the relative abundance of Arctic Grayling  $\geq$  age 1. Similar discharge conditions (i.e., decreasing mean discharge during summer) have also been shown to limit the growth rate of adult Arctic Grayling

(Deegan et al. 1999). Drought may limit Arctic Grayling relative abundance by promoting emigration, decreasing survival, or both; for example, European Grayling occupied relatively shallower water and increased their movement during periods of low discharge, thereby increasing their susceptibility to predation (Riley et al. 2009).

Drought conditions may also influence Arctic Grayling abundance by altering macroinvertebrate assemblage structure (Extence 1981), connectivity among stream reaches (Lake 2003), and water quality (Lake 2003).

Maximum discharge had a similar limiting relationship with both Arctic Grayling CPUE metrics. Whereas a negative influence of maximum discharge on adult salmonids is not common, similar relationships have been observed for age-0 Arctic Grayling. For example, Arctic Grayling recruitment (defined as the estimated abundance of age-3 Arctic Grayling that were sampled three years post-spawn) in the Chena River, AK was negatively related to mean discharge during a 40-day period post-spawn (Clark 1992). Similarly, maximum discharge negatively influenced the survival of age-0 European Grayling for a 150-day period post-spawn (Charles et al. 2006). Several mechanisms are hypothesized regarding the negative influence of stream discharge on the early life-stages of Arctic Grayling and other salmonid species. Elevated stream discharge mobilizes channel substrate and likely dislodges embryos and larvae prior to emergence (Elwood and Waters 1969), which is probable for Arctic Grayling because they broadcast eggs to spawn (i.e., as opposed to excavating a redd) and tend to spawn in smaller diameter substrate than other salmonid species (Vincent 1962). Additionally, newly emerged Arctic Grayling larvae are susceptible to being displaced downstream or stranded in

isolated pools that remain after water levels recede (Clark 1992). Finally, decreased water temperatures often accompany snow-melt driven, maximum discharge events and probably limit the growth and survival of age-0 Arctic Grayling. The influence of these hypothesized mechanisms may act independently or together to limit age-0 Arctic Grayling relative abundance.

The condition of stream and riparian habitats as quantified by the NRCS riparian assessment method was rarely related to Arctic Grayling CPUE; the only significant relationship was between the geomorphic subcategory score and Arctic Grayling  $\geq$  age 1 CPUE. Generally, the geomorphic subcategory characterizes the vertical erosion, lateral erosion, and sediment transport and deposition capabilities of the stream (NRCS 2004). Erosional and depositional processes of a stream regulate habitat characteristics, such as pool depth (Rosgen 2004), that have been linked to Arctic Grayling abundance (Lamothe and Magee 2004) or are preferentially selected for by Arctic Grayling (West et al. 1992; Byorth and Magee 1998). However, these geomorphic processes are, in part, regulated by the quality and condition of riparian vegetation (Rosgen 1994), which were evaluated by the riparian assessment method. Given these associations, it is interesting that riparian assessment scores were not related to Arctic Grayling CPUE more frequently. The lack of relationships between Arctic Grayling CPUE and riparian assessment scores could be attributed to 1) the amount of data that was available for evaluating Arctic Grayling CPUE relationships with riparian assessment scores was considerably less than for the other data sets that were used in this study and may have been insufficient to observe relationships, or 2) the riparian assessment method was intended to provide an general

characterization of stream and riparian habitat condition and assessment criteria may be too broad and susceptible to visual bias to account for relationships that occur at a finer scale. For example, the quantification (i.e., physically measured instead of visually assessed) of physical habitat characteristics that were coarsely assessed by the riparian assessment method have been related to density of other coldwater salmonid species, such as Lahontan Cutthroat Trout *Oncorhynchus clarkii henshawi* (Dunham et al. 2002), Bull Trout (Watson and Hillman 1997), and anadromous cutthroat trout *Oncorhynchus clarki* (Rosenfeld et al. 2000). A better understanding of how physical habitat attributes regulate Arctic Grayling abundance is needed to inform Arctic Grayling management and evaluate the efficacy of using the NRCS riparian assessment method to manage streams that are enrolled in the CCAA program.

In this study, relationships between the biotic or abiotic metrics and Arctic Grayling CPUE varied considerably by age category (i.e.,  $\geq$  age-1 and age-0); the metrics that were supported for having the greatest influence on each Arctic Grayling CPUE were different or had the opposite influence, except for maximum discharge. This dynamic may contribute to age-related distributional patterns within a watershed that have been exhibited by Arctic Grayling populations. For example, in two rivers in Alaska, a distributional gradient with older individuals being predominant in upstream reaches and younger individuals being predominant in downstream reaches was observed and attributed to successive age-related migrations to upstream feeding areas (Hughes 1999). An age-related distributional pattern also exists for the Big Hole River population, although younger individuals are predominant in upstream reaches and older individuals

are predominant in downstream reaches, including habitats downstream of the study area (A. McCullough, Montana Fish, Wildlife and Parks, unpublished data). Age-related distributional patterns are likely related to changing habitat requirements throughout the life-history of Arctic Grayling and demonstrate the importance of maintaining connectivity among these habitats to ensure the species can successfully complete their life cycle.

Differing relationships between age categories complicates Arctic Grayling management, specifically the opposite relationships with water temperature metrics. Given that Arctic Grayling populations persist in thermal regimes cooler than the Big Hole River basin (USOFR 2014), management of stream water temperature to benefit Arctic Grayling  $\geq$  age 1 seems most appropriate. Nonetheless, a practical management strategy for Arctic Grayling in the Big Hole River basin should consider that streams tend to be dominated by either  $\geq$  age-1 or age-0 Arctic Grayling, and stream-specific objectives may be needed depending on the dominant age category.

Temperature and discharge metrics generally had the greatest influence on the CPUE of Arctic Grayling  $\geq$  age 1. Brook Trout CPUE was similarly influenced by temperature and discharge metrics, and improving these abiotic conditions will likely benefit both species. Stream temperature and discharge metrics are largely regulated by ambient weather conditions (Poole and Berman 2001), but can be influenced by agricultural land-use practices. Thus, the prevalent role of agriculture in the Big Hole Valley offers conservation opportunities. Management actions that increase stream discharge or improve the condition of stream and riparian habitat mitigate increasing

water temperature. Thus, CCAA water conservation agreements benefit Arctic Grayling  $\geq$  age 1 by increasing stream discharges and reducing water temperatures. The drought management plan provides similar benefits as the CCAA water conservation agreements by reducing irrigation withdrawals during periods of drought, which increases stream discharge. The continued implementation of CCAA water conservation agreements and the drought management plan was supported by this study.

Management actions to benefit age-0 Arctic Grayling were less clear. Existing management actions that increase stream discharge during drought conditions or improve the condition of stream and riparian habitats were not supported by the relationships observed in this study. Furthermore, alternatives to address the negative relationship between age-0 Arctic Grayling CPUE and Brown Trout CPUE, if necessary, cannot be identified until the underlying mechanism is better understood. This relationship is of particular interest because the abundance and distribution of Brown Trout in the Big Hole River basin have expanded in recent years (Montana Fish, Wildlife & Parks, unpublished data).

Although these results suggested strong relationships between Arctic Grayling and their environment, the data exploration approach used for this study had limitations. Removing Arctic Grayling CPUE values of zero focused analyses on relationships where the species occurred, but omitted sites where environmental conditions may have contributed to local extirpation or prevented recolonization. The influence of biotic and abiotic factors on Arctic Grayling occurrence were presented in Appendix C, but warrants further investigation. Additionally, stream discharge, water temperature, and

channel size are known to influence the capture efficiency of electrofishing gears (Hubert and Fabrizio 2007). Although methods were used to minimize the effects of stream discharge and water temperature (e.g., sampling occurred in water temperatures  $<18^{\circ}\text{C}$ ) on capture efficiency, variation in capture efficiency among sample sites may have influenced the results of this study.

A comprehensive understanding of how Arctic Grayling abundance relates to biotic and abiotic conditions is important for effective management. In this study, historical data were used to examine the interrelationships among nonnative salmonids, stream temperature, stream discharge, stream and riparian habitats, and Arctic Grayling CPUE in the Big Hole River watershed. This study highlighted that interspecific relationships between Arctic Grayling and nonnative salmonids are species-specific and may influence Arctic Grayling age-classes differently. Additionally, the influence of stream water temperature varied depending on the age of Arctic Grayling in the CPUE estimate. In general, these results supported the current management actions outlined by the CCAA program, specifically those that mitigate drought conditions. However, relationships that supported using the NRCS riparian assessment method to manage stream and riparian habitat to benefit Arctic Grayling were lacking. Furthermore, the negative relationship between age-0 Arctic Grayling CPUE and Brown Trout CPUE is disconcerting given that Brown Trout abundance and distribution are increasing in the upper Big Hole River basin. Thus, the following monitoring and research needs are warranted.

## 6. MONITORING AND RESEARCH NEEDS

1. Within the last decade, Brown Trout have replaced Brook Trout as the dominant salmonid in some stream reaches in the study area. More recently, Brown Trout recruitment was observed for the first time in streams that historically had high relative abundance of age-0 Arctic Grayling (A. McCullough, Montana Fish, Wildlife and Parks, unpublished data). Widespread changes to the fishery in the upper Big Hole River will likely to continue, and monitoring the expansion of Brown Trout is warranted to understand fish assemblage dynamics pertinent to Arctic Grayling management.
2. The persistence of Arctic Grayling in the Big Hole River may be in jeopardy if Brown Trout abundance and distribution continues to expand and interspecific interactions between the species limit Arctic Grayling recruitment. Thus, investigating the mechanism driving the negative relationship between Brown Trout CPUE and age-0 Arctic Grayling CPUE is warranted to inform management decisions.
3. Management of stream and riparian habitats likely offers the greatest conservation opportunity for Arctic Grayling because the characteristics of these habitats are largely controlled by landowners and natural resource agencies. Further, literature that relates Arctic Grayling to physical habitat is generally lacking. Identifying physical habitat attributes that regulate Arctic Grayling abundance is warranted to inform Arctic Grayling management.
4. Riparian assessment scores are used extensively to guide stream and riparian habitat management to benefit Arctic Grayling, but were rarely related to their relative abundance in this study. Associations between riparian assessment score and Arctic Grayling should

be established if the methodology will continue to be used to guide management decisions.

## TABLES

Table 1. Slopes and probabilities ( $P$ ) for linear models and the exponential rate of change ( $c$ ) and probabilities ( $P$ ) for nonlinear models from ordinary least squares (OLS) and quantile ( $\tau = 0.90$ ) regression analyses relating the CPUE of Arctic Grayling  $\geq$  age 1 (fish/km) and an explanatory variable. Explanatory variables (described in Methods) were summarized from nonnative salmonid abundance (1983 through 2015), stream water temperature (1992 through 2015), stream discharge (1988 through 2015), and riparian habitat condition (2005 through 2015) data that were collected in the Big Hole Watershed, MT. Significance level was  $P \leq 0.10$  (\*) for all models.

| Explanatory variable                       | Linear  |         |          |         | Nonlinear <sup>1</sup> |         |          |         |
|--------------------------------------------|---------|---------|----------|---------|------------------------|---------|----------|---------|
|                                            | OLS     |         | quantile |         | OLS                    |         | quantile |         |
|                                            | Slope   | $P$     | Slope    | $P$     | $c$                    | $P$     | $c$      | $P$     |
| Brook Trout CPUE <sup>2</sup>              | 0.081   | <0.001* | 0.109    | 0.001*  | 0.013                  | <0.001* | 0.009    | 0.008*  |
| Brown Trout CPUE                           | 0.011   | 0.907   | -0.283   | 0.651   | 0.002                  | 0.933   | -0.031   | 0.701   |
| Rainbow Trout CPUE                         | 0.076   | 0.595   | 0.222    | 0.771   | 0.014                  | 0.693   | -0.010   | 0.917   |
| Median temperature                         | -1.436  | <0.001* | -3.231   | 0.003*  | -0.256                 | 0.005*  | -0.296   | 0.027*  |
| Temperature CV                             | 0.514   | 0.346   | -1.619   | 0.458   | 0.099                  | 0.444   | -0.129   | 0.310   |
| Hours $\geq 18^\circ\text{C}$ <sup>2</sup> | -0.009  | <0.001* | -0.017   | <0.001* | -0.002                 | 0.003*  | -0.002   | 0.003*  |
| Hours $\geq 21^\circ\text{C}$              | -0.022  | 0.001*  | -0.031   | 0.006*  | -0.009                 | 0.011*  | -0.007   | <0.001* |
| Hours $\geq 23^\circ\text{C}$              | -0.038  | 0.019*  | -0.062   | 0.016*  | -0.078                 | 0.115   | -0.027   | <0.001* |
| Hours $\geq 25^\circ\text{C}$              | -0.298  | 0.104   | -0.586   | 0.168   | -0.427                 | 0.470   | -0.132   | 0.006*  |
| Days $\leq$ discharge target <sup>2</sup>  | -0.040  | 0.008*  | -0.102   | 0.012*  | -0.022                 | 0.011*  | -0.021   | <0.001* |
| Maximum discharge <sup>2</sup>             | -0.043  | 0.018*  | -0.050   | 0.270   | -0.020                 | 0.281   | -0.019   | 0.067*  |
| Median discharge                           | -0.119  | 0.354   | -0.491   | 0.097*  | -0.062                 | 0.500   | -0.110   | 0.076*  |
| Maximum discharge/WA <sup>3</sup>          | 1935.8  | 0.391   | 8676.8   | 0.455   | 573.4                  | 0.420   | 1034.4   | 0.447   |
| Median discharge/WA <sup>3</sup>           | 25540.0 | 0.106   | 127288.2 | 0.004*  | 8129.5                 | 0.197   | 21224.0  | 0.053*  |
| Riparian assessment score                  | 0.038   | 0.652   | 0.214    | 0.147   | 0.014                  | 0.724   | 0.053    | 0.147   |
| Geomorphic score                           | 0.200   | 0.382   | 0.636    | 0.059*  | 0.067                  | 0.482   | 0.170    | 0.036*  |
| Vegetative score                           | -0.241  | 0.506   | 0.462    | 0.428   | -0.004                 | 0.957   | 0.071    | 0.590   |
| Functional score                           | 0.204   | 0.513   | 0.500    | 0.519   | 0.086                  | 0.598   | 0.123    | 0.546   |

<sup>1</sup>Nonlinear models structure:  $y = N \cdot \exp(c \cdot x)$ , where  $y$  = response variable;  $N$  = estimated y-intercept;  $c$  = estimated rate of change;  $x$  = explanatory variable.

<sup>2</sup>Explanatory variable included in the global model.

<sup>3</sup>WA=watershed area.

Table 2. Slopes and probabilities ( $P$ ) for linear models and the exponential rate of change ( $c$ ) and probabilities ( $P$ ) for nonlinear models from ordinary least squares (OLS) and quantile ( $\tau = 0.90$ ) regression analyses relating age-0 Arctic Grayling CPUE (fish/km) and an explanatory variable. Explanatory variables (described in Methods section) were summarized from nonnative salmonid abundance (1983 through 2015), stream water temperature (1992 through 2015), stream discharge (1988 through 2015), and riparian habitat condition (2005 through 2015) data that were collected in the Big Hole Watershed, MT. Significance level was  $P \leq 0.10$  (\*) for all models.

| Explanatory variable                       | Linear   |        |          |        | Nonlinear <sup>1</sup> |        |          |         |
|--------------------------------------------|----------|--------|----------|--------|------------------------|--------|----------|---------|
|                                            | OLS      |        | quantile |        | OLS                    |        | quantile |         |
|                                            | Slope    | $P$    | Slope    | $P$    | $c$                    | $P$    | $c$      | $P$     |
| Brook Trout CPUE                           | 0.019    | 0.361  | -0.028   | 0.655  | 0.003                  | 0.370  | -0.003   | 0.621   |
| Brown Trout CPUE <sup>2</sup>              | -0.177   | 0.135  | -0.373   | 0.080* | -0.178                 | 0.344  | -0.112   | <0.001* |
| Rainbow Trout CPUE <sup>2</sup>            | -0.207   | 0.229  | -0.519   | 0.017* | -0.057                 | 0.430  | -0.091   | 0.641   |
| Median temperature                         | 0.683    | 0.129  | 2.113    | 0.007* | 0.193                  | 0.156  | 0.272    | 0.017*  |
| Temperature CV                             | -0.106   | 0.809  | -1.013   | 0.498  | -0.023                 | 0.838  | -0.089   | 0.487   |
| Hours $\geq 18^\circ\text{C}$ <sup>2</sup> | 0.005    | 0.062* | 0.012    | 0.046* | 0.001                  | 0.054* | 0.002    | 0.009*  |
| Hours $\geq 21^\circ\text{C}$              | 0.014    | 0.022* | 0.040    | 0.007* | 0.004                  | 0.005* | 0.003    | 0.008*  |
| Hours $\geq 23^\circ\text{C}$              | 0.031    | 0.014* | 0.083    | 0.022* | 0.007                  | 0.001* | 0.006    | 0.008*  |
| Hours $\geq 25^\circ\text{C}$              | 0.116    | 0.314  | 1.066    | 0.079* | 0.019                  | 0.391  | 0.059    | 0.056*  |
| Days $\leq$ discharge target               | 0.023    | 0.252  | 0.009    | 0.873  | 0.005                  | 0.402  | 0.001    | 0.911   |
| Maximum discharge <sup>2</sup>             | -0.044   | 0.017* | -0.048   | 0.149  | -0.036                 | 0.152  | -0.041   | 0.032*  |
| Median discharge                           | -0.394   | 0.028* | -0.492   | 0.036* | -0.488                 | 0.133  | -0.435   | 0.061*  |
| Maximum discharge/WA <sup>3</sup>          | -1889.2  | 0.482  | -1598.1  | 0.796  | -832.6                 | 0.404  | -640.9   | 0.283   |
| Median discharge/WA <sup>3</sup>           | -22817.2 | 0.316  | -14450.4 | 0.678  | -6899.1                | 0.405  | -1869.1  | 0.818   |
| Riparian assessment score                  | -0.045   | 0.756  | 0.104    | 0.821  | -0.010                 | 0.784  | 0.011    | 0.842   |
| Geomorphic score                           | -0.196   | 0.655  | 0.804    | 0.689  | -0.038                 | 0.754  | 0.008    | 0.972   |
| Vegetative score                           | -0.033   | 0.910  | 0.164    | 0.855  | -0.009                 | 0.904  | 0.021    | 0.823   |
| Functional score                           | -0.140   | 0.749  | 0.231    | 0.905  | -0.026                 | 0.809  | 0.027    | 0.901   |

<sup>1</sup>Nonlinear models structure:  $y = N \cdot \exp(c \cdot x)$ , where  $y$  = response variable;  $N$  = estimated y-intercept;  $c$  = estimated rate of change;  $x$  = explanatory variable.

<sup>2</sup>Explanatory variable included in the global model.

<sup>3</sup>WA=watershed area.

Table 3. Summary of Akaike's information criteria corrected for a small sample size ( $AIC_c$ ), number of model variables ( $k$ ),  $AIC_c$  score relative to the top ranked model ( $\Delta AIC_c$ ), and model weight ( $w_i$ ) for the global model<sup>1</sup> and all nested models that were ranked to the relative influence of biotic and abiotic factors on the CPUE of Arctic Grayling  $\geq$  age 1 (fish/km) in the Big Hole Watershed, MT.

| Rank | Model variables                                                                                   | k | $AIC_c$ | $\Delta AIC_c$ | $w_i$ |
|------|---------------------------------------------------------------------------------------------------|---|---------|----------------|-------|
| 1    | Hours $\geq 18^\circ\text{C}$ , Days $\leq$ discharge target, Maximum discharge                   | 5 | 68.7    | 0.00           | 0.371 |
| 2    | Hours $\geq 18^\circ\text{C}$ , Days $\leq$ discharge target                                      | 4 | 69.8    | 1.07           | 0.217 |
| 3    | Brook Trout CPUE, Hours $\geq 18^\circ\text{C}$                                                   | 4 | 71.1    | 2.40           | 0.112 |
| 4    | Brook Trout CPUE, Hours $\geq 18^\circ\text{C}$ , Days $\leq$ discharge target                    | 5 | 71.7    | 2.94           | 0.085 |
| 5    | Hours $\geq 18^\circ\text{C}$                                                                     | 3 | 72.0    | 3.28           | 0.072 |
| 6    | Brook Trout CPUE, Hours $\geq 18^\circ\text{C}$ , Days $\leq$ discharge target, Maximum discharge | 6 | 72.5    | 3.75           | 0.057 |
| 7    | Hours $\geq 18^\circ\text{C}$ , Maximum discharge                                                 | 4 | 73.9    | 5.22           | 0.027 |
| 8    | Brook Trout CPUE, Hours $\geq 18^\circ\text{C}$ , Maximum discharge                               | 5 | 74.3    | 5.56           | 0.023 |
| 9    | Days $\leq$ discharge target                                                                      | 3 | 74.4    | 5.65           | 0.022 |
| 10   | Days $\leq$ discharge target, Maximum discharge                                                   | 4 | 76.9    | 8.18           | 0.006 |
| 11   | Brook Trout CPUE, Days $\leq$ discharge target                                                    | 4 | 77.0    | 8.3            | 0.006 |
| 12   | Brook Trout CPUE, Days $\leq$ discharge target, Maximum discharge                                 | 5 | 80.5    | 11.79          | 0.001 |
| 13   | Maximum discharge                                                                                 | 3 | 108.9   | 40.18          | 0.000 |
| 14   | Brook Trout CPUE                                                                                  | 3 | 109.4   | 40.68          | 0.000 |
| 15   | Brook Trout CPUE, Maximum discharge                                                               | 4 | 111.6   | 42.89          | 0.000 |

<sup>1</sup>Global model: Arctic Grayling  $\geq$  age 1 CPUE =  $N \cdot \exp(c_1 \cdot \text{Brook Trout CPUE} + c_2 \cdot \text{total hours} \geq 18^\circ\text{C} + c_3 \cdot \text{maximum discharge} + c_4 \cdot \text{total days} \leq \text{discharge target})$ , where  $N$  = estimated y-intercept;  $c_i$  = estimated rate of change for variable  $i$ .

Table 4. Summary of Akaike's information criteria corrected for a small sample size ( $AIC_c$ ), number of model variables ( $k$ ),  $AIC_c$  score relative to the top ranked model ( $\Delta AIC_c$ ), and model weight ( $w_i$ ) for the global model<sup>1</sup> and all nested models that were ranked to the relative influence of biotic and abiotic factors on age-0 Arctic Grayling CPUE (fish/km) in the Big Hole Watershed, MT.

| Rank | Model variables                                                                         | k | $AIC_c$ | $\Delta AIC_c$ | $w_i$ |
|------|-----------------------------------------------------------------------------------------|---|---------|----------------|-------|
| 1    | Brown Trout CPUE, Hours $\geq 18^\circ\text{C}$ , Maximum discharge                     | 5 | 124.1   | 0.00           | 0.682 |
| 2    | Brown Trout CPUE, Rainbow Trout CPUE, Hours $\geq 18^\circ\text{C}$ , Maximum discharge | 6 | 126.2   | 2.11           | 0.238 |
| 3    | Hours $\geq 18^\circ\text{C}$ , Maximum discharge                                       | 4 | 130.7   | 6.68           | 0.024 |
| 4    | Brown Trout CPUE, Maximum discharge                                                     | 4 | 130.9   | 6.81           | 0.023 |
| 5    | Maximum discharge                                                                       | 3 | 132.0   | 7.95           | 0.013 |
| 6    | Brown Trout CPUE, Rainbow Trout CPUE, Maximum discharge                                 | 5 | 134.1   | 9.99           | 0.005 |
| 7    | Rainbow Trout CPUE, Maximum discharge                                                   | 4 | 134.1   | 10.01          | 0.005 |
| 8    | Rainbow Trout CPUE, Hours $\geq 18^\circ\text{C}$ , Maximum discharge                   | 5 | 134.1   | 10.08          | 0.004 |
| 9    | Brown Trout CPUE                                                                        | 3 | 135.2   | 11.18          | 0.003 |
| 10   | Hours $\geq 18^\circ\text{C}$                                                           | 3 | 136.4   | 12.32          | 0.001 |
| 11   | Rainbow Trout CPUE                                                                      | 3 | 136.9   | 12.79          | 0.001 |
| 12   | Brown Trout CPUE, Hours $\geq 18^\circ\text{C}$                                         | 4 | 137.1   | 13.01          | 0.001 |
| 13   | Brown Trout CPUE, Rainbow Trout CPUE                                                    | 4 | 138.2   | 14.16          | 0.001 |
| 14   | Rainbow Trout CPUE, Hours $\geq 18^\circ\text{C}$                                       | 4 | 139.4   | 15.31          | 0.000 |
| 15   | Brown Trout CPUE, Rainbow Trout CPUE, Hours $\geq 18^\circ\text{C}$                     | 5 | 140.5   | 16.40          | 0.000 |

<sup>1</sup>Global model: age-0 Arctic Grayling CPUE =  $N \cdot \exp(c_1 \cdot \text{Brown Trout CPUE} + c_2 \cdot \text{Rainbow Trout CPUE} + c_3 \cdot \text{total hours} \geq 18^\circ\text{C} + c_4 \cdot \text{maximum discharge})$ , where  $N$  = estimated y-intercept;  $c_i$  = estimated rate of change for variable  $i$ .

## FIGURES

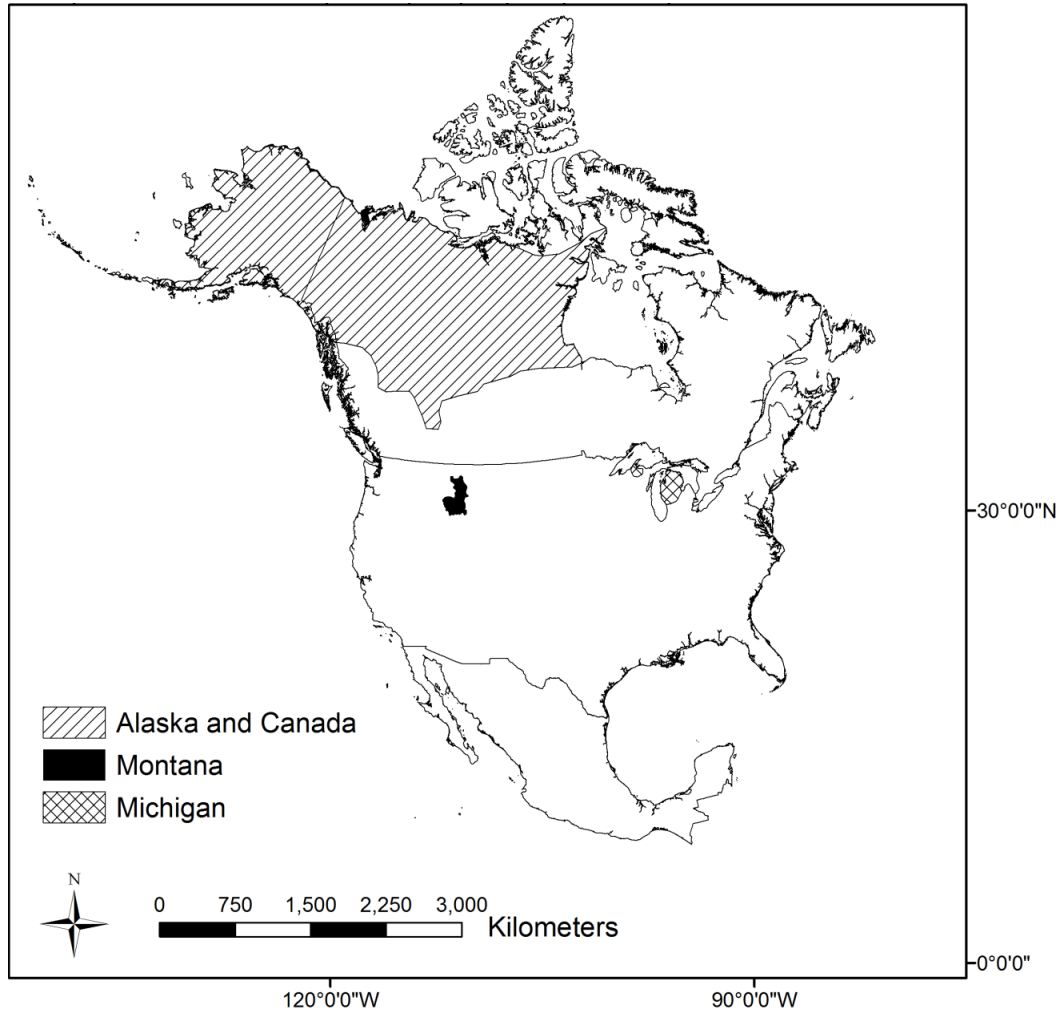


Figure 1. Historical distribution of Arctic Grayling in North America.

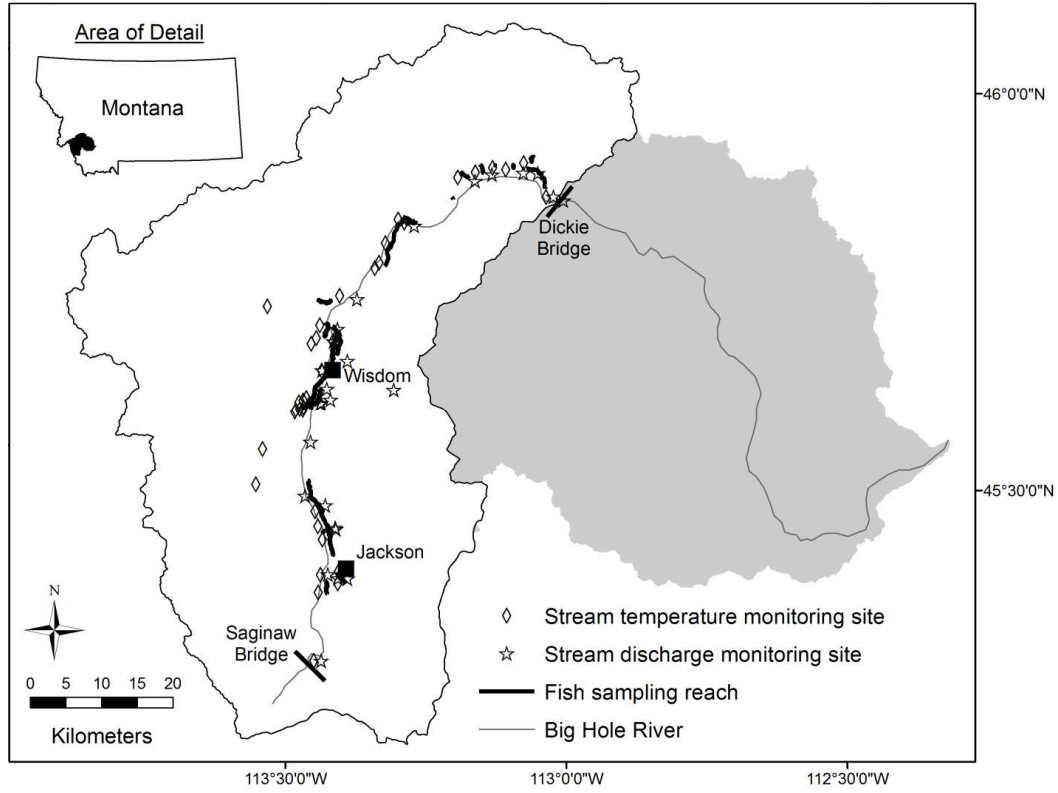


Figure 2. Location of fish sampling reaches, stream temperature sites, and discharge monitoring sites in the study area (delineated in white) in the Big Hole Watershed, MT.

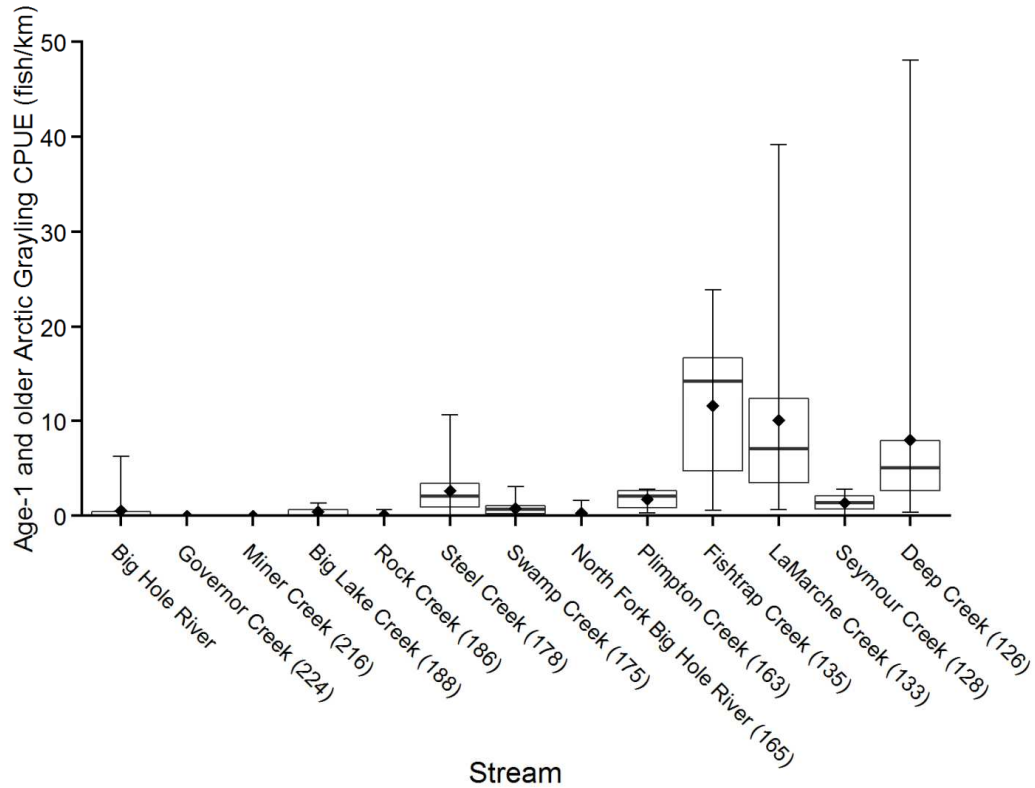


Figure 3. Boxplot of the CPUE (fish/km) of Arctic Grayling  $\geq$  age 1 in streams that were sampled with electrofishing in the Big Hole Watershed from 1983 through 2015. Tributary streams (river km) to the Big Hole River are listed in descending order through the watershed from left to the right after the Big Hole River. Box plots depict the minimum, 25<sup>th</sup> percentile, median, mean (black diamond), 75<sup>th</sup> percentile, and maximum values with horizontal bars.

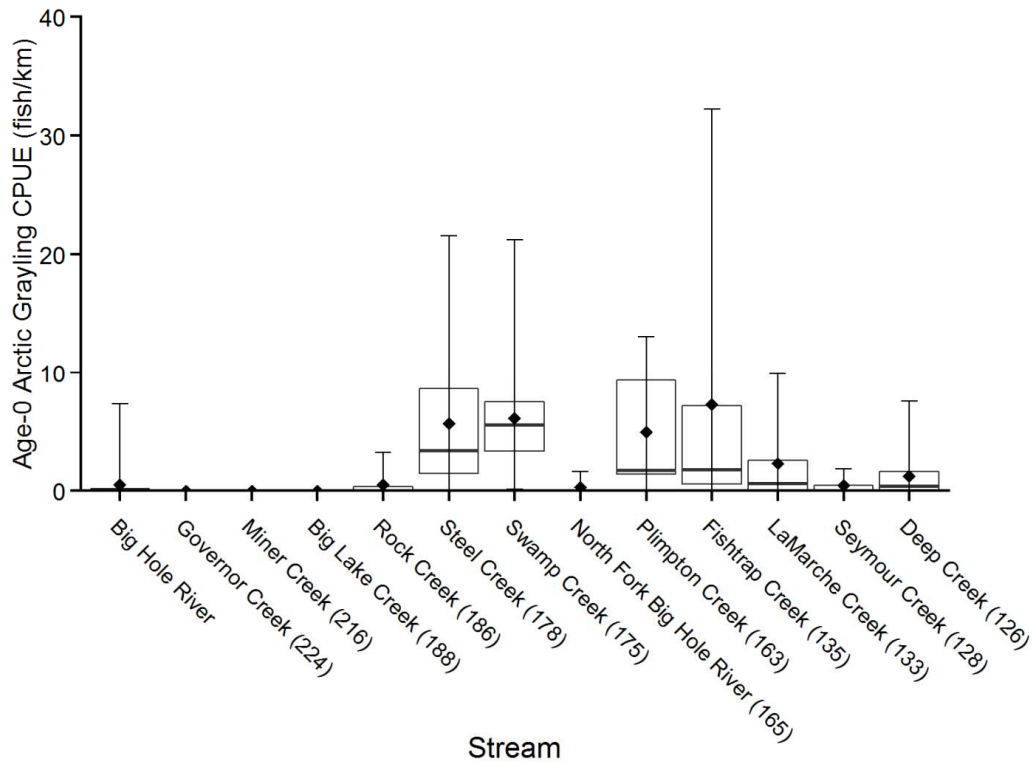


Figure 4. Boxplot of age-0 Arctic Grayling CPUE (fish/km) in streams that were sampled with electrofishing in the Big Hole Watershed from 1983 through 2015. Tributary streams (river km) to the Big Hole River are listed in descending order through the watershed from left to right after the Big Hole River. Box plots depict the minimum, 25<sup>th</sup> percentile, median, mean (black diamond), 75<sup>th</sup> percentile, and maximum values with horizontal bars.

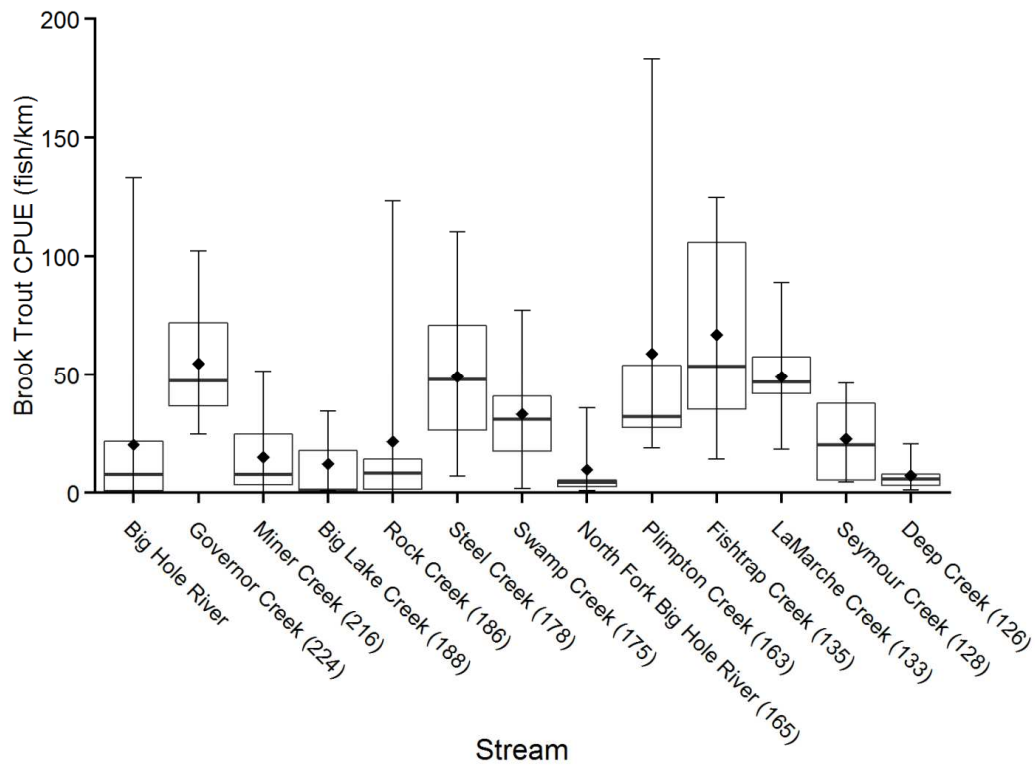


Figure 5. Boxplot of Brook Trout CPUE (fish/km) in streams that were sampled with electrofishing in the Big Hole Watershed from 1983 through 2015. Tributary streams (river km) to the Big Hole River are listed in descending order through the watershed from left to right after the Big Hole River. Box plots depict the minimum, 25<sup>th</sup> percentile, median, mean (black diamond), 75<sup>th</sup> percentile, and maximum values with horizontal bars.

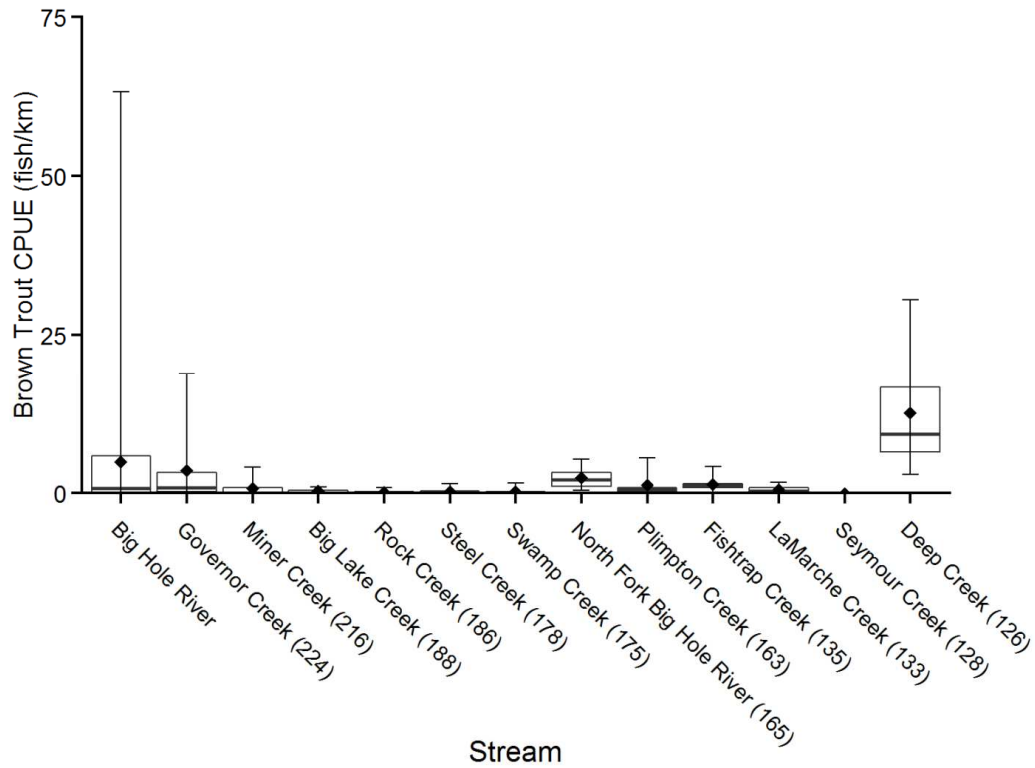


Figure 6. Boxplot of Brown Trout CPUE (fish/km) in streams that were sampled with electrofishing in the Big Hole Watershed from 1983 through 2015. Tributary streams (river km) to the Big Hole River are listed in descending order through the watershed from left to right after the Big Hole River. Box plots depict the minimum, 25<sup>th</sup> percentile, median, mean (black diamond), 75<sup>th</sup> percentile, and maximum values with horizontal bars.

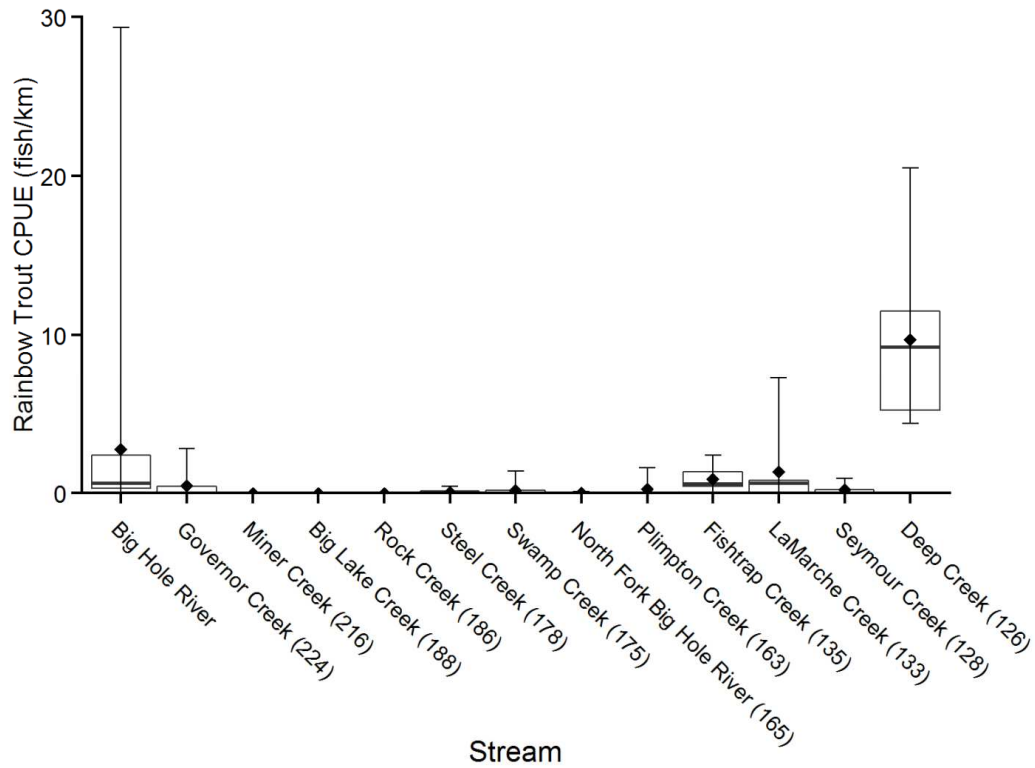


Figure 7. Boxplot of Rainbow Trout CPUE (fish/km) in streams that were sampled with electrofishing in the Big Hole Watershed from 1983 through 2015. Tributary streams (river km) to the Big Hole River are listed in descending order through the watershed from left to right after the Big Hole River. Box plots depict the minimum, 25<sup>th</sup> percentile, median, 75<sup>th</sup> percentile, and maximum values with horizontal bars and mean with a black diamond.

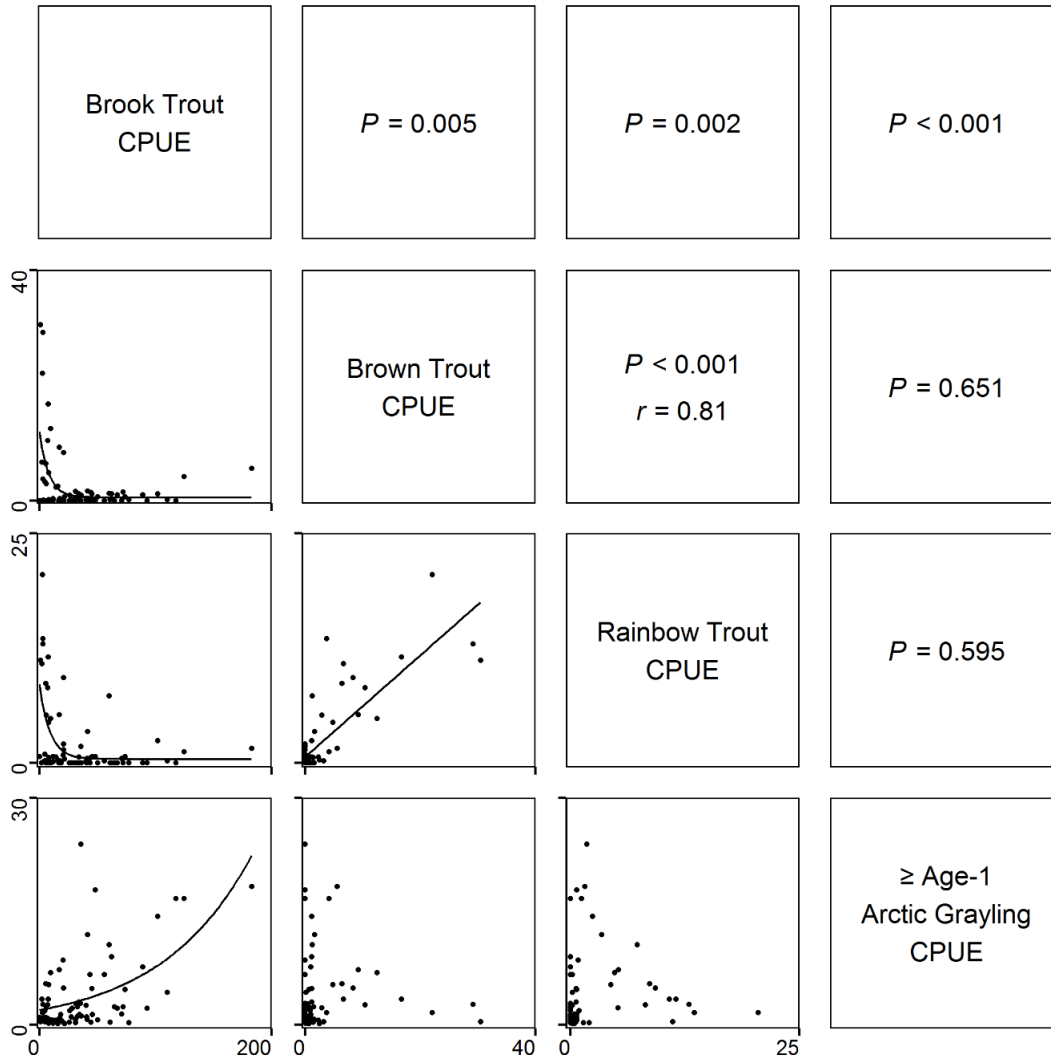


Figure 8. Scatter plots for the univariate relationships between Brook Trout, Brown Trout, Rainbow Trout, and Arctic Grayling  $\geq$  age 1 CPUE (fish/km) for streams that were sampled with electrofishing in the Big Hole Watershed from 1983 through 2015. Ordinary least squares (OLS) and quantile ( $\tau = 0.90$ ) regression statistics for linear and nonlinear models that describe these relationships are listed in Table 1. The lowest  $P$ -value among the four modelling methods is shown for each relationship, and the corresponding regression line is depicted on the scatter plot for significant relationships ( $P \leq 0.10$ ). Correlation coefficients ( $r$ ) are also shown if linear OLS regression had the lowest significant  $P$ -value.

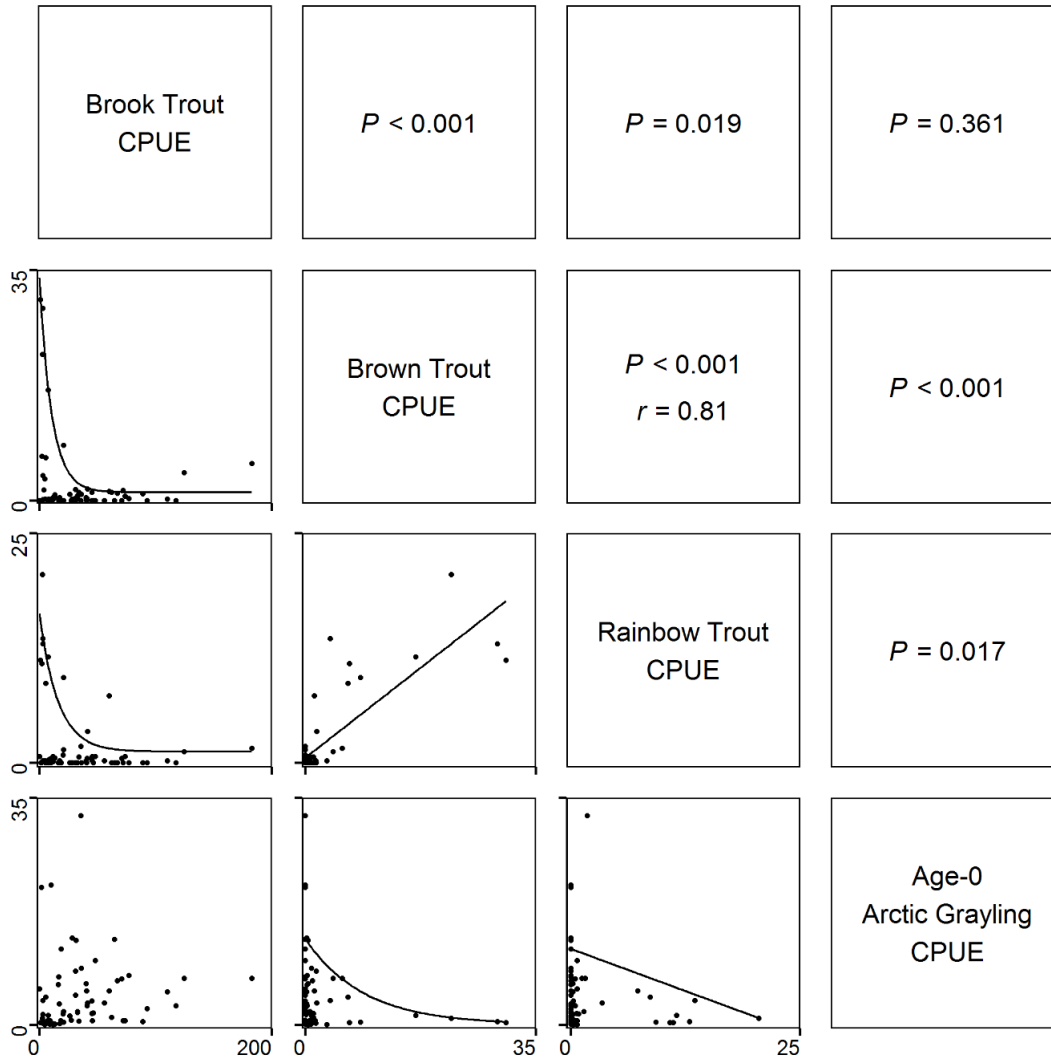


Figure 9. Scatter plots for the univariate relationships between Brook Trout, Brown Trout, Rainbow Trout, and age-0 Arctic Grayling CPUE (fish/km) for streams that were sampled with electrofishing in the Big Hole Watershed from 1983 through 2015. Ordinary least squares (OLS) and quantile ( $\tau = 0.90$ ) regression statistics for linear and nonlinear models that describe these relationships are listed in Table 2. The lowest  $P$ -value among the four modelling methods is shown for each relationship, and the corresponding regression line is depicted on the scatter plot for significant relationships ( $P \leq 0.10$ ). Correlation coefficients ( $r$ ) are also shown if linear OLS regression had the lowest significant  $P$ -value.

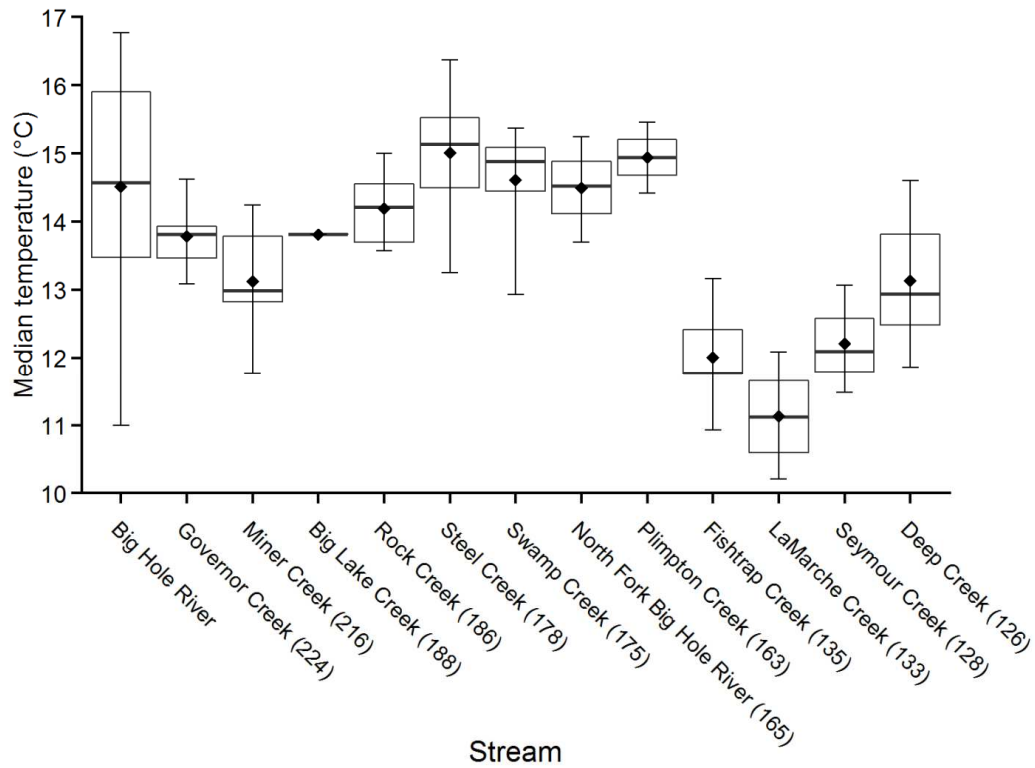


Figure 10. Boxplot of the median water temperature (°C) in streams that were monitored in the Big Hole Watershed from 1992 through 2015. Tributary streams (river km) to the Big Hole River are listed in descending order through the watershed from left to right after the Big Hole River. Box plots depict the minimum, 25<sup>th</sup> percentile, median, mean (black diamond), 75<sup>th</sup> percentile, and maximum values with horizontal bars.

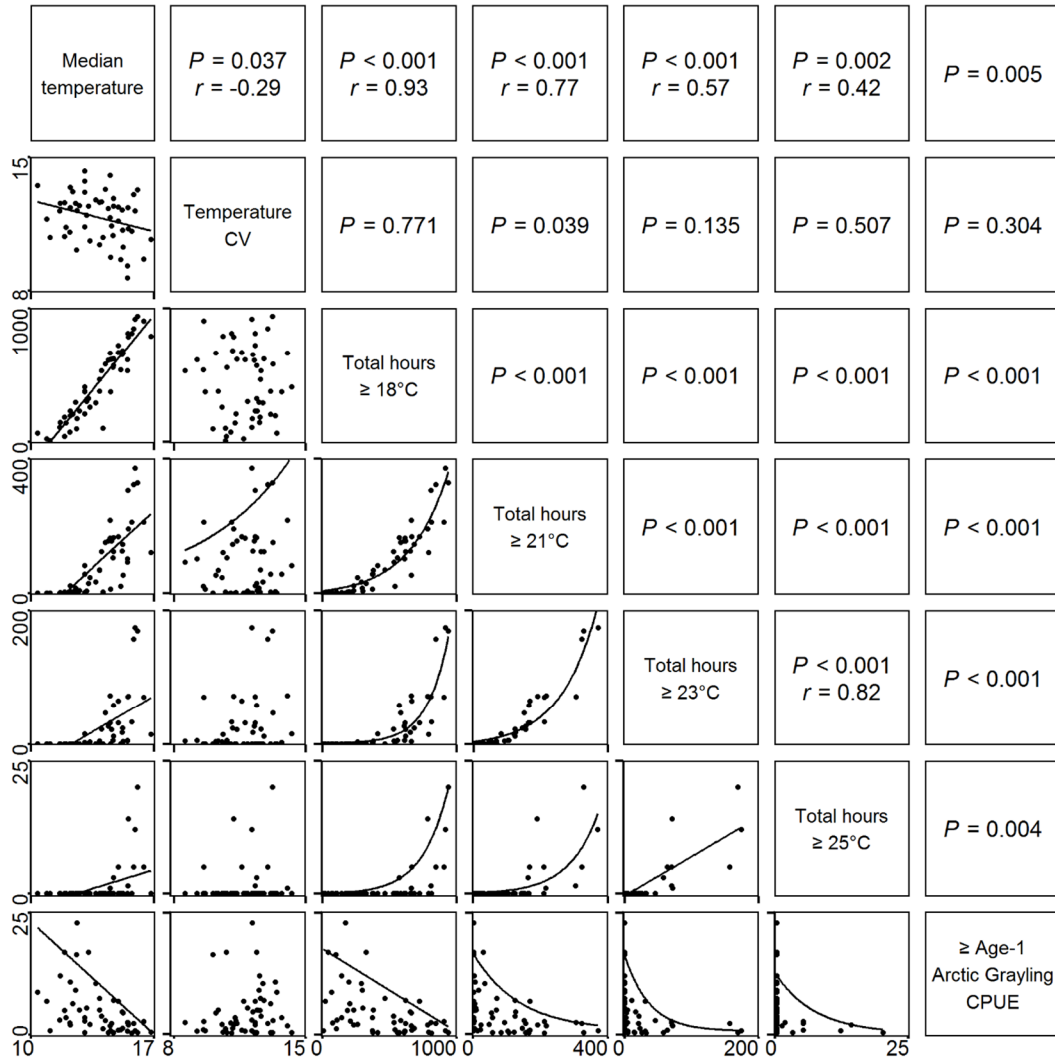


Figure 11. Scatter plots for the univariate relationships between median water temperature ( $^{\circ}\text{C}$ ), water temperature CV ( $100 \cdot \text{SD}/\text{mean}$ ), total hours  $\geq 18^{\circ}\text{C}$ ,  $21^{\circ}\text{C}$ ,  $23^{\circ}\text{C}$ , and  $25^{\circ}\text{C}$ , and CPUE of Arctic Grayling  $\geq \text{age 1}$  (fish/km) that were sampled in the Big Hole Watershed from 1992 through 2015. Ordinary least squares (OLS) and quantile ( $\tau = 0.90$ ) regression statistics for linear and nonlinear models that describe these relationships are listed in Table 1. The lowest  $P$ -value among the four modelling methods is shown for each relationship, and the corresponding regression line is depicted on the scatter plot for significant relationships ( $P \leq 0.10$ ). Correlation coefficients ( $r$ ) are also shown if linear OLS regression had the lowest significant  $P$ -value.

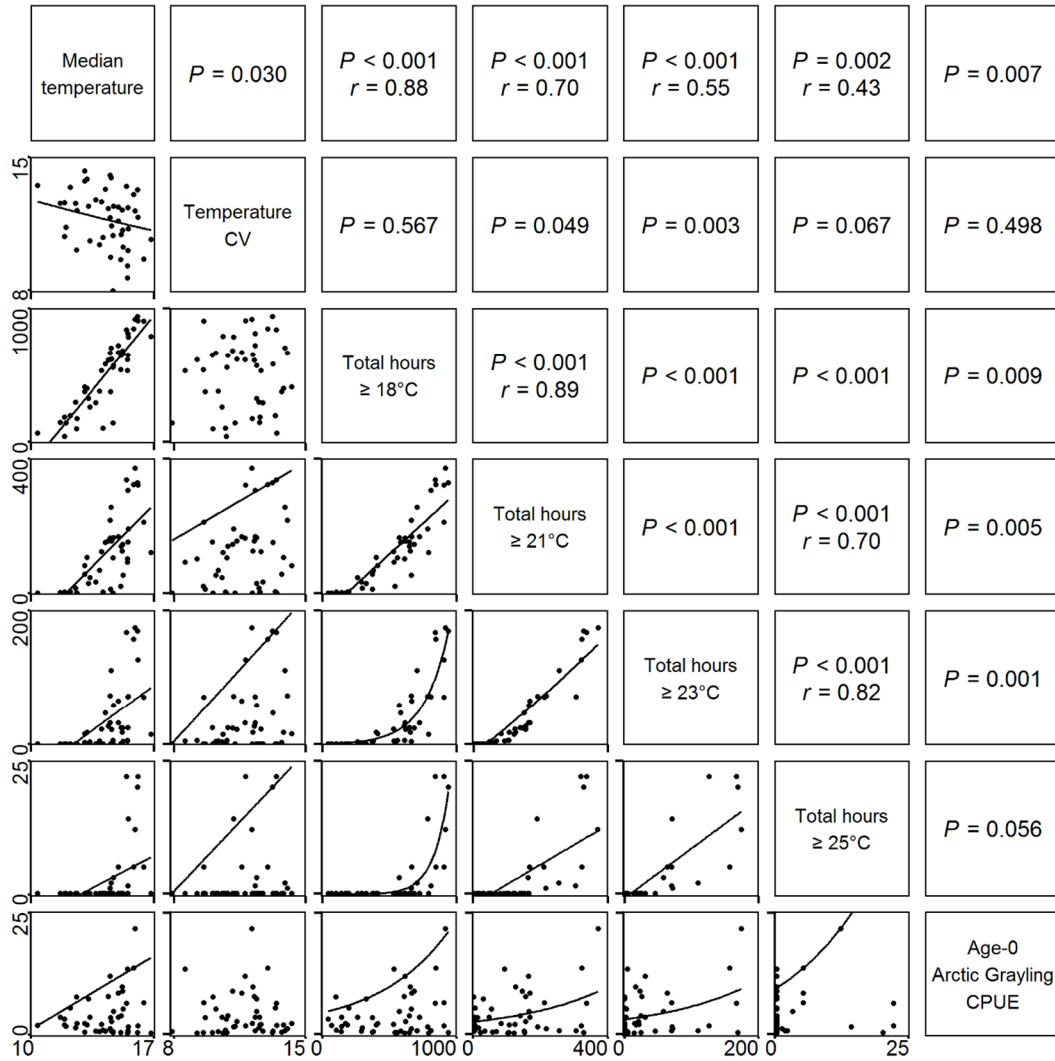


Figure 12. Scatter plots for the univariate relationships between median water temperature ( $^{\circ}\text{C}$ ), water temperature CV ( $100 \cdot \text{SD}/\text{mean}$ ), total hours  $\geq 18^{\circ}\text{C}$ ,  $21^{\circ}\text{C}$ ,  $23^{\circ}\text{C}$ , and  $25^{\circ}\text{C}$ , and age-0 Arctic Grayling CPUE (fish/km) that were sampled in the Big Hole Watershed from 1992 through 2015. Ordinary least squares (OLS) and quantile ( $\tau = 0.90$ ) regression statistics for linear and nonlinear models that describe these relationships are listed in Table 2. The lowest  $P$ -value among the four modelling methods is shown for each relationship, and the corresponding regression line is depicted on the scatter plot for significant relationships ( $P \leq 0.10$ ). Correlation coefficients ( $r$ ) are also shown if linear OLS regression had the lowest significant  $P$ -value.

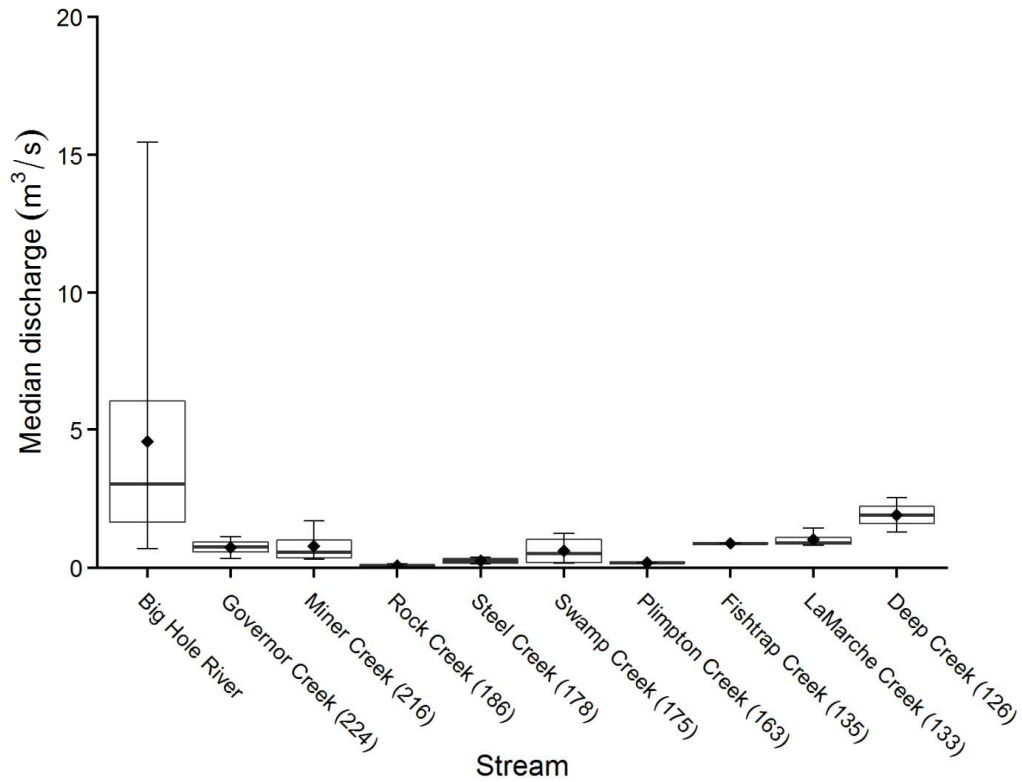


Figure 13. Boxplot of the median discharge (m³/s) in streams that were monitored in the Big Hole Watershed from 1988 through 2015. Tributary streams (river km) to the Big Hole River are listed in descending order through the watershed from left to right after the Big Hole River. Box plots depict the minimum, 25<sup>th</sup> percentile, median, mean (black diamond), 75<sup>th</sup> percentile, and maximum values with horizontal bars.

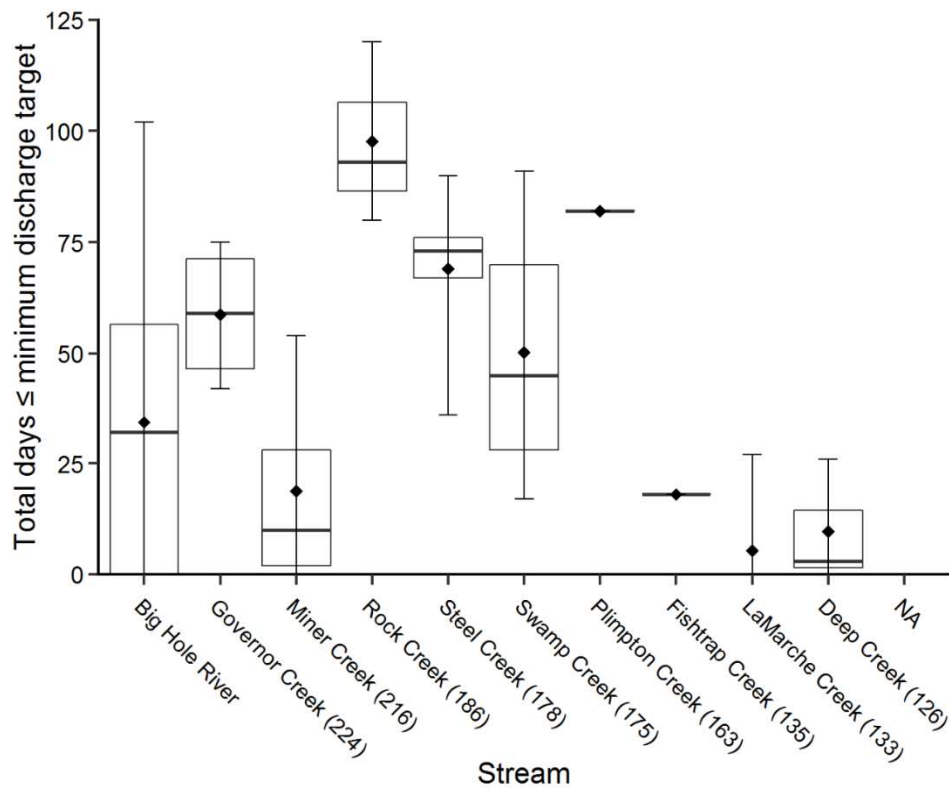


Figure 14. Boxplot of the total days less than or equal to minimum discharge target in streams that were monitored in the Big Hole Watershed from 1988 through 2015. Tributary streams (river km) to the Big Hole River are listed in descending order through the watershed from left to right after the Big Hole River. Box plots depict the minimum, 25<sup>th</sup> percentile, median, mean (black diamond), 75<sup>th</sup> percentile, and maximum values with horizontal bars.

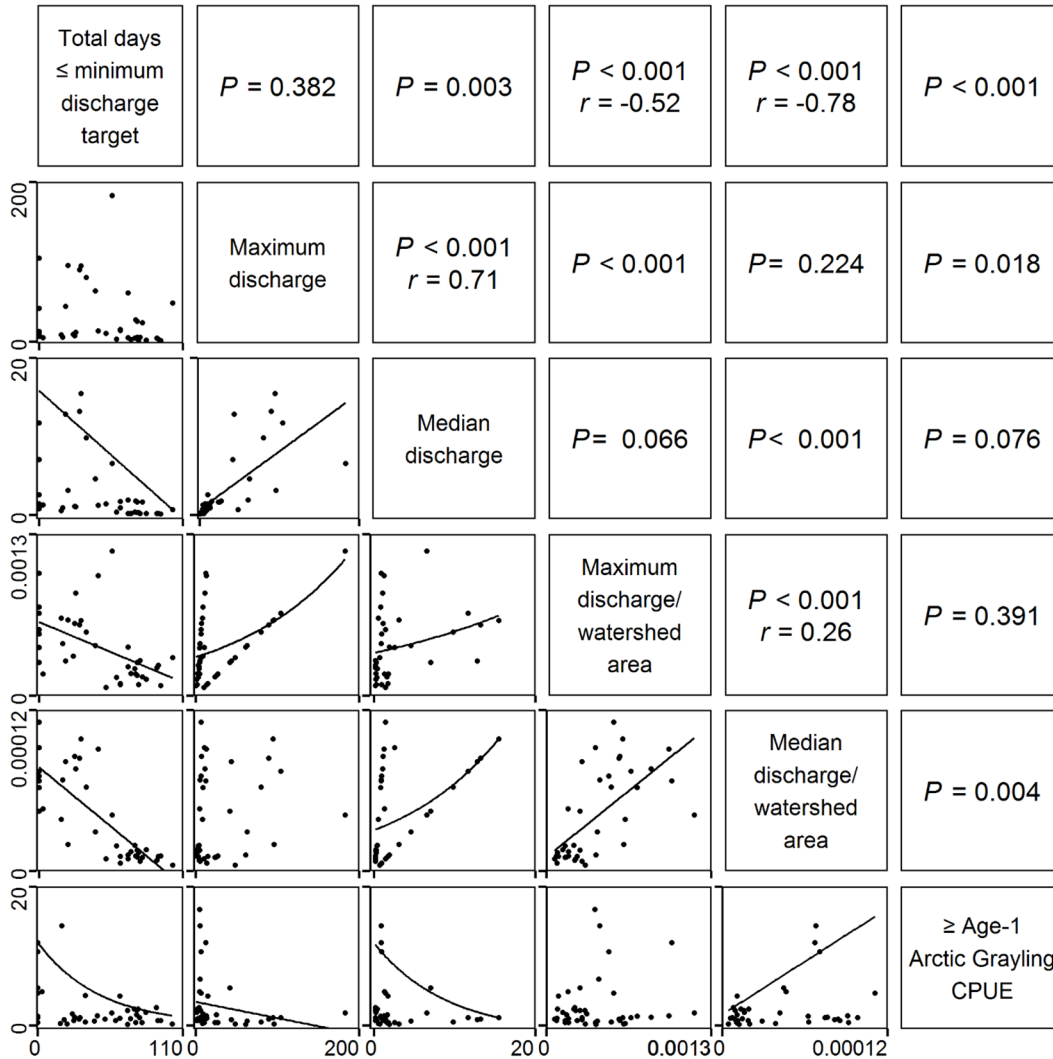


Figure 15. Scatter plots for the univariate relationships between total days  $\leq$  minimum discharge target, maximum discharge ( $\text{m}^3/\text{s}$ ), median discharge ( $\text{m}^3/\text{s}$ ), maximum discharge/watershed area ( $[\text{m}^3/\text{s}]/\text{ha}$ ), median discharge/watershed area ( $[\text{m}^3/\text{s}]/\text{ha}$ ), and CPUE of Arctic Grayling  $\geq$  age 1 (fish/km) that were sampled in the Big Hole Watershed from 1988 through 2015. Ordinary least squares (OLS) and quantile ( $\tau = 0.90$ ) regression statistics for linear and nonlinear models that describe these relationships are listed in Table 1. The lowest  $P$ -value among the four modelling methods is shown for each relationship, and the corresponding regression line is depicted on the scatter plot for significant relationships ( $P \leq 0.10$ ). Correlation coefficients ( $r$ ) are also shown if linear OLS regression had the lowest significant  $P$ -value.

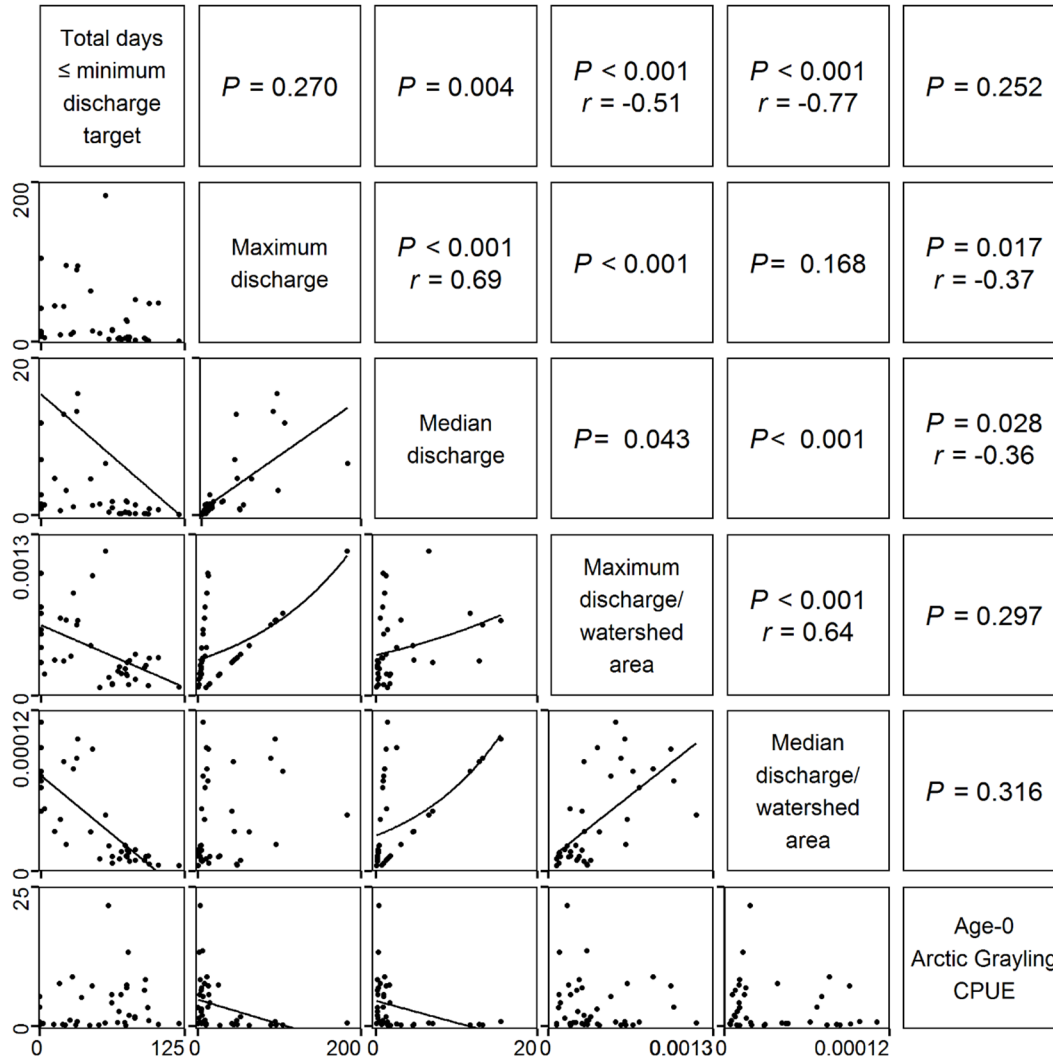


Figure 16. Scatter plots for the univariate relationships between total days  $\leq$  minimum discharge target, maximum discharge ( $\text{m}^3/\text{s}$ ), median discharge ( $\text{m}^3/\text{s}$ ), maximum discharge/watershed area ( $[\text{m}^3/\text{s}]/\text{ha}$ ), median discharge/watershed area ( $[\text{m}^3/\text{s}]/\text{ha}$ ), and age-0 Arctic Grayling CPUE (fish/km) that were sampled in the Big Hole Watershed from 1988 through 2015. Ordinary least squares (OLS) and quantile ( $\tau = 0.90$ ) regression statistics for linear and nonlinear models that describe these relationships are listed in Table 2. The lowest  $P$ -value among the four modelling methods is shown for each relationship, and the corresponding regression line is depicted on the scatter plot for significant relationships ( $P \leq 0.10$ ). Correlation coefficients ( $r$ ) are also shown if linear OLS regression had the lowest significant  $P$ -value.

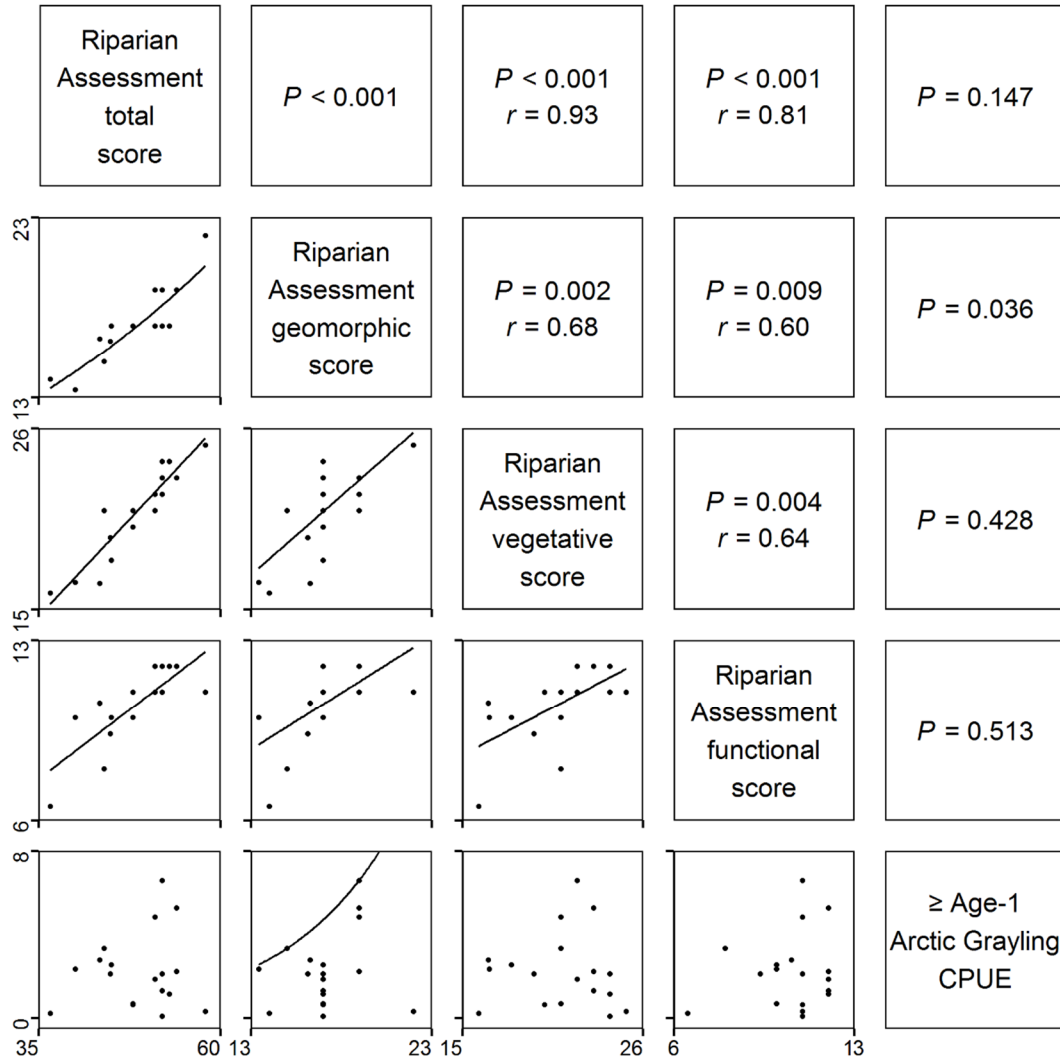


Figure 17. Scatter plots for the univariate relationships between the riparian assessment total score, geomorphic subcategory score, vegetative subcategory score, and functional subcategory score, and the CPUE of Arctic Grayling  $\geq$  age 1 (fish/km) that were sampled in the Big Hole Watershed from 2005 through 2015. Ordinary least squares (OLS) and quantile ( $\tau=0.90$ ) regression statistics for linear and nonlinear models that describe these relationships are listed in Table 1. The lowest  $P$ -value among the four modelling methods is shown for each relationship, and the corresponding regression line is depicted on the scatter plot for significant relationships ( $P \leq 0.10$ ). Correlation coefficients ( $r$ ) are also shown if linear OLS regression had the lowest significant  $P$ -value.

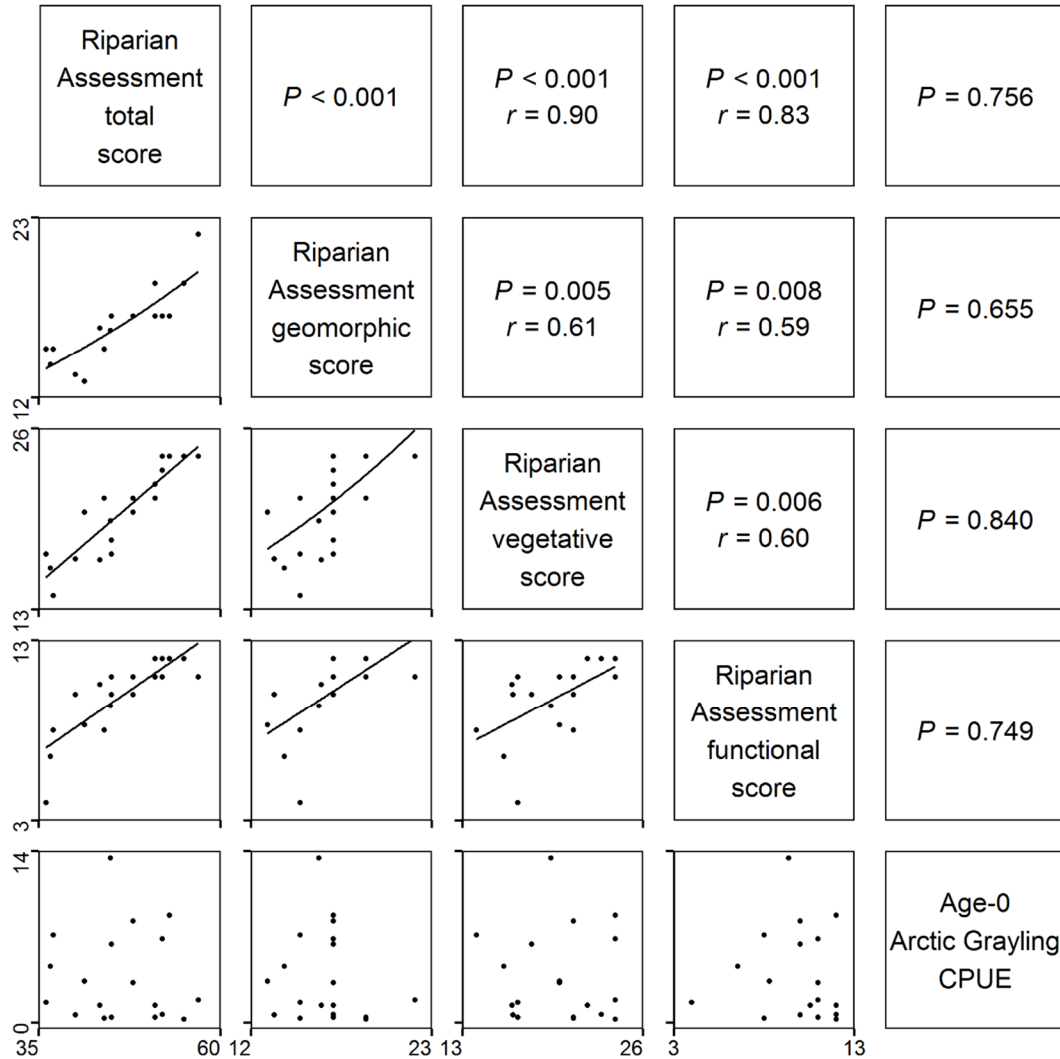


Figure 18. Scatter plots for the univariate relationships between the riparian assessment total score, geomorphic subcategory score, vegetative subcategory score, and functional subcategory score, and age-0 Arctic Grayling CPUE (fish/km) that were sampled in the Big Hole Watershed from 2005 through 2015. Ordinary least squares (OLS) and quantile ( $\tau=0.90$ ) regression statistics for linear and nonlinear models that describe these relationships are listed in Table 2. The lowest  $P$ -value among the four modelling methods is shown for each relationship, and the corresponding regression line is depicted on the scatter plot for significant relationships ( $P \leq 0.10$ ). Correlation coefficients ( $r$ ) are also shown if linear OLS regression had the lowest significant  $P$ -value.

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## APPENDICES

APPENDIX A

SUMMARY OF ARCTIC GRAYLING CPUE (FISH/KM), NONNATIVE  
SALMONID, TEMPERATURE, DISCHARGE, AND RIPARIAN ASSESSMENT  
DATA COLLECTION

Summary of data used in analyses by year and location (e.g., stream, river km, watershed area [ha], upstream latitude and longitude, downstream latitude and longitude). For Big Hole River reaches, river km indicates the distance to the top of the sample reach to the confluence with the Jefferson River, and, for tributary reaches, river km indicates the distance from the mouth of the tributary to the confluence with the Jefferson River.

| Stream            | River<br>km | Watershed<br>area (ha) | Upstream<br>waypoint    | Downstream<br>waypoint  | Year | ≥Age-1<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Age-0<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Nonnative<br>salmonid<br>data | Temperature<br>data | Discharge<br>data | Riparian<br>assessment<br>data |
|-------------------|-------------|------------------------|-------------------------|-------------------------|------|---------------------------------------------------|--------------------------------------------------|-------------------------------|---------------------|-------------------|--------------------------------|
| Big Hole<br>River | 226         | 29579                  | 45.33445,<br>-113.44064 | 45.35098,<br>-113.44346 | 2004 | 0                                                 | 0                                                | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2005 | 0                                                 | 0                                                | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2006 | 0                                                 | 0                                                | x                             |                     |                   | x                              |
|                   |             |                        |                         |                         | 2007 | 0                                                 | 0                                                | x                             | x                   |                   |                                |
|                   |             |                        |                         |                         | 2008 | 0                                                 | 0                                                | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2009 | 0                                                 | 0                                                | x                             | x                   |                   | x                              |
|                   |             |                        |                         |                         | 2010 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2011 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2012 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   | 221         | 101980                 | 45.38281,<br>-113.43399 | 45.40522,<br>-113.44087 | 2005 | 0.29                                              | 0                                                | x                             | x                   |                   |                                |
|                   |             |                        |                         |                         | 2006 | 0                                                 | 0                                                | x                             | x                   |                   |                                |
|                   |             |                        |                         |                         | 2007 | 0                                                 | 0                                                | x                             | x                   |                   | x                              |
|                   |             |                        |                         |                         | 2008 | 0                                                 | 0                                                | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2009 | 0                                                 | 0                                                | x                             | x                   |                   |                                |
|                   |             |                        |                         |                         | 2010 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2011 | 0                                                 | 0                                                | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2012 | 0                                                 | 0                                                | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                         | 2013 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2014 | 0                                                 | 0                                                | x                             | x                   | x                 | x                              |
|                   | 217         | 109770                 | 45.40522,<br>-113.44087 | 45.44048,<br>-113.45657 | 2015 | 0                                                 | 0                                                | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                         | 2005 | 0                                                 | 0                                                | x                             | x                   |                   | x                              |
|                   |             |                        |                         |                         | 2006 | 0                                                 | 0                                                | x                             |                     |                   |                                |

| Stream            | River<br>km | Watershed<br>area (ha) | Upstream<br>waypoint    | Downstream<br>waypoint  | Year | ≥Age-1<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Age-0<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Nonnative<br>salmonid<br>data | Temperature<br>data | Discharge<br>data | Riparian<br>assessment<br>data |
|-------------------|-------------|------------------------|-------------------------|-------------------------|------|---------------------------------------------------|--------------------------------------------------|-------------------------------|---------------------|-------------------|--------------------------------|
| Big Hole<br>River | 217         | 109770                 | 45.40522,<br>-113.44087 | 45.44048,<br>-113.45657 | 2007 | 0                                                 | 0                                                | x                             | x                   |                   |                                |
|                   |             |                        |                         |                         | 2008 | 0                                                 | 0                                                | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2009 | 0                                                 | 0                                                | x                             | x                   |                   |                                |
|                   |             |                        |                         |                         | 2014 | 0                                                 | 0                                                | x                             |                     |                   | x                              |
|                   | 214         | 123854                 | 45.44048,<br>-113.45657 | 45.47756,<br>-113.48654 | 1997 | 0.14                                              | 0                                                |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1998 | 0.14                                              | 0                                                |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 2004 | 0                                                 | 0                                                | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2005 | 0                                                 | 0                                                | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2006 | 0                                                 | 0.14                                             | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2007 | 0.14                                              | 0                                                | x                             |                     |                   |                                |
|                   |             |                        |                         |                         |      |                                                   |                                                  |                               |                     |                   |                                |
|                   | 208         | 135917                 | 45.47756,<br>-113.48654 | 45.52673,<br>-113.48379 | 1992 | 0.24                                              | 0                                                | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2006 | 0                                                 | 0                                                | x                             |                     |                   |                                |
|                   | 196         | 157052                 | 45.56698,<br>-113.48726 | 45.61853,<br>-113.45691 | 1985 | 6.29                                              | 0                                                |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1986 | 3.25                                              | 6.19                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1987 | 1.57                                              | 0.30                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1989 | 1.48                                              | 7.37                                             |                               |                     | x                 |                                |
|                   |             |                        |                         |                         | 1990 | 4.23                                              | 4.13                                             |                               |                     | x                 |                                |
|                   |             |                        |                         |                         | 1991 | 1.77                                              | 0.49                                             |                               |                     | x                 |                                |
|                   |             |                        |                         |                         | 1992 | 0.98                                              | 5.60                                             | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 1993 | 5.41                                              | 0.39                                             |                               |                     | x                 |                                |
|                   |             |                        |                         |                         | 1995 | 1.08                                              | 0.79                                             |                               | x                   | x                 |                                |

| Stream            | River<br>km | Watershed<br>area (ha) | Upstream<br>waypoint    | Downstream<br>waypoint  | Year | ≥Age-1<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Age-0<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Nonnative<br>salmonid<br>data | Temperature<br>data | Discharge<br>data | Riparian<br>assessment<br>data |
|-------------------|-------------|------------------------|-------------------------|-------------------------|------|---------------------------------------------------|--------------------------------------------------|-------------------------------|---------------------|-------------------|--------------------------------|
| Big Hole<br>River | 196         | 157052                 | 45.56698,<br>-113.48726 | 45.61853,<br>-113.45691 | 1996 | 0.49                                              | 0                                                |                               |                     | x                 |                                |
|                   |             |                        |                         |                         | 1997 | 1.08                                              | 0.20                                             |                               |                     | x                 |                                |
|                   |             |                        |                         |                         | 1998 | 0.79                                              | 0.30                                             |                               |                     | x                 |                                |
|                   |             |                        |                         |                         | 2003 | 0                                                 | 0.94                                             |                               |                     | x                 |                                |
|                   |             |                        |                         |                         | 2004 | 0.89                                              | 0.20                                             | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2005 | 0.39                                              | 0                                                | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2006 | 0                                                 | 1.67                                             | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                         | 2007 | 0.20                                              | 0.30                                             | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2008 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2009 | 0.59                                              | 0.10                                             | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2010 | 0.20                                              | 0.20                                             | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2011 | 0.89                                              | 0.20                                             | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2012 | 0.10                                              | 0                                                | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                         | 2013 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2014 | 0                                                 | 0.30                                             | x                             | x                   | x                 | x                              |
|                   | 187         | 180535                 | 45.61853,<br>-113.45691 | 45.67197,<br>-113.45254 | 2015 | 0.39                                              | 0.10                                             | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 1983 | 2.65                                              | 0                                                |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1984 | 6.11                                              | 0                                                |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1985 | 7.15                                              | 0                                                |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1987 | 2.08                                              | 0                                                |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1989 | 2.31                                              | 2.77                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1990 | 3.11                                              | 1.85                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1991 | 5.65                                              | 2.08                                             |                               |                     |                   |                                |

| Stream            | River<br>km | Watershed<br>area (ha) | Upstream<br>waypoint    | Downstream<br>waypoint  | Year | ≥Age-1<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Age-0<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Nonnative<br>salmonid<br>data | Temperature<br>data | Discharge<br>data | Riparian<br>assessment<br>data |
|-------------------|-------------|------------------------|-------------------------|-------------------------|------|---------------------------------------------------|--------------------------------------------------|-------------------------------|---------------------|-------------------|--------------------------------|
| Big Hole<br>River | 187         | 180535                 | 45.61853,<br>-113.45691 | 45.67197,<br>-113.45254 | 1993 | 2.42                                              | 0.12                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1994 | 4.15                                              | 1.15                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1995 | 2.31                                              | 1.04                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1996 | 1.04                                              | 0.12                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1997 | 2.31                                              | 0.23                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1998 | 3.11                                              | 0.12                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1999 | 1.61                                              | 0.12                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 2000 | 0.12                                              | 0.23                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 2003 | 0                                                 | 3.80                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 2004 | 0.12                                              | 0.58                                             | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2005 | 0.35                                              | 1.04                                             | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2006 | 0.12                                              | 2.54                                             | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2007 | 0                                                 | 1.50                                             | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2008 | 0.92                                              | 0.81                                             | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2009 | 0.35                                              | 0.35                                             | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2011 | 0.23                                              | 0.46                                             | x                             |                     |                   |                                |
|                   | 176         | 277077                 | 45.67197,<br>-113.45254 | 45.70843,<br>-113.42644 | 1992 | 0.11                                              | 0.11                                             | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 1993 | 0.57                                              | 0.46                                             |                               |                     |                   |                                |
|                   | 158         | 321881                 | 45.75238,<br>-113.36619 | 45.80773,<br>-113.31317 | 1992 | 0.21                                              | 3.52                                             | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 1993 | 0.21                                              | 0.21                                             |                               | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2005 | 0.11                                              | 0.11                                             | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2006 | 0                                                 | 0                                                | x                             | x                   | x                 | x                              |

| Stream            | River<br>km | Watershed<br>area (ha) | Upstream<br>waypoint    | Downstream<br>waypoint  | Year | ≥Age-1<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Age-0<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Nonnative<br>salmonid<br>data | Temperature<br>data | Discharge<br>data | Riparian<br>assessment<br>data |
|-------------------|-------------|------------------------|-------------------------|-------------------------|------|---------------------------------------------------|--------------------------------------------------|-------------------------------|---------------------|-------------------|--------------------------------|
| Big Hole<br>River | 158         | 321881                 | 45.75238,<br>-113.36619 | 45.80773,<br>-113.31317 | 2007 | 0.31                                              | 0.85                                             | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2008 | 0.53                                              | 0.53                                             | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2009 | 0.75                                              | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2010 | 2.82                                              | 0.57                                             | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2011 | 0.21                                              | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2012 | 2.24                                              | 0.32                                             | x                             |                     | x                 | x                              |
|                   |             |                        |                         |                         | 2013 | 0.64                                              | 0.11                                             | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2014 | 0.85                                              | 0.53                                             | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                         | 2015 | 0.21                                              | 0.85                                             | x                             | x                   | x                 |                                |
|                   | 147         | 337683                 | 45.80773,<br>-113.31317 | 45.84222,<br>-113.25122 | 1993 | 1.75                                              | 0                                                |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1995 | 1.97                                              | 0                                                |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1997 | 2.05                                              | 0                                                |                               |                     |                   |                                |
|                   | 140         | 409820                 | 45.84222,<br>-113.25122 | 45.85825,<br>-113.08448 | 1993 | 2.05                                              | 0                                                |                               | x                   |                   |                                |
|                   |             |                        |                         |                         | 1995 | 2.05                                              | 0                                                |                               | x                   |                   |                                |
|                   |             |                        |                         |                         | 1996 | 2.39                                              | 0.23                                             |                               | x                   |                   |                                |
|                   |             |                        |                         |                         | 1997 | 4.09                                              | 0                                                |                               | x                   |                   |                                |
|                   |             |                        |                         |                         | 1998 | 1.82                                              | 0                                                |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 1999 | 4.66                                              | 0                                                |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 2002 | 0.57                                              | 0                                                |                               |                     |                   |                                |
|                   | 131         | 409820                 | 45.88472,<br>-113.18020 | 45.85825,<br>-113.08448 | 2004 | 0.68                                              | 0                                                | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2005 | 0                                                 | 0                                                | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                         | 2006 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2006 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |

| Stream            | River<br>km | Watershed<br>area (ha) | Upstream<br>waypoint    | Downstream<br>waypoint  | Year | ≥Age-1<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Age-0<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Nonnative<br>salmonid<br>data | Temperature<br>data | Discharge<br>data | Riparian<br>assessment<br>data |
|-------------------|-------------|------------------------|-------------------------|-------------------------|------|---------------------------------------------------|--------------------------------------------------|-------------------------------|---------------------|-------------------|--------------------------------|
| Big Hole<br>River | 126         | 409820                 | 45.88435,<br>-113.13328 | 45.85825,<br>-113.08448 | 2007 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2008 | 0.20                                              | 0                                                | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2009 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2010 | 0.20                                              | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2011 | 0.40                                              | 0                                                | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                         | 2012 | 1.01                                              | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2013 | 0.60                                              | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2014 | 0                                                 | 0                                                | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                         | 2015 | 0.60                                              | 0                                                | x                             | x                   | x                 | x                              |
| Berry<br>Creek    | 120         | 409820                 | 45.85825,<br>-113.08448 | 45.85078,<br>-113.06876 | 1990 | 12.08                                             | 0                                                |                               |                     |                   |                                |
| Governor<br>Creek | 245         | 3885                   | 45.27088,<br>-113.46999 | 45.27533,<br>-113.46409 | 2006 | 0                                                 | 0                                                | x                             |                     |                   |                                |
|                   | 224         | 35378                  | 45.35112,<br>-113.40933 | 45.37127,<br>-113.42446 | 2005 | 0                                                 | 0                                                | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2006 | 0                                                 | 0                                                | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2007 | 0                                                 | 0                                                | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                         | 2008 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2009 | 0                                                 | 0                                                | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2010 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2011 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2012 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
| Miner<br>Creek    | 216         | 7790                   | 45.43071,<br>-113.46724 | 45.43561,<br>-113.46079 | 2005 | 0                                                 | 0                                                | x                             | x                   |                   |                                |
|                   |             |                        |                         |                         | 2006 | 0                                                 | 0                                                | x                             | x                   |                   |                                |

| Stream            | River<br>km | Watershed<br>area (ha) | Upstream<br>waypoint    | Downstream<br>waypoint   | Year | ≥Age-1<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Age-0<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Nonnative<br>salmonid<br>data | Temperature<br>data | Discharge<br>data | Riparian<br>assessment<br>data |
|-------------------|-------------|------------------------|-------------------------|--------------------------|------|---------------------------------------------------|--------------------------------------------------|-------------------------------|---------------------|-------------------|--------------------------------|
| Miner<br>Creek    | 216         | 7790                   | 45.43071,<br>-113.46724 | 45.43561,<br>-113.46079  | 2007 | 0                                                 | 0                                                | x                             | x                   |                   |                                |
|                   |             |                        |                         |                          | 2008 | 0                                                 | 0                                                | x                             |                     | x                 |                                |
|                   |             |                        |                         |                          | 2009 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                          | 2010 | 0                                                 | 0                                                | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                          | 2011 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                          | 2012 | 0                                                 | 0                                                | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                          | 2015 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
| Big Lake<br>Creek | 188         | 12309                  | 45.54707,<br>-113.49926 | 45.57511,<br>-113.48687  | 2005 | 0                                                 | 0                                                | x                             |                     |                   |                                |
|                   |             |                        |                         |                          | 2006 | 0                                                 | 0                                                | x                             | x                   |                   | x                              |
|                   |             |                        |                         |                          | 2011 | 1.34                                              | 0                                                | x                             |                     |                   |                                |
| Rock<br>Creek     | 186         | 11950                  | 45.56025,<br>-113.50635 | 45.58002,<br>-113.48756  | 2005 | 0                                                 | 0                                                | x                             |                     |                   |                                |
|                   |             |                        |                         |                          | 2006 | 0                                                 | 0.36                                             | x                             |                     |                   |                                |
|                   |             |                        |                         |                          | 2007 | 0                                                 | 0                                                | x                             | x                   |                   |                                |
|                   |             |                        |                         |                          | 2008 | 0                                                 | 0                                                | x                             | x                   |                   | x                              |
|                   |             |                        |                         |                          | 2009 | 0                                                 | 0                                                | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                          | 2014 | 0.65                                              | 3.26                                             | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                          | 2015 | 0                                                 | 0.44                                             | x                             | x                   | x                 | x                              |
| Steel<br>Creek    | 178         | 19420                  | 45.63537,<br>-113.44344 | 45.66473,<br>-113.444468 | 1990 | 10.68                                             | 7.69                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                          | 1991 | 3.20                                              | 1.92                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                          | 1992 | 5.77                                              | 12.81                                            |                               |                     |                   |                                |
|                   |             |                        |                         |                          | 1993 | 0.85                                              | 2.99                                             |                               |                     |                   |                                |

| Stream         | River<br>km | Watershed<br>area (ha) | Upstream<br>waypoint    | Downstream<br>waypoint   | Year | ≥Age-1<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Age-0<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Nonnative<br>salmonid<br>data | Temperature<br>data | Discharge<br>data | Riparian<br>assessment<br>data |
|----------------|-------------|------------------------|-------------------------|--------------------------|------|---------------------------------------------------|--------------------------------------------------|-------------------------------|---------------------|-------------------|--------------------------------|
| Steel<br>Creek | 178         | 19420                  | 45.63537,<br>-113.44344 | 45.66473,<br>-113.444468 | 1994 | 4.27                                              | 4.06                                             |                               |                     |                   |                                |
|                |             |                        |                         |                          | 1995 | 2.56                                              | 11.10                                            |                               |                     |                   |                                |
|                |             |                        |                         |                          | 1996 | 4.48                                              | 9.61                                             |                               | x                   |                   |                                |
|                |             |                        |                         |                          | 1997 | 1.92                                              | 3.42                                             |                               | x                   |                   |                                |
|                |             |                        |                         |                          | 1998 | 2.99                                              | 3.84                                             |                               |                     |                   |                                |
|                |             |                        |                         |                          | 1999 | 3.63                                              | 1.92                                             |                               | x                   |                   |                                |
|                |             |                        |                         |                          | 2000 | 1.50                                              | 0.43                                             |                               |                     |                   |                                |
|                |             |                        |                         |                          | 2002 | 1.07                                              | 1.07                                             |                               |                     |                   |                                |
|                |             |                        |                         |                          | 2003 | 0.85                                              | 15.80                                            |                               |                     |                   |                                |
|                |             |                        |                         |                          | 2004 | 0.85                                              | 0.64                                             | x                             |                     |                   |                                |
|                |             |                        |                         |                          | 2005 | 0                                                 | 0.64                                             | x                             | x                   | x                 |                                |
|                |             |                        |                         |                          | 2006 | 0.64                                              | 21.57                                            | x                             | x                   | x                 |                                |
|                |             |                        |                         |                          | 2007 | 2.14                                              | 13.45                                            | x                             | x                   | x                 | x                              |
|                |             |                        |                         |                          | 2008 | 6.62                                              | 3.42                                             | x                             | x                   | x                 |                                |
|                |             |                        |                         |                          | 2009 | 2.35                                              | 13.24                                            | x                             | x                   | x                 |                                |
|                |             |                        |                         |                          | 2010 | 2.14                                              | 2.56                                             | x                             | x                   | x                 |                                |
|                |             |                        |                         |                          | 2011 | 4.27                                              | 5.13                                             | x                             |                     | x                 |                                |
|                |             |                        |                         |                          | 2012 | 2.35                                              | 0.64                                             | x                             |                     | x                 | x                              |
|                |             |                        |                         |                          | 2013 | 1.07                                              | 1.92                                             | x                             |                     | x                 |                                |
|                |             |                        |                         |                          | 2014 | 2.14                                              | 6.83                                             | x                             |                     | x                 | x                              |
|                |             |                        |                         |                          | 2015 | 2.56                                              | 6.41                                             | x                             | x                   | x                 | x                              |
|                |             |                        | 45.62171,<br>-113.43835 | 45.63537,<br>-113.44344  | 2008 | 0.33                                              | 0                                                | x                             |                     |                   |                                |
|                |             |                        |                         |                          | 2009 | 0                                                 | 0                                                | x                             |                     |                   |                                |

| Stream                             | River<br>km | Watershed<br>area (ha) | Upstream<br>waypoint    | Downstream<br>waypoint  | Year | ≥Age-1<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Age-0<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Nonnative<br>salmonid<br>data | Temperature<br>data | Discharge<br>data | Riparian<br>assessment<br>data |
|------------------------------------|-------------|------------------------|-------------------------|-------------------------|------|---------------------------------------------------|--------------------------------------------------|-------------------------------|---------------------|-------------------|--------------------------------|
| Swamp<br>Creek                     | 175         | 13509                  | 45.65912,<br>-113.46988 | 45.67884,<br>-113.46755 | 1992 | 0.46                                              | 21.25                                            | x                             |                     | x                 |                                |
|                                    |             |                        |                         |                         | 2003 | 3.11                                              | 56.55                                            |                               |                     | x                 |                                |
|                                    |             |                        |                         |                         | 2004 | 0.69                                              | 7.39                                             | x                             |                     | x                 |                                |
|                                    |             |                        |                         |                         | 2005 | 0.23                                              | 2.08                                             | x                             | x                   | x                 |                                |
|                                    |             |                        |                         |                         | 2006 | 0                                                 | 6.24                                             | x                             | x                   | x                 |                                |
|                                    |             |                        |                         |                         | 2007 | 0.23                                              | 4.62                                             | x                             | x                   | x                 | x                              |
|                                    |             |                        |                         |                         | 2008 | 0.69                                              | 3.00                                             | x                             |                     | x                 |                                |
|                                    |             |                        |                         |                         | 2009 | 0                                                 | 3.70                                             | x                             | x                   | x                 |                                |
|                                    |             |                        |                         |                         | 2010 | 0.23                                              | 7.62                                             | x                             | x                   | x                 |                                |
|                                    |             |                        |                         |                         | 2011 | 1.39                                              | 7.16                                             | x                             |                     | x                 |                                |
|                                    |             |                        |                         |                         | 2013 | 0.93                                              | 5.61                                             |                               |                     | x                 |                                |
|                                    |             |                        |                         |                         | 2014 | 1.16                                              | 8.78                                             | x                             | x                   | x                 | x                              |
|                                    |             |                        |                         |                         | 2015 | 0.69                                              | 8.32                                             | x                             | x                   | x                 | x                              |
|                                    |             |                        | 45.63150,<br>-113.50106 | 45.65912,<br>-113.46988 | 2004 | 0.60                                              | 0.15                                             | x                             |                     | x                 |                                |
|                                    |             |                        |                         |                         | 2008 | 1.05                                              | 0.75                                             | x                             |                     | x                 |                                |
|                                    |             |                        |                         |                         | 2009 | 1.05                                              | 5.24                                             | x                             |                     | x                 |                                |
| North<br>Fork<br>Big Hole<br>River | 165         | 72794                  | 45.69612,<br>-113.56100 | 45.70564,<br>-113.45932 | 2003 | 1.64                                              | 1.64                                             |                               |                     |                   |                                |
|                                    |             |                        |                         |                         | 2005 | 0                                                 | 0                                                | x                             | x                   |                   |                                |
|                                    |             |                        |                         |                         | 2006 | 0                                                 | 0                                                | x                             | x                   |                   | x                              |
|                                    |             |                        |                         |                         | 2007 | 0                                                 | 0                                                | x                             | x                   |                   |                                |
|                                    |             |                        |                         |                         | 2012 | 0                                                 | 0                                                | x                             |                     |                   | x                              |
|                                    |             |                        |                         |                         | 2015 | 0                                                 | 0                                                | x                             | x                   |                   |                                |

| Stream            | River<br>km | Watershed<br>area (ha) | Upstream<br>waypoint    | Downstream<br>waypoint  | Year | ≥Age-1<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Age-0<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Nonnative<br>salmonid<br>data | Temperature<br>data | Discharge<br>data | Riparian<br>assessment<br>data |
|-------------------|-------------|------------------------|-------------------------|-------------------------|------|---------------------------------------------------|--------------------------------------------------|-------------------------------|---------------------|-------------------|--------------------------------|
| Howell<br>Creek   | 164         | 5435                   | 45.73792,<br>-113.41825 | 45.73206,<br>-113.41152 | 2011 | 0.81                                              | 1.61                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 2013 | 0.40                                              | 3.21                                             |                               |                     |                   |                                |
| Plimpton<br>Creek | 163         | 12174                  | 45.73596,<br>-113.44000 | 45.73456,<br>-113.40638 | 2009 | 2.74                                              | 13.06                                            | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2010 | 0.57                                              | 11.75                                            | x                             | x                   |                   |                                |
|                   |             |                        |                         |                         | 2011 | 2.35                                              | 2.11                                             | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2012 | 18.32                                             | 7.17                                             | x                             |                     |                   | x                              |
|                   |             |                        |                         |                         | 2013 | 2.80                                              | 1.40                                             |                               |                     |                   | x                              |
|                   |             |                        |                         |                         | 2015 | 1.87                                              | 1.40                                             | x                             |                     | x                 | x                              |
| Pintlar<br>Creek  | 157         | 7691                   | 45.74717,<br>-113.45881 | 45.73591,<br>-113.44022 | 2011 | 0.33                                              | 0                                                | x                             |                     |                   | x                              |
|                   |             |                        | 45.75620,<br>-113.38143 | 45.75167,<br>-113.38252 | 2006 | 0                                                 | 0                                                | x                             |                     |                   | x                              |
|                   |             |                        |                         |                         | 2009 | 0.93                                              | 12.06                                            |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 2011 | 2.39                                              | 2.39                                             |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 2013 | 1.68                                              | 0.84                                             |                               |                     |                   |                                |
| York<br>Gulch     | 151         | 3055                   | 45.81356,<br>-113.35652 | 45.80004,<br>-113.34918 | 2008 | 0.85                                              | 34.47                                            |                               |                     |                   | x                              |
|                   |             |                        |                         |                         | 2009 | 0.88                                              | 1.32                                             |                               |                     |                   |                                |
| Squaw<br>Creek    | 148         | 5596                   | 45.80750,<br>-113.33472 | 45.80839,<br>-113.32228 | 2007 | 0                                                 | 12.79                                            |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 2013 | 4.14                                              | 15.88                                            |                               |                     |                   |                                |
| Fishtrap<br>Creek | 135         | 13142                  | 45.87433,<br>-113.23687 | 45.86865,<br>-113.22623 | 2003 | 15.53                                             | 19.72                                            |                               |                     |                   |                                |
|                   |             |                        |                         |                         | 2004 | 23.90                                             | 32.26                                            | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2005 | 4.78                                              | 1.79                                             | x                             | x                   |                   |                                |
|                   |             |                        |                         |                         | 2006 | 8.96                                              | 1.20                                             | x                             | x                   |                   |                                |

| Stream            | River<br>km | Watershed<br>area (ha) | Upstream<br>waypoint    | Downstream<br>waypoint  | Year | ≥Age-1<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Age-0<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Nonnative<br>salmonid<br>data | Temperature<br>data | Discharge<br>data | Riparian<br>assessment<br>data |
|-------------------|-------------|------------------------|-------------------------|-------------------------|------|---------------------------------------------------|--------------------------------------------------|-------------------------------|---------------------|-------------------|--------------------------------|
| Fishtrap<br>Creek | 135         | 13142                  | 45.87433,<br>-113.23687 | 45.86865,<br>-113.22623 | 2007 | 16.73                                             | 7.17                                             | x                             | x                   |                   |                                |
|                   |             |                        |                         |                         | 2008 | 14.34                                             | 0                                                | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2009 | 16.73                                             | 2.99                                             | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2010 | 0.60                                              | 0                                                | x                             | x                   |                   |                                |
|                   |             |                        |                         |                         | 2011 | 2.99                                              | 0.60                                             | x                             |                     |                   |                                |
| LaMarche<br>Creek | 133         | 12827                  | 45.88471,<br>-113.20356 | 45.87494,<br>-113.19704 | 1993 | 4.26                                              | 0                                                |                               |                     | x                 |                                |
|                   |             |                        |                         |                         | 2002 | 39.16                                             | 0                                                |                               |                     | x                 |                                |
|                   |             |                        |                         |                         | 2003 | 18.73                                             | 8.51                                             |                               |                     | x                 |                                |
|                   |             |                        |                         |                         | 2004 | 17.85                                             | 9.92                                             | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2005 | 8.51                                              | 1.70                                             | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2006 | 11.92                                             | 3.41                                             | x                             | x                   | x                 | x                              |
|                   |             |                        |                         |                         | 2007 | 10.58                                             | 5.29                                             | x                             | x                   | x                 |                                |
|                   |             |                        |                         |                         | 2008 | 7.64                                              | 0.51                                             | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2009 | 4.63                                              | 0.66                                             | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2010 | 1.32                                              | 0.66                                             | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2011 | 1.32                                              | 0.66                                             | x                             |                     | x                 | x                              |
|                   |             |                        |                         |                         | 2012 | 0.66                                              | 0                                                | x                             |                     | x                 |                                |
|                   |             |                        |                         |                         | 2014 | 6.61                                              | 0                                                | x                             | x                   | x                 | x                              |
| Seymour<br>Creek  | 128         | 8550                   | 45.88785,<br>-113.14465 | 45.88264,<br>-113.14342 | 2005 | 0.93                                              | 0                                                | x                             |                     |                   |                                |
|                   |             |                        |                         |                         | 2006 | 1.86                                              | 0                                                | x                             | x                   |                   |                                |
| Seymour<br>Creek  | 128         | 8550                   | 45.88785,<br>-113.14465 | 45.88264,<br>-113.14342 | 2007 | 0                                                 | 1.86                                             | x                             | x                   |                   | x                              |
|                   |             |                        |                         |                         | 2009 | 2.78                                              | 0                                                | x                             | x                   |                   |                                |

| Stream        | River<br>km | Watershed<br>area (ha) | Upstream<br>waypoint    | Downstream<br>waypoint  | Year | ≥Age-1<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Age-0<br>Arctic<br>Grayling<br>CPUE<br>(fish/km) | Nonnative<br>salmonid<br>data | Temperature<br>data | Discharge<br>data | Riparian<br>assessment<br>data |
|---------------|-------------|------------------------|-------------------------|-------------------------|------|---------------------------------------------------|--------------------------------------------------|-------------------------------|---------------------|-------------------|--------------------------------|
| Deep<br>Creek | 126         | 27543                  | 45.90063,<br>-113.10896 | 45.88326,<br>-113.11718 | 1988 | 10.05                                             | 0                                                |                               |                     |                   |                                |
|               |             |                        |                         |                         | 1990 | 6.70                                              | 0                                                |                               |                     |                   |                                |
|               |             |                        |                         |                         | 1991 | 1.62                                              | 0                                                |                               |                     |                   |                                |
|               |             |                        |                         |                         | 1992 | 1.62                                              | 3.78                                             | x                             |                     |                   |                                |
|               |             |                        |                         |                         | 1993 | 48.09                                             | 3.78                                             |                               |                     |                   |                                |
|               |             |                        |                         |                         | 1995 | 22.69                                             | 2.16                                             |                               | x                   |                   |                                |
|               |             |                        |                         |                         | 1996 | 4.86                                              | 0                                                |                               | x                   |                   |                                |
|               |             |                        |                         |                         | 1997 | 16.21                                             | 7.57                                             |                               | x                   |                   |                                |
|               |             |                        |                         |                         | 1999 | 6.21                                              | 0                                                |                               | x                   |                   |                                |
|               |             |                        |                         |                         | 2001 | 10.27                                             | 0.54                                             |                               | x                   |                   |                                |
|               |             |                        |                         |                         | 2002 | 2.70                                              | 0.54                                             |                               |                     |                   |                                |
|               |             |                        |                         |                         | 2003 | 15.13                                             | 3.24                                             |                               |                     |                   |                                |
|               |             |                        |                         |                         | 2004 | 5.40                                              | 4.32                                             | x                             |                     |                   |                                |
|               |             |                        |                         |                         | 2005 | 3.35                                              | 0.37                                             | x                             | x                   |                   | x                              |
|               |             |                        |                         |                         | 2006 | 2.70                                              | 0.54                                             | x                             | x                   |                   |                                |
|               |             |                        |                         |                         | 2007 | 1.62                                              | 1.08                                             | x                             | x                   | x                 |                                |
|               |             |                        |                         |                         | 2008 | 0.37                                              | 0.37                                             | x                             |                     | x                 |                                |
|               |             |                        |                         |                         | 2009 | 2.61                                              | 0                                                | x                             | x                   |                   |                                |
|               |             |                        |                         |                         | 2010 | 3.35                                              | 1.49                                             | x                             | x                   |                   |                                |
|               |             |                        |                         |                         | 2011 | 2.23                                              | 0                                                | x                             |                     |                   | x                              |
|               |             |                        |                         |                         | 2012 | 7.26                                              | 0                                                | x                             |                     |                   |                                |
|               |             |                        |                         |                         | 2013 | 6.86                                              | 0                                                | x                             |                     |                   |                                |
|               |             |                        |                         |                         | 2014 | 5.29                                              | 0                                                | x                             |                     |                   | x                              |
|               |             |                        |                         |                         | 2015 | 4.85                                              | 0.44                                             | x                             |                     | x                 | x                              |

## APPENDIX B

### RELATIONSHIPS BETWEEN NONNATIVE SALMONID CPUE AND ABIOTIC CONDITIONS

Relationships between nonnative salmonid CPUE (fish/km) and temperature, discharge, or habitat condition metrics are evaluated in this appendix. The methods used to collect and summarize the data and model the relationships are described in the Methods section of this manuscript.

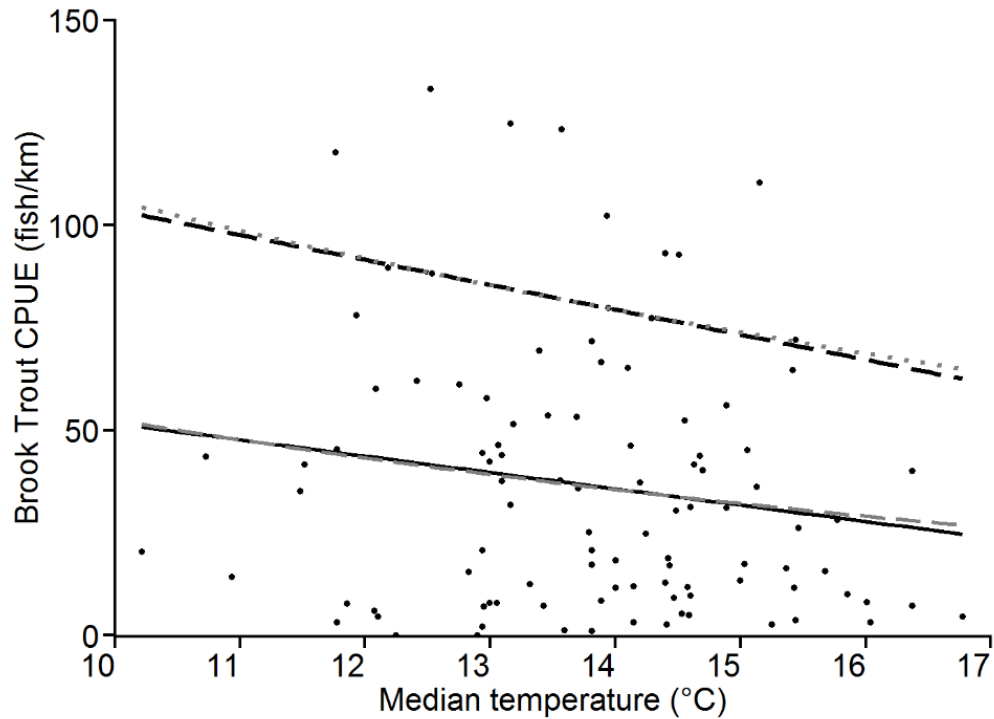


Figure 1. Scatter plot relating Brook Trout CPUE (fish/km) and median water temperature (°C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE= $91.454-3.979 \cdot \text{median temperature}$ ;  $P=0.105$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE= $126.96 \cdot \exp(-0.091 \cdot \text{median temperature})$ ;  $P=0.163$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE= $164.48-6.078 \cdot \text{median temperature}$ ;  $P=0.518$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE= $218.81 \cdot \exp(-0.072 \cdot \text{median temperature})$ ;  $P=0.482$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

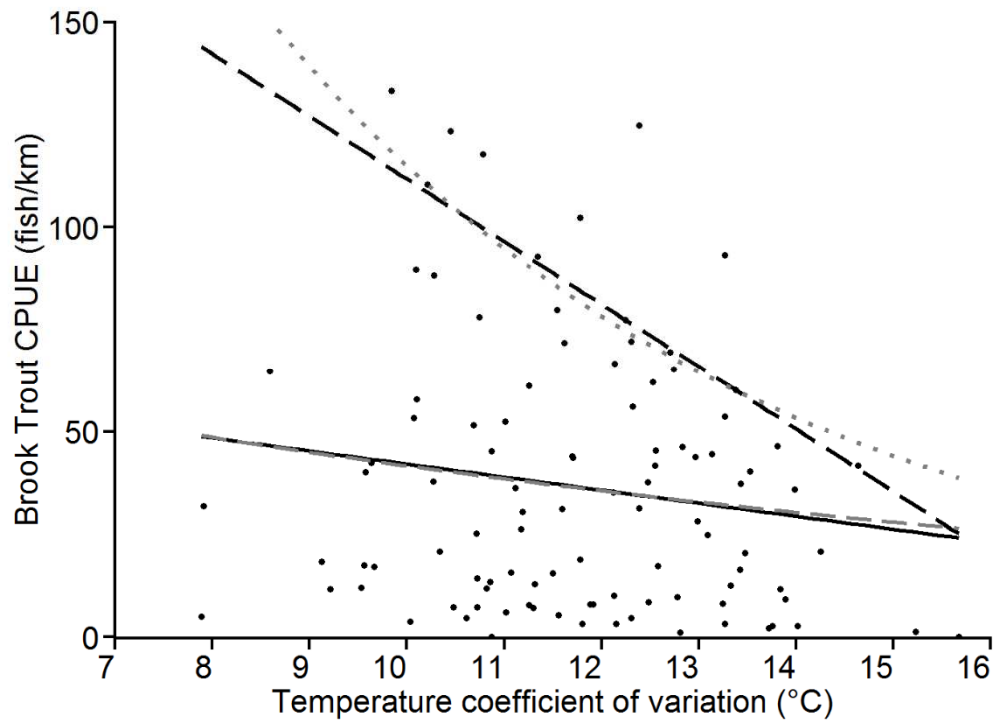


Figure 2. Scatter plot relating Brook Trout CPUE (fish/km) and water temperature CV ( $^{\circ}\text{C}$ ;  $100 \cdot \text{SD}/\text{mean}$ ;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE =  $73.807 - 3.172 \cdot \text{temperature CV}$ ;  $P=0.133$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE =  $83.909 \cdot \exp(-0.071 \cdot \text{temperature CV})$ ;  $P=0.212$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE =  $264.39 - 15.267 \cdot \text{temperature CV}$ ;  $P=0.016$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE =  $781.81 \cdot \exp(-0.191 \cdot \text{temperature CV})$ ;  $P=0.023$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

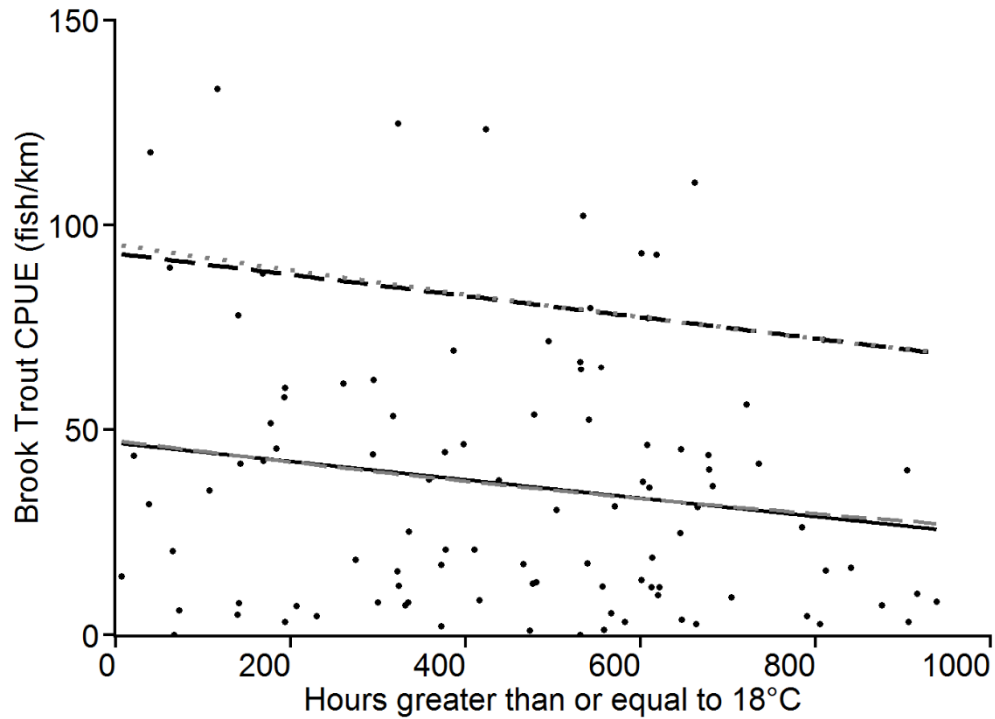


Figure 3. Scatter plot relating Brook Trout CPUE (fish/km) and water temperature total hours  $\geq 18^{\circ}\text{C}$  (18C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE= $46.758-0.022 \cdot 18\text{C}$ ;  $P=0.096$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE= $47.057 \cdot \exp(-0.0005 \cdot 18\text{C})$ ;  $P=0.119$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE= $93.141-0.026 \cdot 18\text{C}$ ;  $P=0.513$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE= $93.834 \cdot \exp(-0.0003 \cdot 18\text{C})$ ;  $P=0.582$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

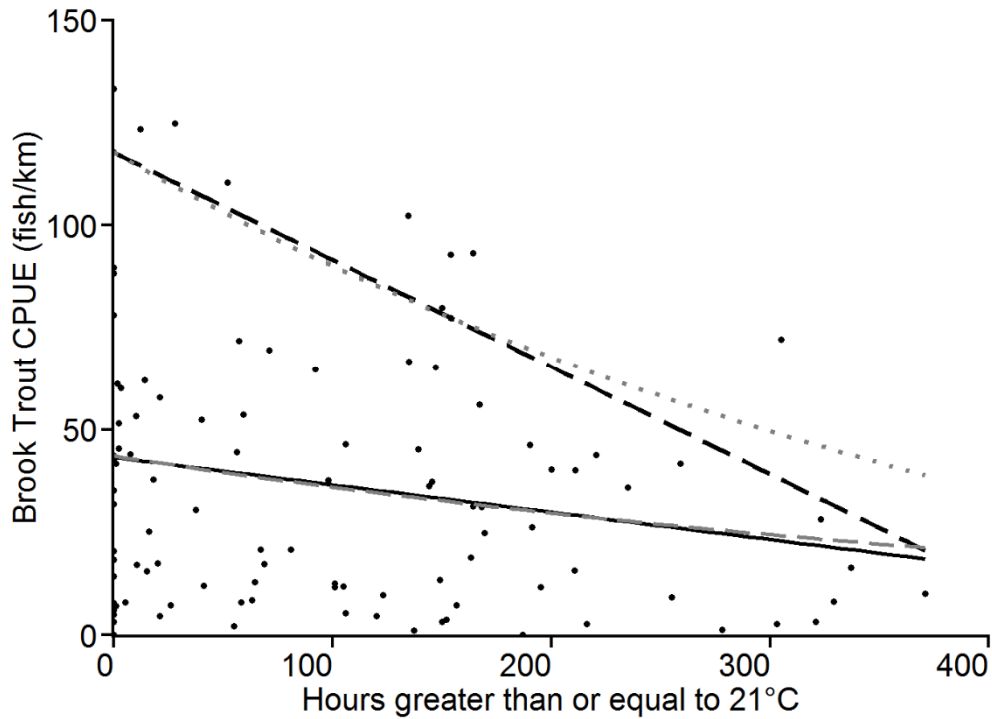


Figure 4. Scatter plot relating Brook Trout CPUE (fish/km) and water temperature total hours  $\geq 21^{\circ}\text{C}$  (21C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE= $43.222-0.067\cdot 21\text{C}$ ;  $P=0.042$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE= $43.413\cdot \exp(-0.002\cdot 21\text{C})$ ;  $P=0.074$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE= $117.70-0.262\cdot 21\text{C}$ ;  $P=0.023$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE= $107.36\cdot \exp(-0.002\cdot 21\text{C})$ ;  $P=0.147$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

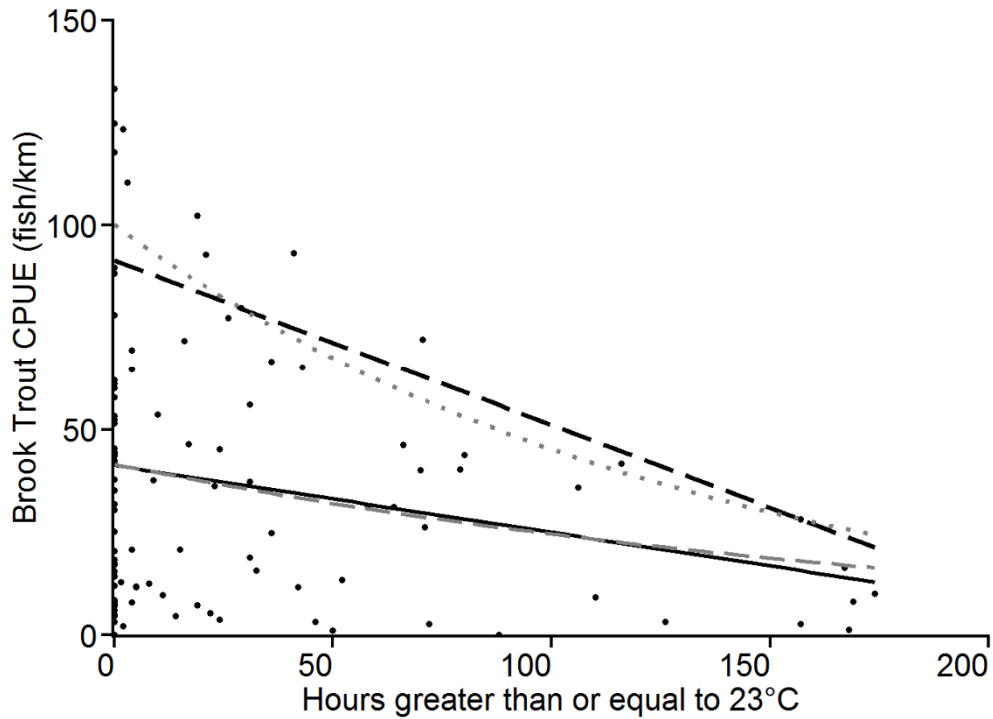


Figure 5. Scatter plot relating Brook Trout CPUE (fish/km) and water temperature total hours  $\geq 23^{\circ}\text{C}$  (23C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE= $41.288-0.163 \cdot 23\text{C}$ ;  $P=0.021$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE= $41.325 \cdot \exp(-0.005 \cdot 23\text{C})$ ;  $P=0.090$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE= $91.423 - 0.403 \cdot 23\text{C}$ ;  $P<0.001$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE= $100.24 \cdot \exp(-0.008 \cdot 23\text{C})$ ;  $P=0.147$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

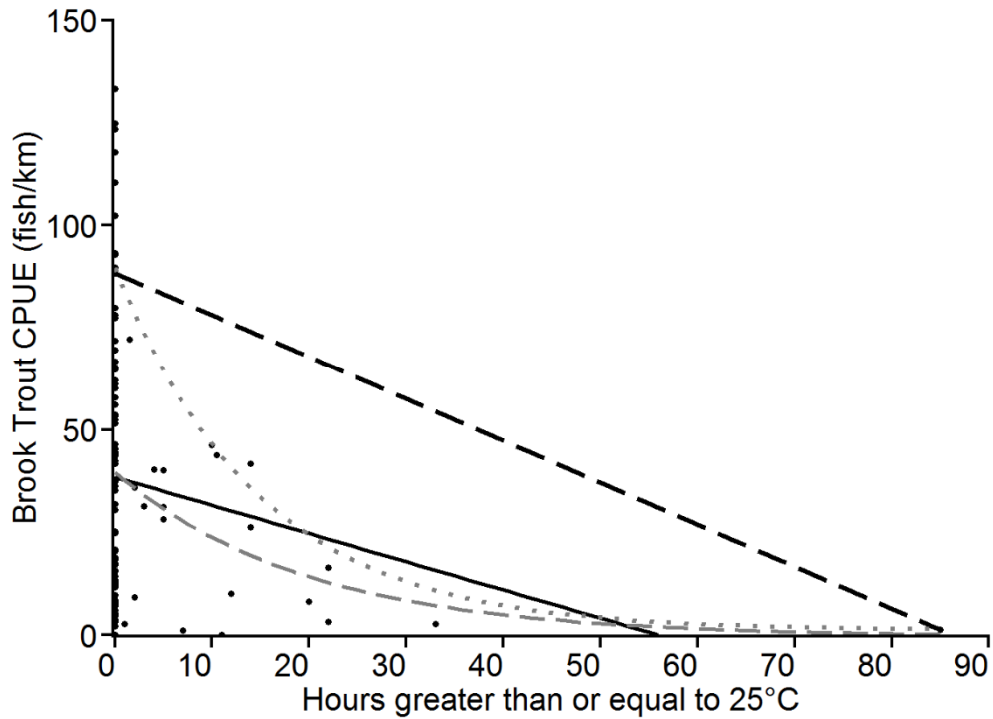


Figure 6. Scatter plot relating Brook Trout CPUE (fish/km) and water temperature total hours  $\geq 25^{\circ}\text{C}$  (25C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE= $38.441-0.687 \cdot 25\text{C}$ ;  $P=0.034$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE= $39.665 \cdot \exp(-0.050 \cdot 25\text{C})$ ;  $P=0.152$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE= $88.300 - 1.023 \cdot 25\text{C}$ ;  $P=0.291$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE= $90.302 \cdot \exp(-0.067 \cdot 25\text{C})$ ;  $P<0.001$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

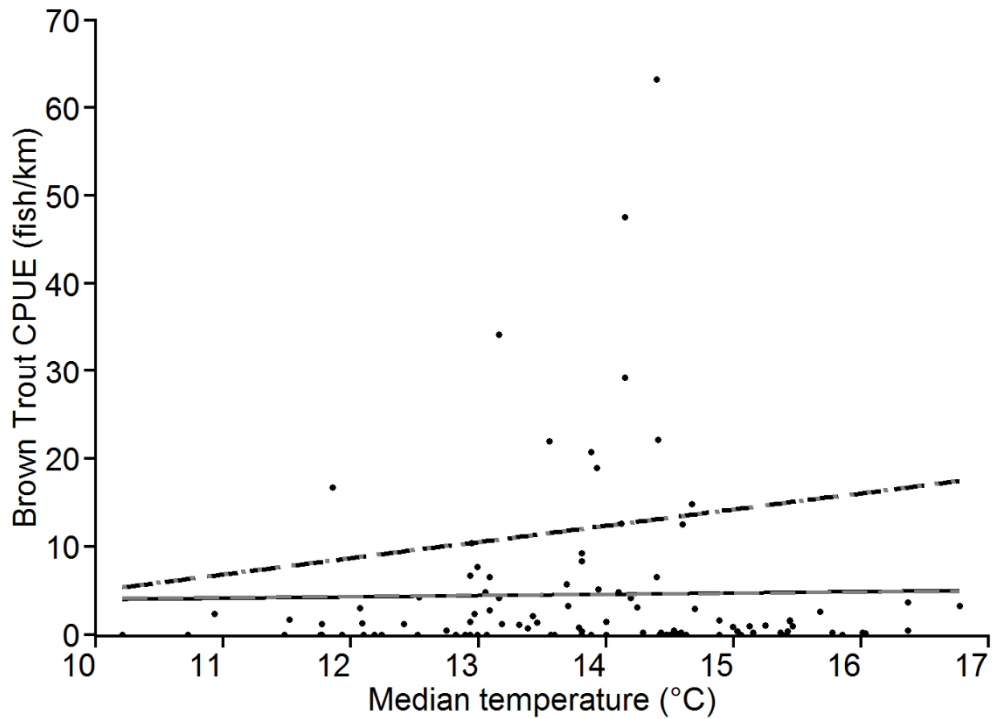


Figure 7. Scatter plot relating Brown Trout CPUE (fish/km) and median water temperature (°C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE= $2.499+0.149 \cdot \text{median temperature}$ ;  $P=0.841$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE= $3.431 \cdot \exp(0.021 \cdot \text{median temperature})$ ;  $P=0.900$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE= $-13.444+1.844 \cdot \text{median temperature}$ ;  $P=0.580$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE= $11.839 \cdot \exp(0.004 \cdot \text{median temperature})$ ;  $P=0.986$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

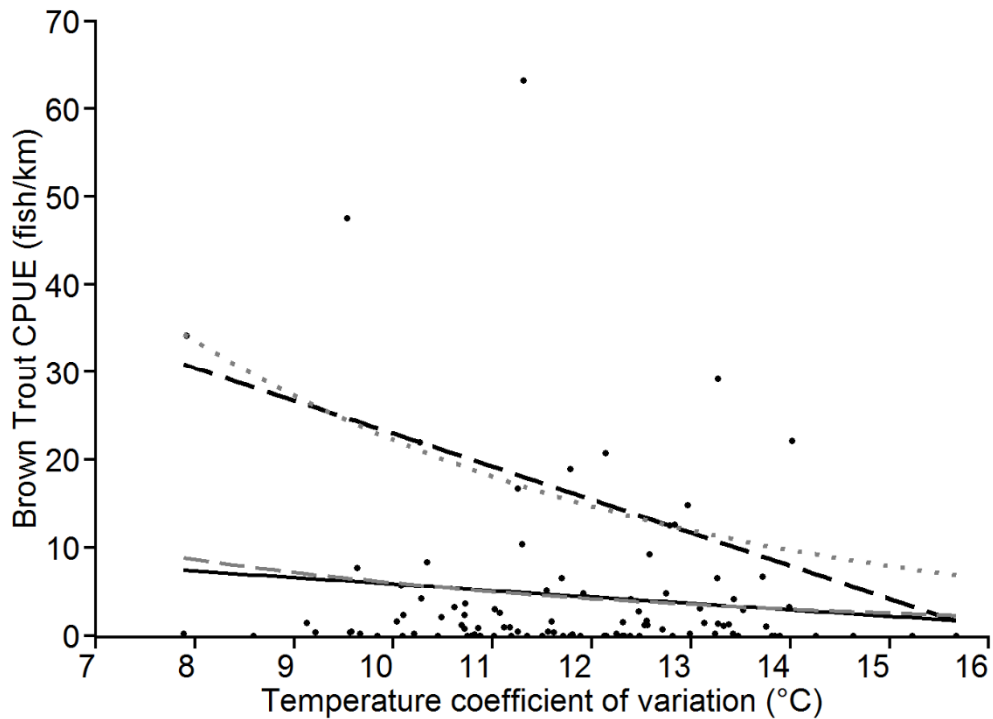


Figure 8. Scatter plot relating Brown Trout CPUE (fish/km) and water temperature CV (°C;  $100 \cdot \text{SD}/\text{mean}$ ;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE =  $13.178 - 0.732 \cdot \text{temperature CV}$ ;  $P=0.251$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE =  $43.399 \cdot \exp(-0.196 \cdot \text{temperature CV})$ ;  $P=0.144$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE =  $60.491 - 3.754 \cdot \text{temperature CV}$ ;  $P=0.199$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE =  $175.41 \cdot \exp(-0.207 \cdot \text{temperature CV})$ ;  $P=0.163$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

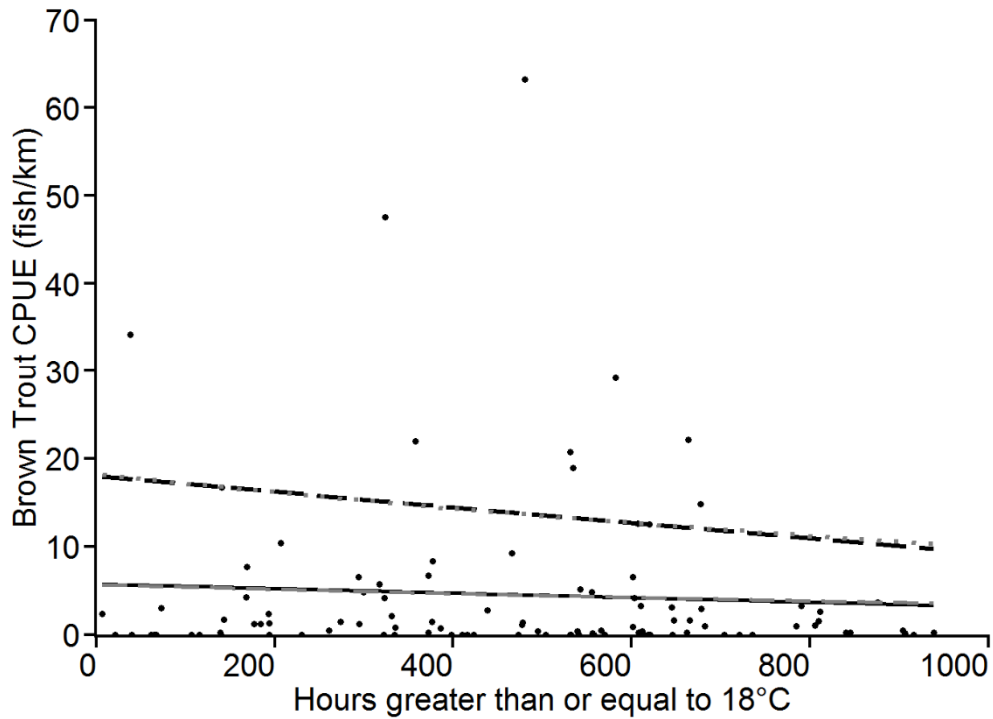


Figure 9. Scatter plot relating Brown Trout CPUE (fish/km) and water temperature total hours  $\geq 18^{\circ}\text{C}$  (18C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE= $5.750-0.003 \cdot 18\text{C}$ ;  $P=0.525$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE= $5.546 \cdot \exp(-0.0004 \cdot 18\text{C})$ ;  $P=0.626$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE= $17.990-0.009 \cdot 18\text{C}$ ;  $P=0.679$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE= $18.021 \cdot \exp(-0.0006 \cdot 18\text{C})$ ;  $P=0.654$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

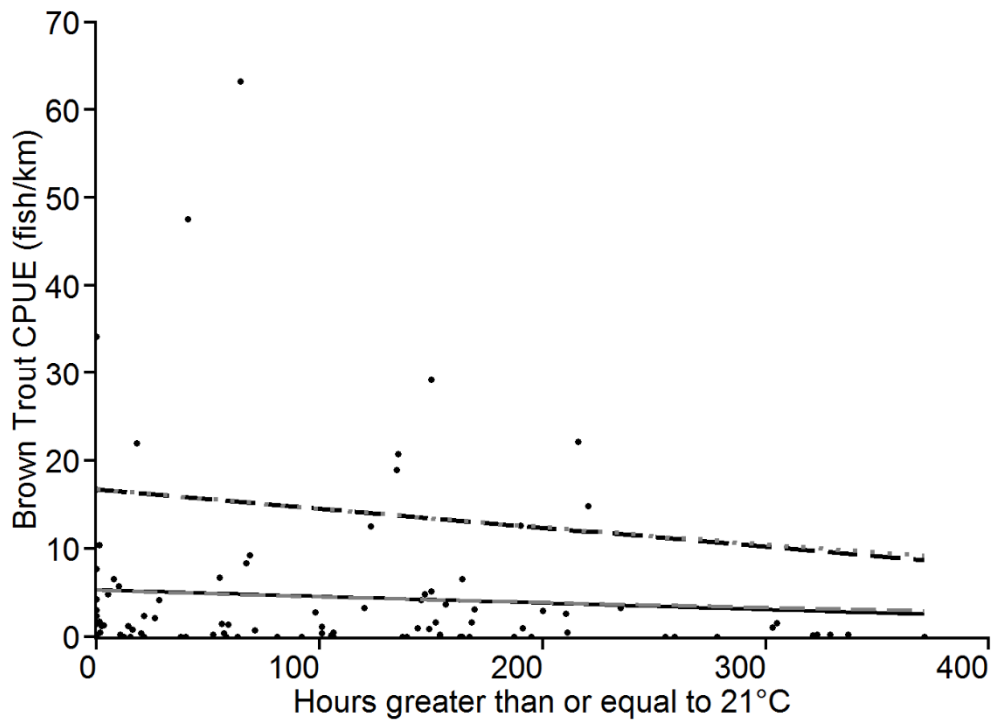


Figure 10. Scatter plot relating Brown Trout CPUE (fish/km) and water temperature total hours  $\geq 21^{\circ}\text{C}$  (21C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE= $5.315-0.007 \cdot 21\text{C}$ ;  $P=0.454$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE= $5.184 \cdot \exp(-0.001 \cdot 21\text{C})$ ;  $P=0.587$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE= $16.744 - 0.022 \cdot 21\text{C}$ ;  $P=0.596$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE= $14.637 \cdot \exp(-0.0008 \cdot 21\text{C})$ ;  $P=0.816$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

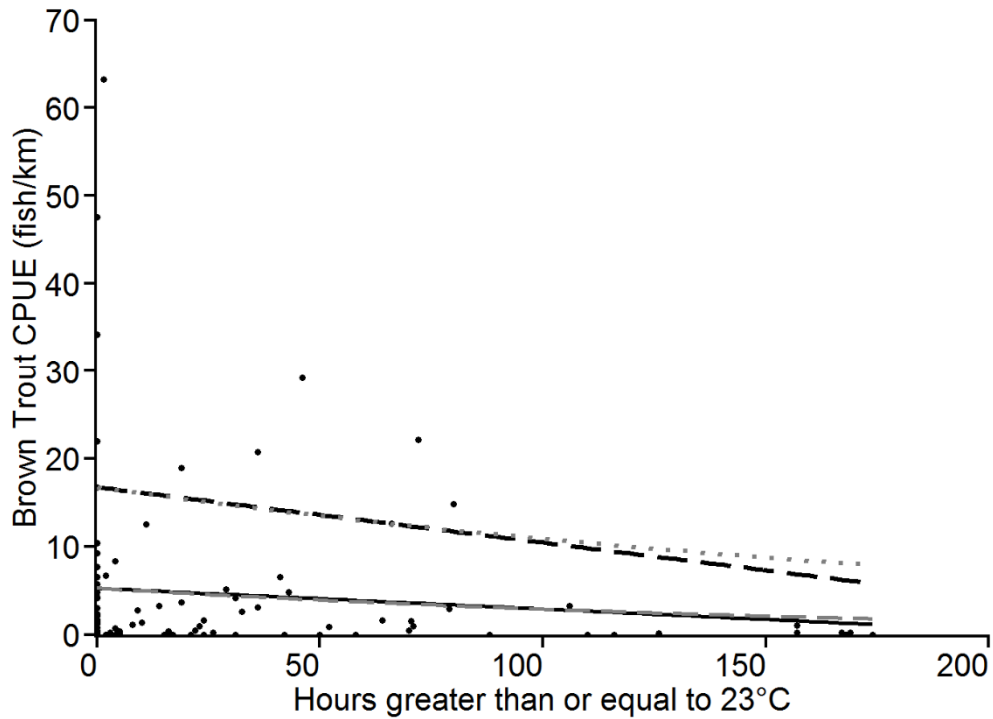


Figure 11. Scatter plot relating Brown Trout CPUE (fish/km) and water temperature total hours  $\geq 23^{\circ}\text{C}$  (23C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE= $5.255-0.023 \cdot 23\text{C}$ ;  $P=0.276$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE= $5.221 \cdot \exp(-0.005 \cdot 23\text{C})$ ;  $P=0.467$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE= $16.744 - 0.063 \cdot 23\text{C}$ ;  $P=0.450$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE= $16.682 \cdot \exp(-0.004 \cdot 23\text{C})$ ;  $P=0.597$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

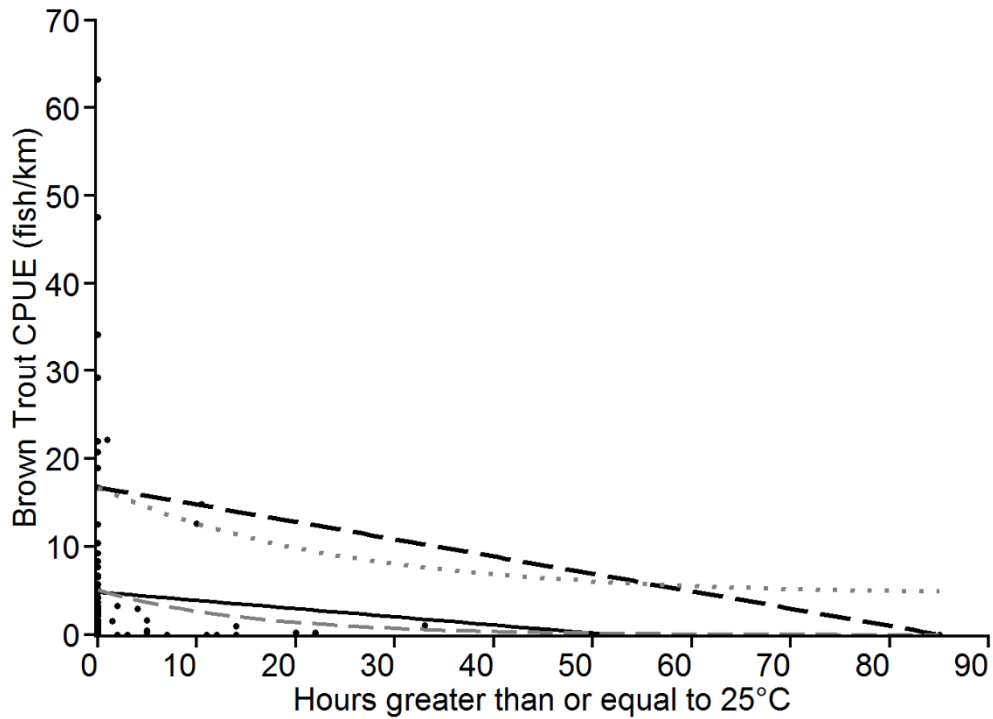


Figure 12. Scatter plot relating Brown Trout CPUE (fish/km) and water temperature total hours  $\geq 25^{\circ}\text{C}$  (25C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE= $4.829-0.093 \cdot 25\text{C}$ ;  $P=0.343$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE= $5.024 \cdot \exp(-0.064 \cdot 25\text{C})$ ;  $P=0.536$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE= $16.744 - 0.197 \cdot 25\text{C}$ ;  $P=0.455$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE= $16.746 \cdot \exp(-0.041 \cdot 25\text{C})$ ;  $P=0.312$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

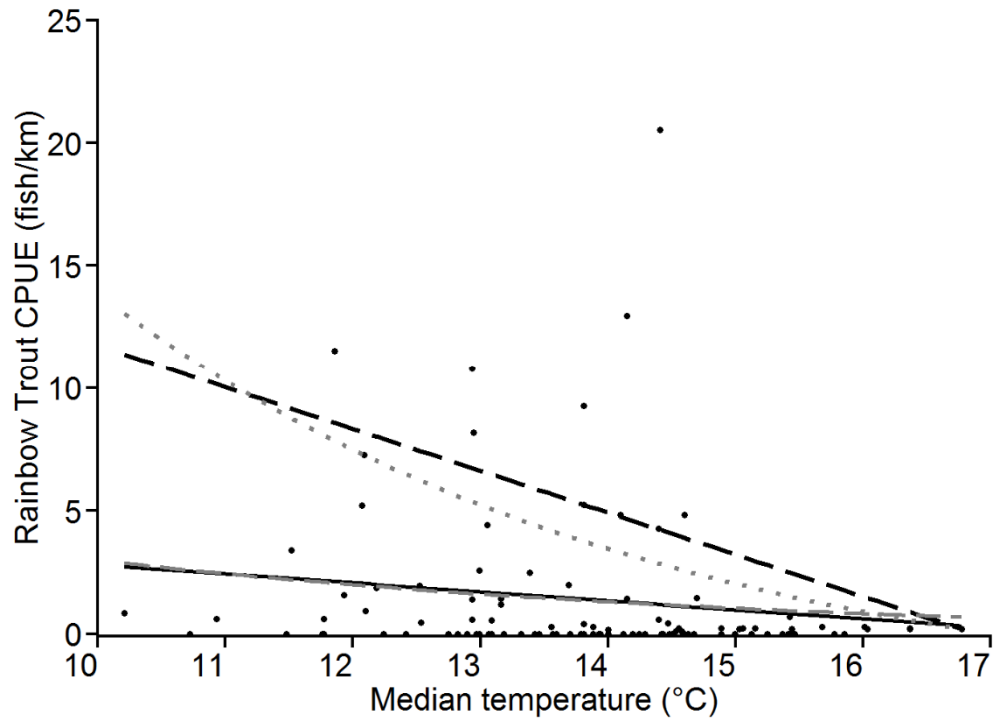


Figure 13. Scatter plot relating Rainbow Trout CPUE (fish/km) and median water temperature (°C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE =  $6.466 - 0.366 \cdot \text{median temperature}$ ;  $P=0.134$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE =  $16.589 \cdot \exp(-0.180 \cdot \text{median temperature})$ ;  $P=0.262$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE =  $28.776 - 1.704 \cdot \text{median temperature}$ ;  $P=0.017$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE =  $116.74 \cdot \exp(-0.230 \cdot \text{median temperature})$ ;  $P=0.273$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

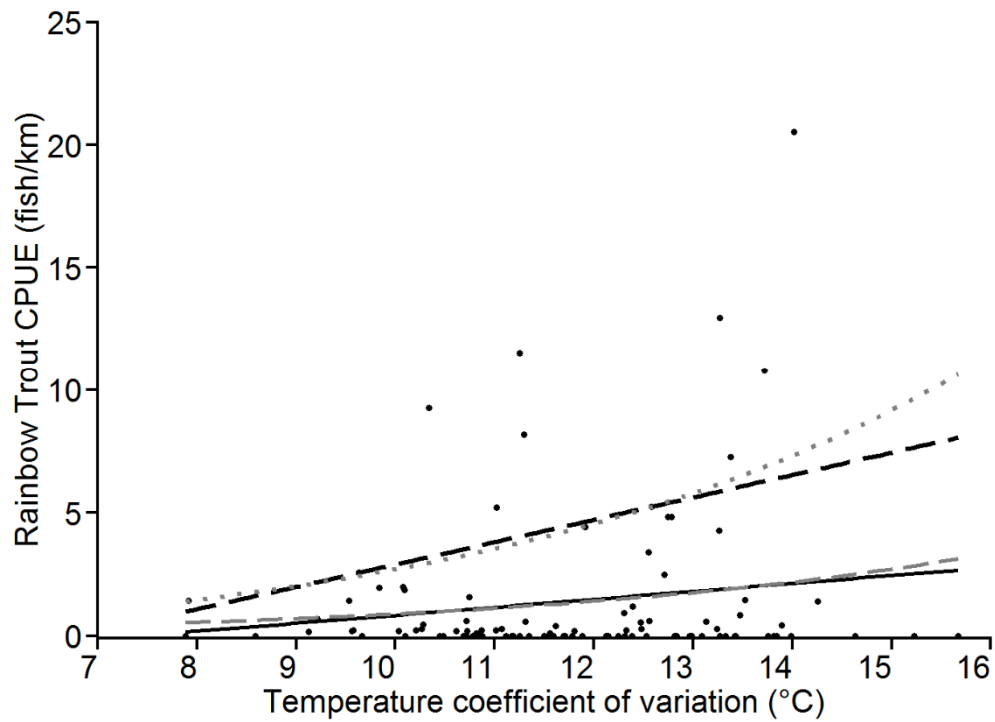


Figure 14. Scatter plot relating Rainbow Trout CPUE (fish/km) and water temperature CV (°C;  $100 \cdot \text{SD}/\text{mean}$ ;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE =  $-2.396 + 0.323 \cdot \text{temperature CV}$ ;  $P=0.124$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE =  $0.119 \cdot \exp(0.207 \cdot \text{temperature CV})$ ;  $P=0.161$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE =  $-6.200 + 0.909 \cdot \text{temperature CV}$ ;  $P=0.230$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE =  $0.374 \cdot \exp(0.200 \cdot \text{temperature CV})$ ;  $P=0.338$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

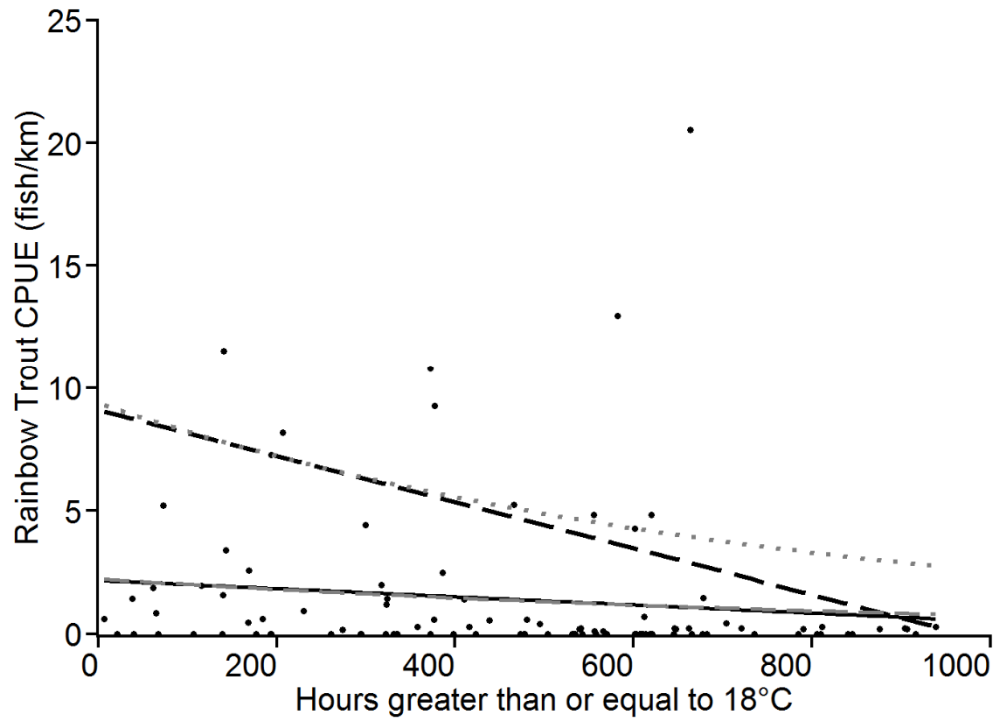


Figure 15. Scatter plot relating Rainbow Trout CPUE (fish/km) and water temperature total hours  $\geq 18^{\circ}\text{C}$  ( $18\text{C}$ ;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE= $2.173-0.002\cdot 18\text{C}$ ;  $P=0.215$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE= $2.164\cdot \exp(-0.001\cdot 18\text{C})$ ;  $P=0.304$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE= $9.090-0.009\cdot 18\text{C}$ ;  $P=0.043$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE= $9.366\cdot \exp(-0.001\cdot 18\text{C})$ ;  $P=0.281$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

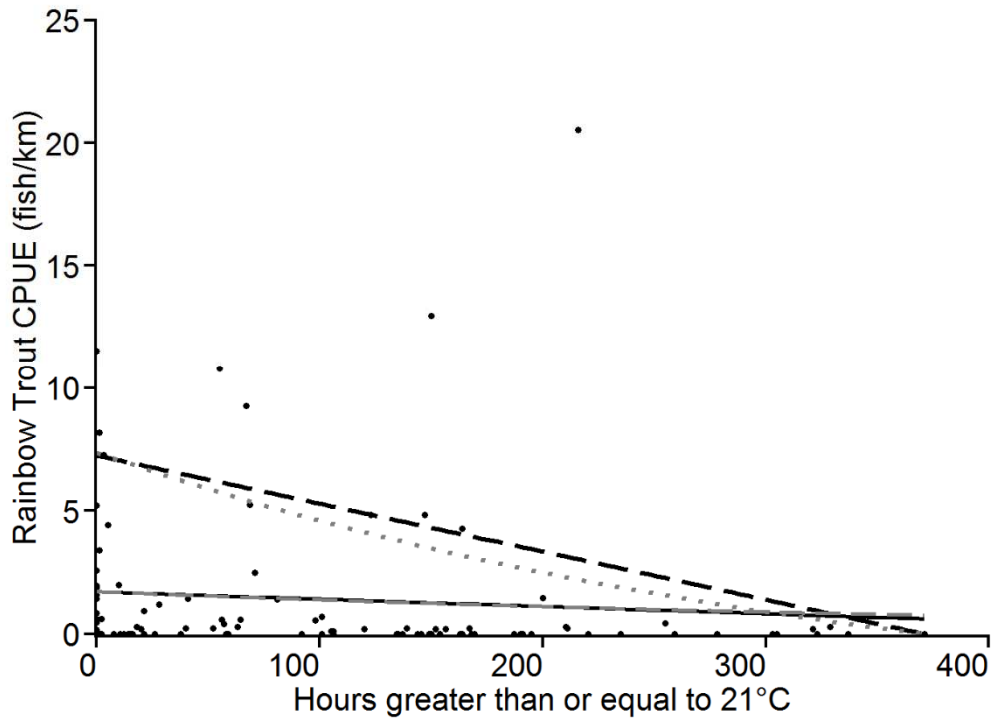


Figure 16. Scatter plot relating Rainbow Trout CPUE (fish/km) and water temperature total hours  $\geq 21^{\circ}\text{C}$  (21C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE= $1.710-0.003 \cdot 21\text{C}$ ;  $P=0.366$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE= $1.704 \cdot \exp(-0.002 \cdot 21\text{C})$ ;  $P=0.459$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE= $7.243-0.020 \cdot 21\text{C}$ ;  $P=0.259$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE= $6.719 \cdot \exp(-0.003 \cdot 21\text{C})$ ;  $P=0.542$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

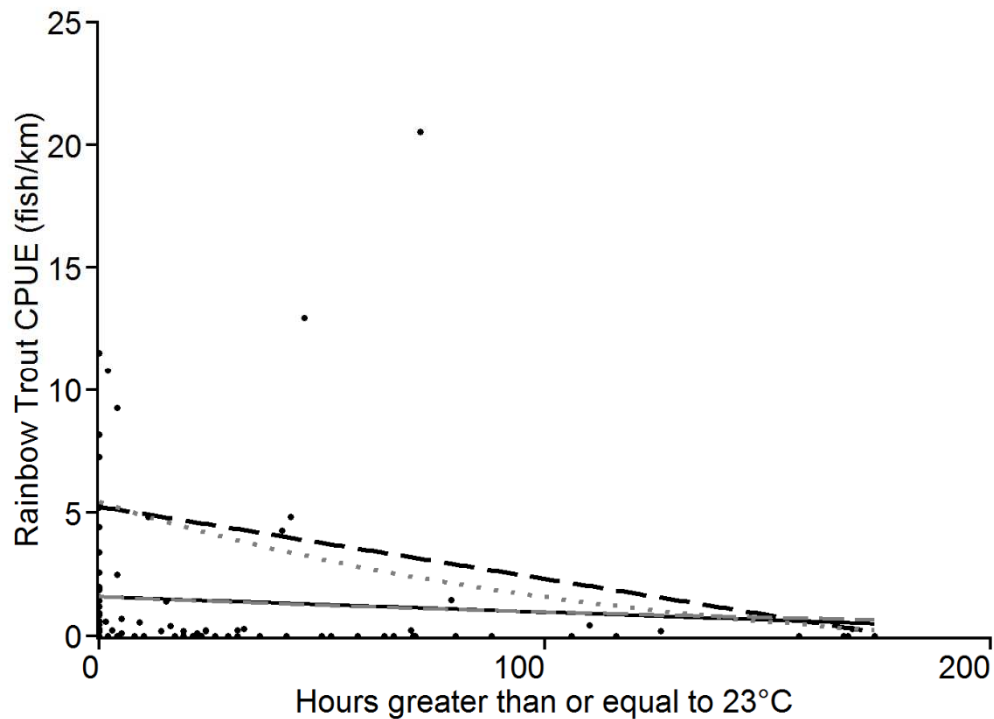


Figure 17. Scatter plot relating Rainbow Trout CPUE (fish/km) and water temperature total hours  $\geq 23^{\circ}\text{C}$  (23C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE= $1.594-0.006 \cdot 23\text{C}$ ;  $P=0.378$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE= $1.579 \cdot \exp(-0.004 \cdot 23\text{C})$ ;  $P=0.550$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE= $5.245-0.029 \cdot 23\text{C}$ ;  $P=0.548$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE= $5.314 \cdot \exp(-0.008 \cdot 23\text{C})$ ;  $P=0.678$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

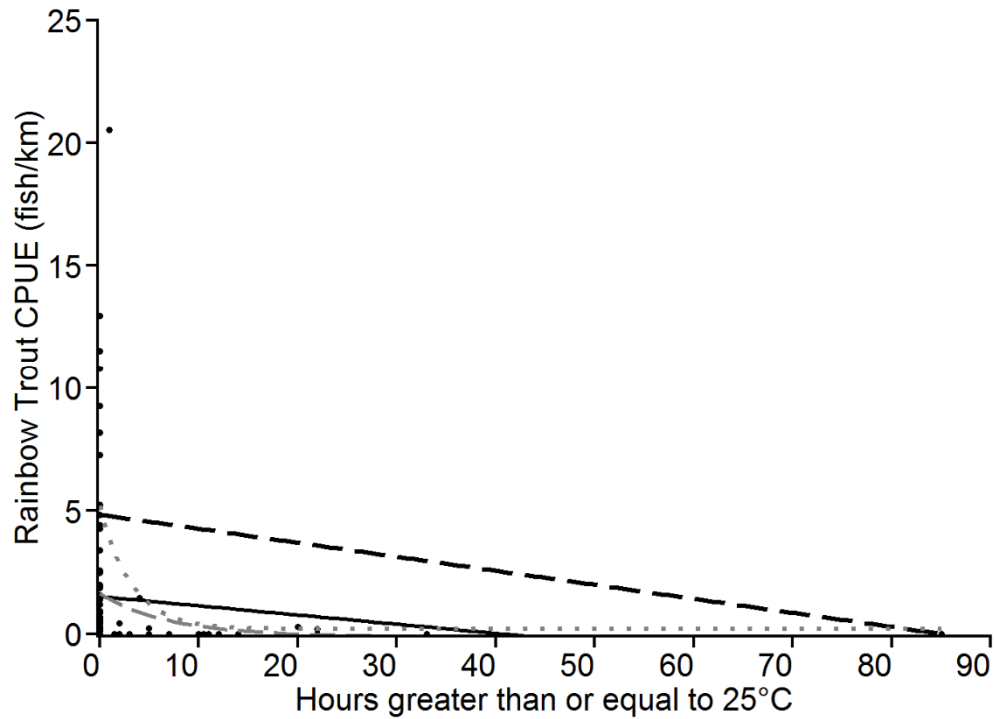


Figure 18. Scatter plot relating Rainbow Trout CPUE (fish/km) and water temperature total hours  $\geq 25^{\circ}\text{C}$  (25C;  $N=100$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE= $1.516-0.037 \cdot 25\text{C}$ ;  $P=0.251$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE= $1.639 \cdot \exp(-0.141 \cdot 25\text{C})$ ;  $P=0.542$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE= $4.846-0.057 \cdot 25\text{C}$ ;  $P=0.471$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE= $5.209 \cdot \exp(-0.316 \cdot 25\text{C})$ ;  $P=0.870$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

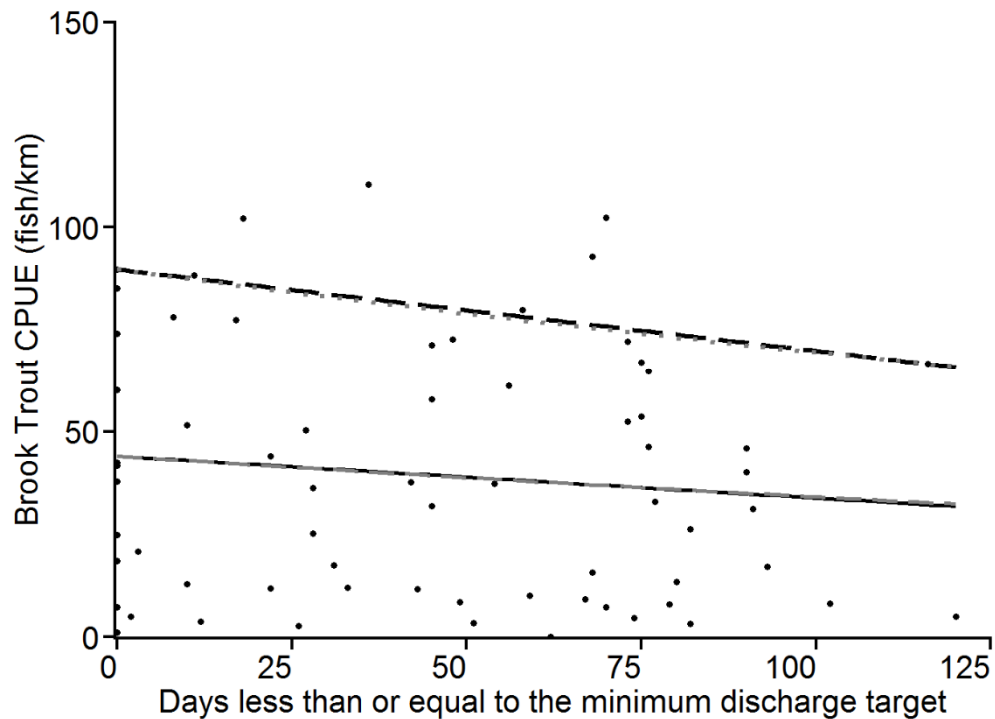


Figure 19. Scatter plot relating Brook Trout CPUE (fish/km) and total days  $\leq$  minimum discharge target (DisMin;  $N=66$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE= $43.605-0.089 \cdot \text{DisMin}$ ;  $P=0.409$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE= $43.625 \cdot \exp(-0.002 \cdot \text{DisMin})$ ;  $P=0.426$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE= $89.702-0.199 \cdot \text{DisMin}$ ;  $P=0.227$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE= $89.702 \cdot \exp(-0.003 \cdot \text{DisMin})$ ;  $P=0.210$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

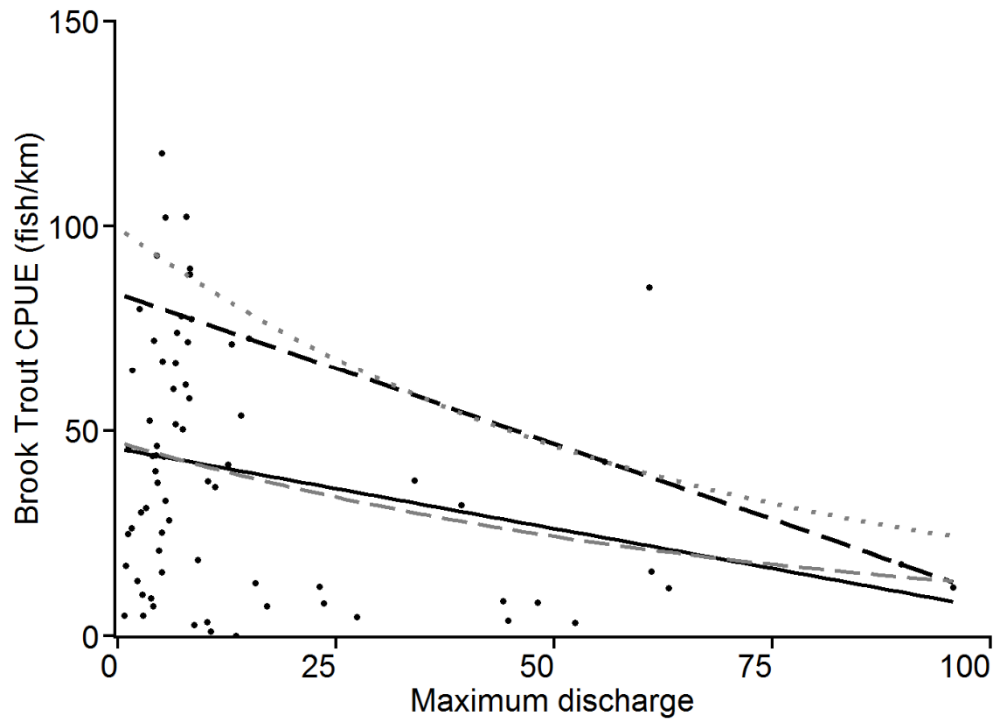


Figure 20. Scatter plot relating Brook Trout CPUE (fish/km) and maximum discharge ( $\text{m}^3/\text{s}$ ; DisMax;  $N=71$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE =  $45.610 - 0.389 \cdot \text{DisMax}$ ;  $P=0.022$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE =  $47.314 \cdot \exp(-0.014 \cdot \text{DisMax})$ ;  $P=0.073$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE =  $83.626 - 0.737 \cdot \text{DisMax}$ ;  $P=0.097$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE =  $100.152 \cdot \exp(-0.017 \cdot \text{DisMax})$ ;  $P=0.160$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

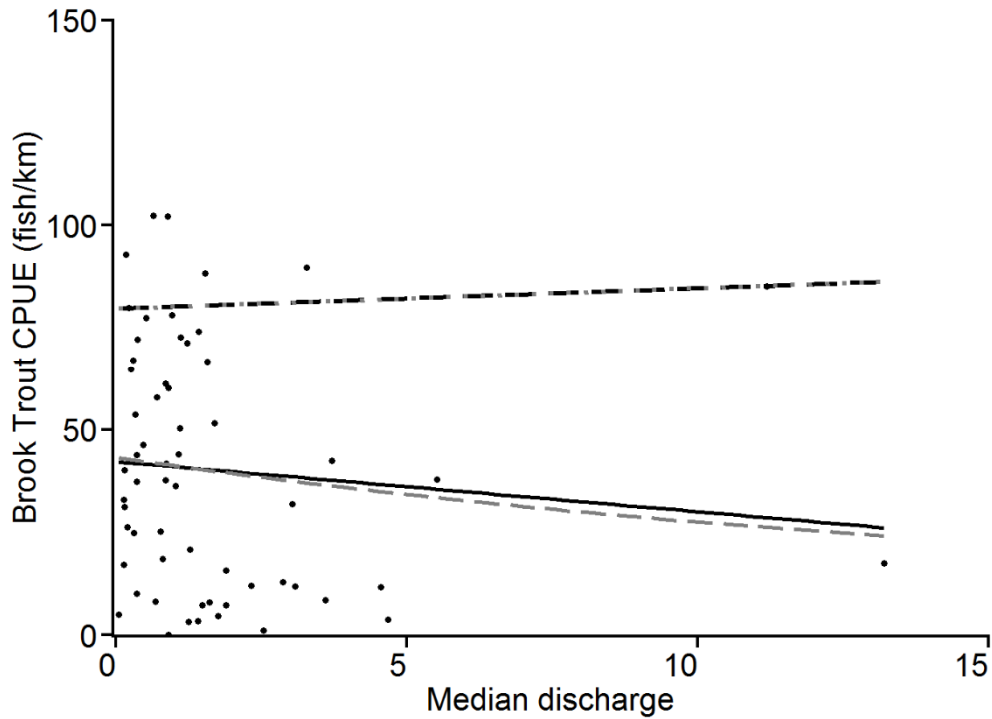


Figure 21. Scatter plot relating Brook Trout CPUE (fish/km) and median discharge ( $\text{m}^3/\text{s}$ ; DisMed;  $N=59$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE= $42.195-1.218 \cdot \text{DisMed}$ ;  $P=0.468$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE= $43.952 \cdot \exp(-0.060 \cdot \text{DisMed})$ ;  $P=0.343$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE= $79.630+0.496 \cdot \text{DisMed}$ ;  $P=0.904$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE= $82.110 \cdot \exp(0.003 \cdot \text{DisMed})$ ;  $P=0.942$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

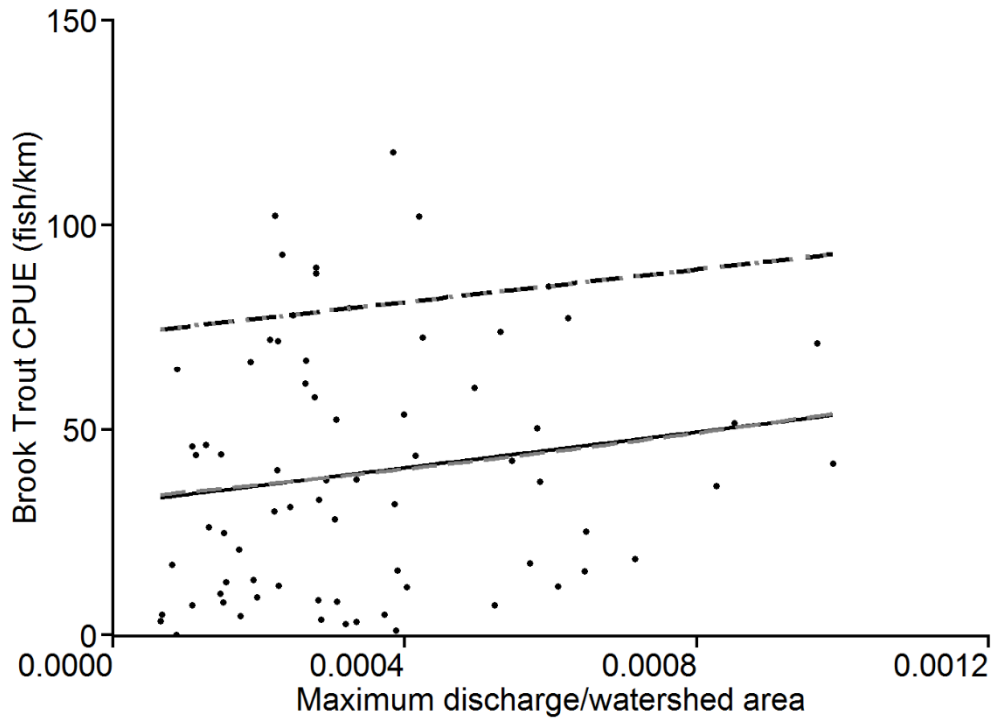


Figure 22. Scatter plot relating Brook Trout CPUE (fish/km) and maximum discharge/watershed area ( $\text{[m}^3\text{/s]}/\text{ha}$ ; DisMaxWA;  $N=71$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE =  $32.008 + 21745.2 \cdot \text{DisMaxWA}$ ;  $P=0.195$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE =  $33.433 \cdot \exp(470.35 \cdot \text{DisMaxWA})$ ;  $P=0.217$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE =  $73.298 + 19897.0 \cdot \text{DisMaxWA}$ ;  $P=0.582$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE =  $79.295 \cdot \exp(17.390 \cdot \text{DisMaxWA})$ ;  $P=0.970$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

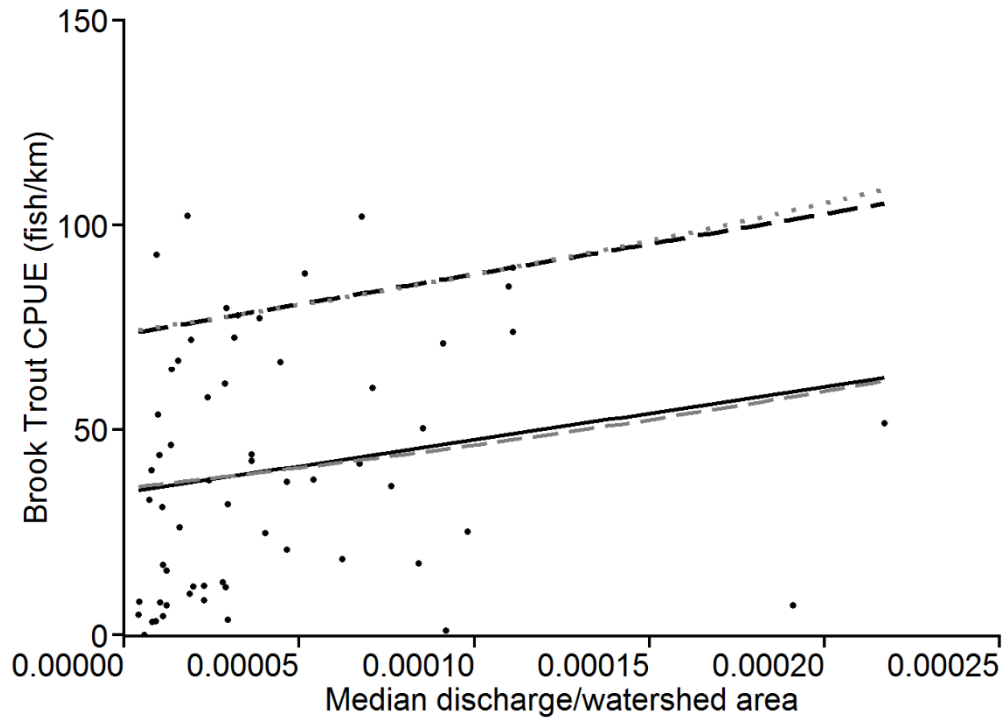


Figure 23. Scatter plot relating Brook Trout CPUE (fish/km) and median discharge/watershed area ( $\text{[m}^3\text{/s]}/\text{ha}$ ; DisMedWA;  $N=59$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE =  $34.670 + 128511.1 \cdot \text{DisMedWA}$ ;  $P=0.156$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE =  $36.320 \cdot \exp(2264.5 \cdot \text{DisMedWA})$ ;  $P=0.218$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE =  $73.384 + 14.935 \cdot \text{DisMedWA}$ ;  $P=0.535$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE =  $70.795 \cdot \exp(2129.0 \cdot \text{DisMedWA})$ ;  $P=0.435$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

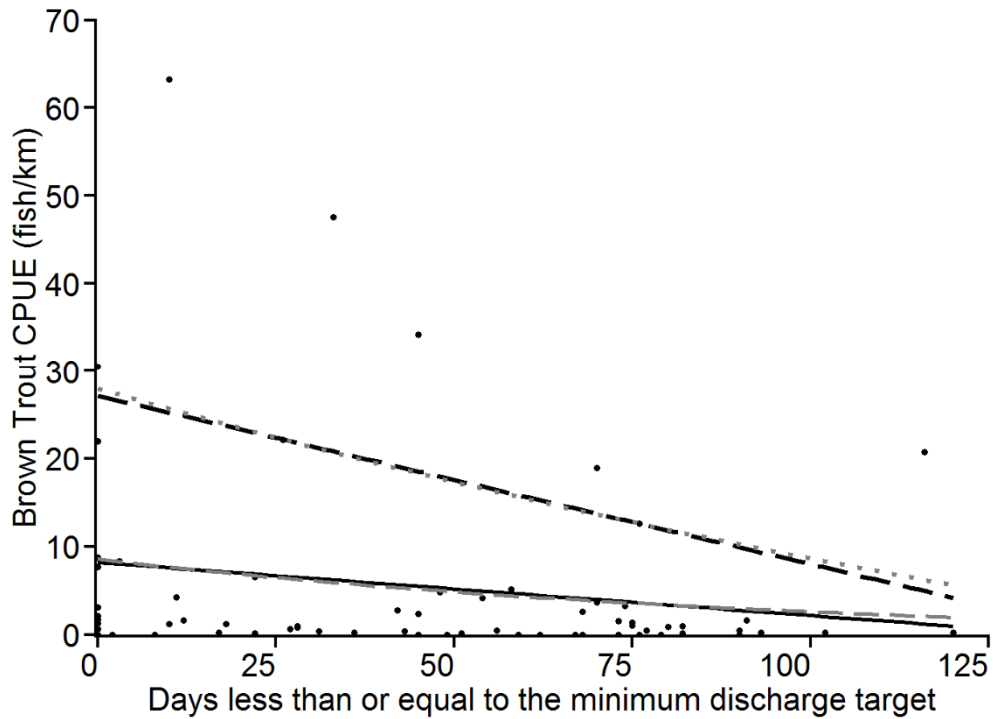


Figure 24. Scatter plot relating Brown Trout CPUE (fish/km) and total days  $\leq$  minimum discharge target (DisMin;  $N=66$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE =  $7.766 - 0.046 \cdot \text{DisMin}$ ;  $P=0.256$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE =  $8.335 \cdot \exp(-0.010 \cdot \text{DisMin})$ ;  $P=0.238$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE =  $24.066 - 0.074 \cdot \text{DisMin}$ ;  $P=0.605$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE =  $24.605 \cdot \exp(-0.004 \cdot \text{DisMin})$ ;  $P=0.549$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

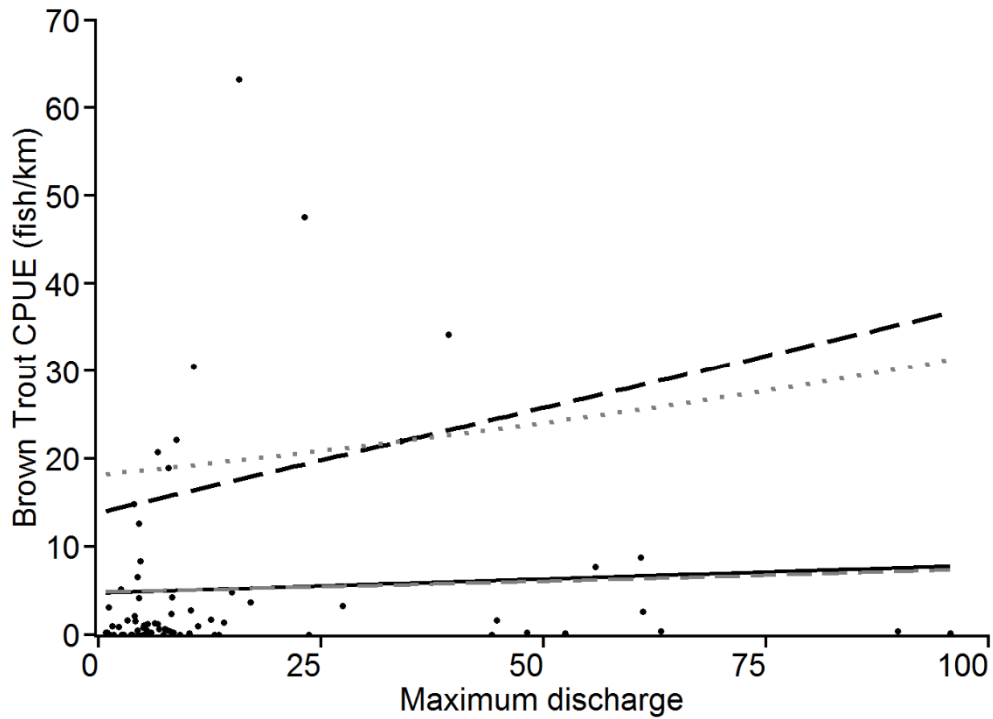


Figure 25. Scatter plot relating Brown Trout CPUE (fish/km) and maximum discharge ( $\text{m}^3/\text{s}$ ; DisMax;  $N=71$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE= $4.738+0.032\cdot\text{DisMax}$ ;  $P=0.623$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE= $4.964\cdot\exp(0.003\cdot\text{DisMax})$ ;  $P=0.751$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE= $13.839+0.239\cdot\text{DisMax}$ ;  $P=0.664$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE= $17.842\cdot\exp(0.006\cdot\text{DisMax})$ ;  $P=0.782$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

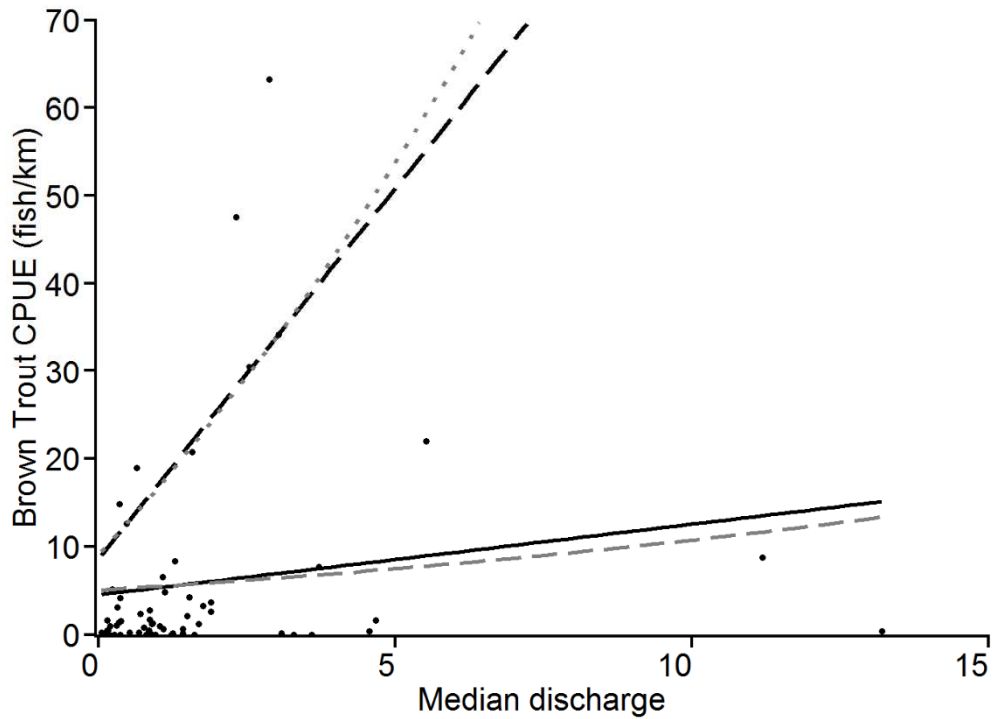


Figure 26. Scatter plot relating Brown Trout CPUE (fish/km) and median discharge ( $\text{m}^3/\text{s}$ ; DisMed;  $N=71$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE= $4.522+0.802 \cdot \text{DisMed}$ ;  $P=0.232$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE= $5.350 \cdot \exp(0.057 \cdot \text{DisMed})$ ;  $P=0.428$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE= $8.621+8.444 \cdot \text{DisMed}$ ;  $P=0.195$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE= $15.542 \cdot \exp(0.072 \cdot \text{DisMed})$ ;  $P=0.840$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

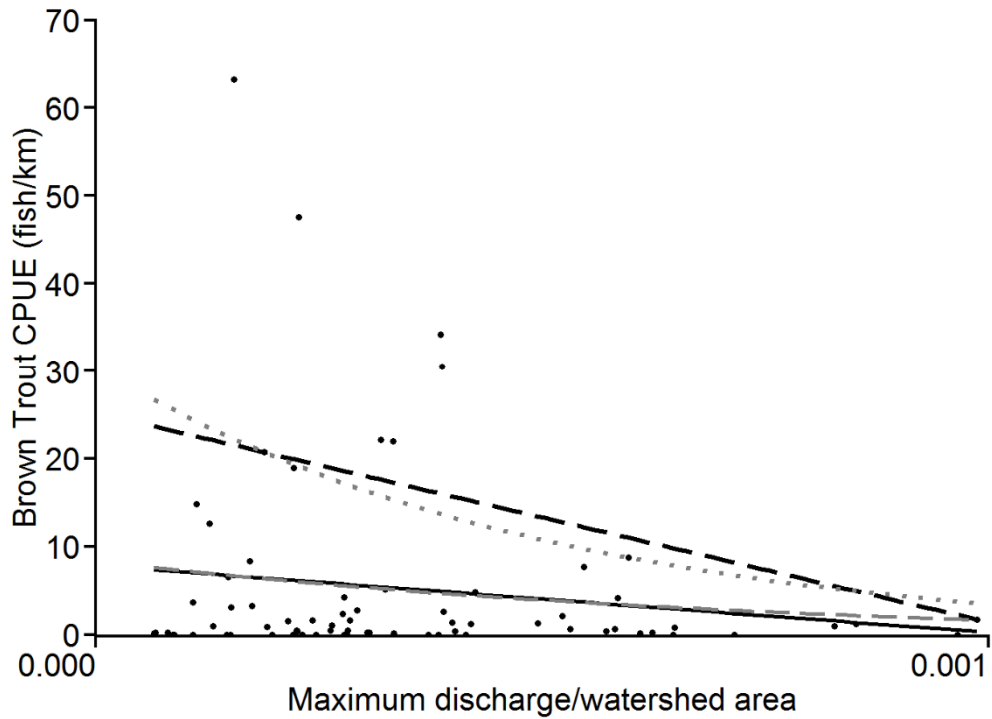


Figure 27. Scatter plot relating Brown Trout CPUE (fish/km) and maximum discharge/watershed area ( $\text{[m}^3\text{/s]}/\text{ha}$ ; DisMaxWA;  $N=71$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE= $7.853-7612.2 \cdot \text{DisMaxWA}$ ;  $P=0.224$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE= $8.017 \cdot \exp(-1315.3 \cdot \text{DisMaxWA})$ ;  $P=0.402$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE= $25.202-23808.9 \cdot \text{DisMaxWA}$ ;  $P=0.215$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE= $30.150 \cdot \exp(-1994.0 \cdot \text{DisMaxWA})$ ;  $P=0.443$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

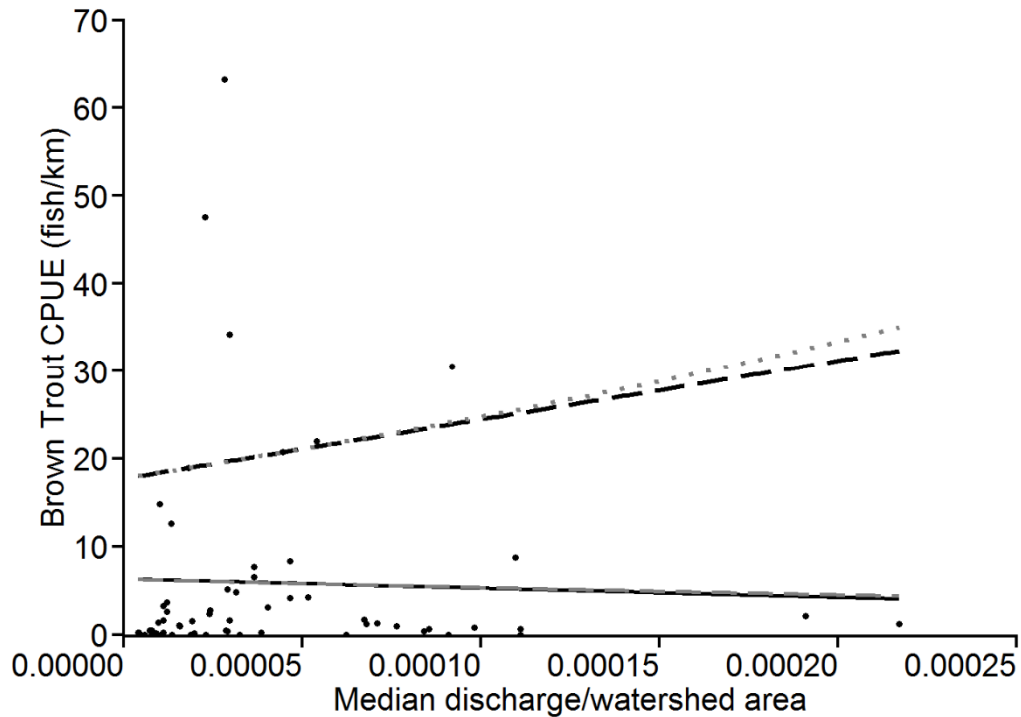


Figure 28. Scatter plot relating Brown Trout CPUE (fish/km) and median discharge/watershed area ( $\text{[m}^3\text{/s]}/\text{ha}$ ; DisMedWA;  $N=59$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE =  $6.338 - 10488.5 \cdot \text{DisMedWA}$ ;  $P=0.775$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE =  $6.230 \cdot \exp(-1333.3 \cdot \text{DisMedWA})$ ;  $P=0.848$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE =  $17.713 + 67248.0 \cdot \text{DisMedWA}$ ;  $P=0.444$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE =  $18.879 \cdot \exp(2058.0 \cdot \text{DisMedWA})$ ;  $P=0.781$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

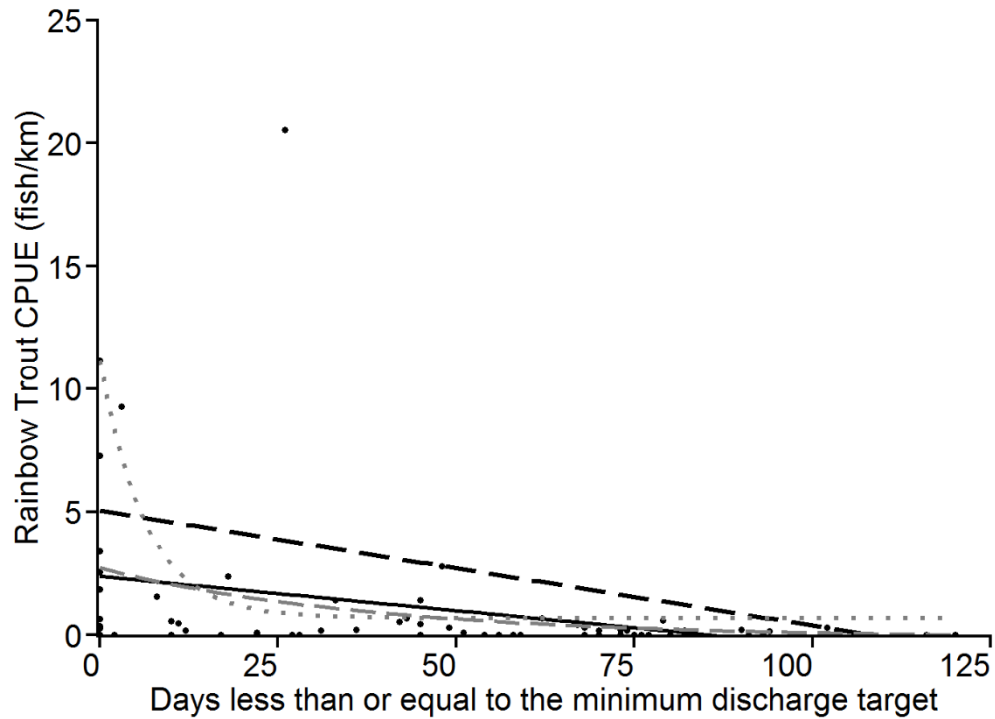


Figure 29. Scatter plot relating Rainbow Trout CPUE (fish/km) and total days  $\leq$  minimum discharge target (DisMin;  $N=67$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE =  $2.348 - 0.027 \cdot \text{DisMin}$ ;  $P=0.012$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE =  $2.669 \cdot \exp(-0.026 \cdot \text{DisMin})$ ;  $P=0.096$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE =  $4.787 - 0.041 \cdot \text{DisMin}$ ;  $P=0.108$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE =  $9.604 \cdot \exp(-0.042 \cdot \text{DisMin})$ ;  $P=0.190$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

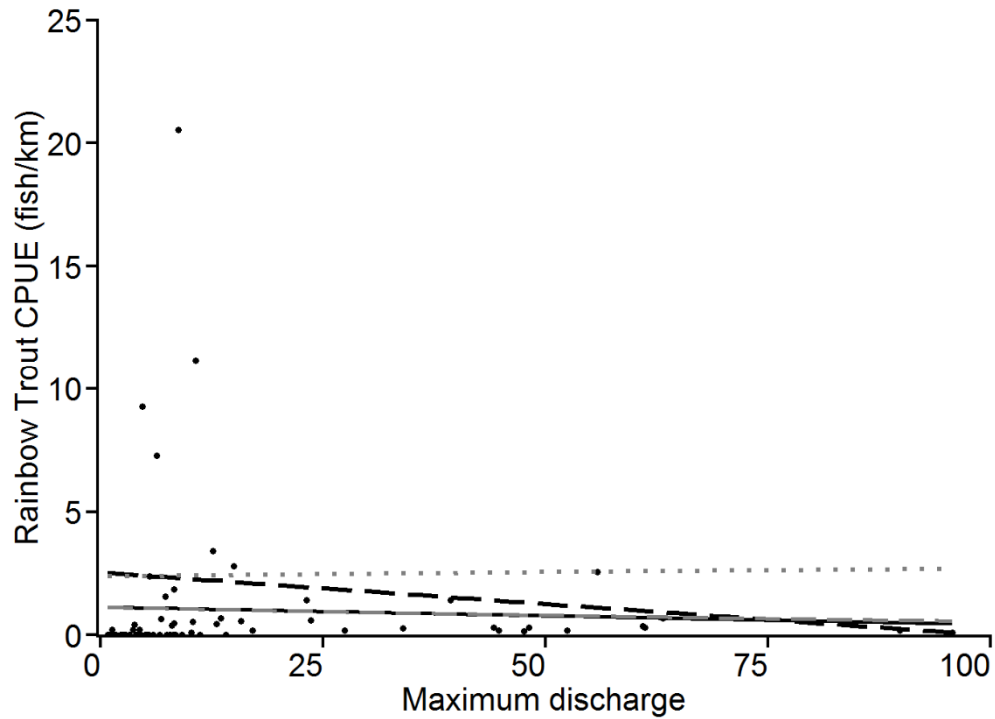


Figure 30. Scatter plot relating Rainbow Trout CPUE (fish/km) and maximum discharge ( $\text{m}^3/\text{s}$ ; DisMax;  $N=71$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE =  $1.136 - 0.007 \cdot \text{DisMax}$ ;  $P=0.682$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE =  $1.118 \cdot \exp(-0.006 \cdot \text{DisMax})$ ;  $P=0.786$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE =  $2.530 - 0.025 \cdot \text{DisMax}$ ;  $P=0.450$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE =  $2.459 \cdot \exp(-0.005 \cdot \text{DisMax})$ ;  $P=0.780$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

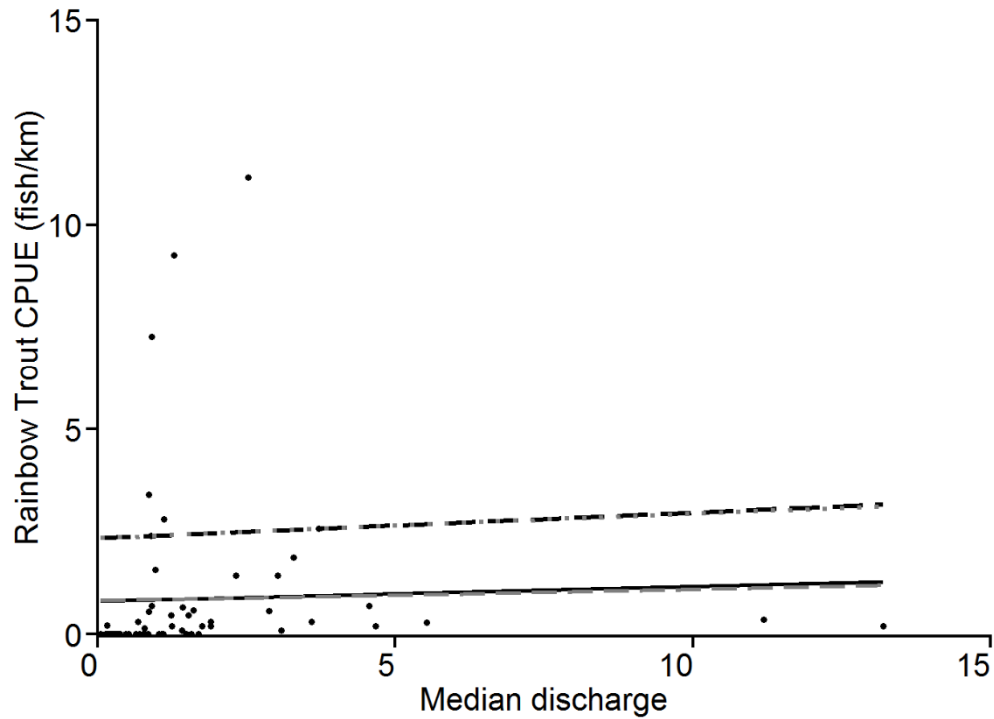


Figure 31. Scatter plot relating Rainbow Trout CPUE (fish/km) and median discharge ( $\text{m}^3/\text{s}$ ; DisMed;  $N=60$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE= $0.806+0.036\cdot\text{DisMed}$ ;  $P=0.762$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE= $0.836\cdot\exp(0.021\cdot\text{DisMed})$ ;  $P=0.855$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE= $2.334+0.062\cdot\text{DisMed}$ ;  $P=0.959$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE= $2.708\cdot\exp(-0.015\cdot\text{DisMed})$ ;  $P=0.977$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

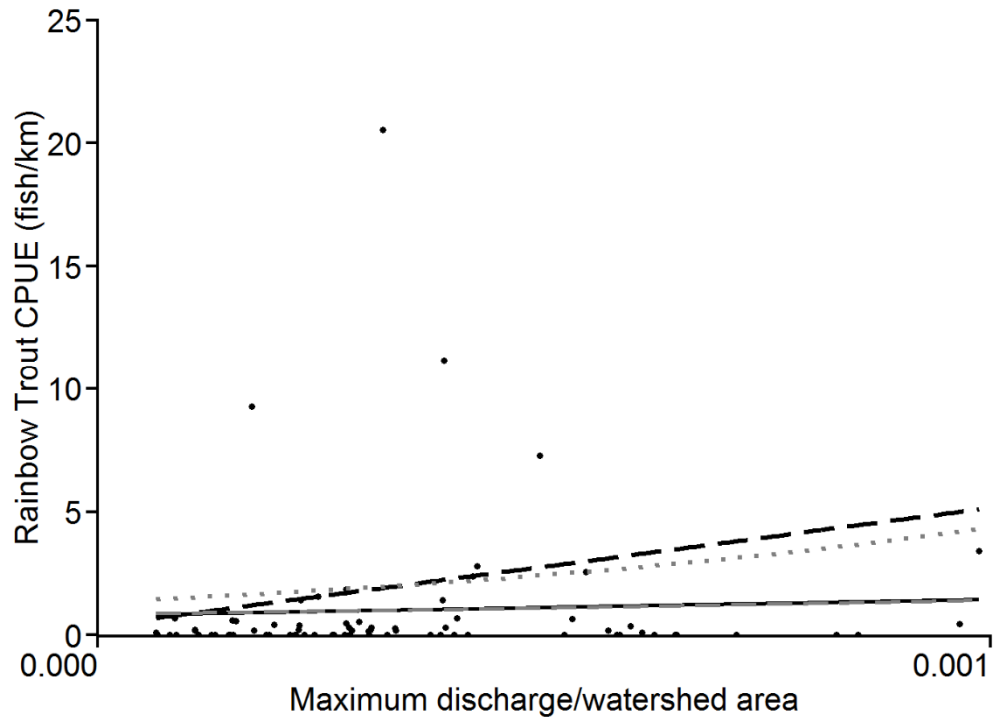


Figure 32. Scatter plot relating Rainbow Trout CPUE (fish/km) and maximum discharge/watershed area ( $\text{[m}^3\text{/s]}/\text{ha}$ ; DisMaxWA;  $N=72$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE= $0.799+651.85\cdot\text{DisMaxWA}$ ;  $P=0.700$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE= $0.876\cdot\exp(443.39\cdot\text{DisMaxWA})$ ;  $P=0.765$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE= $0.381+4785.7\cdot\text{DisMaxWA}$ ;  $P=0.352$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE= $1.349\cdot\exp(1171.0\cdot\text{DisMaxWA})$ ;  $P=0.627$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

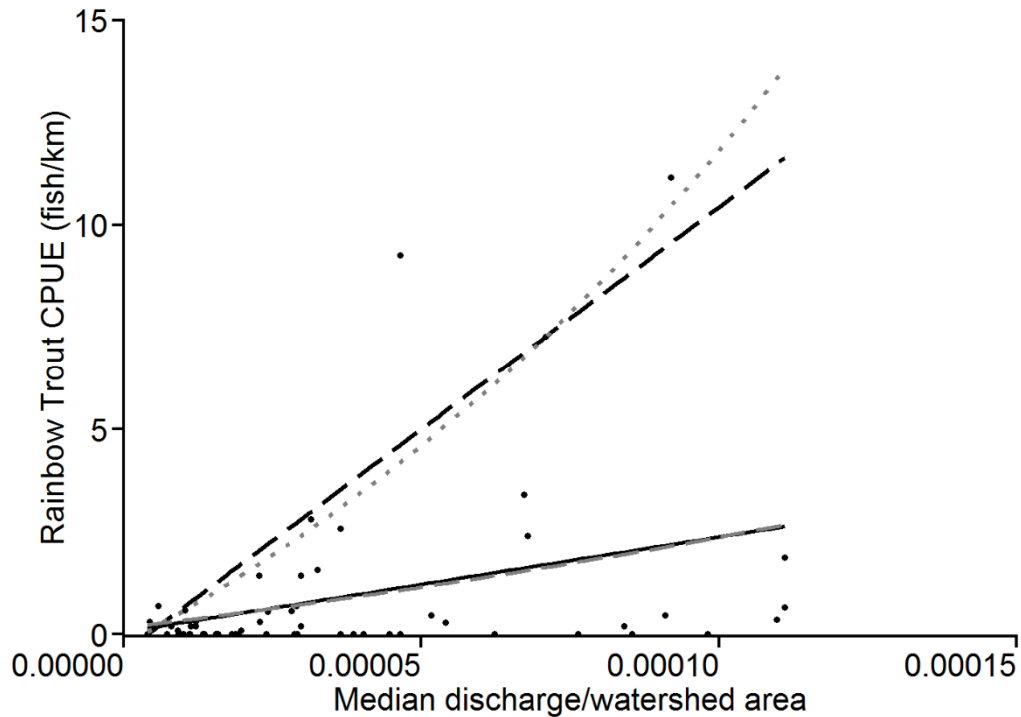


Figure 33. Scatter plot relating Rainbow Trout CPUE (fish/km) and median discharge/watershed area ( $\text{[m}^3\text{/s]}/\text{ha}$ ; DisMedWA;  $N=60$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE= $0.496+8879.8\cdot\text{DisMedWA}$ ;  $P=0.162$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE= $0.734\cdot\exp(4088.8\cdot\text{DisMedWA})$ ;  $P=0.406$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE= $-0.190+75685.2\cdot\text{DisMedWA}$ ;  $P=0.023$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE= $1.922\cdot\exp(7924.6\cdot\text{DisMedWA})$ ;  $P=0.619$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

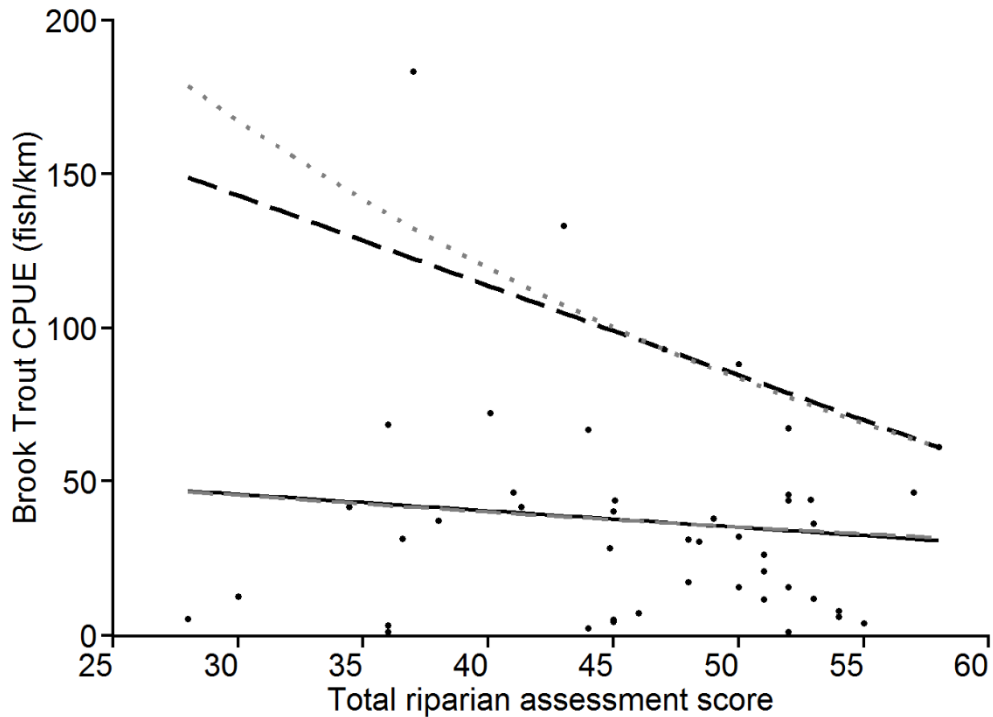


Figure 34. Scatter plot relating Brook Trout CPUE (fish/km) and total riparian assessment score (RAtot;  $N=44$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE =  $61.844 - 0.536 \cdot \text{RAtot}$ ;  $P=0.482$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE =  $63.566 \cdot \exp(-0.012 \cdot \text{RAtot})$ ;  $P=0.547$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE =  $230.95 - 2.290 \cdot \text{RAtot}$ ;  $P=0.357$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE =  $310.17 \cdot \exp(-0.028 \cdot \text{RAtot})$ ;  $P=0.396$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

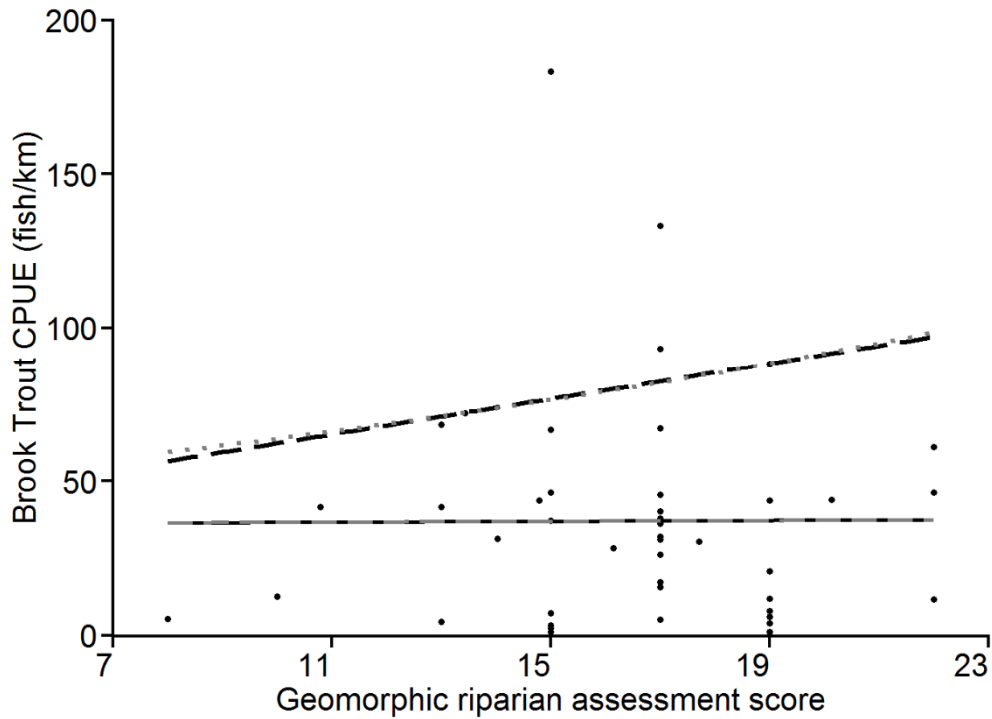


Figure 35. Scatter plot relating Brook Trout CPUE (fish/km) and geomorphic riparian assessment score (RAgeo;  $N=44$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE =  $35.879 + 0.075 \cdot \text{RAgeo}$ ;  $P=0.968$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE =  $36.109 \cdot \exp(-0.002 \cdot \text{RAgeo})$ ;  $P=0.974$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE =  $33.315 + 2.894 \cdot \text{RAgeo}$ ;  $P=0.633$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE =  $43.810 \cdot \exp(0.037 \cdot \text{RAgeo})$ ;  $P=0.627$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

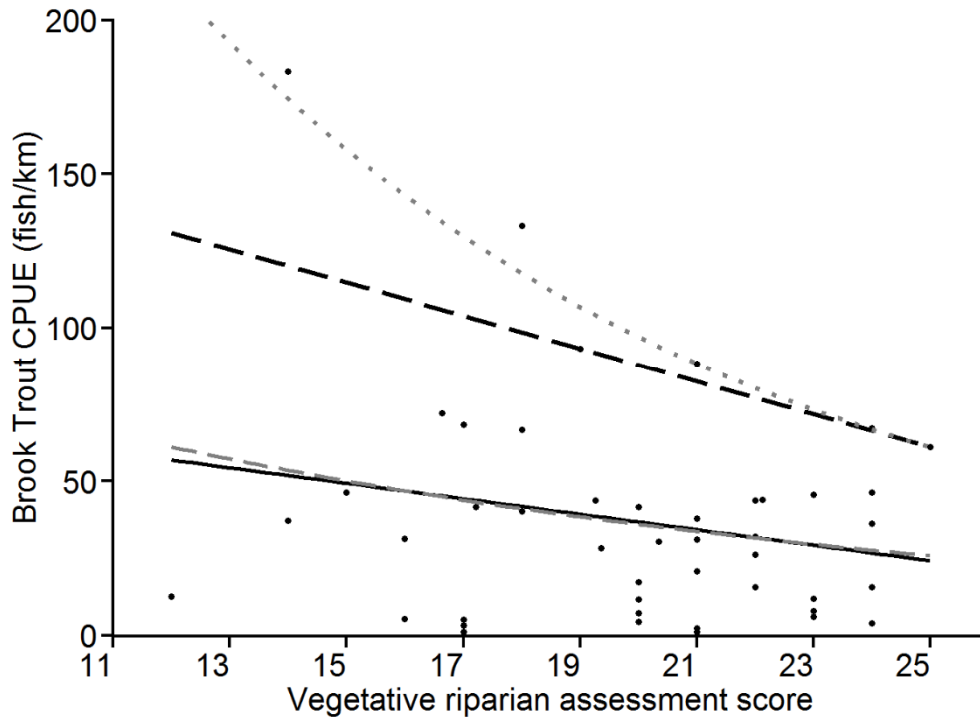


Figure 36. Scatter plot relating Brook Trout CPUE (fish/km) and vegetative riparian assessment score (RAveg;  $N=44$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE =  $86.986 - 2.511 \cdot \text{RAveg}$ ;  $P=0.151$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE =  $136.41 \cdot \exp(-0.067 \cdot \text{RAveg})$ ;  $P=0.123$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE =  $195.29 - 5.373 \cdot \text{RAveg}$ ;  $P=0.355$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE =  $788.92 \cdot \exp(-0.104 \cdot \text{RAveg})$ ;  $P=0.024$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

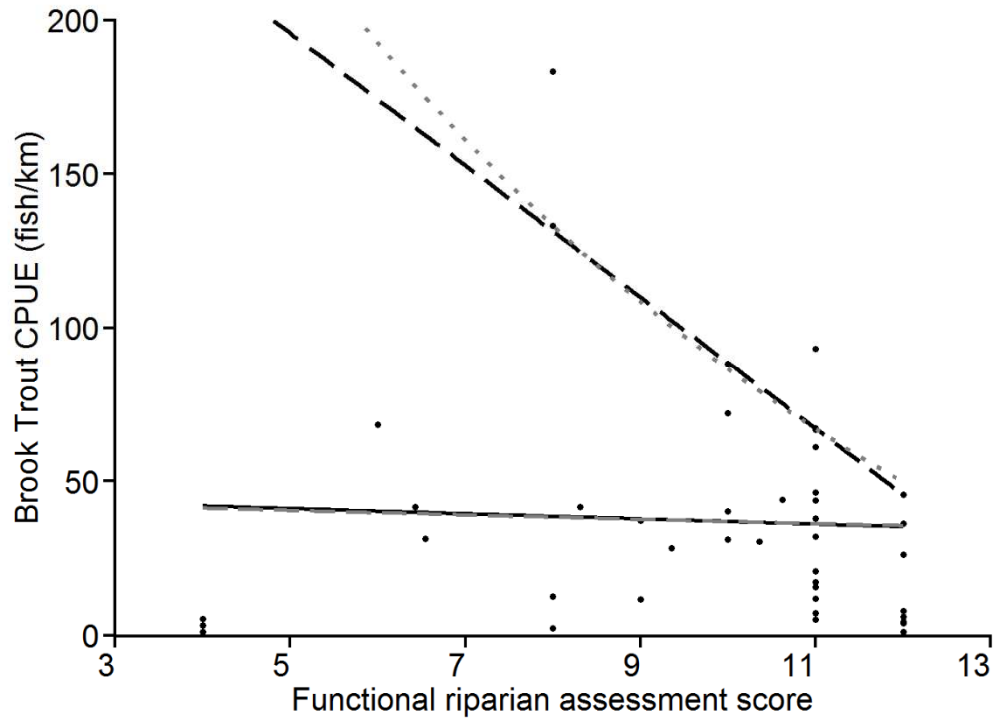


Figure 37. Scatter plot relating Brook Trout CPUE (fish/km) and functional riparian assessment score (RAfun;  $N=44$ ) with a linear ordinary least squares regression line (black solid; Brook Trout CPUE= $45.357-0.839 \cdot \text{RAfun}$ ;  $P=0.735$ ), nonlinear ordinary least squares regression line (gray dashed; Brook Trout CPUE= $43.107 \cdot \exp(-0.015 \cdot \text{RAfun})$ ;  $P=0.811$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brook Trout CPUE= $302.86-21.437 \cdot \text{RAfun}$ ;  $P=0.132$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brook Trout CPUE= $248.44 \cdot \exp(-0.120 \cdot \text{RAfun})$ ;  $P=0.430$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

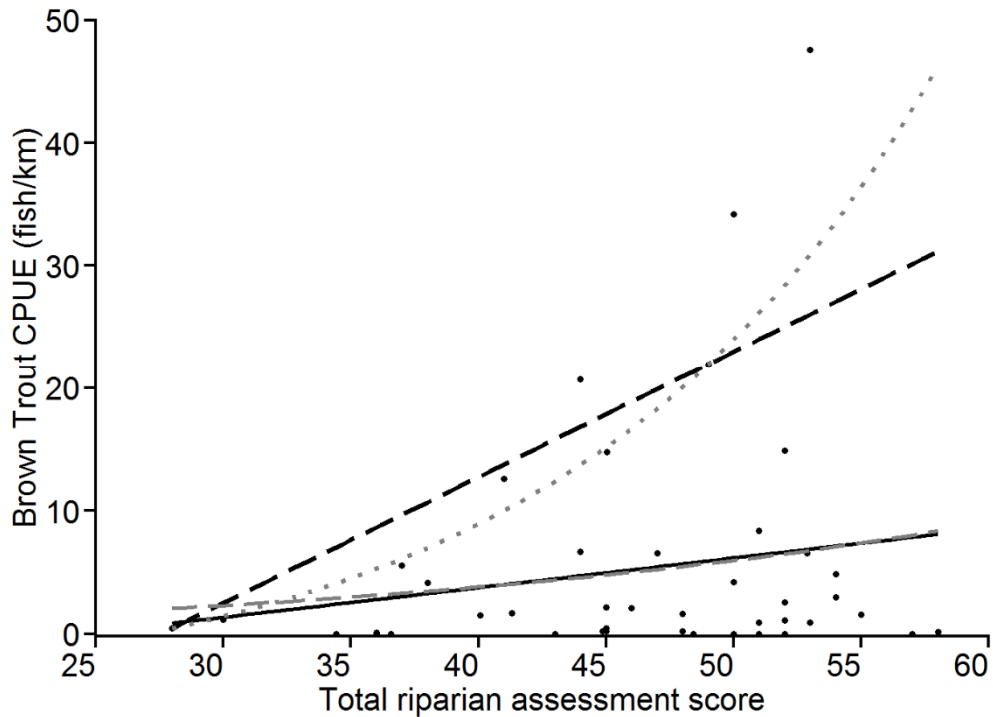


Figure 38. Scatter plot relating Brown Trout CPUE (fish/km) and total riparian assessment score (RAtot;  $N=44$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE =  $-5.887 + 0.241 \cdot \text{RAtot}$ ;  $P=0.232$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE =  $0.949 \cdot \exp(0.037 \cdot \text{RAtot})$ ;  $P=0.419$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE =  $-28.215 + 1.024 \cdot \text{RAtot}$ ;  $P=0.151$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE =  $0.730 \cdot \exp(0.069 \cdot \text{RAtot})$ ;  $P=0.256$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

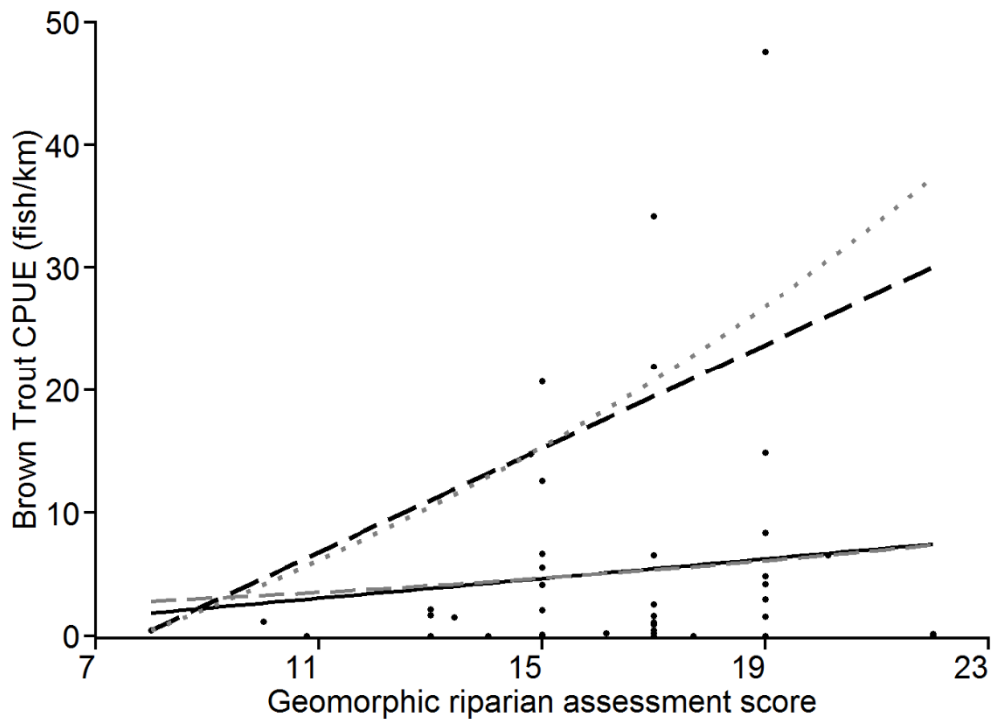


Figure 39. Scatter plot relating Brown Trout CPUE (fish/km) and geomorphic riparian assessment score (RAgeo;  $N=44$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE =  $-1.337 + 0.400 \cdot \text{RAgeo}$ ;  $P=0.423$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE =  $2.193 \cdot \exp(0.053 \cdot \text{RAgeo})$ ;  $P=0.419$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE =  $-16.462 + 2.114 \cdot \text{RAgeo}$ ;  $P=0.285$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE =  $6.471 \cdot \exp(0.056 \cdot \text{RAgeo})$ ;  $P=0.721$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

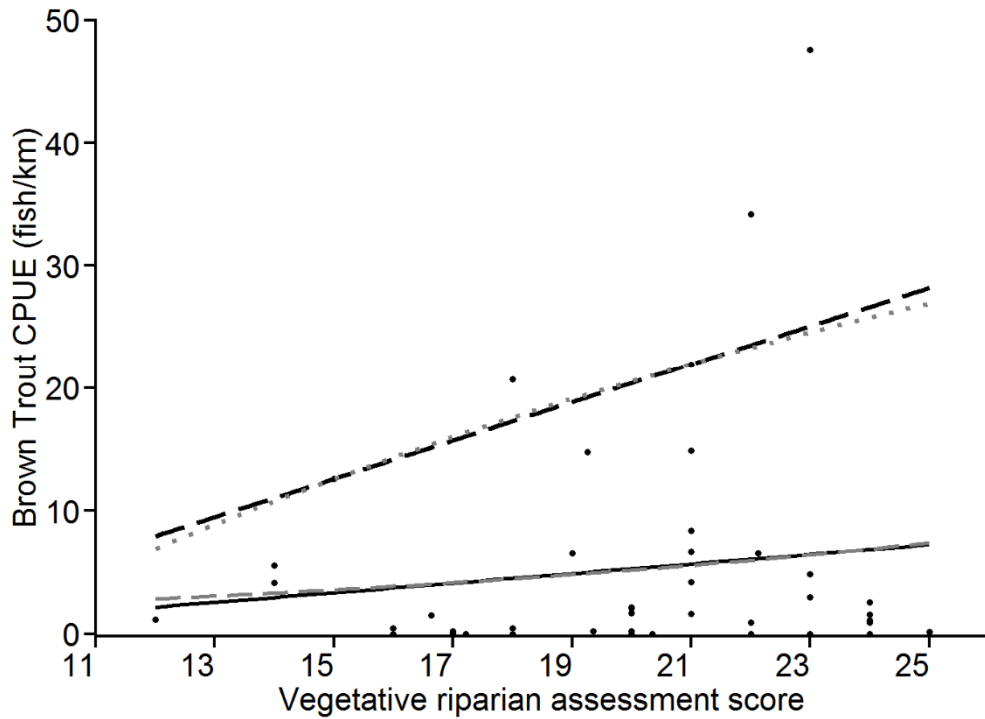


Figure 40. Scatter plot relating Brown Trout CPUE (fish/km) and vegetative riparian assessment score (RAveg;  $N=44$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE =  $-2.504 + 0.390 \cdot \text{RAveg}$ ;  $P=0.406$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE =  $1.422 \cdot \exp(0.065 \cdot \text{RAveg})$ ;  $P=0.510$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE =  $-10.804 + 1.560 \cdot \text{RAveg}$ ;  $P=0.390$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE =  $3.138 \cdot \exp(0.093 \cdot \text{RAveg})$ ;  $P=0.379$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

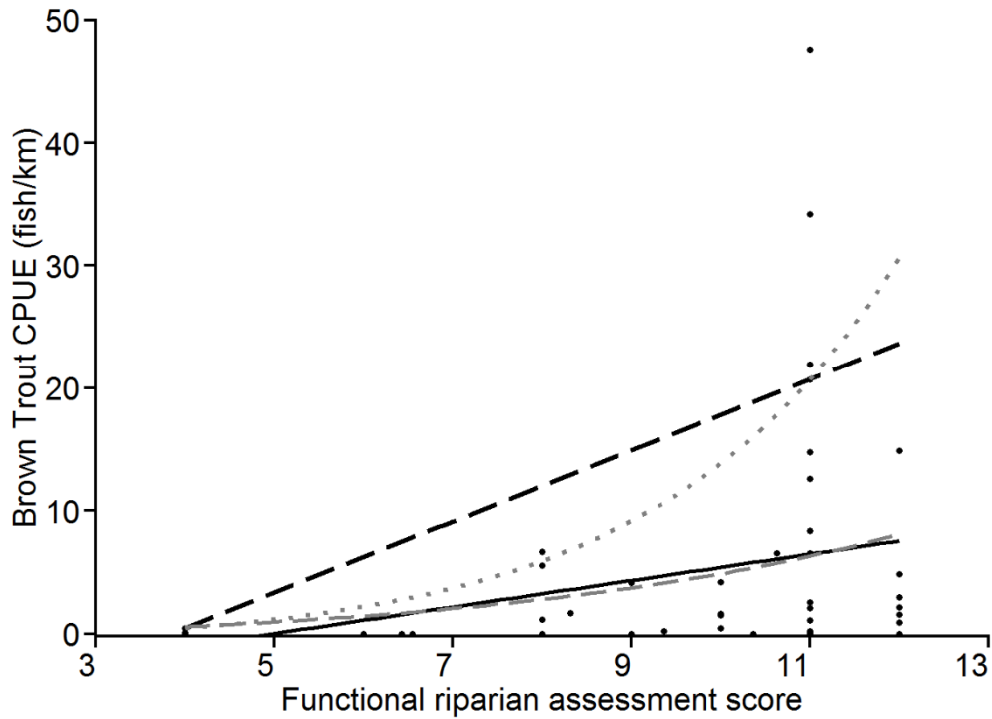


Figure 41. Scatter plot relating Brown Trout CPUE (fish/km) and functional riparian assessment score (RAfun;  $N=44$ ) with a linear ordinary least squares regression line (black solid; Brown Trout CPUE =  $-5.356 + 1.077 \cdot \text{RAfun}$ ;  $P=0.097$ ), nonlinear ordinary least squares regression line (gray dashed; Brown Trout CPUE =  $0.582 \cdot \exp(0.216 \cdot \text{RAfun})$ ;  $P=0.324$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Brown Trout CPUE =  $-11.129 + 2.895 \cdot \text{RAfun}$ ;  $P=0.010$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Brown Trout CPUE =  $0.330 \cdot \exp(0.376 \cdot \text{RAfun})$ ;  $P=0.249$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

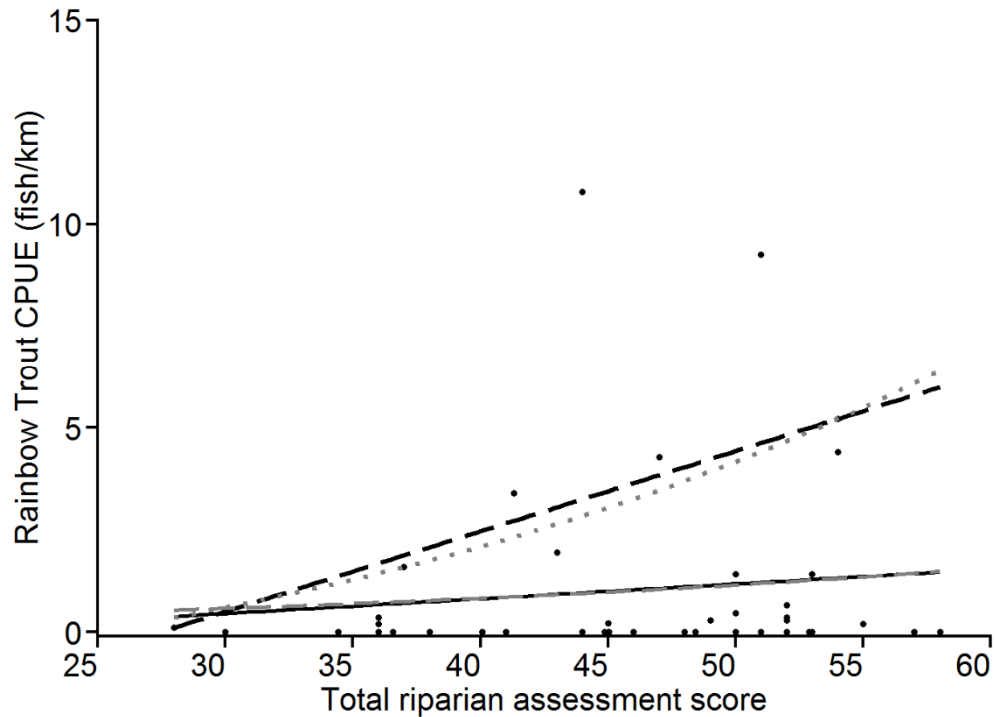


Figure 42. Scatter plot relating Rainbow Trout CPUE (fish/km) and total riparian assessment score (RA<sub>tot</sub>;  $N=44$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE =  $-0.629 + 0.036 \cdot \text{RA}_{\text{tot}}$ ;  $P=0.465$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE =  $0.287 \cdot \exp(0.028 \cdot \text{RA}_{\text{tot}})$ ;  $P=0.608$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE =  $-5.376 + 0.196 \cdot \text{RA}_{\text{tot}}$ ;  $P=0.281$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE =  $0.852 \cdot \exp(0.034 \cdot \text{RA}_{\text{tot}})$ ;  $P=0.562$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

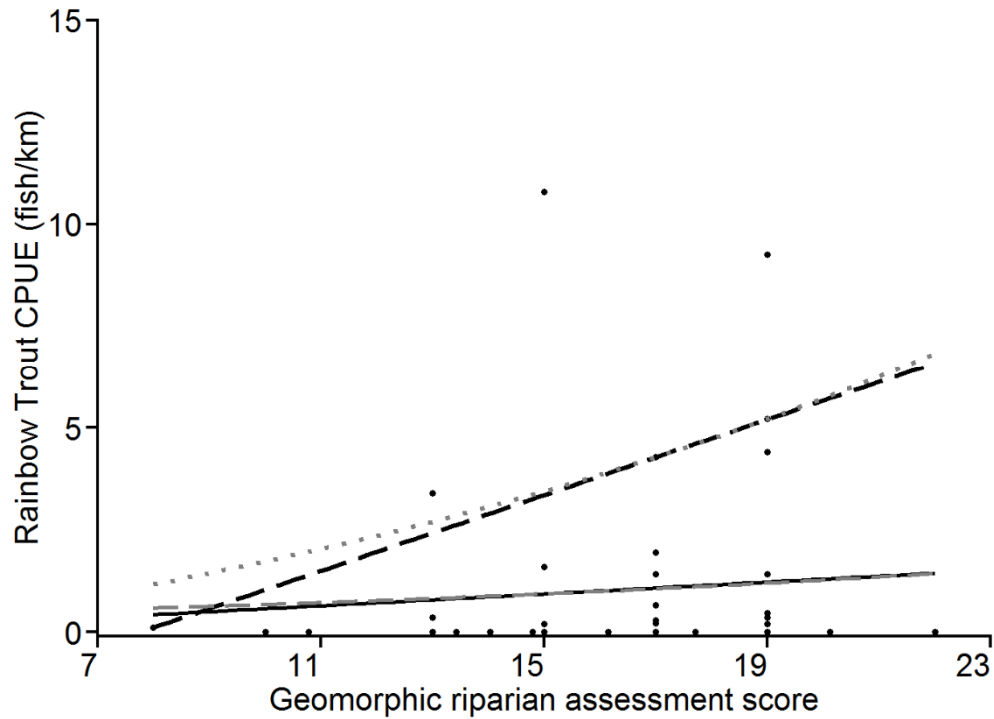


Figure 43. Scatter plot relating Rainbow Trout CPUE (fish/km) and geomorphic riparian assessment score (RAgeo;  $N=44$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE =  $-0.149 + 0.072 \cdot \text{RAgeo}$ ;  $P=0.553$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE =  $0.451 \cdot \exp(0.051 \cdot \text{RAgeo})$ ;  $P=0.681$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE =  $-3.588 + 0.463 \cdot \text{RAgeo}$ ;  $P=0.263$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE =  $1.624 \cdot \exp(0.057 \cdot \text{RAgeo})$ ;  $P=0.629$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

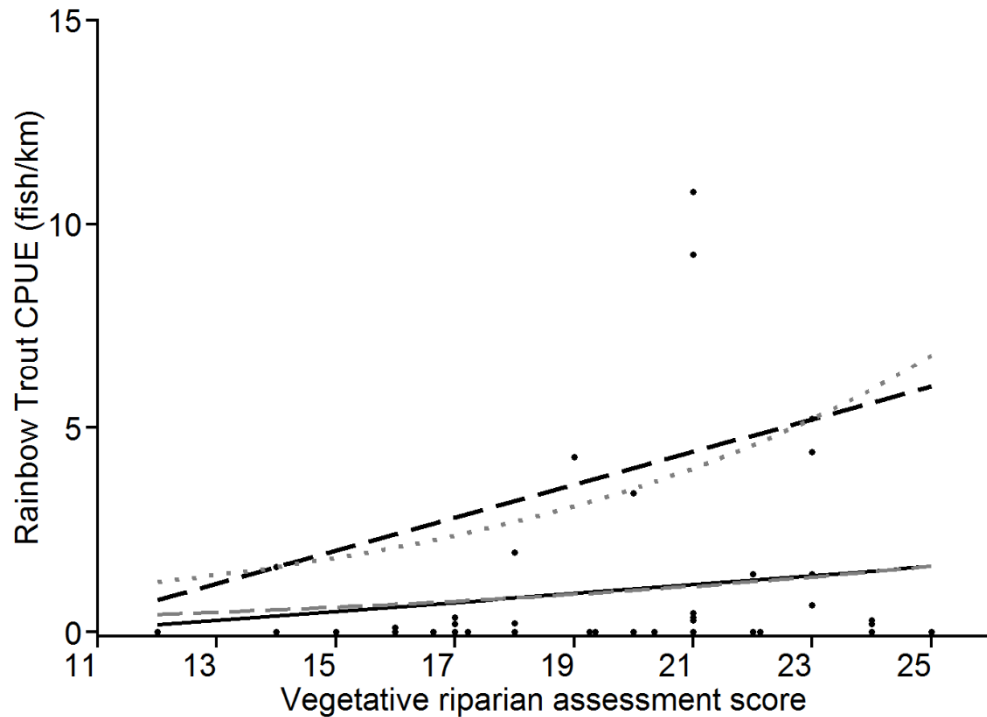


Figure 44. Scatter plot relating Rainbow Trout CPUE (fish/km) and vegetative riparian assessment score (RAveg;  $N=44$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE =  $-1.140 + 0.110 \cdot \text{RAveg}$ ;  $P=0.337$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE =  $0.229 \cdot \exp(0.076 \cdot \text{RAveg})$ ;  $P=0.535$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE =  $-4.031 + 0.402 \cdot \text{RAveg}$ ;  $P=0.252$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE =  $0.252 \cdot \exp(0.132 \cdot \text{RAveg})$ ;  $P=0.451$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

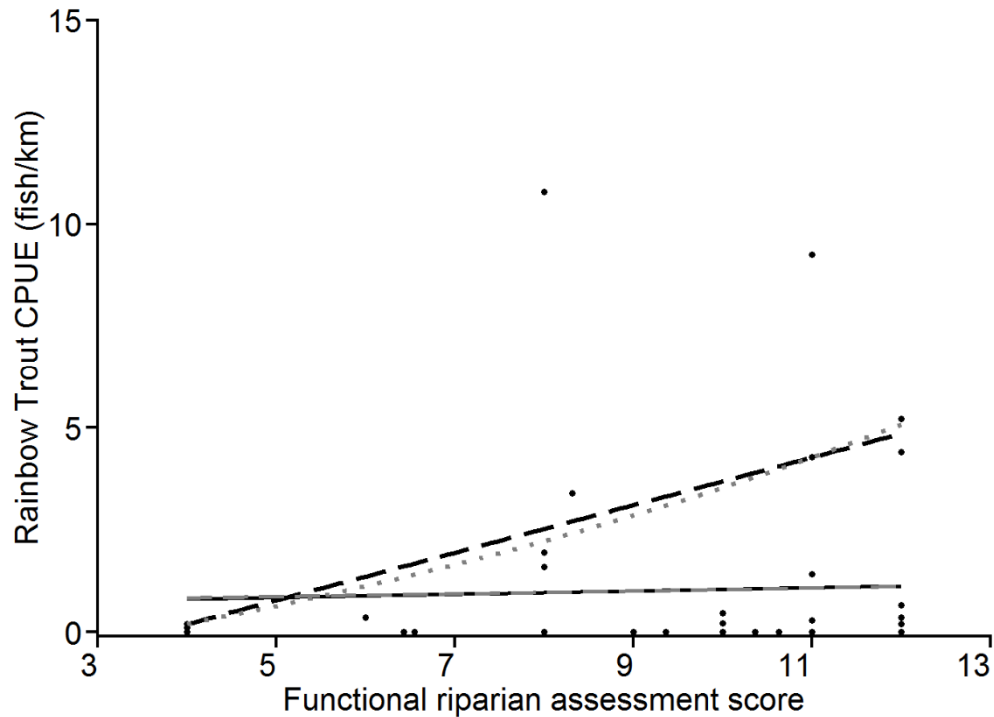


Figure 45. Scatter plot relating Rainbow Trout CPUE (fish/km) and functional riparian assessment score (RAfun;  $N=44$ ) with a linear ordinary least squares regression line (black solid; Rainbow Trout CPUE= $0.654+0.039 \cdot \text{RAfun}$ ;  $P=0.807$ ), nonlinear ordinary least squares regression line (gray dashed; Rainbow Trout CPUE= $0.761 \cdot \exp(0.032 \cdot \text{RAfun})$ ;  $P=0.852$ ), linear quantile ( $\tau=0.90$ ) regression line (black dashed; Rainbow Trout CPUE= $-2.134+0.583 \cdot \text{RAfun}$ ;  $P=0.409$ ), and nonlinear quantile ( $\tau=0.90$ ) regression line (gray dotted; Rainbow Trout CPUE= $1.682 \cdot \exp(0.085 \cdot \text{RAfun})$ ;  $P=0.761$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

### APPENDIX C

#### RELATIONSHIPS BETWEEN THE PROBABILITY OF ARCTIC GRAYLING OCCURRENCE AND NONNATIVE SALMONID CPUE OR ABIOTIC CONDITIONS

Relationships between the probability of Arctic Grayling occurrence and nonnative salmonid CPUE, temperature, discharge, or habitat condition metrics are evaluated in this appendix. Arctic Grayling abundance data were partitioned into two demographics (i.e.,  $\geq$  age 1 and age 0) and summarized as the binary response of presence or absence. The methods used to summarize nonnative CPUE, temperature, discharge, and habitat condition data are described in the Methods section of this manuscript. Logistic regression was used to model the relationships (Williams et al. 2002).

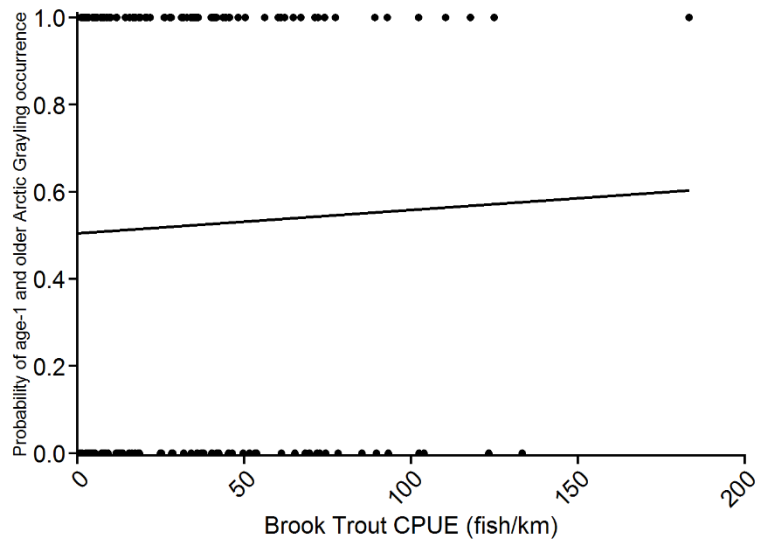


Figure 1. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of Brook Trout CPUE (fish/km;  $N=149$ ) that was modelled using logistic regression (black line;  $P=0.662$ ) from data that were collected in the Big Hole Watershed from 1983 through 2015.

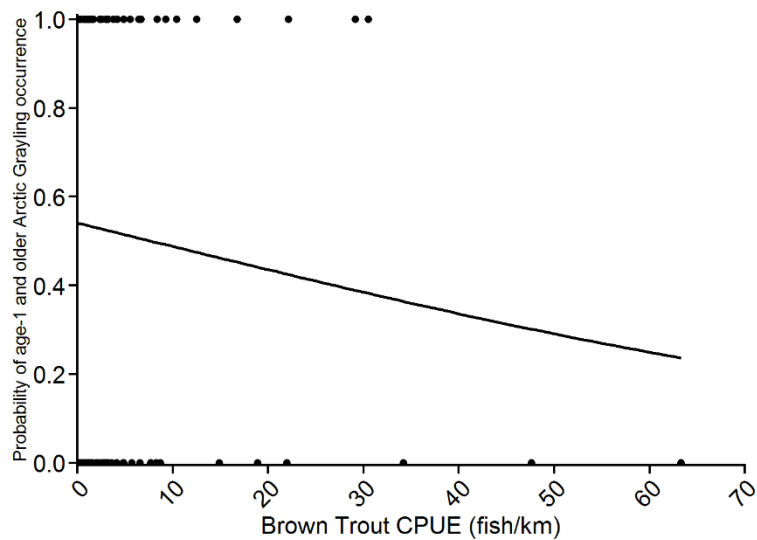


Figure 2. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of Brown Trout CPUE (fish/km;  $N=149$ ) that was modelled using logistic regression (black line;  $P=0.317$ ) from data that were collected in the Big Hole Watershed from 1983 through 2015.

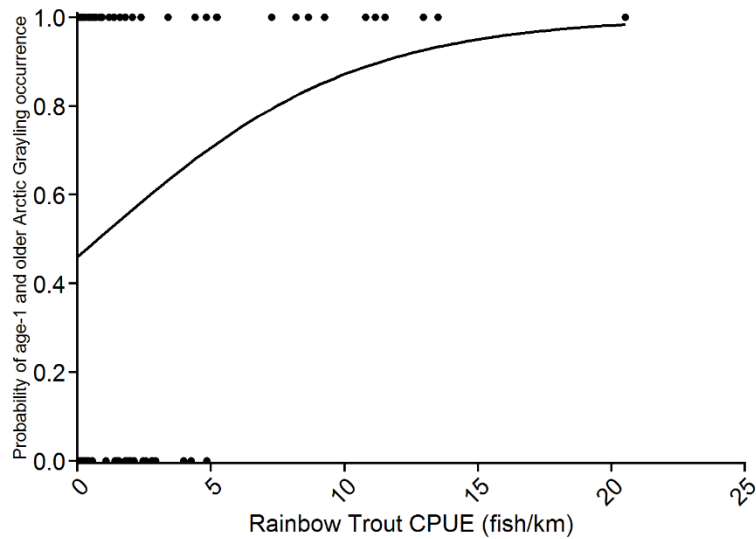


Figure 3. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of Rainbow Trout CPUE (fish/km;  $N=149$ ) that was modelled using logistic regression (black line;  $P=0.017$ ) from data that were collected in the Big Hole Watershed from 1983 through 2015.

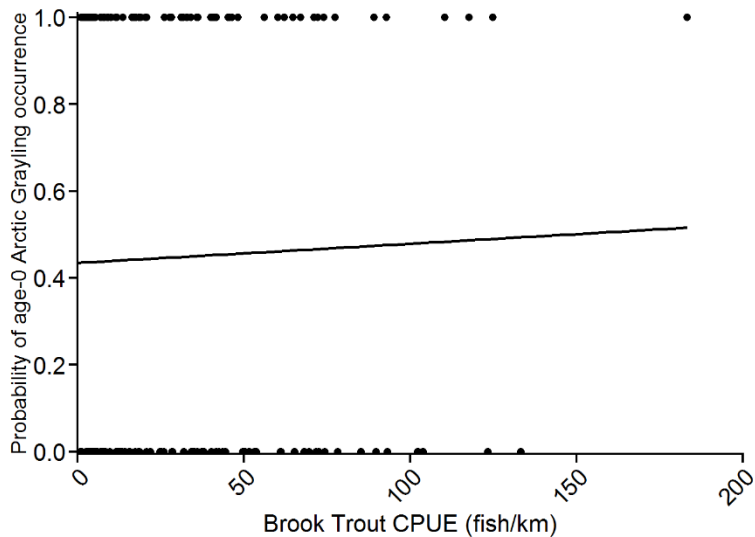


Figure 4. Probability of age-0 Arctic Grayling occurrence as a function of Brook Trout CPUE (fish/km;  $N=149$ ) that was modelled using logistic regression (black line;  $P=0.719$ ) from data that were collected in the Big Hole Watershed from 1983 through 2015.

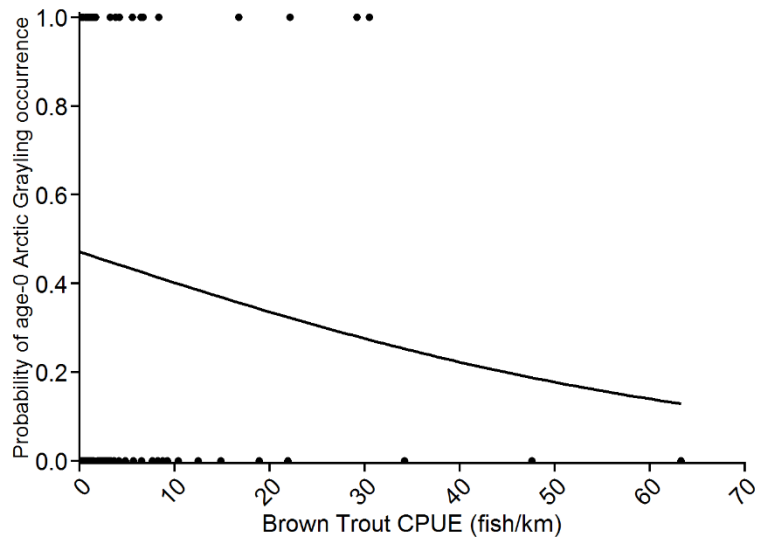


Figure 5. Probability of age-0 Arctic Grayling occurrence as a function of Brown Trout CPUE (fish/km;  $N=149$ ) that was modelled using logistic regression (black line;  $P=0.234$ ) from data that were collected in the Big Hole Watershed from 1983 through 2015.

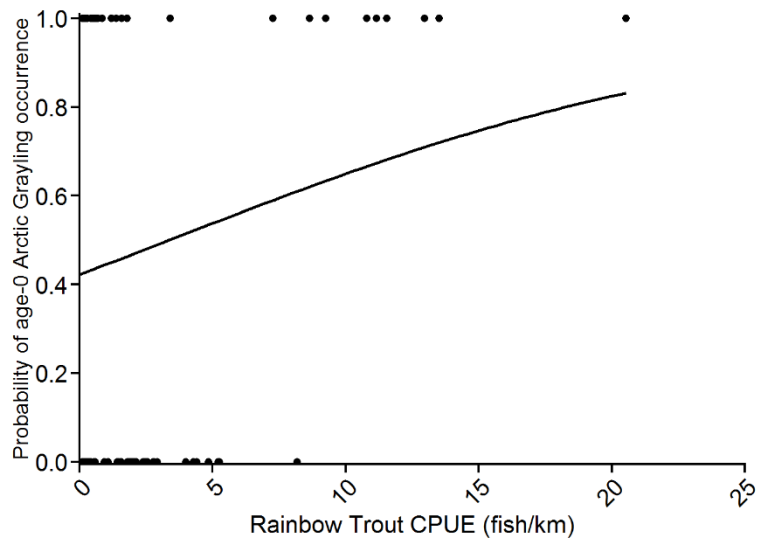


Figure 6. Probability of age-0 Arctic Grayling occurrence as a function of Rainbow Trout CPUE (fish/km;  $N=149$ ) that was modelled using logistic regression (black line;  $P=0.117$ ) from data that were collected in the Big Hole Watershed from 1983 through 2015.

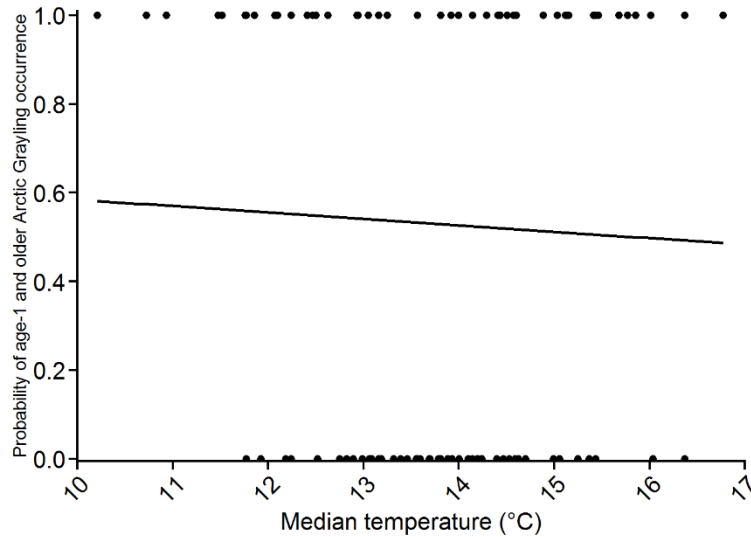


Figure 7. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of median water temperature ( $^{\circ}\text{C}$ ;  $N=100$ ) that was modelled using logistic regression (black line;  $P=0.698$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

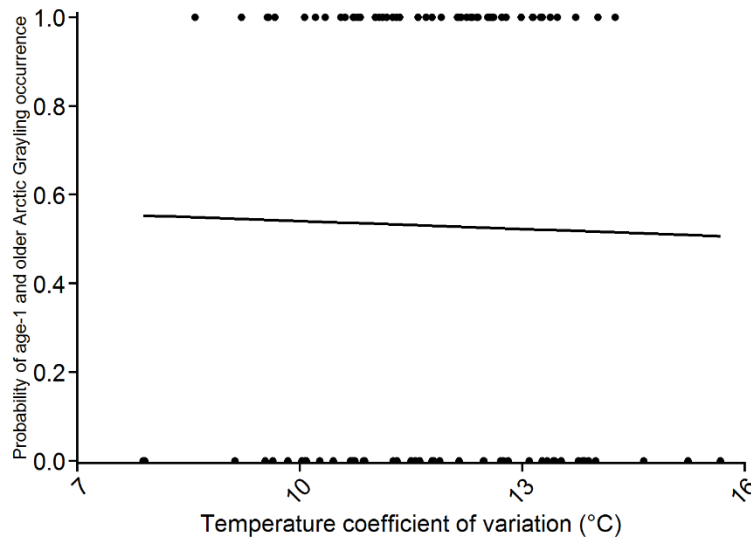


Figure 8. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of water temperature CV ( $^{\circ}\text{C}$ ;  $100 \cdot \text{SD}/\text{mean}$ ;  $N=100$ ) that was modelled using logistic regression (black line;  $P=0.855$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

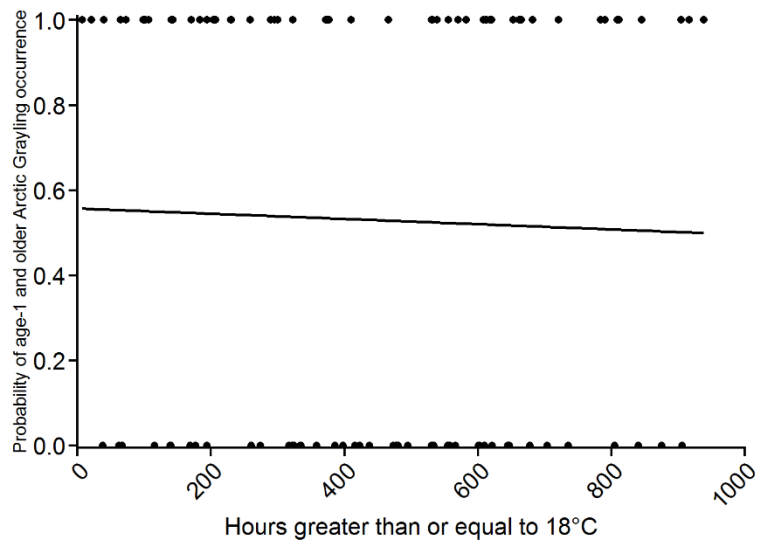


Figure 9. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of the total hours  $\geq 18^{\circ}\text{C}$  ( $N=100$ ) that was modelled using logistic regression (black line;  $P=0.761$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

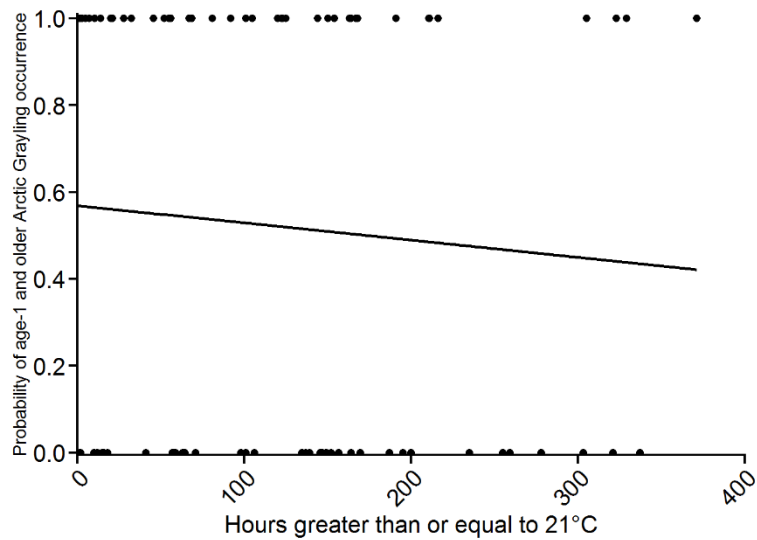


Figure 10. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of the total hours  $\geq 21^{\circ}\text{C}$  ( $N=100$ ) that was modelled using logistic regression (black line;  $P=0.437$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

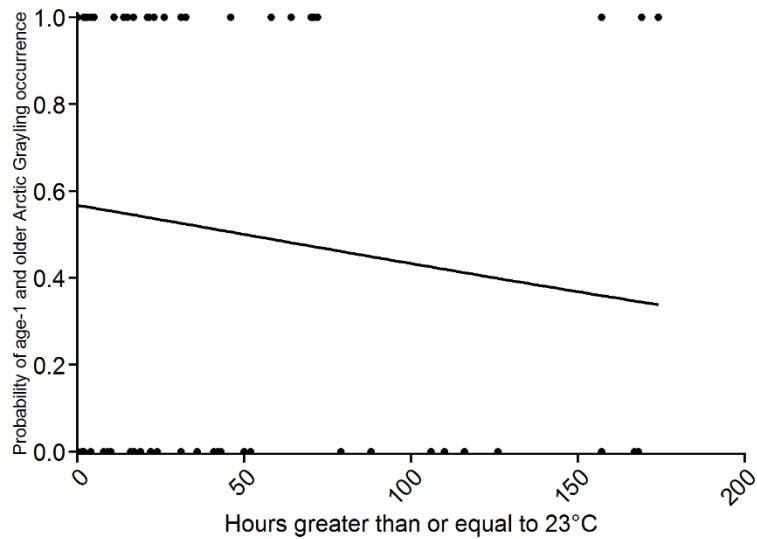


Figure 11. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of the total hours  $\geq 23^{\circ}\text{C}$  ( $N=100$ ) that was modelled using logistic regression (black line;  $P=0.237$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

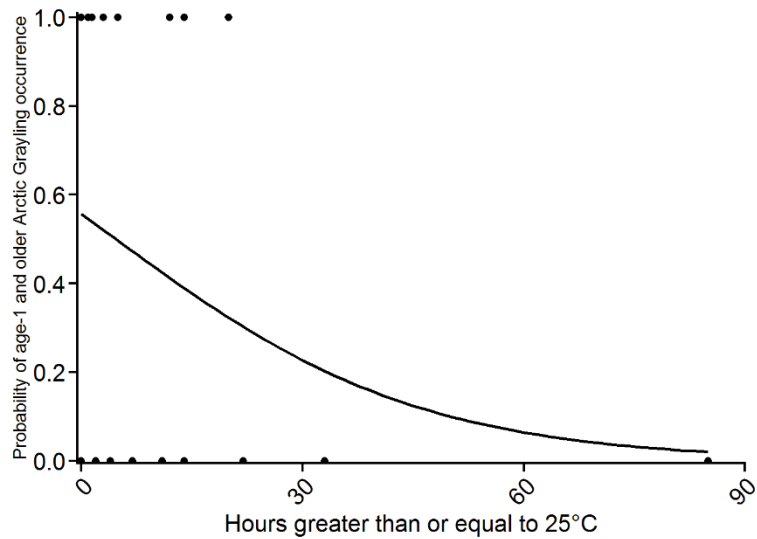


Figure 12. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of the total hours  $\geq 25^{\circ}\text{C}$  ( $N=100$ ) that was modelled using logistic regression (black line;  $P=0.189$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

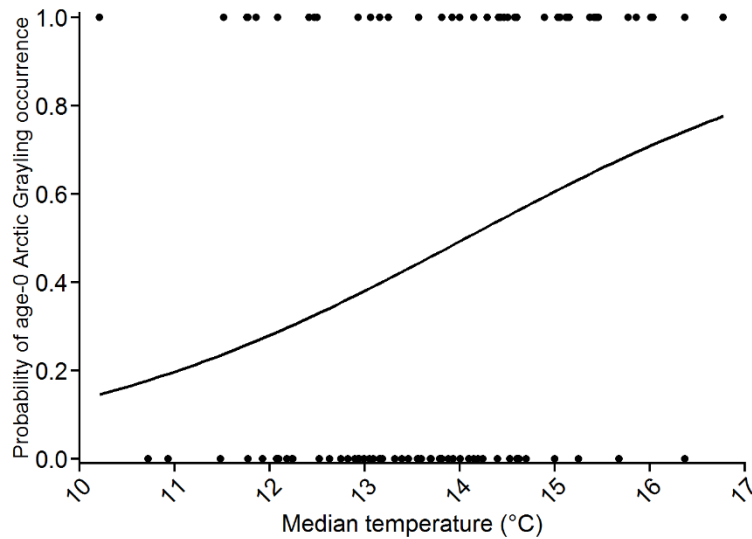


Figure 13. Probability of age-0 Arctic Grayling occurrence as a function of median water temperature ( $^{\circ}\text{C}$ ;  $N=100$ ) that was modelled using logistic regression (black line;  $P=0.006$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

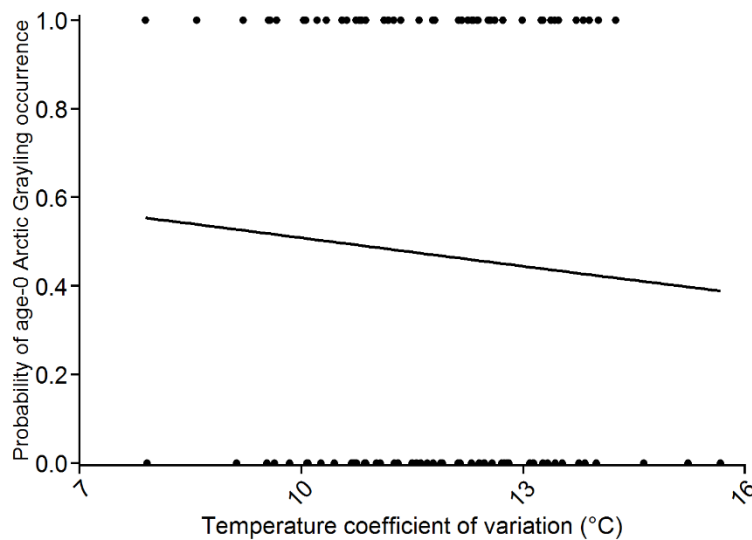


Figure 14. Probability of age-0 Arctic Grayling occurrence as a function of water temperature CV ( $^{\circ}\text{C}$ ;  $100 \cdot \text{SD}/\text{mean}$ ;  $N=100$ ) that was modelled using logistic regression (black line;  $P=0.513$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

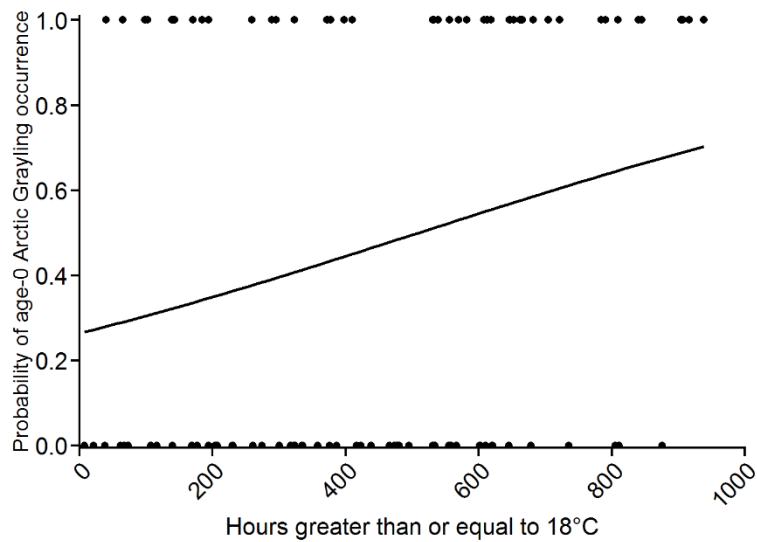


Figure 15. Probability of age-0 Arctic Grayling occurrence as a function of the total hours  $\geq 18^{\circ}\text{C}$  ( $N=100$ ) that was modelled using logistic regression (black line;  $P=0.020$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

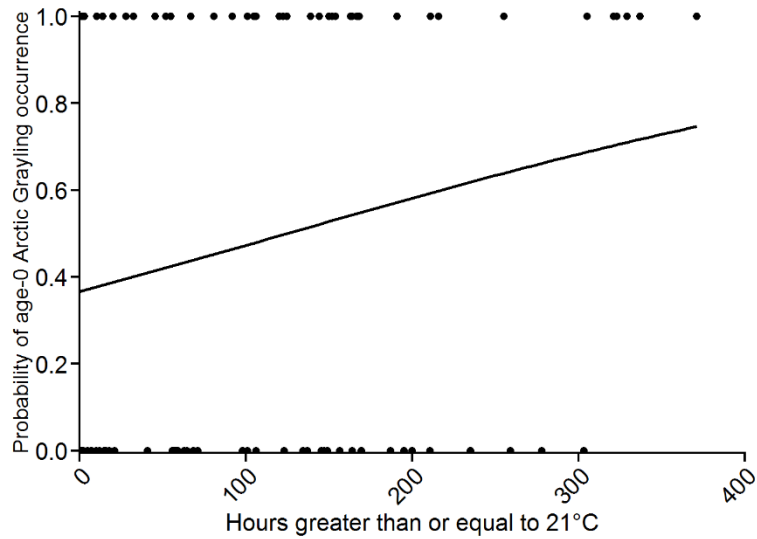


Figure 16. Probability of age-0 Arctic Grayling occurrence as a function of the total hours  $\geq 21^{\circ}\text{C}$  ( $N=100$ ) that was modelled using logistic regression (black line;  $P=0.042$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

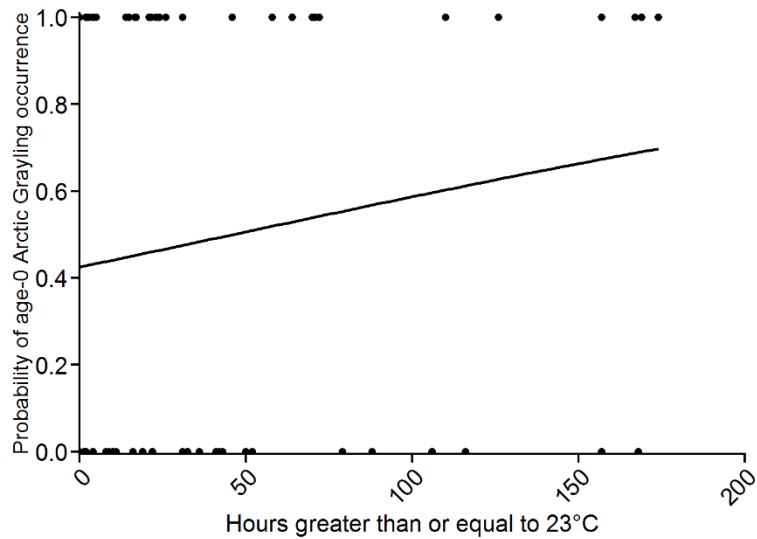


Figure 17. Probability of age-0 Arctic Grayling occurrence as a function of the total hours  $\geq 23^{\circ}\text{C}$  ( $N=100$ ) that was modelled using logistic regression (black line;  $P=0.160$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

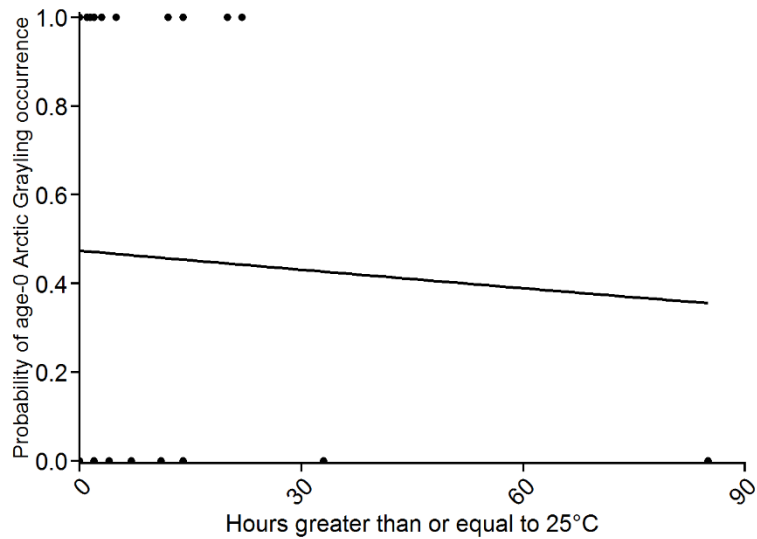


Figure 18. Probability of age-0 Arctic Grayling occurrence as a function of the total hours  $\geq 25^{\circ}\text{C}$  ( $N=100$ ) that was modelled using logistic regression (black line;  $P=0.783$ ) from data that were collected in the Big Hole Watershed from 1992 through 2015.

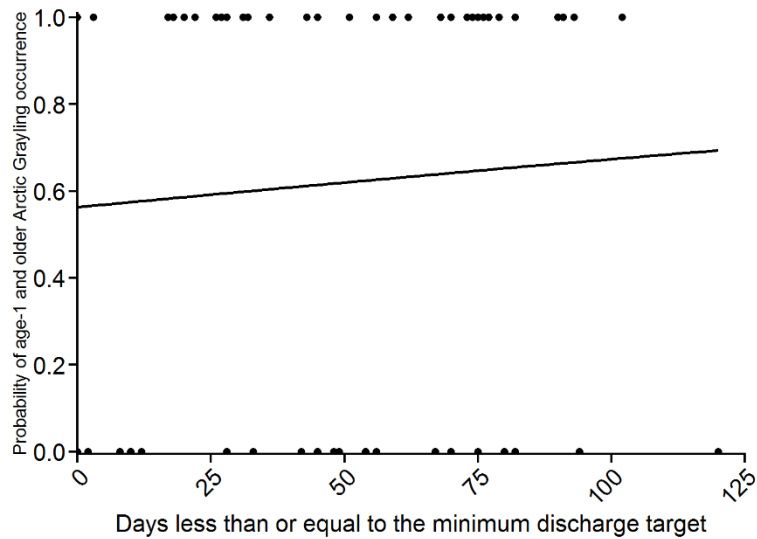


Figure 19. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of total days  $\leq$  minimum discharge target ( $N=67$ ) that was modelled using logistic regression (black line;  $P=0.544$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

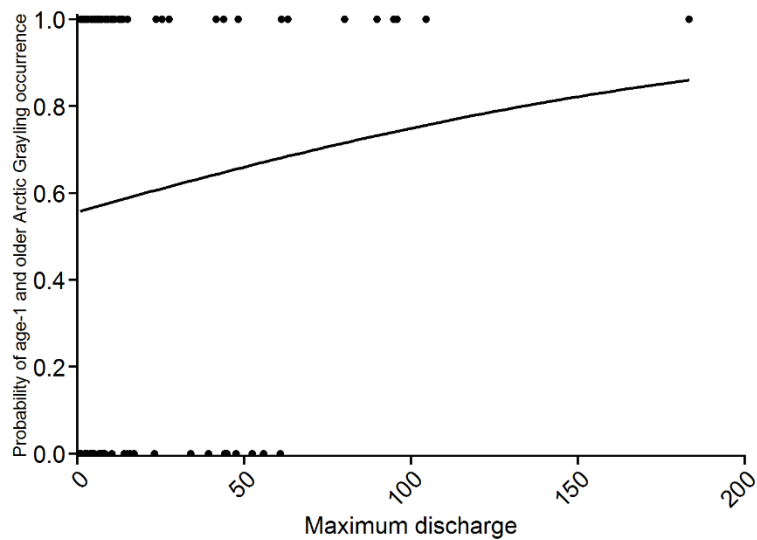


Figure 20. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of maximum discharge target ( $\text{m}^3/\text{s}$ ;  $N=71$ ) that was modelled using logistic regression (black line;  $P=0.320$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

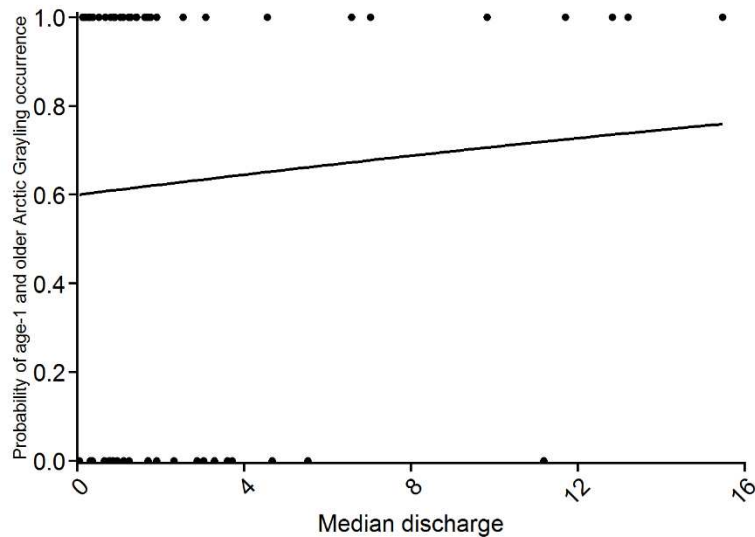


Figure 21. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of median discharge target ( $\text{m}^3/\text{s}$ ;  $N=62$ ) that was modelled using logistic regression (black line;  $P=0.541$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

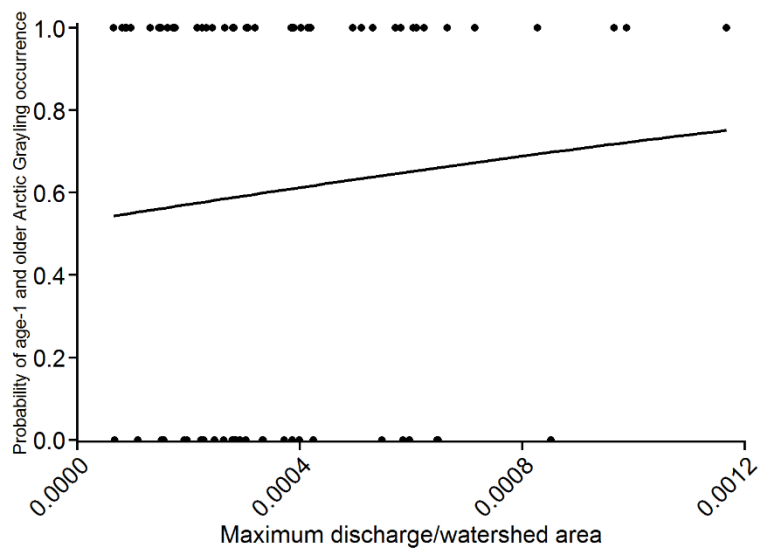


Figure 22. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of maximum discharge/watershed area ( $[\text{m}^3/\text{s}]/\text{ha}$ ;  $N=71$ ) that was modelled using logistic regression (black line;  $P=0.433$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

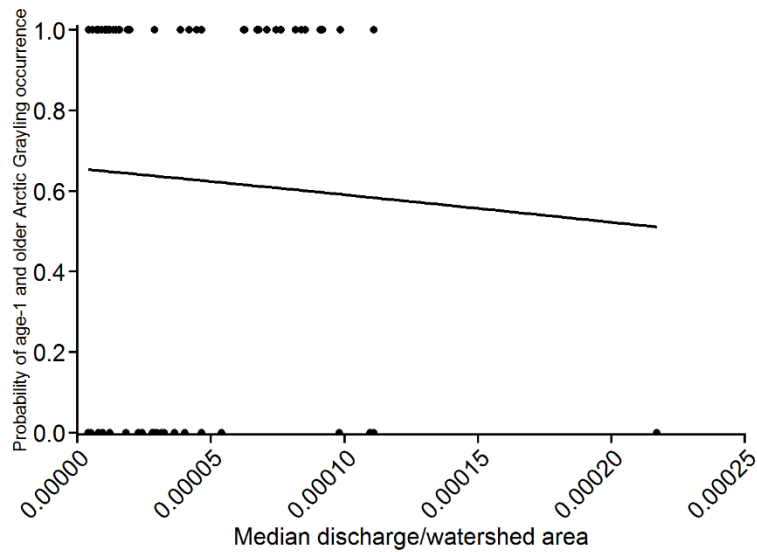


Figure 23. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of median discharge/watershed area ( $\text{[m}^3/\text{s]}/\text{ha}$ ;  $N=62$ ) that was modelled using logistic regression (black line;  $P=0.677$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

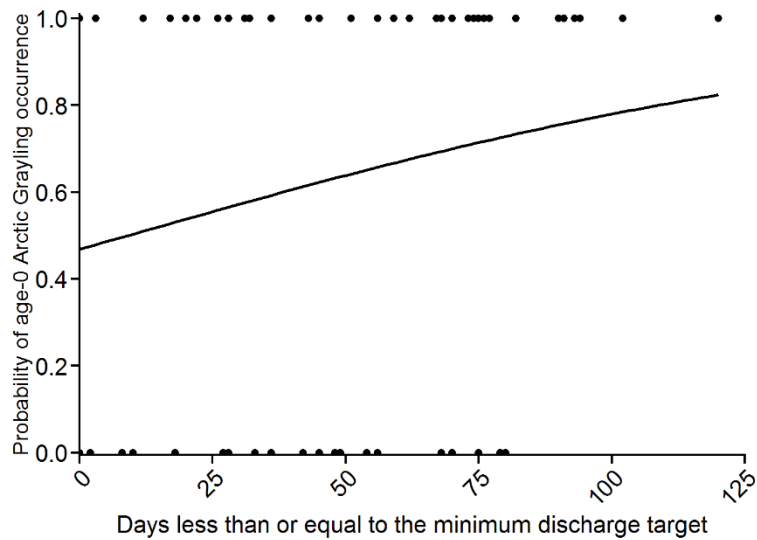


Figure 24. Probability of age-0 Arctic Grayling occurrence as a function of total days  $\leq$  minimum discharge target ( $N=67$ ) that was modelled using logistic regression (black line;  $P=0.087$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

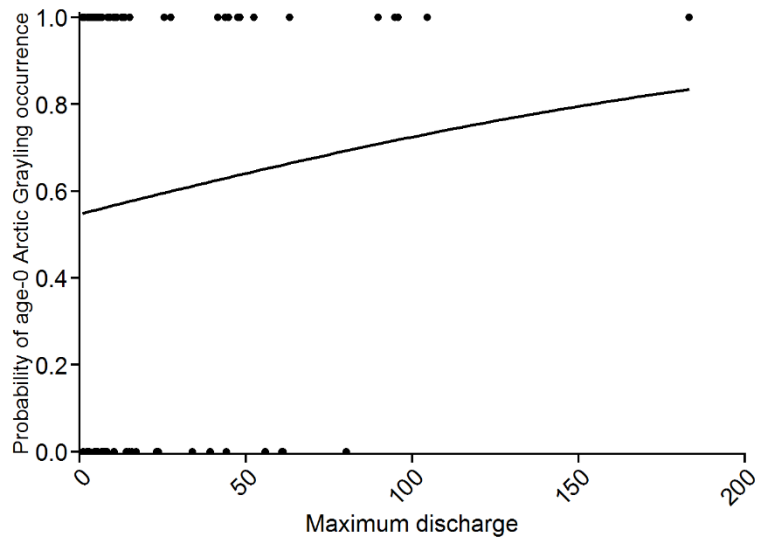


Figure 25. Probability of age-0 Arctic Grayling occurrence as a function of maximum discharge target ( $\text{m}^3/\text{s}$ ;  $N=71$ ) that was modelled using logistic regression (black line;  $P=0.357$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

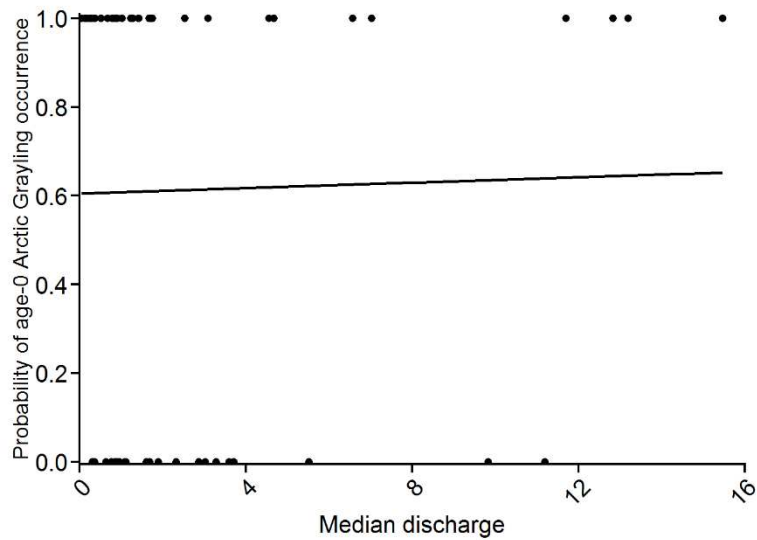


Figure 26. Probability of age-0 Arctic Grayling occurrence as a function of median discharge target ( $\text{m}^3/\text{s}$ ;  $N=62$ ) that was modelled using logistic regression (black line;  $P=0.859$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

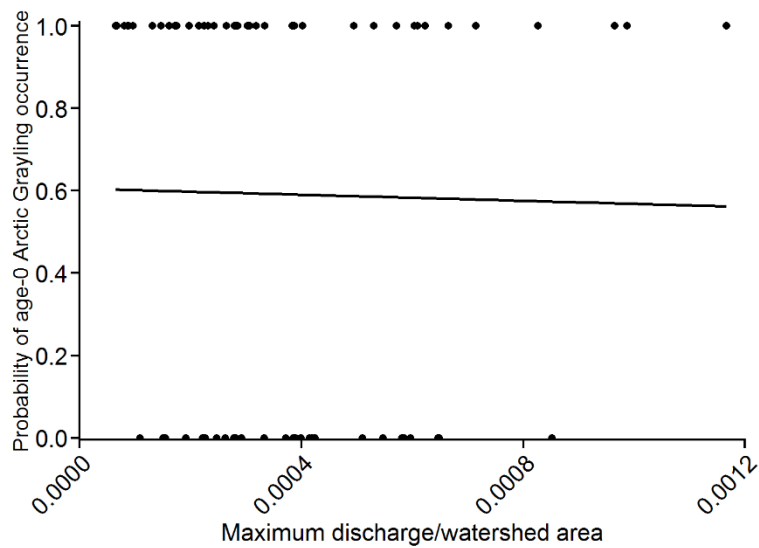


Figure 27. Probability of age-0 Arctic Grayling occurrence as a function of maximum discharge/watershed area ( $\text{[m}^3\text{/s]}/\text{ha}$ ;  $N=71$ ) that was modelled using logistic regression (black line;  $P=0.882$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

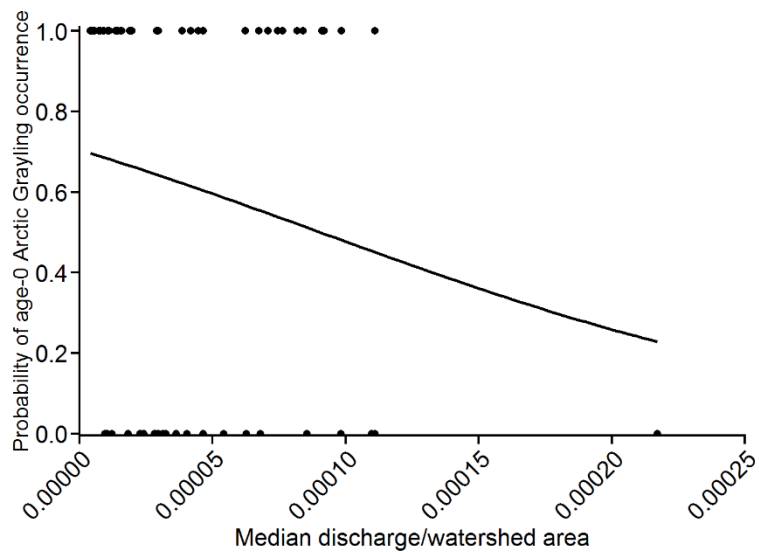


Figure 28. Probability of age-0 Arctic Grayling occurrence as a function of median discharge/watershed area ( $\text{[m}^3\text{/s]}/\text{ha}$ ;  $N=62$ ) that was modelled using logistic regression (black line;  $P=0.172$ ) from data that were collected in the Big Hole Watershed from 1988 through 2015.

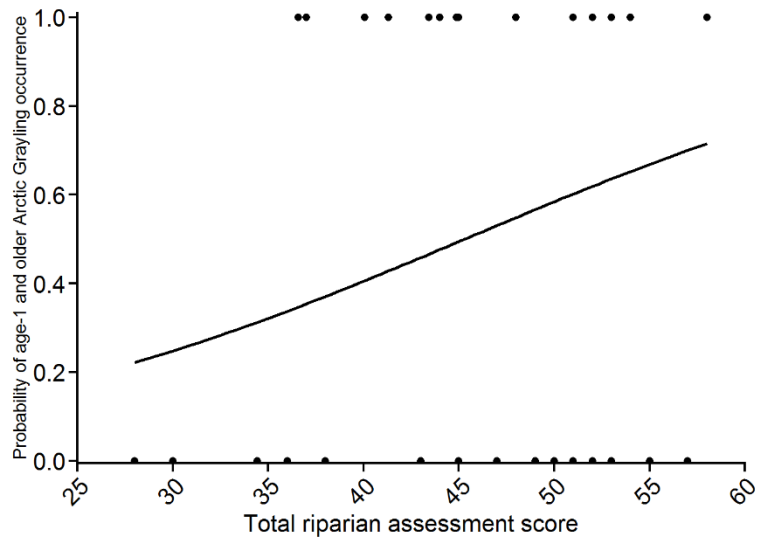


Figure 29. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of total riparian assessment score ( $N=39$ ) that was modelled using logistic regression (black line;  $P=0.116$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

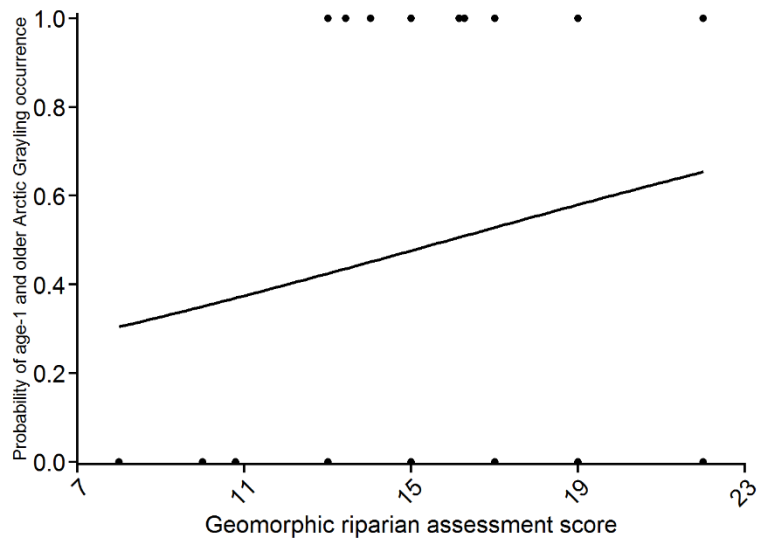


Figure 30. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of geomorphic riparian assessment score ( $N=39$ ) that was modelled using logistic regression (black line;  $P=0.350$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

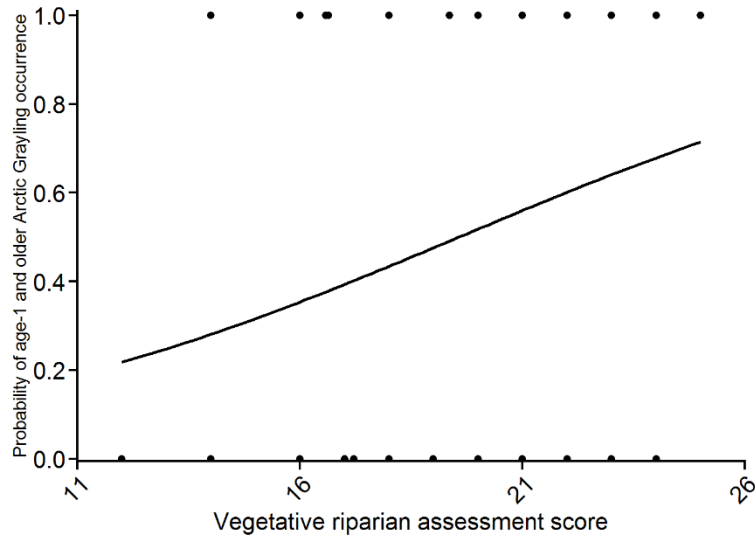


Figure 31. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of vegetative riparian assessment score ( $N=39$ ) that was modelled using logistic regression (black line;  $P=0.116$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

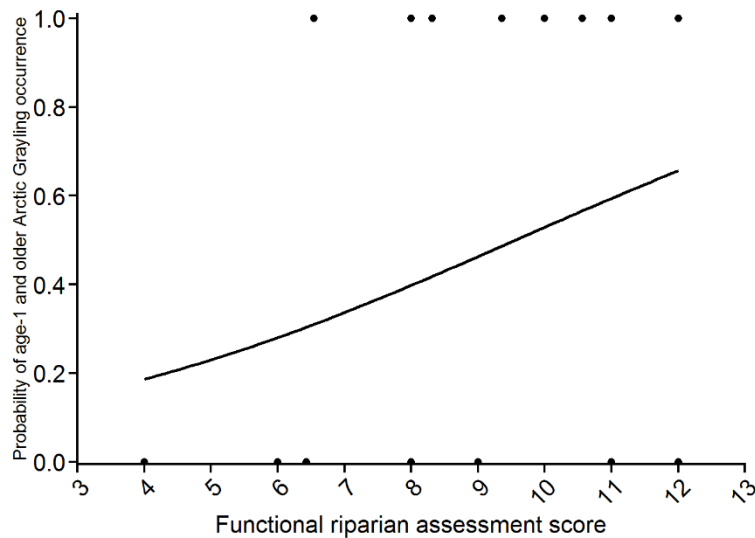


Figure 32. Probability of Arctic Grayling  $\geq$  age 1 occurrence as a function of functional riparian assessment score ( $N=39$ ) that was modelled using logistic regression (black line;  $P=0.093$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

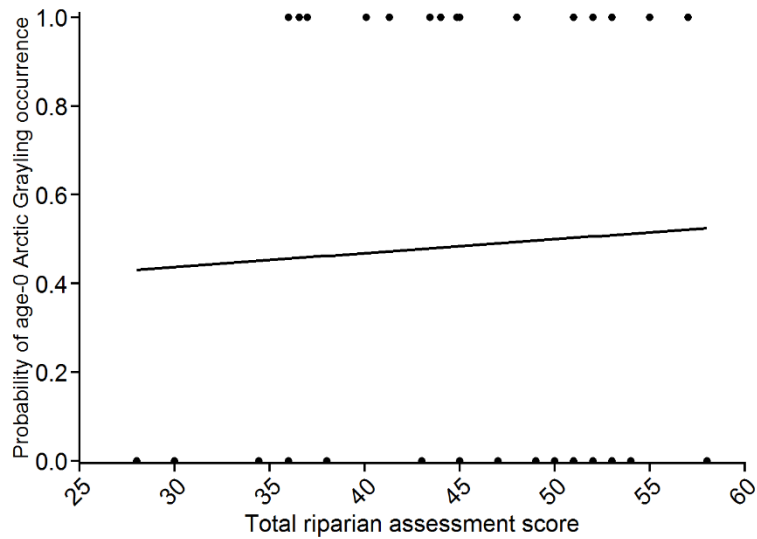


Figure 33. Probability of age-0 Arctic Grayling occurrence as a function of total riparian assessment score ( $N=39$ ) that was modelled using logistic regression (black line;  $P=0.769$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

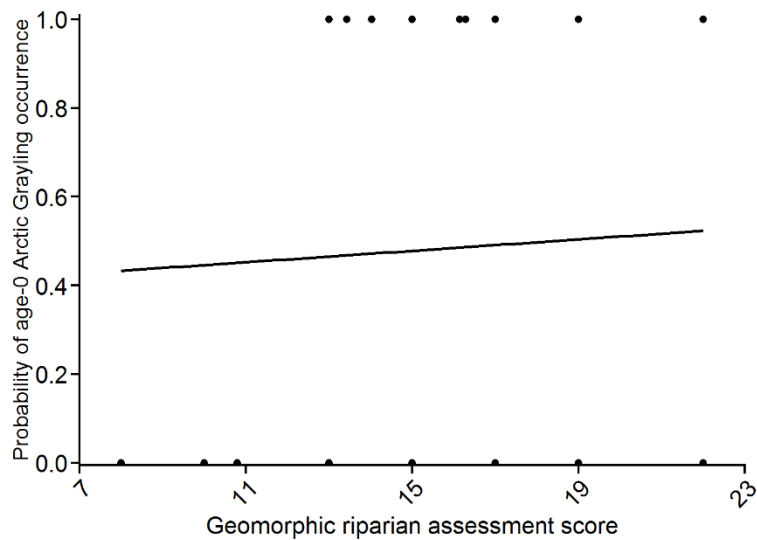


Figure 34. Probability of age-0 Arctic Grayling occurrence as a function of geomorphic riparian assessment score ( $N=39$ ) that was modelled using logistic regression (black line;  $P=0.810$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

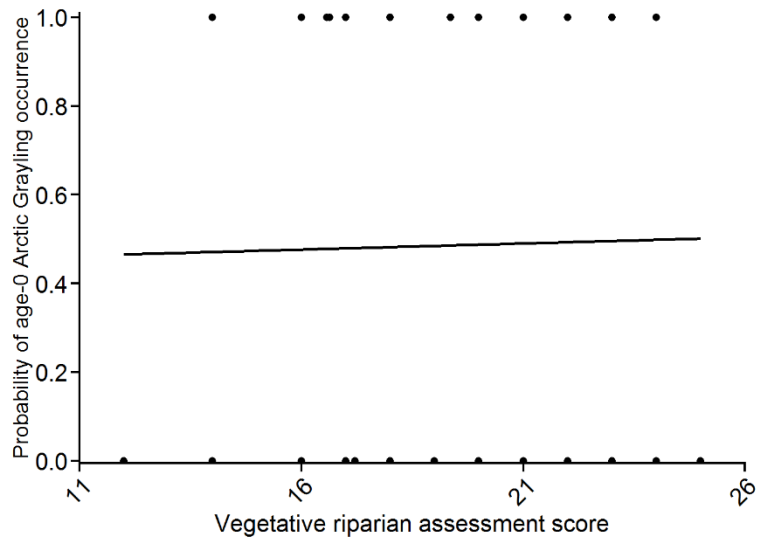


Figure 35. Probability of age-0 Arctic Grayling occurrence as a function of vegetative riparian assessment score ( $N=39$ ) that was modelled using logistic regression (black line;  $P=0.912$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.

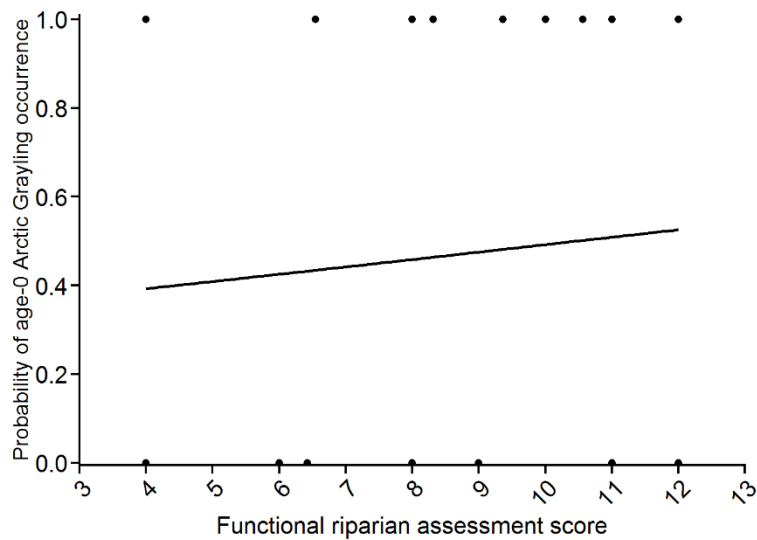


Figure 36. Probability of age-0 Arctic Grayling occurrence as a function of functional riparian assessment score ( $N=39$ ) that was modelled using logistic regression (black line;  $P=0.629$ ) from data that were collected in the Big Hole Watershed from 2005 through 2015.