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# Abiotic and Biotic Factors Associated with Sculpin Presence and Density in Northern Idaho Streams

## Abstract

Sculpins (family Cottidae) are a group of small nongame fishes, native to Idaho's colder streams, and have value for biodiversity and as indicators of water quality. We analyzed abiotic and biotic data, including habitat characteristics and presence of co-occurring trout and char (family Salmonidae) species, from 115 streams from the northern Idaho Panhandle to identify the physical characteristics and biotic communities of the streams associated with sculpin presence (or absence) and population density. For comparison, and to determine if the results of the northern dataset could be attributed to the rest of the state, a second dataset from state-wide sampling was also analyzed, as was a subset of both datasets that had no observations of non-native brook trout and rainbow trout. Sculpins were more likely to be present and in higher densities in streams with abundant riffle microhabitats that were mostly free of sediment (identified as Rosgen channel types B, C, and F for northern Idaho and types B and C for the entire state). More sculpins were also found in streams lacking brook trout and rainbow trout. Knowledge of sculpin habitats and the impacts of non-native salmonids may be useful in interpreting water quality evaluations, as well as in improving native fisheries restoration projects and fisheries management for Idaho streams.

**Keywords:** sculpins, Idaho, streams, salmonid, ecology

## Introduction

Sculpins and their closest relatives (suborder Cottoidei; Berra 2003, Smith and Busby 2014) are a large, widespread group of primarily bottom-dwelling teleost fishes with more than 600 identified species worldwide (Nelson 1994). These fish inhabit a diversity of freshwater (Goto et al. 2015) and marine habitats (Knope 2013), principally in northern latitudes. Twenty freshwater species have been identified in the Pacific Northwest (Tabor et al. 2007, Goto et al. 2015, Rowsey and Egge 2017), which includes the recently described cedar sculpin (*Cottus schitsuumsh*). Ten species, all in the genus *Cottus,* have been identified in Idaho (Wallace and Zaroban 2013, LeMoine et al. 2014; Table 1).

In Idaho, sculpin importance stems, in part, from their frequent abundance in the fish fauna of streams they inhabit (Hawkins et al. 1983), their unusual coldwater-adapted physiology and life history characteristics that allow them to persist in streams that few other fish species are able to inhabit (Adams and Schmetterling 2007), and their general intolerance of excessive fine sediments (Mebane 2001). Idaho sculpin species have lotic life histories (Goto et al. 2015) and exhibit little to no migration (Petty and Grossman 2007, Hudy and Shiflet 2009), typically inhabiting streams and small rivers with low turbidity and without major pollution or sedimentation (Simpson and Wallace 1982). Sedimentation and heavy-metal pollution are particularly harmful to sculpin spawning and foraging (Haro and Brusven 1994, Yagow et al. 2006). As a result of this environmental sensitivity, freshwater sculpins are viewed as an important component of healthy Northwest streams and are used as a bio-indicator for water quality monitor-

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TABLE 1. Sculpin (*Cottus*) species identified in Idaho, including range and distribution (Wallace and Zaroban 2013, LeMoine et al. 2014).

| Common name | *Cottus* species | Range | Distribution |
|---|---|---|---|
| Mottled | *bairdaii* | south and central Idaho | abundant |
| Paiute | *beldingii* | south and central Idaho | abundant |
| Slimy | *cognatus* | north Idaho | abundant |
| Shorthead | *confusus* | statewide | abundant |
| Bear Lake | *extensus* | Bear Lake | rare |
| Shoshone | *greenei* | isolated reach of the Snake River | rare |
| Wood River | *leiopomus* | Wood River basin | rare |
| Torrent | *rhotheus* | north and central Idaho | abundant |
| Columbia | *hubbsi* | central and southheast Idaho | rare |
| Cedar | *schitsuumsh* | Spokane River basin | rare |

ing in the state of Idaho (Mebane 2001, Adams and Schmetterling 2007).

Despite their prevalence in Idaho's coldwater habitats, only modest information is available on habitat requirements and preferences of sculpins statewide, as well as regionally and throughout North America (Brown 1991, White and Harvey 1999, Roni 2002, Adams and Schmetterling 2007). Sculpins can be difficult to observe in streams because of their small size, cryptic nature (Moyle 1976), and ability to change the color of their outer integument to match their surroundings (Whiteley et al. 2009). These factors, sculpins' minimal value as recreational fishes, and their taxonomic complexity result in them being much less well known and appreciated than the native salmonids often co-inhabiting Idaho's coldwater streams.

In view of the high prevalence of sculpins in Idaho, stream fisheries managers would benefit from a better understanding of sculpin micro- and macro-habitat use and requirements in relation to water quality assessments (Mebane et al. 2003, Adams and Schmetterling 2007). It would, for example, be helpful to understand if the Rosgen stream classification system (Rosgen 1996) used by the Idaho Department of Environmental Quality (IDEQ) Beneficial Use Reconnaissance Program (BURP) (IDEQ 2017a) could be used as a baseline predictor of sculpin presence (or absence) and relative abundance. It would also be helpful to gain a more comprehensive understanding of specific freshwater sculpin microhabitat and macrohabitat requirements by evaluating which individual physical and geomorphological variables of streams may influence sculpin populations independently of any stream channel classification scheme.

Another important ecological question is how both native and non-native salmonid species in Idaho streams may affect freshwater sculpin distribution and relative abundance through interactions such as predation and competition (Ruetz et al. 2003, Zimmerman and Vondracek 2006). With an abundance of native salmonid fishes in Idaho streams and the region's history of non-native salmonid introductions, it is important to determine if non-native salmonids affect sculpins differently than native salmonids (Cucherousset and Olden 2011). In places where native and non-native salmonids co-exist, they may affect sculpins in complex ways beyond the effects of native salmonids alone (Macneale et al. 2010).

The goal of this study was to investigate if these questions could be answered through an analysis of IDEQ electrofishing survey data, in combination with physical stream habitat and biological data previously collected under the BURP water quality monitoring program. The first objective of this study was to determine if the Rosgen stream channel classification, which categorizes streams based on gradient, meander frequency, and channel shape, may be used as a baseline predictor of sculpin presence or absence and sculpin relative abundance. The second objective was to identify what individual abiotic variables of streams measured under the BURP monitoring program influence sculpin presence or absence and density . The third objective was to investigate if introduced salmonids influence sculpin presence or absence and density in ways different than native salmonids alone.

## Methods

The study area included small wadable streams throughout Idaho. BURP stream assessments from 2010 to 2019 were analyzed. No additional data outside of the standard sampling were collected by the authors. Sculpins were analyzed as a group, not by species, because field identification of individual sculpin species is not part of the BURP protocol, as their field identification is notoriously difficult (Adams and Schmetterling 2007). Available evidence from Idaho coldwater streams suggests that differences in life history and ecology between sculpin species (e.g., behavior, food habits) are small compared to differences between sculpins as a group and other fish species (Sigler and Zaroban 2018).

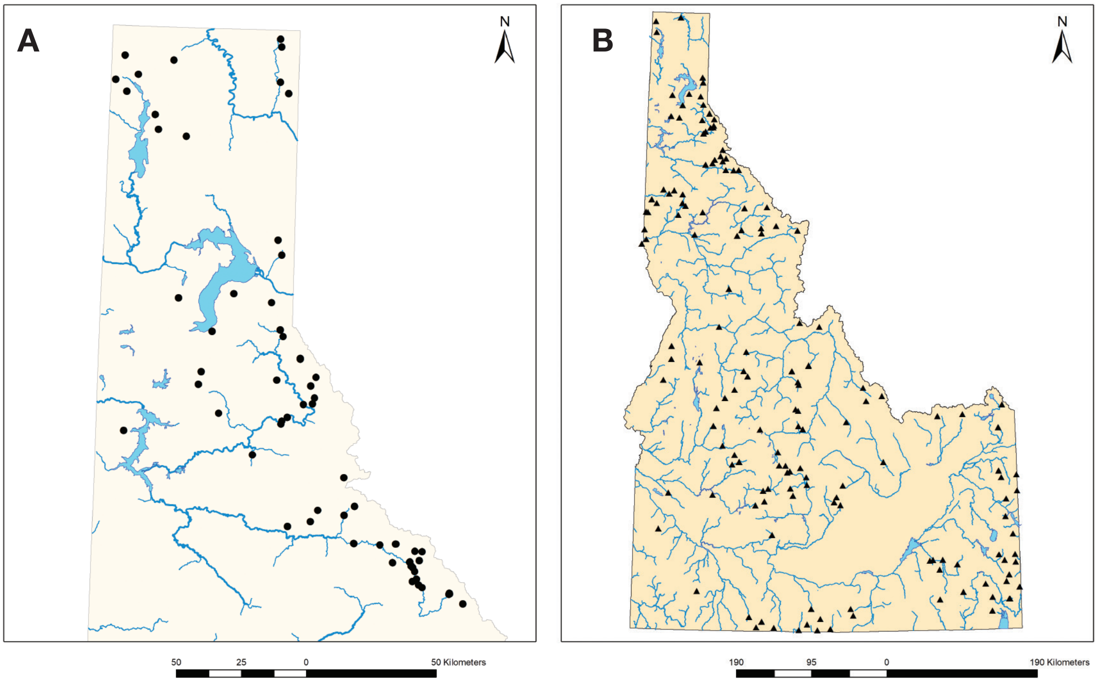
We analyzed three separate datasets consisting of randomly selected BURP assessment sites. The first dataset included only streams from northern Idaho (Figure 1a). This set of 115 sites was used to represent a more limited geographical area where there were fewer large-scale abiotic (e.g., climatic) and biotic (e.g., biogeographical) differences among sampled streams. Streams had relatively homogeneous geology and land uses. They were dominated by the torrent sculpin (*Cottus rhotheus*), shorthead sculpin (*C. confusus*), and slimy sculpin (*C. cognatus*). The second dataset consisted of 160 randomly selected BURP sites from all regions of the state (Figure 1b). This dataset included streams with much wider variations in geographic features and land uses, and included all species of sculpin occurring in Idaho, excluding the Bear Lake sculpin that is confined to Bear Lake. A third dataset was created for analysis because of the prevalence of the non-native brook trout (*Salvelinus fontinalis*) and hatchery reared rainbow trout (*Oncorhynchus mykiss*) in many of Idaho's watersheds. The third dataset allowed a separate analysis to identify which stream variables were most associated with sculpin presence/absence and density in the streams without non-native salmonids. This dataset was assembled by combining the northern region dataset with the statewide dataset (eliminating duplicate sites that occurred in both datasets) and removing the BURP sites with brook trout or introduced rainbow trout observations (118 sites; Figure 1c). Sites were not typically sampled each year. Therefore, the lack of catch of non-native trout was assumed to reflect their absence in that stream section in that particular year.

### BURP Assessment Data

The IDEQ BURP protocol serves as a rapid field survey of small wadable, perennial streams to quickly assess streams for water quality to satisfy the State's total maximum daily load process (IDEQ 2017a). IDEQ has a published and EPA-approved quality assurance plan for the BURP program to ensure all data for the BURP assessments are collected, analyzed, and published with quality control and consistency (IDEQ 2017a, 2017b).

BURP assessments were completed each summer from late June through September while the streams were at base flows. Stream assessments were completed in a representative reach of each stream with a reach length of 30 times the average bankfull width of the stream (with a minimum reach length of 100 m). The physical data collected in each survey and used in this project included bankfull width, water temperature, sinuosity (meander frequency), stream flow, air temperature, riffle embeddedness, substrate material size using the Wolman pebble count method (Kondolf 1997), Strahler stream order (Strahler 1952), and Rosgen channel type (Rosgen 1996, IDEQ 2017a). The biological data collected in each survey included macroinvertebrate samples and a fish survey using electrofishing. The median size of fish (mm) of each species caught for each BURP assessment was included as a variable.

Because of the large number of streams to be surveyed, the electrofishing surveys consisted of a one-pass survey to determine what fish species were present and to obtain density rather than a prohibitively costly and time-consuming population estimate utilizing net barriers and multiple electrofishing passes. Although a multiple-pass survey may be beneficial, in this case the single-pass survey was adequate to get a representative sample of the fish present for this project (Reid et al. 2009). Under BURP protocol, the electro-



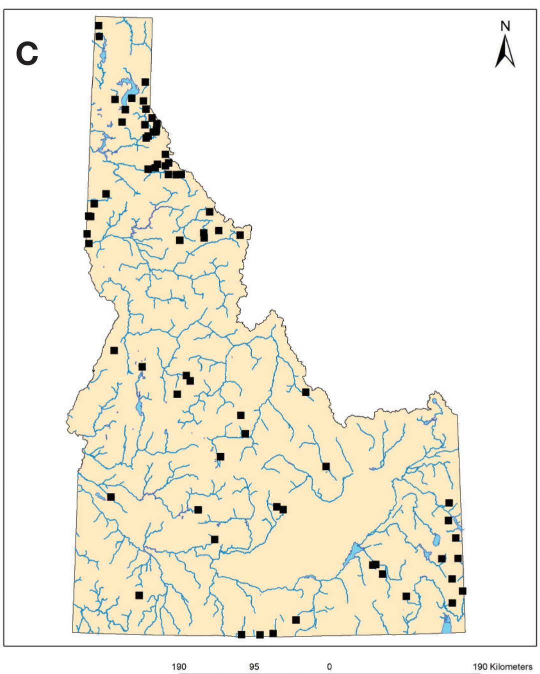




Figure 1. Beneficial Use Reconnaissance Program (BURP) assessment sites shown in the following panels: A) sites selected for northern Idaho study area (115); B) selected statewide sites (160); and C) selected sites (118) with no brook trout and/or no rainbow trout presence.

fishing survey covered the entire survey reach, with a minimum duration of 300 seconds of total electrofishing effort (i.e., power on), and all stream habitat types of glides, riffles, runs, and pools were surveyed equally (IDEQ 2017a). Only wadable streams were surveyed under the BURP protocol. The sculpin and salmonid catch efficiency were not estimated under the protocol, but the survey methodology was consistent for each stream (IDEQ 2017a). The senior author participated in the northern Idaho surveys during the summers of 2015, 2016, and 2017.

## Statistical Analysis and Variable Selection

All data collected for this project were extracted from the online IDEQ BURP Data viewer (IDEQ 2020). For the first dataset and model building, 115 BURP assessment sites from the northern Idaho Panhandle were used (Figure 1a). The sculpin data were quantified as two dependent variables: sculpin presence or absence, a dichotomous variable, and sculpin density, a continuous variable. The observations of all fish species were standardized to Catch Per Unit of Effort (CPUE) of fish caught per 100 s of electrofishing. To satisfy the requirement of normality, the sculpin density data (sculpins caught per 100 s of electrofishing effort) were transformed using the "Box Cox" transformation method (Ott and Longnecker 2010).

The sculpin presence or absence dependent variable was analyzed with logistic regression, and the continuous dependent variable of sculpin density was analyzed with multiple linear regression. The most appropriate combination of independent variables for explaining variation in the two sculpin dependent variables were identified with a forward stepwise model selection process using the Akaike's Information Criterion (AIC); the model with the lowest AIC score was used for the final statistical analysis (Burnham and Anderson 2002, Lattin et al. 2003).

The physical variables included in the analysis as independent variables were a mixture of categorical and continuous variables: bankfull width (m), Rosgen channel type, Strahler stream order (Strahler 1952, Rosgen 1996), dominant substrate size category using the Wolman pebble count procedure (Kondolf 1997, reach length (m), streamflow ($m^3$ $sec^{-1}$), and water temperature (°C). The biological variables included fish species observations and macroinvertebrate sample evaluations. Non-sculpin fish data included the density of salmonids including native cutthroat trout (*Oncorhynchus clarkii lewisi*), native bull trout (*Salvelinus confluentus*), introduced brook trout, and rainbow trout (rainbow trout are native to some streams but introduced in most of the northern basins) (Sigler and Zaroban 2018). All salmonid density data were also standardized as fish caught per 100 s of electrofishing effort.

The macroinvertebrate data were expressed in two variables based on the IDEQ scoring matrix for macroinvertebrate samples. IDEQ categorized macroinvertebrate samples from each stream with a quality score (number of macroinvertebrates present typical of waters with "good" water quality) ranging from 0 to 100, and a macroinvertebrate rating for community index (presence of multiple species of "good" macroinvertebrates) composition with a score of 1 as a poor-quality community, 2 for a moderate-quality community, or 3 for a good-quality community (IDEQ 2017a).

## Results

### Northern Idaho Streams

Sculpin presence or absence in northern Idaho streams was significantly associated with model variables (null deviance = 150.96, df = 114; residual deviance = 92.93, df = 106; $P < 0.001$). The independent biological variables associated with sculpin presence or absence were brook trout ($P = < 0.001$), rainbow trout ($P = < 0.001$) and bull trout ($P = 0.015$); sculpin presence was associated with fewer of each of these salmonids. Among physical variables, there was a significant positive relationship between sculpin presence and Rosgen channel types B ($P < 0.001$) and C ($P < 0.001$) (Table 2).

Sculpin density within northern Idaho streams was also significantly associated with model variables ($R^2 = 0.4495$; df = 9, 105; $P < 0.001$). The independent biological variables that were associated with sculpin density were brook trout ($P < 0.001$), rainbow trout ($P = 0.003$) and bull trout ($P = 0.012$); sculpin density was positively associated with lower densities of each of the three salmonid species. Among physical variables, Rosgen channel types B and C were again associated with higher sculpin density ($P < 0.001$); decreasing bankfull widths were also associated with higher sculpin density ($P < 0.001$; Figure 2, Table 2).

### Statewide Streams

Sculpin presence or absence in the statewide dataset also showed a significant relationship with model variables (null deviance = 217.94, df = 160; residual deviance = 168.86, df = 145; $P < 0.001$). The independent biological variables significantly associated with sculpin presence or absence were rainbow trout ($P = 0.011$), bull trout ($P = 0.016$), and macroinvertebrate scores ($P = 0.021$); sculpin presence was positively associated with lower densities of bull trout, rainbow trout, and moderate- to high-quality macroinvertebrate communities. Among physical variables, Rosgen channel types B ($P = 0.007$) and C ($P < 0.001$), large cobble substrate ($P = 0.009$), and small boulder substrate ($P = 0.029$) were positively associated with sculpin presence (Table 3).

TABLE 2. Statistically significant independent variables ($P \leq 0.05$) associated with the northern Idaho streams, including the dichotomous sculpin presence or absence dependent variable analyzed with logistic regression, and the continuous dependent variable of sculpin population density analyzed with multiple linear regression.

| Sculpin presence or absence (north)[a] | | |
|---|---|---|
| Variable | Estimate | *P* |
| Rosgen channel type B | 0.48 | < 0.001 |
| Rosgen channel type C | 0.62 | < 0.001 |
| Rainbow trout | –0.05 | < 0.001 |
| Brook trout | –0.08 | <0.001 |
| Bull trout | –0.15 | 0.015 |
| **Sculpin density (north)[b]** | | |
| Variable | Estimate | *P* |
| Rosgen channel type B | 1.93 | < 0.001 |
| Rosgen channel type C | 1.93 | < 0.001 |
| Rainbow trout | –0.38 | 0.003 |
| Brook trout | –0.13 | < 0.001 |
| Bull trout | –0.56 | 0.012 |
| Bankfull width (m) | –0.10 | 0.001 |

[a]Null deviance = 150.96, df = 114; Residual deviance = 92.93, df = 106, $P < 0.000$

[b]Multiple $R^2 = 0.449$; $F_{9,106} = 8.55$, $P < 0.001$

Sculpin density in the statewide dataset showed a significant relationship with model variables ($R^2 = 0.117$; df = 7, 153; $P = 0.007$). Sculpin density was significantly associated with bull trout ($P = 0.050$); sculpin presence was positively associated with lower densities of bull trout. Sculpin density was also positively associated with Rosgen channel type B ($P < 0.001$; Table 3).

### Statewide Streams with No Non-Native Salmonids

For the subset of statewide streams without non-native salmonids present, sculpin presence or absence was positively associated with model variables (null deviance = 158.63, df = 120; residual deviance = 102.29, df = 106; $P < 0.001$). No biological (fish or invertebrate) variables were significantly associated with the presence or absence of sculpin. Among physical variables, Rosgen channel types B ($P < 0.001$) and C ($P < 0.001$), and all mid-sized substrates (i.e., all except sand/silt and large boulder) were positively associated with sculpin presence (Figure 4, Table 4).

Sculpin density was associated with model variables ($R^2 = 0.416$; df = 16, 104; $P < 0.001$). No biological (fish or invertebrate) variables were significantly associated with sculpin density. Among physical variables, density was positively associated with Rosgen channel type B ($P < 0.001$), type C ($P = 0.004$), and all substrate size categories except for the sand/silt and pebble categories (Table 4).

## Discussion

The presence and higher density of sculpins associated with Rosgen channel types B and C within the study areas is best understood based on the specific macrohabitat and microhabitat features of those channel types and information on sculpin ecological requirements, habitat use, and preferences. Type B channels have gradients between 2% and 4%, are moderately entrenched, exhibit low sinuosity (meander frequency), and have rapids-dominated bed morphologies with riffles or runs as the dominant microhabitats. Often there are numerous small scour pools located within run habitats, and the larger pools are spaced 4 to 5 bankfull widths along the longitudinal gradient (Figures 5, 6; Rosgen 1996). Substrates of all sizes may occur in type B channels, depending on geology and land uses (Rosgen 1996).

Stability is a key feature for sculpins in type B channels. Type B channels are inherently stable, as streams in this category are not typically characterized by degradation or aggregation of substrate materials (Rosgen 1996, Buffington and Tonina 2009). The moderately entrenched channel and moderate gradient creates enough hydraulic force to transport fine materials downstream, while leaving the larger substrates of the riffles in place and mostly unembedded (Rosgen 1996, Buffington and Tonina 2009). This stability promotes homogenous and unembedded pebble, cobble, or boulder substrates in the riffles and runs, which studies have found are ideal for sculpin foraging and spawning (Rabeni and Jacobson 1993, Montgomery et al. 1999). As both a benthic and resident fish, this habitat stability is crucial for stable sculpin

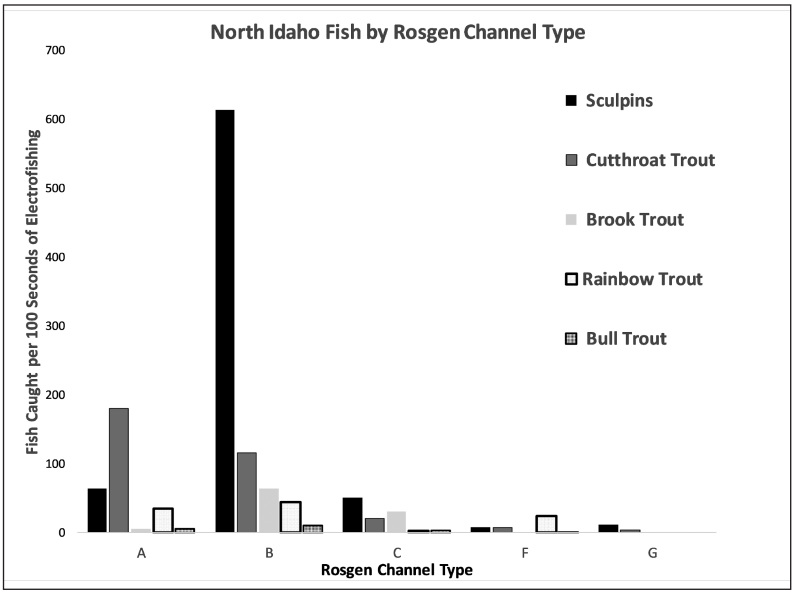



Figure 2. Fish caught by Rosgen channel type for the northern Idaho dataset.

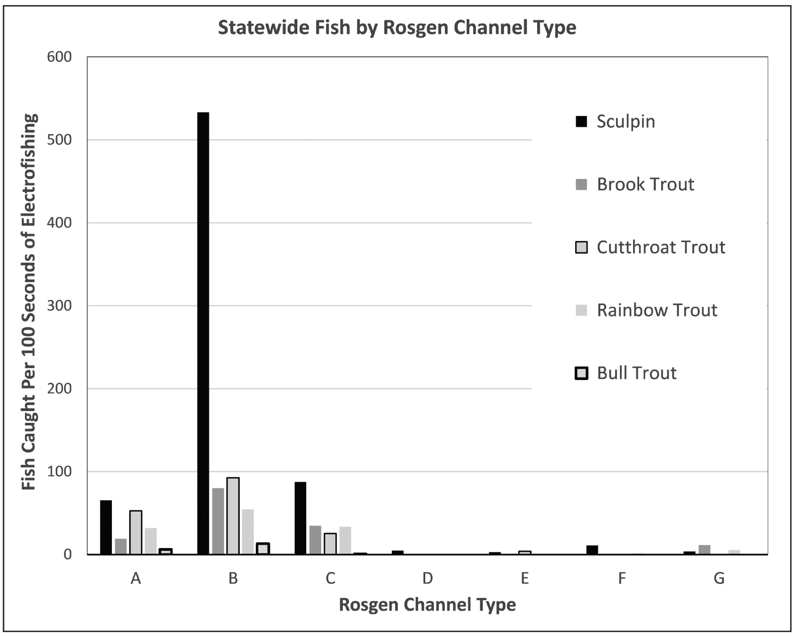



Figure 3. Fish caught by Rosgen channel type for the statewide dataset.

habitats through seasonal variations of high spring flows and low summer base flows (Grossman et al. 2006, Edwards and Cunjak 2007).

Typical type C channels, also found associated with sculpins in this study, have low to flat gradients (< 2%) and moderate to high sinuosity (Rosgen 1996). Type C channels are dominated by riffle-pool habitats, with large deep pools spaced at approximately 5 to 7 bankfull widths along the latitudinal gradient. The pools are on the outsides of sharp meanders and flow into flat laminar glides, followed by depositional point bars and riffles just before the next meander and pool (Figures 5, 6; Rosgen 1996). Substrates of all size categories are common in type C channels, with the composition depending on the local geology (Rosgen 1996). Type C channels are somewhat less stable than type B channels, with more depositional features, bedload aggradation, higher streambank erosion rates, and increased sedimentation of the interstitial spaces of riffle substrates and microhabitats (Rosgen 1996, Buffington and Tonina 2009) often used by sculpins (Rabeni and Jacobson 1993, Montgomery et al. 1999).

While the Rosgen stream classification may be useful as a coarse means to predict sculpin presence, the classification may be best suited for stable river systems with relatively low disturbance (Kasprak et al. 2016). Whereas in highly disturbed or altered streams, other channel classification systems such as the channel evolution model (Cluer and Thorne 2013)

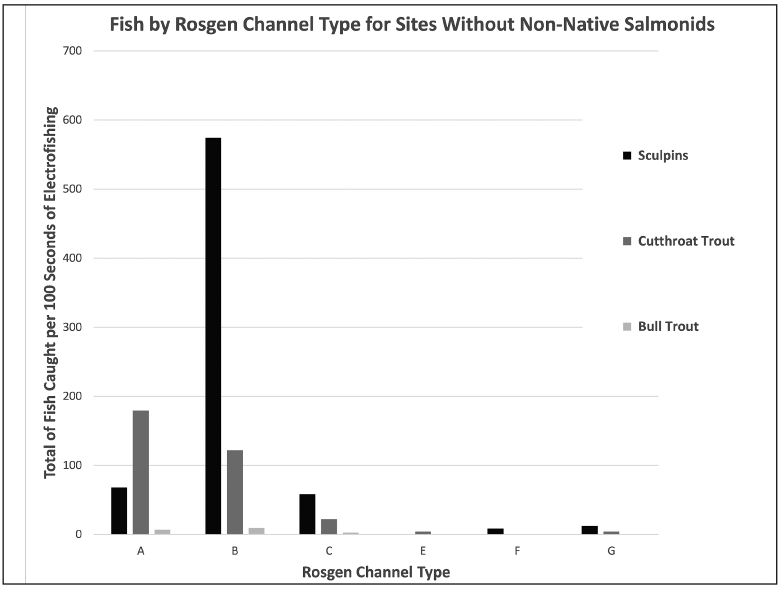



Figure 4. Fish caught by Rosgen channel type for the statewide dataset with Beneficial Use Reconnaissance Program sites that had no observations of brook trout and rainbow trout.

or the river styles framework may be more appropriate (Kasprak et al. 2016). Regardless of their applicability, any stream classification scheme used as a predictor of biotic or abiotic stream components is going to be somewhat limiting, and no classification system will be a perfect fit for all situations (Kasprak et al. 2016).

Although channel classifications evidently provide a coarse indicator of sculpin presence in Idaho streams, using the actual physical variables of streams, regardless of channel type, may be more useful as a refined predictor of sculpin presence/absence and abundance. Results from this study are consistent with prior research showing substrate size, water velocity, and stream gradient as important for some stream-dwelling sculpins (Hawkins et al 1983, Brown 1991, Davey et al. 2005). Substrate size is critical, as stream-dwelling sculpin species in Idaho are cavity nesters who forage and spawn in the interstitial spaces of cobble and boulder substrates that are not heavily embedded by fine materials (Brusven and Rose 1981, Haro and Brusven 1994, White and Harvey 1999, Koczaja et al. 2005). The turbulent and well-oxygenated flow over riffles and runs promotes invertebrate growth and provides spawning habitat for many species of salmonids and sculpins. Resident sculpins will wedge themselves in the cobble substrates to spawn and feed on the rich food sources (Johnson et al. 1983, Anderson 1985, Edwards and Cunjak 2007). Medium- to large-diameter substrates also provide refuge for sculpins from predation, as they can use their adaptive morphologies and camouflage (Edwards and Cunjak 2007, Whiteley et al. 2009) to hide in the cavities of large and relatively unembedded substrates either undetected or unreachable by predatory salmonids (White and Harvey 1999, Bryer et al. 2001, Chivers et al. 2001).

The lower likelihood of presence and lower density of sculpins in the presence of salmonids, including bull trout, brook trout, and rainbow trout, may be a complex response involving predation and competition by native sympatric, native reintroduced, and non-native species. For that reason, it is best evaluated by species and situation. In this study, sculpins sometimes occurred in high numbers despite the presence of abundant native, sympatric cutthroat trout. Juvenile- and intermediate-sized cutthroat trout may function more as a competitor than a predator, as they typically feed primarily on invertebrates (Nowak et al. 2004, Hansen et al. 2013), although they show piscivory in some situations (e.g., Lowry 1966, Tabor et al. 2014). However, cutthroat trout piscivory does increase with age and size, and when environmental stressors limit zooplankton and invertebrate production (Nowak et al. 2004, Hansen et al. 2013). This competition for food is also not necessarily highly pervasive, as juvenile cutthroat trout also prefer shallow, low-velocity fringe areas of streams (Spangler and Scarnec-

TABLE 3. Statistically significant independent variables ($P \leq 0.05$) associated with the statewide streams, including the dichotomous sculpin presence or absence dependent variable analyzed with logistic regression, and the continuous dependent variable of sculpin population density analyzed with multiple linear regression.

| Sculpin presence or absence statewide[a] | | |
|---|---|---|
| Variable | Estimate | *P* |
| Rosgen channel type B | 0.28 | 0.007 |
| Rosgen channel type C | 0.44 | < 0.001 |
| Large cobble substrate (128 to 256 mm) | 0.40 | 0.009 |
| Small boulder substrate (256 to 1,024 mm) | 2.95 | 0.029 |
| Rainbow trout | –0.04 | 0.011 |
| Bull trout | –1.17 | 0.016 |
| Macroinvertebrate score | 0.01 | 0.021 |
| **Sculpin density statewide[b]** | | |
| Variable | Estimate | *P* |
| Rosgen channel type B | 1.00 | < 0.001 |
| Bull trout | –0.46 | < 0.050 |

[a]Null deviance = 217.94, df = 160; Residual deviance = 168.86, df = 145, $P < 0.001$

[b]Multiple $R^2 = 0.117$; $F_{7,153} = 2.9$, $P < 0.007$

TABLE 4. Statistically significant independent variables ($P \leq 0.05$) associated with the statewide streams with no observations of non-native salmonids, including the dichotomous sculpin presence or absence dependent variable analyzed with logistic regression, and the continuous dependent variable of sculpin population density analyzed with multiple linear regression.

| Sculpin presence or absence (native salmonids only)[a] | | |
|---|---|---|
| Variable | Estimate | *P* |
| Rosgen channel type B | 0.36 | < 0.001 |
| Rosgen channel type C | 0.61 | < 0.001 |
| Course pebble substrate (32 to 64 mm) | 0.67 | 0.002 |
| Small cobble substrate (64 to 128 mm) | 0.71 | < 0.001 |
| Large cobble substrate (128 to 256 mm) | 0.84 | < 0.001 |
| Small boulder substrate (256 to 1,024 mm) | 0.95 | < 0.001 |
| **Sculpin density (native salmonids only)[b]** | | |
| Variable | Estimate | *P* |
| Rosgen channel type B | 1.79 | < 0.001 |
| Rosgen channel type C | 1.69 | 0.004 |
| Course pebble substrate (32to 64 mm) | 2.91 | < 0.001 |
| Small cobble substrate (64 to 128 mm) | 3.49 | < 0.001 |
| Large cobble substrate (128 to 256 mm) | 3.39 | < 0.001 |
| Small boulder substrate (256 to 1,024 mm) | 3.32 | < 0.001 |
| Large boulder substrate (> 1,024 mm) | 3.19 | 0.016 |

[a]Null deviance = 158.63, df = 120; Residual deviance = 102.29, df = 106, $P < 0.001$

chia 2001), and adult cutthroat do not occupy riffles for long as they have diel and seasonal migrations to pools, deep runs, undercut banks, and beneath large organic debris (Bonneau and Scarnecchia 1998, Spangler and Scarnecchia 2001). There, cutthroat trout can feed on the variety of deep-water macroinvertebrates in habitats that sculpin would not typically occupy (Logan and Booker 1983).

Bull trout, in contrast, may impact sculpin through predation more than competition (Bryant et al. 2004). Bull trout are highly piscivorous, aggressive, and opportunistic feeders that prey on other salmonids, dace *(Rhinichthys* spp.), and sculpins (D'Angelo and Muhfield 2013, Brenkman et al. 2019). Bull trout sometimes spawn in stream reaches containing sculpins, leading to predation during the bull trout fall spawning period (Bryant et al. 2004, Nakano et al. 1998). Despite bull trout piscivory, the negative impact on sculpins may be limited because of low bull trout density and their well-documented migratory behavior (Hogen and Scarnecchia 2006, Benjamin and Baxter 2010).

The negative relationship between non-native brook trout and rainbow trout and sculpin presence and density in this study is consistent with other studies, which have shown that non-native species in high numbers can be detrimental to sculpins (Dunham et al. 2002, Seiler and Keeley 2009). High densities of non-native salmonids typically result in increased competition for resources (Benjamin 2010, Shephard 2004) and increased predation on native sculpins, beyond the impacts experienced by only native cutthroat trout or bull trout (Dunham et al. 2002, Seiler and Keeley 2009).

For brook trout, potential effects on sculpins beyond those of native salmonids may result from the phenotypic and ecological plasticity of *Salvelinus*

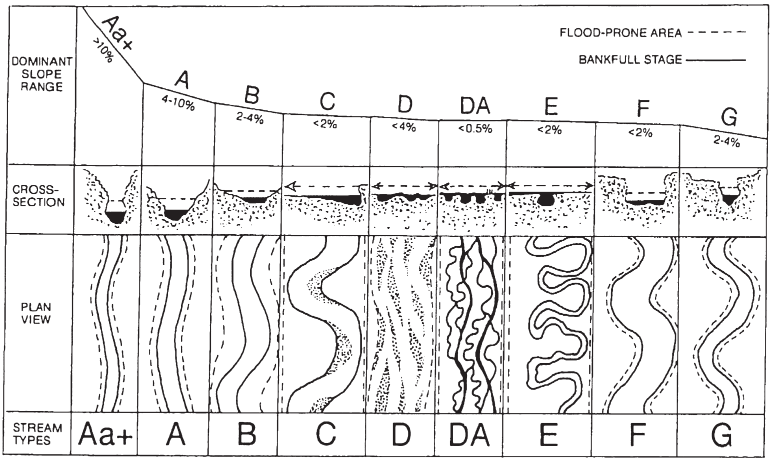



Figure 5. Rosgen stream classification identification diagram with the delineative criteria of stream gradient, channel cross-section, and sinuosity pattern (Rosgen 1996).

in general (Power 2002, Salmenkova and Omelchenko 2013), their fall spawning, and their ability to reproduce rapidly and in high numbers (Peterson et al. 2004). Fall spawning gives age-0 brook trout a size advantage over cutthroat the following spring (Griffith 1972, Benjamin and Baxter 2010), commonly resulting in a range of sizes of age-0 fish the following spring and early summer when cutthroat trout may just be emerging (Scarnecchia 1983). These characteristics often lead to high juvenile biomass and density in streams (Scarnecchia and Bergersen 1987, Benjamin and Baxter 2010), higher than typically found in native cutthroat trout (Griffith 1972, Dunham et al. 2002). In addition to high densities and biomass, and their ability to occupy diverse microhabitats, brook trout are territorial and aggressively piscivorous (Dunham et al. 2002, Seiler and Keeley 2009). Brook trout often deplete the stream of food sources in conjunction with aggressive predation on native fishes, including sculpins (Nakano et al. 1998). The high density and biomass of brook trout allows them to occupy habitat niches in streams that sculpin and cutthroat may otherwise occupy (Peterson et al. 2004, Benjamin and Baxter 2010). Brook trout utilize cover and low velocity microhabitats but venture into the high-velocity shallow riffles and runs to forage for food, including sculpin. As a result, sculpin have been known to leave riffles, runs, and sometimes whole stream reaches to escape further predation (Bryer et al. 2001, Chivers et al. 2001). Research has shown that surviving sculpin will often leave their normal habitats as a threat avoidance mechanism initiated by chemical and sensory cues when brook trout are in the stream and actively preying on sculpin (Bryer et al. 2001, Chivers et al. 2001). The end result can be local extirpation of the native sculpins. In one dissenting study, Zimmerman and Vondracek (2006) found no evidence of interactions between equal-sized brook trout and sculpins in experimental trials, a situation not likely to occur naturally in streams.

Rainbow trout, although typically spring spawners (Scott and Crossman 1983), can impact sculpin populations through competition and predation similar to brook trout. Rainbow trout of any life history (i.e., hatchery raised, native resident, or anadromous steelhead) introduced or re-introduced into waters can alter the interactions within that native aquatic community, including sculpins (Einum and Fleming 2001, Matala et al. 2008). The impact of introduced rainbow trout hybridization with cutthroat trout can further complicate interactions (Hitt et al. 2003). In many Idaho river basins, sympatric cutthroat and rainbow can hybridize (Hitt et al. 2003, DeHaan et al. 2010), leading to increased numbers of the more aggressive rainbow trout or cutbow trout hybrids (*Oncorhynchus clarkii* x *Oncorhynchus mykiss*) and an overall reduction of cutthroat trout and sculpins (Einum and Fleming 2001). The result of brook trout and rainbow trout introductions can thus be a reduction of the total biota of a stream (Simon and Townsend 2003), and a reduction or extirpation of sculpins and other native fish that might otherwise exist in high numbers (Chivers et al. 2001, Rieman et al. 2006, Cucherousset and Olden 2011). Depending on the specific habitat

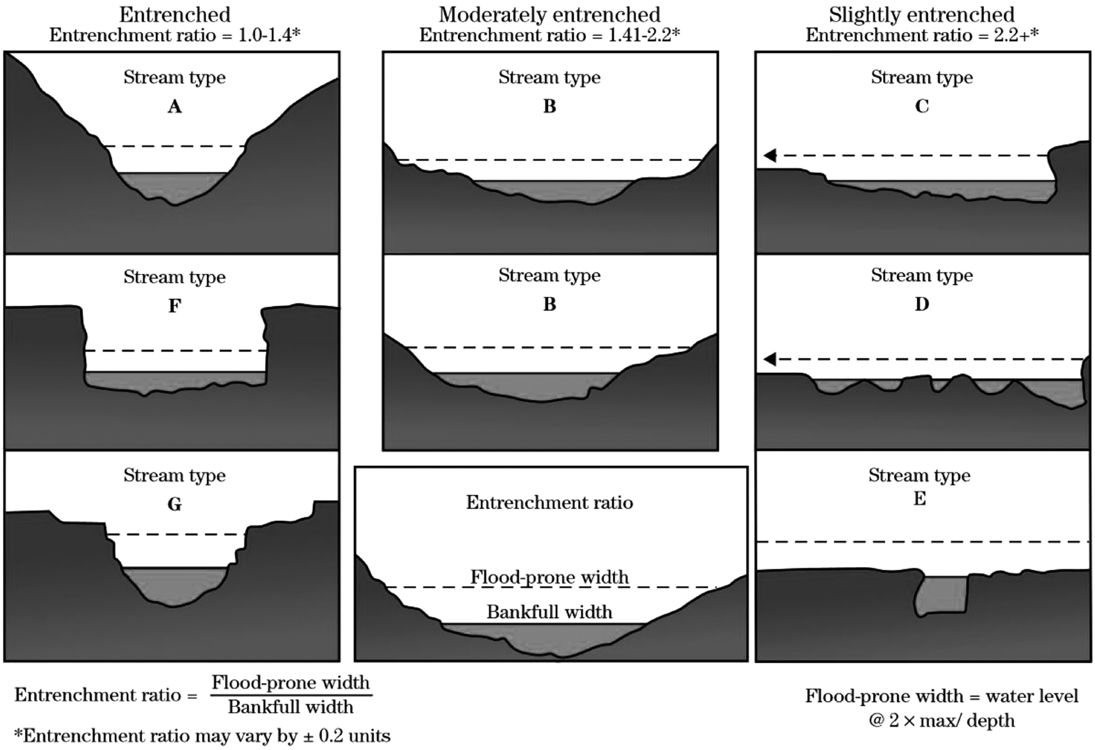



Figure 6. Examples of general channel shape, entrenchment diagrams, and entrenchment ratios for all Rosgen channel types (Rosgen 1996).

conditions, outcomes among native trout, non-natives, and sculpins can be expected to vary among streams and localities (e.g., Shepard 2004). Results from this study using BURP survey data suggest several possible species interactions that are worthy of being addressed with more intensive, focused field research studies. Such studies can address our limitations of using survey data, including any possible species-specific differences among sculpins, differences in density among species, and actual fish size distributions of sculpins and salmonids.

Sculpins, as generally sedentary denizens of many of Idaho's coldwater streams, are likely to remain useful in water quality assessment (Mebane 2001, Mebane et al. 2003). Results of this study may provide some clarification on how to interpret their presence or absence in relation to other abiotic and biotic factors besides standard water quality measurements. It may be possible to develop a general baseline predictor of sculpin presence/absence and density based on channel morphology, channel habitat characteristics, and the presence or absence of other fish species, and these predictors would lead to a clearer interpretation of sculpin data in water quality and stream health assessments (Mundahl et al. 2012). Any evidence that introduced salmonids such as brook trout may negatively impact sculpin above those impacts experienced from native salmonids alone may provide scientific rationale for non-native suppression. It may also create an opportunity to use sculpin as a tool for monitoring the effects of such suppression, as well as indicators of other fisheries habitat management actions. Sculpin populations can be an indicator of success or failure when agencies are working to restore native fisheries and their habitats. In these ways, the often overlooked and understudied sculpins may play an increasingly important role in interpreting the health of the region's coldwater streams and watersheds.

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