FISHERY RESEARCH

STATUS AND POPULATION CHARACTERISTICS OF WOOD RIVER SCULPIN IN IDAHO

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Status and Population Characteristics Of Wood River Sculpin in Idaho

Part #1: Distribution, Abundance, and Mitochondrial DNA Differentiation of Wood River Sculpin Throughout Its Endemic Range

Part #2: Life History Characteristics of the Wood River Sculpin in Idaho

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ABSTRACT

The Wood River sculpin *Cottus leiopomus* is endemic to the Wood River basin in central Idaho and is a nongame species of concern because of its limited distribution, but the status of this species has not been assessed. We used backpack electrofishers to survey streams that were small enough (i.e. <10 m wide; first- to fourth-order streams) to collect quantitative distribution and abundance data for Wood River sculpin. Mitochondrial DNA control region sequencing was also used to investigate the distribution of genetic variation across the species' range. Of the 102 study sites surveyed, Wood River sculpin were present at 20 (20%) sites, including 50, 15, and 0% of the sites predicted *a priori* to contain, possibly contain, or not contain them, respectively. Comparatively, native redband trout *Oncorhynchus mykiss gairdneri* were present at 21 (21%) study sites, including 18 (90%) of the 20 sites that contained Wood River sculpin. Sixty-one (60%) study sites were dry or nearly dry (i.e. had too little water to contain any fish). We estimated that about 1.36 million Wood River sculpin (≥20 mm total length) currently reside in the Wood River basin. The presence of Wood River sculpin was positively associated with stream width:depth ratio and percent cobble/boulder substrate and negatively associated with stream gradient. Mitochondrial DNA haplotype differences were observed both between and within the three major river subbasins supporting Wood River sculpin. The most striking differences were observed between populations in the Camas Creek subbasin and the other two subbasins in which no haplotypes were shared, suggesting relatively long-term isolation. Our results suggest that Wood River sculpin are as widespread as and far more abundant than redband trout within their endemic range, despite obvious changes in historical stream connectivity due to irrigation diversions and other chronic habitat alterations.

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INTRODUCTION

The Wood River sculpin *Cottus leiopomus* is one of eight sculpin species found in Idaho (Simpson and Wallace 1982). Although some of Idaho's sculpin species are widely distributed throughout the state, the Wood River sculpin is endemic only to the Wood River basin and its three associated subbasins, the Big Wood River, Little Wood River, and Camas Creek. The Wood River sculpin is a benthic species that inhabits flowing water from small streams to large rivers, and is often found in sympatry with native redband trout *Oncorhynchus mykiss gairdneri*.

The Wood River sculpin is recognized as a nongame species of concern by the Idaho Department of Fish and Game (IDFG 2006) due to its historically restricted distribution and more recent habitat fragmentation and alterations. However, little is known of the species' current distribution, abundance, population trends, connectivity, or genetic population structure. To our knowledge, no peer-reviewed publications exist on this species except a few unpublished agency reports (e.g., Merkley and Griffith 1993). Although most likely a sedentary species like other stream-dwelling sculpin (Hill and Grossman 1987; Petty and Grossman 2004), the large number and size of irrigation withdrawals and diversions in the basin (Thurow 1988; Megargle 1999) could exacerbate the lack of connectivity.

In light of the scarcity of existing data and the sensitive status of the species, the main objective of this study was to evaluate the current distribution and abundance of Wood River sculpin throughout their historical range. To assess the sympatric relationship between Wood River sculpin and redband trout, we also collected distribution and abundance data on trout as well. We measured a variety of habitat conditions to assess what factors might influence the distribution and abundance of Wood River sculpin across their range. Finally, we examined the genetic population structure of Wood River sculpin populations found in the Big Wood River, Little Wood River, and Camas Creek subbasins.

OBJECTIVES

1. Assess the distribution and abundance of Wood River sculpin in Idaho.

2. Assess what environmental factors relate to Wood River sculpin distribution and abundance.

3. Assess the genetic population structure of Wood River sculpin in Idaho.

METHODS

The Wood River is a tributary of the Snake River in central Idaho. The river does not connect with the Snake River because there is a geologic barrier (i.e. a 20 m waterfall) about 5 km from the mouth. Also, it goes dry before it reaches the Snake River, partly due to percolation of surface water into the Snake River Aquifer and partly because of irrigation diversion of surface water. However, before its confluence with the Snake River it reemerges as what is known as the Malad River. Two dams with no fish passage further isolate sculpin populations and other fishes: Magic Reservoir in the Big Wood River subbasin (built in 1910) and Little Wood Reservoir in the Little Wood River subbasin (built in 1939).

The basin contains over 6,000 km of stream covering 7,778 km² of semiarid valleys and mountainous headwaters that range from 837 m to over 3,600 m in elevation (Figure 1). Vegetation includes western spruce-fir and pine forests at upper elevations and sagebrush steppe at lower elevations. Precipitation is mostly in the form of winter snowpack and ranges from 18 cm in the lower valleys to 64 cm in the mountains. Discharge is driven by snowmelt and peaks between April and June, but is modified by numerous irrigation diversions in mainstem and tributary streams. Native species in the Wood River basin include the Wood River sculpin, redband trout, mountain whitefish *Prosopium williamsoni*, bridgelip sucker *Catostomus columbianus*, largescale sucker *Catostomus macrocheilus*, Utah chub *Gila atraria*, longnose dace *Rhinichthys cataractae*, speckled dace *Rhinichthys osculus*, and redside shiner *Richardsonius balteatus*. Piute sculpin *Cottus beldingii* also appear to be present in the basin (Merkley and Griffith 1993) and are difficult to distinguish from Wood River sculpin, but their distribution is sparse and it is unclear if they are native to the basin. Introduced species that have established self-sustaining populations include brook trout *Salvelinus fontinalis* and brown trout *Salmo trutta*.

Study Site Selection

Data collection occurred in 2003. Spatially balanced randomly selected study sites were generated with the help of the Environmental Protection Agency's Environmental Monitoring and Assessment Program (Figure 1). The technique maps two-dimensional space (i.e. a 1:100,000 scale hydrography layer) into one-dimensional space with defined, ordered spatial addresses, and uses restricted randomization to randomly order the spaces, which when systematically sampled results in a spatially balanced sample (Stevens and Olsen 2004). The study design and sampling frame was stratified in two ways to reduce overall variation in the abundance data and make estimates more accurate. First, based on professional knowledge of the geomorphology and anthropogenic alterations in the basin, and the suspected sympatry between redband trout and Wood River sculpin combined with our knowledge of redband trout distribution, all stream reaches were categorized *a priori* as either (1) likely to contain, (2) not likely to contain, or (3) possibly contain Wood River sculpin. Stream order (Strahler 1964) was used as a second stratification.

Fish and Habitat Sampling

At each study site, fish were captured using electrofishing gear. Depending on stream width, crews of two to four people performed multiple-pass electrofishing removals using one or two gas-powered backpack electrofishing units. Pulsed DC was used, with pulses of 3-5 ms, 500-900 volts, and 30-60Hz. Sampling occurred during low to moderate flow conditions (i.e. after spring runoff and before the onset of winter) to facilitate effective fish capture and standardize sampling conditions. Only Wood River sculpin and trout were depleted in this process. Fish were identified, enumerated, measured to the nearest millimeter (total length, TL) and gram, and released. Study sites were typically (91% of the time) between 80 and 120 m in length (depending on habitat types, riparian vegetation, and ability to place block nets) and averaged 96 m (range 45-130 m).

Maximum-likelihood abundance and variance estimates for Wood River sculpin and trout were calculated for each study site with the MicroFish software package (Van Deventer and Platts 1989). Wood River sculpin abundance estimates could not be obtained from larger mainstem reaches of the Wood River basin (>10 m in width, 5th order streams and larger). These reaches (497 km in total length) were excluded from our analyses despite the fact that sculpin and trout were usually present in these reaches. Subsequently, this study focuses only on the smaller (<10 m in width) tributary streams and upper ends of the mainstem rivers.

Because electrofishing is known to be size selective (Sullivan 1956; Reynolds 1996), Wood River sculpin were separated into two length categories (<60 mm TL and ≥60 mm TL), and trout were similarly separated into two length categories (<100 mm TL and ≥100 mm TL). Abundance estimates were made separately for these size groups and summed for an overall estimate. Capture efficiency for sculpin <20 mm and trout <40 mm was especially low relative to larger fish, and thus, abundance estimates for sculpin <60 mm and trout <100 mm were probably underestimated (Peterson et al. 2004).

At each study site, we determined elevation (in meters) from U.S. Geological Survey 1:24,000 topographic maps using Universal Transverse Mercator (UTM) coordinates obtained at the lower end of the reach electrofished. Stream order was determined from a 1:100,000 stream hydrology scale. Gradient (%) was determined using the software package All Topo Maps Version 2.1 for Windows (iGage Mapping Corporation, Salt Lake City, Utah); stream length (in meters) was traced between the two contour lines that bounded the study site (average traced distance was about 1,500 m), and gradient was calculated as the elevational increment between the contours divided by the traced distance. Conductivity (µS/cm) was measured with a calibrated hand-held conductivity meter accurate to ± 2%. Land ownership was noted as private or public.

Ten equally spaced transects were established within each study site from which the remaining measurements took place. Stream width (m) was calculated from the average of all transect readings. Across the transects, depth was measured at 1/4, 1/2, and 3/4 distance across the channel, and the sum of the measurements was divided by four to account for zero depths at the stream margins (Platts et al. 1983). Percent substrate composition, unstable banks, and overhead stream shading were occularly estimated at each transect and averaged for an overall mean for each study site.

Estimation of Fish Abundance

We estimated total Wood River sculpin and trout abundance separately for each subbasin using the stratified random sampling formulas from Scheaffer et al. (1996). We first summed the total length of stream for each stream order (or stratum) using the ArcView® geographic information system (GIS), and divided this total by 100 meters of stream (our typical study site length) to calculate the number of sampling units (N_i) in each stratum (L). Our abundance estimates were also standardized to density per 100 linear meters of stream. We calculated a mean abundance ($\overline{y}_i$) within each stream order (stratum) and an associated variance. For total population size (N_{census}), we used the formula:

$$N_{census} = \sum_{i=1}^{L} N_i \overline{y}_i$$

and for variance of N_{census} we used the formula:

$$\widehat{V}(N_{census}) = \sum_{i=1}^{L} N_i^2 \left(\frac{N_i - n_i}{N_i} \right) \left(\frac{s_i^2}{n_i} \right)$$

where s_i^2 is the variance of the observations in stratum *i*, and n_i is the sample size within stratum *i*. From this, we calculated 90% confidence intervals (CIs) around the abundance estimates. All sample sites, including dry and fishless sites, were included in these estimates.

Fish/Habitat Relationships

We assessed whether any stream characteristics that we measured were related to Wood River sculpin distribution and abundance. To do this we first removed all sites that were dry or had too little water to contain any fish. All potential independent variables were then plotted against presence/absence and abundance data to look for abnormalities and nonlinearity in the data. Multicollinearity between independent variables was assessed with correlation analysis. Because percent cobble/boulder substrate and percent fine substrate were highly correlated (r = -0.71), and because percent fine substrate could not be normalized with data transformations, it was removed from further analysis. Because width was used in the calculation of areal abundance (fish/m^2), correlations of areal abundance to width and width:depth ratio were not made. We calculated a mean and 95% CIs for stream conditions with and without Wood River sculpin, with statistically significant differences determined by nonoverlapping CIs (Johnson 1999).

To assess the relationship between each independent variable and presence/absence and abundance of Wood River sculpin, we used logistic and multiple linear regression, respectively. For logistic regression analysis, we used stepwise methods for including variables in the model and used Akaike's Information Criteria (AIC) to assess the best logistic regression models. AIC is an extension of the maximum likelihood principle with a bias correction term that penalizes for added parameters in the model (Akaike 1973), with lower AIC values indicating better-fitting models. For comparison, we also calculated an adjusted R^2 for discrete models (Nagelkerke 1991). For multiple regression analysis, we used stepwise methods for including variables in the model, and used R^2 to judge the strengths of each model.

Genetic Population Structure

We chose mitochondrial NDA (mtDNA) analysis for this assessment because its high mutation rate, strict maternal inheritance, and low effective population size makes it a useful tool for investigating the population structure of recently diverged or closely related groups of taxa (Avise 1994). Additionally, the mtDNA control or “D-loop” gene region has already been successfully amplified and sequenced in several species of sculpin and has demonstrated differences at the subbasin level between populations of fluvial sculpin *Cottus nozawae* (Yokoyama and Goto 2002) in Japan, as well as shorthead sculpin *Cottus confusus* and mottled sculpin *Cottus bairdi* in Idaho (IDFG, unpublished data).

Ten to 22 nonlethal fin clips from Wood River sculpin (total n = 187) were collected from 15 sample locations within the Wood River basin (Table 1), but not necessarily the same locations as the fish abundance study sites (Figure 1). Total genomic DNA was extracted from a 1 x 1 mm piece of fin clip following methods described by Campbell (2000). DNA was re-suspended in 100 µl TE. Approximately 450 b.p. of the mtDNA control region were amplified in a 20 µl reaction consisting of 1 µl DNA extract (approx. 2.5 ng/µl), 2.0 µl 10X buffer (Perkin Elmer), 2.0 µl MgCl2, 1.6 µl BSA, 1.0 µl of each primer, L/5'-TTC CAC CTC TAA CTC CCA AAG CTA G-3' (Lee et al. 1995) and R/5'-CCT GAA GTA GGA ACC AGA TG-3' (Meyer et al. 1990), 1.6 µl 10.0 mM dNTPs (10mM each of dATP, dCTP, dGTP, and dTTP), 0.05 µl Perkin-Elmer Taq polymerase, and 9.3 µl dH2O. Polymerase chain reaction conditions consisted of an initial denaturing cycle of 94°C for 3 minutes, followed by 32 cycles of denaturation at 94°C for 45 seconds, annealing at 52°C for 45 seconds, and extension at 72°C for 1 minute, with a final extension at 72°C for 3 minutes.

Sequencing reactions were performed with a BigDye Terminator Cycle Sequencing Ready Reaction Kit (Applied Biosystems, version 3.1) using both the forward and reverse primers. Sequenced products were cleaned using Edge Biosystems gel filtration plates (Edge Biosystems) and were run out on a Prism 3730 DNA sequencer (Applied Biosystems). Sequences were edited using Sequencher (Gene Codes Corporation, version 4.1.2) and the consensus sequences were aligned using the Clustal W program (Thompson et al. 1994) in the software program MEGA3 (molecular evolutionary genetics analysis, version 3.0; Kumar et al. 2004).

Differences in mtDNA haplotype frequency distributions among the three major subbasins were tested for significance using a Monte Carlo chi-square simulation (Roff and Bentzen 1989). Sequence divergence (p-distance) between haplotypes and a neighbor joining tree (Nei and Kumar 2000) depicting relationships between haplotypes were obtained from aligned sequences using MEGA3 (Kumar et al. 2004). Previously sequenced samples of shorthead sculpin from the Salmon River and Lost River basins; mottled sculpin from the Jarbidge River, Salmon River, and Sinks basins; and torrent sculpin *Cottus rhotheus* from Ames Lake, Washington were included in our analyses for reference purposes.

RESULTS

Wood River sculpin distribution and abundance was determined at 102 study sites in first- to fourth-order streams throughout the Wood River basin, 61 of which were dry or had too little water to sustain fish (Table 1). Fifty-two of the study sites were on private property (65% of which were dry or nearly dry), whereas 50 sites were on public land (52% of which were dry or nearly dry).

The *a priori* categorization of Wood River sculpin distribution was reasonably accurate, demonstrated by the fact that sculpin were present at 10 of 20 sites (50%) where they were expected to be found, 0 of 16 sites where they were not expected, and 10 of 66 sites (15%) where we were unsure if they would be present (Table 1). Comparatively, redband trout were found at 18 of 20 sites (90%) where Wood River sculpin were found, and 3 of the 82 sites (4%) where Wood River sculpin were not found.

Estimation of Fish Abundance

Estimated abundance of Wood River sculpin in Idaho, including only first- through fourth-order streams, was 1,356,600 ± 594,660 (Table 2). Forty-six percent of that abundance came from areas that were *a priori* identified as likely to contain Wood River sculpin, whereas 54% were estimated to be in streams where we were unsure if Wood River sculpin would be present. Comparatively, we estimated there were 175,630 ± 97,200 redband trout in the Wood River basin in first- through fourth-order streams (Table 2). Among all study sites (including those that were dry or had no fish), average linear and areal density of Wood River sculpin was 0.4/m and 2.0/m^2, respectively. At only those sites where sculpin were present, average linear and areal abundance was 2.0/m and 10.2/m^2, respectively.

Fish/Habitat Relationships

At sites that contained enough water for fish to be present (*n* = 43), there appeared to be differences between certain stream conditions and the distribution of Wood River sculpin (Table 3). Most notably, the likelihood of Wood River sculpin presence increased as stream width:depth ratio and percent cobble/boulder substrate increased and stream gradient decreased (Figure 2). The inclusion of all three variables in a logistic regression model gave the best AIC score and explained 52% of the total variation in the model (using the adjusted R^2 for discrete models). At sites that contained Wood River sculpin (*n* = 20), there was little correlation between stream conditions and Wood River sculpin linear or areal abundance, but average depth was the most strongly correlated condition for each abundance parameter (Table 4). For redband trout, linear density was most positively correlated to percent stream shading and most negatively correlated to percent cobble/boulder substrate, whereas areal density was most positively correlated to percent stream shading and most negatively correlated to elevation (Table 4).

Genetic Population Structure

Seven haplotypes (unique DNA sequences) were observed in samples of Wood River sculpin (Figure 3 and Table 5). Because previous sequencing in our lab of the D-loop mtDNA region in other sculpin species has yielded 13 haplotypes, the new haplotypes were labeled HAP14-HAP20.

Statistically significant haplotype frequency differences were observed between the three subbasins ($P < 0.005$, $\chi^2 = 197$). Haplotype 14 (HAP14) was the most common haplotype (66.3%), and was found in all sample locations within the Big and Little Wood river subbasins (Table 5). Haplotype 14 was fixed within eight of 11 sample locations in the Big Wood and Little Wood subbasins and was the dominant haplotype in the other three locations. Haplotypes 15, 16, and 20 were present in the Big Wood subbasin and Haplotype 19 in the Little Wood subbasin but all were found at low frequencies and at only one location. In contrast, haplotype 14 was not observed within any of the sampling locations within the Camas Creek subbasin, where instead the most common haplotype was HAP17 (63.2%). Haplotype 18 was also observed, but only in two sample locations in one stream. Sequence divergence between the five haplotypes observed within the Wood River basin ranged from 0.3% to 1.0%.

All of the haplotypes observed in the Wood River basin clustered together in a neighbor-joining tree into one clade (100% bootstrap support; Figure 4). Haplotypes 17 and 18 in the Camas Creek subbasin formed a weakly supported subclade (56%). The Wood River sculpin clade clustered more closely with Shorthead Sculpin from the Salmon River and Lost River basins than with any of the haplotypes observed in Mottled Sculpin, although this relationship was also weakly supported (61%).

DISCUSSION

We found that Wood River sculpin were somewhat limited in distribution and resided in disconnected populations in the Wood River basin, but for several reasons we do not believe such findings suggest that their distribution or abundance has been reduced to a critical level. First, our assessment probably underestimated both distribution and abundance. For example, we did not take into account fifth- and higher-order streams because sampling efficiency constraints in larger river segments prevented us from making abundance estimates. Sculpin were captured in many of these reaches when sampled independently for salmonid populations (K. Meyer, unpublished data). This negatively biased our total estimates of distribution and abundance. Furthermore, depletion electrofishing typically underestimates fish distribution (Bayley and Peterson 2001; Reynolds et al. 2003) and abundance (Junge and Libosvarsky 1965; Riley and Fausch 1992; Peterson et al. 2004).

Second, because of their sedentary nature, stream-dwelling sculpin already tend to be somewhat fragmented into disconnected populations (Hill and Grossman 1987; Goto 1998; Petty and Grossman 2004). Consequently, habitat alteration and fragmentation may have less impact on such populations as long as individual populations are large enough to maintain genetic diversity. Third, although Wood River sculpin currently occupy only about 11% of the stream kilometers in the Wood River basin (not counting the fifth- and higher-order river reaches), much of their meager distribution was because many sites were dry, due in part to irrigation diversions but also due to natural hydrologic conditions common in the Wood River basin (Castelin and Chapman 1972), thus their connectivity was probably always naturally restricted at some level (also see Meyer et al. 2006). Moreover, Wood River sculpin occurred at 63% of the 32 sites that contained some species of fish, and were nearly as widely distributed and far more abundant than redband trout in the Wood River basin, which are considered to have robust populations in this drainage (Thurow 1988).

Although Wood River sculpin were over seven times more numerous than redband trout, at sites where both were present, Wood River sculpin biomass averaged only 23.5 kg/ha compared to 208.3 kg/ha for redband trout. Previous studies have shown similar relationships between trout and sculpin abundance and biomass (Neves and Pardue 1983; Erman 1986).

The biggest factor associated with Wood River sculpin presence was the presence of redband trout. Wood River sculpin were almost always present when redband trout were present, and almost always absent when redband trout were absent (Figure 1). However, it seems unlikely that there was any causal effect to this relationship. At sites that contained Wood River sculpin, their abundance and that of redband trout were not correlated, and habitat variables that were correlated to fish abundance were different between species. The most likely explanation is that both species require similar basic habitat requirements such as cold water for metabolic function and coarse substrate for spawning and rearing. Once these basic needs are met, our results suggest that additional factors affecting distribution and abundance differ between the two species, as has been shown for other salmonid/sculpin sympatric populations (e.g., Prenda et al. 1997; Inoue and Nakano 2001). Competition between sculpin and trout has been shown to sometimes occur (Brocksen et al. 1968; Ruetz et al. 2003; Hesthagen and Heggenes 2003), but habitat selection shifts can minimize potential competition between sculpin and trout (Prenda et al. 1997).

Few stream conditions we measured were strongly correlated to Wood River sculpin distribution and abundance. Nevertheless, considering their bottom-dwelling nature and need for cobble-boulder substrate for spawning and rearing, it was not surprising to find that Wood River sculpin were more likely to occur where gradient was lower and cobble/boulder substrate was more prevalent. The fact that fish-habitat models usually are region-specific and difficult to transfer to areas outside the original study area (Fausch et al. 1988) is irrelevant for this study because Wood River sculpin only exist in the Wood River basin. Nevertheless, our results should be viewed as introductory, and more research on habitat requirements and preferences for Wood River sculpin is warranted.

Results from this study indicate important haplotype frequency differences both between and within the three major river subbasins supporting Wood River sculpin. The most striking difference was observed between the Camas Creek subbasin and the other two subbasins, in which no haplotypes were shared. Additionally, significant genetic differences were observed within the Camas Creek subbasin, with Willow Creek exhibiting a predominant haplotype not found in the other two sample locations. These results suggest that there is limited gene flow between populations in the Camas Creek subbasin and populations in the Big and Little Wood river subbasins. Similar conclusions can be drawn between Willow Creek and the other two sample locations within the Camas Creek subbasin.

Fewer genetic differences were observed between sample locations in the Big and Little Wood river subbasins, with one haplotype dominant throughout these subbasins. Several additional haplotypes were also observed in low frequency within Gladiator Creek and Warm Springs Creek in the Big Wood River subbasin and in Muldoon Creek in the Little Wood River subbasin. While the majority of the sample locations in the Big and Little Wood river subbasins share the same haplotype, the lack of haplotype diversity within these subbasins prevents any conclusions being drawn regarding current levels of gene flow among these populations. However, as previously mentioned, other species of sculpin have been shown to have low dispersal distances (<50 m; Hill and Grossman 1987; Goto 1998; Petty and Grossman 2004) and exhibit restricted gene flow over short distances (Lamphere 2005; Yokoyama and Goto 2002). Our results suggest similarly low gene flow between populations of Wood River sculpin.

The genetic differences between the Camas Creek subbasin and the other two subbasins are unlikely to be the result of sampling separate species of sculpin. This has been a concern in other drainages in Idaho where some sculpin species have been very difficult, if not impossible, to distinguish morphologically (D. Zaroban, Albertson College Museum Fish Curator, personal communication). Sequencing of the mtDNA D-loop region in Fluvial Sculpin in Japan indicated that intraspecific sequence divergence at the basin level ranged between 0.6% and 1.8% (Yokoyama and Goto 2002). In this study, pairwise sequence divergence estimates among the seven haplotypes observed in the Wood River basin were relatively low (0.3%-1.0%) and similar in range to what we have observed at the basin level in other species of sculpin in Idaho (Campbell, unpublished data). Additionally, the two haplotypes observed in the Camas Creek subbasin, while weakly clustering together in the neighbor-joining tree, did not cluster outside the other haplotypes observed in the Big and Little Wood river subbasins. It is likely that a combination of other factors are responsible for the haplotype differences observed between the Camas Creek subbasin and the other two subbasins, including contemporary influences (dispersal behavior, population isolation as the result of anthropogenic influences, and population size) and historical processes. For example, a review of the geological history of the Wood River basin suggests that numerous quaternary basalt flows occurred in the Camas Creek subbasin (Cluer 1987). Such flows have provided opportunities for isolation and divergence of fish populations and species in the upper Snake River basin (Link et al. 1999).

In summary, Wood River sculpin was the most abundant and one of the most widely distributed species of fish in first- to fourth-order streams in the Wood River basin, being present in most (63%) locations where any species of fish were present. Genetic results indicate restricted gene flow among populations between subbasins and within the Camas Creek subbasin. This is consistent with the life history and low dispersal of many species of stream-dwelling sculpin, although natural (droughts) and anthropogenic changes (habitat alterations and irrigation diversions) may have exacerbated population fragmentation and isolation. The long-term consequences of population isolation (demographic and genetic) for such a sedentary species will probably depend mostly on population size, which appears to be large in many streams throughout the species' range, although highly variable. The stability of population size over time should be monitored. Initially, we suggest that any conservation monitoring and management efforts focus on the Camas Creek subbasin, since estimated abundance was lowest in this subbasin and sampled populations contained mtDNA diversity not found in the other two subbasins.

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Table 1. Stream network (at the 1:100,000 scale) and distributional extent of Wood River sculpin (WRS) from study sites in first- to fourth-order streams sampled in 2003 within three subbasins of the Wood River, Idaho.

Stream network and study sites	Big Wood River	Camas Creek	Little Wood River	Total
Total stream km in Wood River drainage	2,847	1,418	1,738	6,003
Stream km categorized a priori as "WRS present"	244	60	211	515
Stream km categorized a priori as "WRS unknown"	1,455	470	746	2,671
Stream km categorized a priori as "WRS absent"	1,148	888	781	2,817
Total number of sites sampled	52	15	35	102
Sites containing fish	19	4	9	32
Sites within "WRS present" streams...	10	4	6	20
that contained WRS	7	2	1	10
Sites within "WRS unknown" streams...	35	8	23	66
that contained WRS	5	0	5	10
Sites within "WRS absent" streams...	7	3	6	16
that contained WRS	0	0	0	0
Sites containing redband trout	12	3	6	21
Dry or nearly dry sites	29	9	23	61

Table 2. Estimated number (N_{census}) of Wood River sculpin and redband trout present in 2003 in first- to fourth-order streams of the Wood River basin, Idaho.

Size group	Occurrence category	N_{census}	Lower 90% CI	Upper 90% CI
		Wood River sculpin		
≥ 60 mm	Present	402,313	89,977	714,652
	Absent	0		
	Unknown	550,461	126,130	974,792
< 60 mm	Present	226,533	24,915	428,151
	Absent	0		
	Unknown	177,293	503	365,333
Total	All	1,356,600	761,940	1,951,260
		Redband trout		
≥ 100 mm	Present	55,175	14,044	96,306
	Absent	0		
	Unknown	21,297	9,427	33,167
< 100 mm	Present	18,602	54	42,982
	Absent	0		
	Unknown	80,556	156	164,346
Total	All	175,630	78,430	272,830

Table 3. Stream conditions at sites with (n = 20) and without (n = 23) Wood River sculpin in the Wood River basin, Idaho.

Variable	With Wood River Sculpin		Without Wood River Sculpin	
	Mean	95% CI	Mean	95% CI
Stream order	2.7	0.4	2.1	0.6
Elevation (m)	1944.9	89.0	2010.4	171.9
Gradient (%)	2.5	0.8	6.6	3.3
Conductivity (µS/cm)	220.0	55.0	207.0	55.0
Width (m)	4.4	1.1	2.8	0.6
Depth (m)	0.13	0.02	0.16	0.06
W:D ratio	32.5	4.8	22.6	4.7
Percent fine substrate	0.5	0.3	1.4	0.7
Percent cobble/boulder substrate	3.6	0.7	2.5	0.9
Percent shading	1.6	0.4	1.7	0.6
Percent unstable banks	0.5	0.4	0.6	0.4
Redband Trout density (No./m)	0.16	0.10	0.05	0.10

Table 4. Correlations (r) between stream attributes and linear (fish/m) and areal (fish/m²) densities for Wood River sculpin and redband trout at study sites surveyed in 2003 in the Wood River basin, Idaho. Correlations for areal densities did not include width attributes since width is used to calculate areal density.

Stream attribute	Wood River Sculpin density		Redband Trout density	
	Linear	Areal	Linear	Areal
Gradient (%)	- 0.18	- 0.30	0.17	-0.12
Stream order	0.28	0.47	-0.22	-0.11
Elevation (m)	- 0.28	- 0.16	-0.14	-0.35
Conductivity (µS/cm)	0.23	0.22	0.17	0.13
Width (m)	0.21		-0.12	
Depth (m)	0.35	0.53	-0.31	0.07
Width:depth ratio	0.02		0.07	
Percent cobble/boulder substrate	0.22	0.23	-0.37	-0.20
Percent unstable banks	0.01	- 0.07	-0.04	-0.08
Percent shading	- 0.01	0.04	0.56	0.43
Redband Trout density	-0.23	-0.01		

Table 5. Sample number (corresponding to Figure 1) and location, polymorphisms (associated with each haplotype), haplotype, sample size (n), and haplotype frequency at genetic sample locations in the Camas Creek (CA), Big Wood River (BW), and Little Wood River (LW) subbasins in the Wood River basin, Idaho.

	Sub-basin	Sample location	Polymorphisms					Haplo-type	*n*	Freq-uency
			129	185	218	281	290			
1	CA	Soldier Creek	C	G	-	C	C	17	22	1.00
2	CA	Phillips Creek	C	G	-	C	C	17	13	1.00
3	CA	Willow Creek	C	G	-	C	C	17	1	0.08
3	CA	Willow Creek	C	G	A	C	C	18	11	0.92
4	CA	Upper Willow Creek	C	G	A	C	C	18	10	1.00
5	BW	Big Wood River	C	G	-	C	T	14	12	1.00
6	BW	Warm Springs Creek	C	G	-	C	T	14	11	0.92
6	BW	Warm Springs Creek	A	G	-	C	T	20	1	0.08
7	BW	Trail Creek	C	G	-	C	T	14	12	1.00
8	BW	Silver Creek	C	G	-	C	T	14	10	1.00
9	BW	Gladiator Creek	C	G	-	C	T	14	9	0.75
9	BW	Gladiator Creek	T	G	-	T	C	15	2	0.17
9	BW	Gladiator Creek	T	G	-	C	C	16	1	0.08
10	LW	Little Wood River	C	G	-	C	T	14	14	1.00
11	LW	Iron Mine Creek	C	G	-	C	T	14	10	1.00
12	LW	Friedman Creek	C	G	-	C	T	14	10	1.00
13	LW	Muldoon Creek	C	G	-	C	T	14	13	0.87
13	LW	Muldoon Creek	C	A	-	C	T	19	2	0.13
14	LW	Little Copper Creek	C	G	-	C	T	14	10	1.00
15	LW	Porcupine Creek	C	G	-	C	T	14	13	1.00

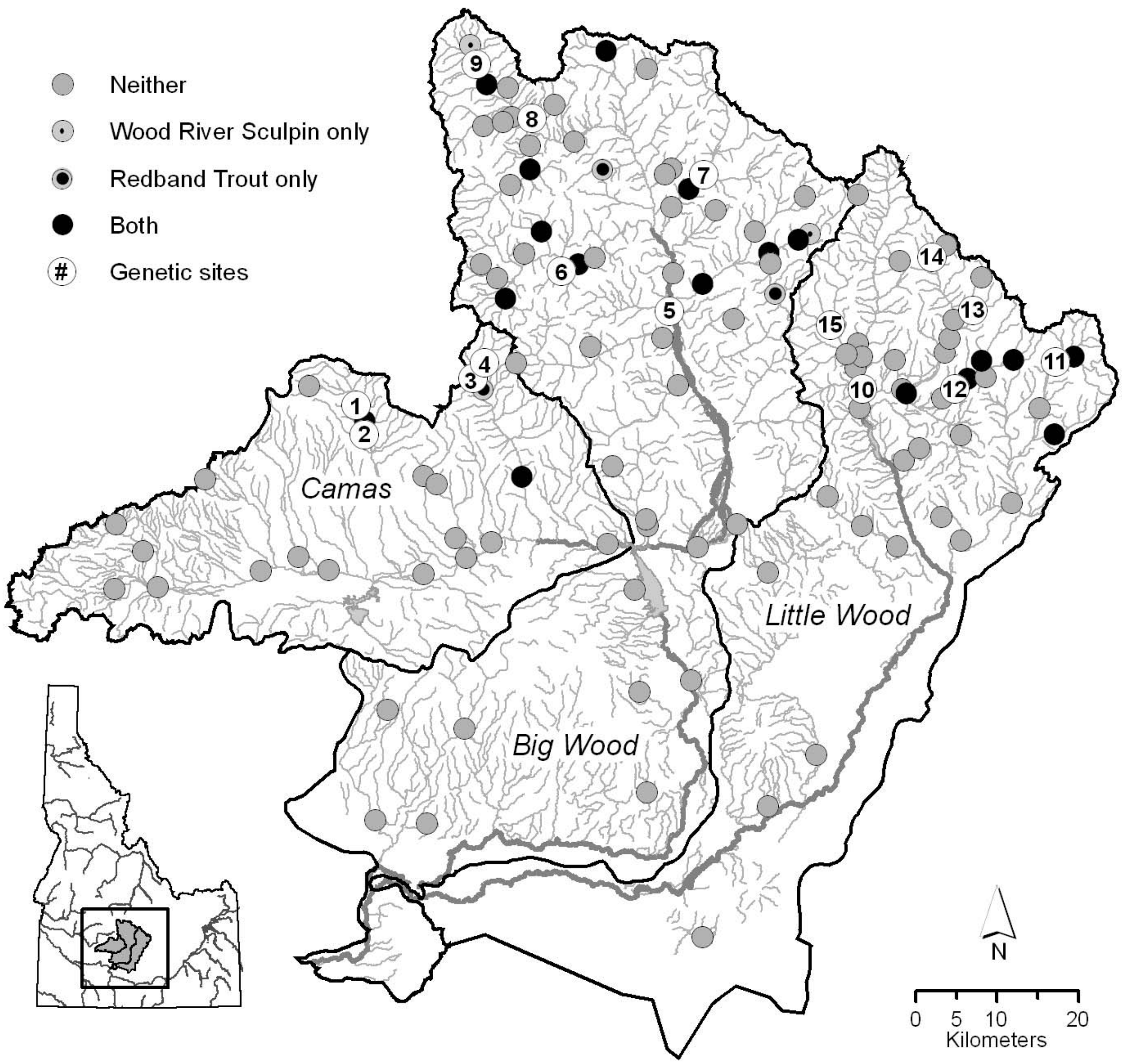

Figure 1. Location of study sites where Wood River sculpin and redband trout were present or absent and where genetic samples were collected in 2003 in the Wood River basin, Idaho. Numbers correspond to genetic sample locations in Part II (Table 6). Fifth-order and higher streams that were excluded from analyses (see methods) are shown as wider gray lines compared to other stream segments.

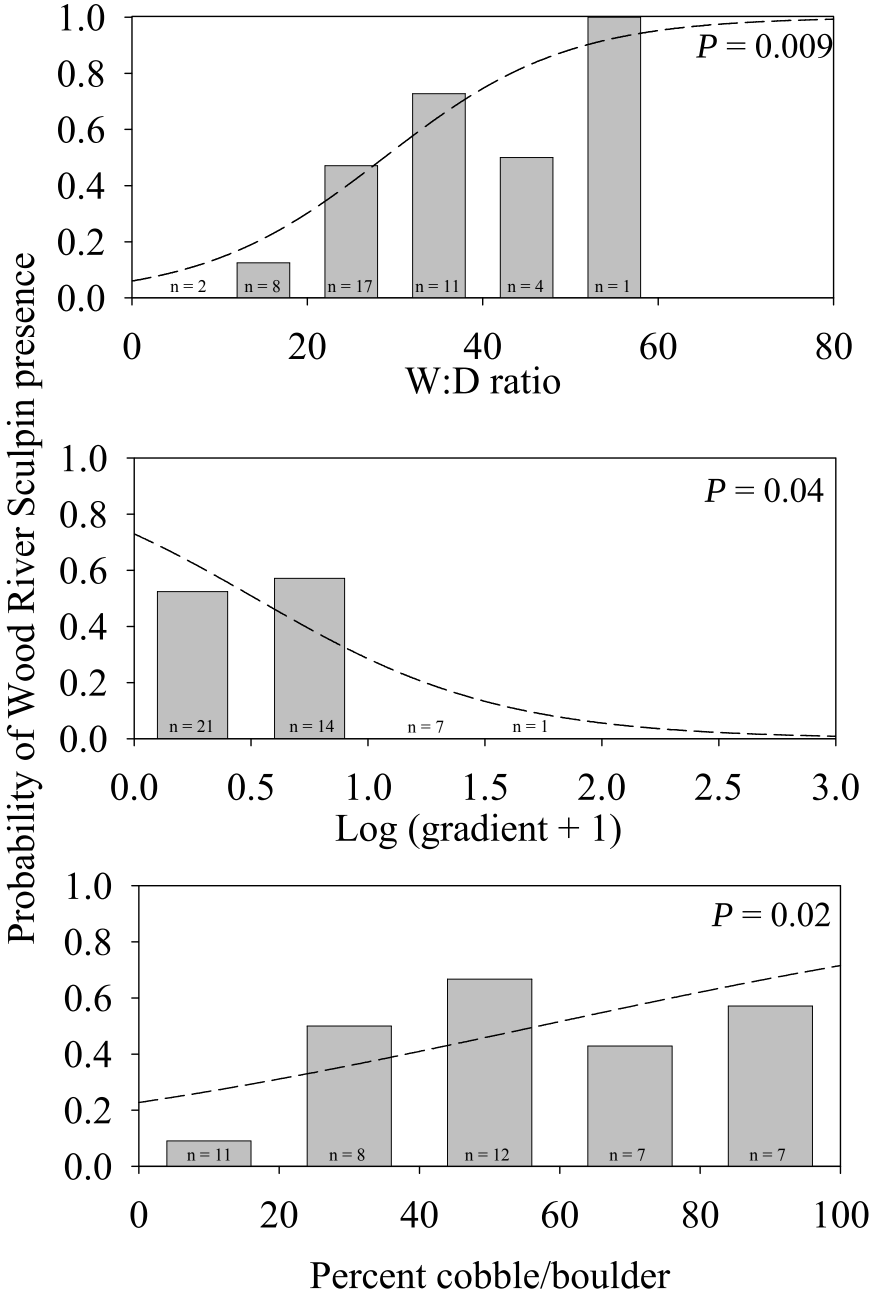

Figure 2. Observed frequency of occurrence (histograms) and probability of occurrence predicted from logistic regression models (dashed lines) for Wood River sculpin against stream conditions in the Wood River basin, Idaho. The centers of the histograms are the mid-points of the bins used in the frequency distributions. P-values are from the combined logistic regression model that included all three stream variables (see text).

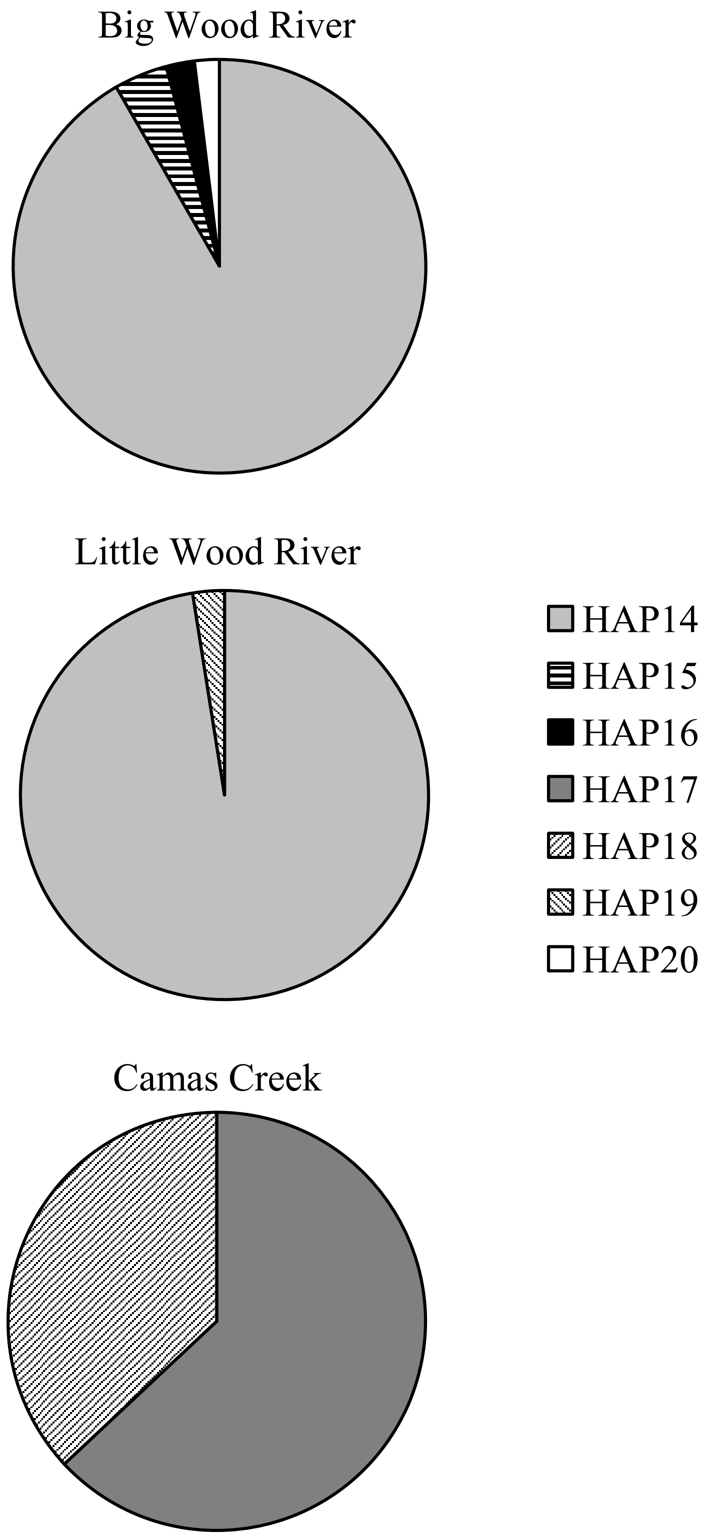

Figure 3 Distribution of mtDNA haplotypes in the Camas River, Big Wood River, and Little Wood River drainages.

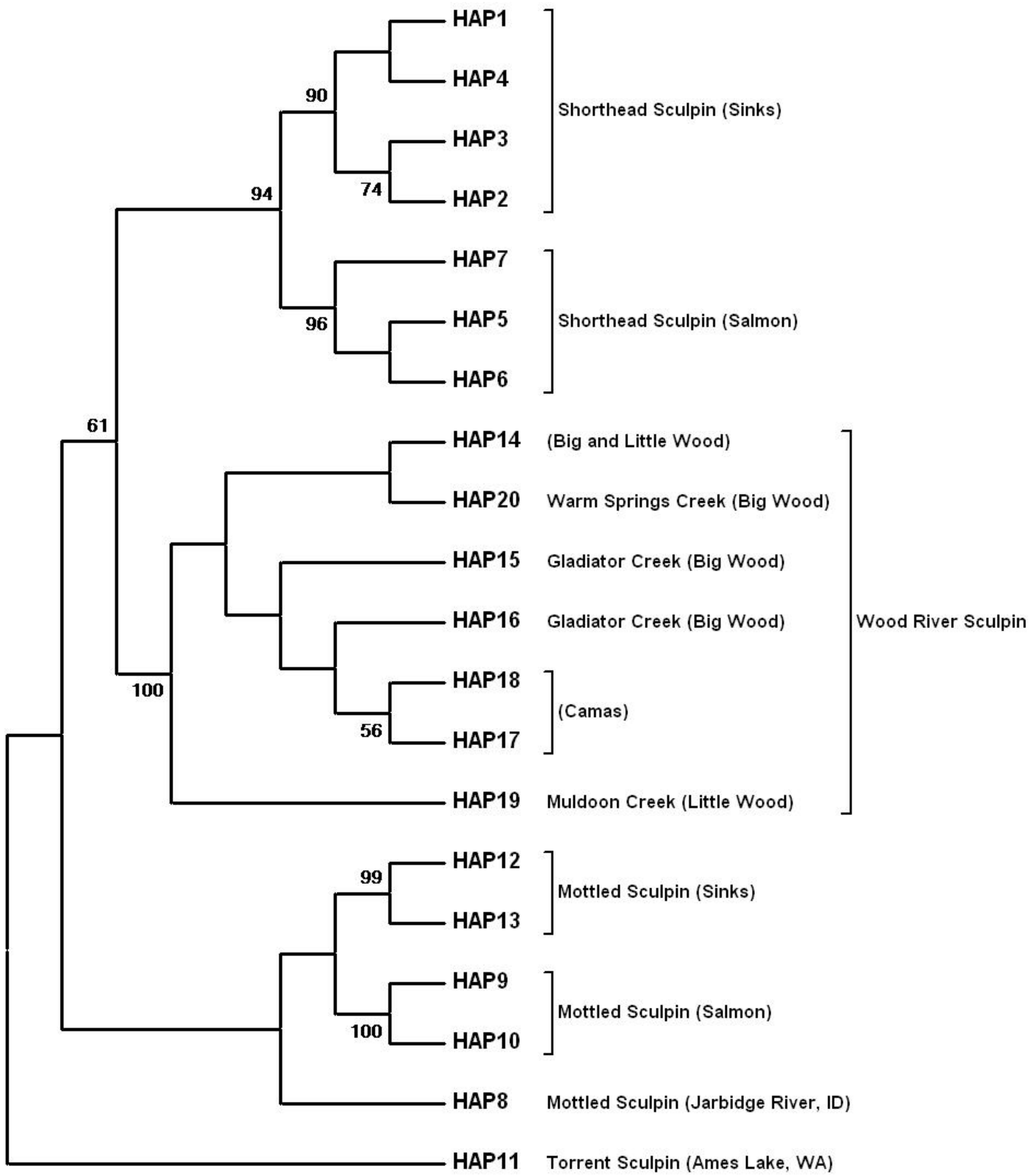

Figure 4. Neighbor-joining tree of observed mitochondrial haplotypes. Haplotypes 14-20 observed in Wood River sculpin. Bootstrap values (in percentage) shown when above 50.

PART #2: LIFE HISTORY CHARACTERISTICS OF THE WOOD RIVER SCULPIN IN IDAHO

ABSTRACT

The Wood River sculpin *Cottus leiopomus* is endemic to the Wood River basin in Idaho and is a nongame species of concern because of its limited distribution, but the status and biological characteristics of this species were previously unknown. We collected 733 Wood River sculpin from 10 populations across the Wood River basin from streams with a variety of physiochemical conditions to determine length and age at sexual maturity and other demographic characteristics. Of the 716 Wood River sculpin whose age could be estimated, most were estimated to be age-1 (16%), age-2 (33%), age-3 (30%), and age-4 (12%). The oldest Wood River sculpin was estimated to be age-8. Estimated total annual survival rate was consistent across all study sites, averaging 66% and ranging from 56 to 70%. Survival was positively correlated with stream order and width and negatively correlated with elevation, gradient, and percent fines and percent gravel substrate. Wood River sculpin reached 60 mm (total length) by age-2 and reached 100 mm at around age-4; the largest Wood River sculpin captured was 121 mm. Sex ratio was near 50:50 for most populations and averaged 51% female across all populations. Fecundity ranged from 38 to 314 eggs and formed a somewhat curvilinear relationship with fish length (r^2 = 0.52). Where spring sampling occurred and maturity could be more definitively determined, almost all Wood River sculpin age-3 and older were mature, regardless of gender. No age-1 fish were mature, and no age-2 males were mature, but 83% of age-2 females were mature. We estimated that females transitioned from immature to mature at about 55 mm and males at about 60 mm. These results are the first published data on the demographic characteristics of Wood River sculpin and provide useful information for the management and preservation of this species.

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INTRODUCTION

The Wood River sculpin *Cottus leiopomus* is endemic to the Wood River basin in Idaho, USA. It is a benthic species that inhabits flowing water from small streams to larger rivers, and is often found in sympatry with native redband Trout Oncorhynchus *mykiss gairdneri*, serving as a prey item for redband trout and as a predator on trout eggs and small young-of-the-year trout. This sympatry is likely due to similar requirements of clean, cool water and coarse substrate (gravel and larger) which stream-dwelling sculpin typically select for spawning and rearing (Bailey 1952; Jones 1972; van Snik Gray and Stauffer 1999). Although the Wood River sculpin appears to be one of the most abundant species of fish in the Wood River basin (Meyer et al., companion paper), because of its limited range it is recognized as a nongame species of concern by the Idaho Department of Fish and Game (IDFG 2006). Little is known of this species, and to our knowledge, there are no published accounts for the species' distribution, abundance, or population characteristics.

OBJECTIVE

1. Examine growth rates, mortality rates, longevity, length-weight relationships, length- and age-specific fecundity, and length- and age-specific maturity of Wood River sculpin.

METHODS

The Wood River is a tributary of the Snake River in central Idaho, which is composed of three major subbasins: the Big Wood River, Little Wood River, and Camas Creek. The river does not connect directly with the Snake River because there is a geologic barrier (i.e. a 20 m waterfall) about 5 km from the mouth. Also, it goes dry before it reaches the Snake River, partly because of percolation of surface water into the Snake River Aquifer and partly because of irrigation diversion of surface water. However, before its confluence with the Snake River it reemerges as what is known as the Malad River. Two dams with no fish passage further isolate sculpin and other fishes: Magic Reservoir in the Big Wood River subbasin (built in 1910) and Little Wood Reservoir in the Little Wood River subbasin (built in 1939).

The basin covers 7,778 km² of semiarid valleys and mountainous headwaters ranging from 837 m to over 3,600 m in elevation. Precipitation is mostly in the form of winter snowpack and ranges from 18 cm in the lower valleys to 64 cm in the mountains. Discharge is driven by snowmelt and peaks between April and June, but is modified by numerous irrigation diversions in mainstem and tributary streams.

Field Sampling

Using backpack- and canoe-mounted electrofishing units, 733 Wood River sculpin were collected from 10 study sites during base flow conditions between July 2003 and February 2004 (Table 6). Most of the samples were collected during the summer, but two samples were collected in late winter prior to spring spawning in order to estimate maturity and fecundity (see below). Sample streams and the study sites within the streams were selected arbitrarily, but we purposefully distributed study sites across a broad geographic area in the Wood River basin that contained a variety of stream conditions (Table 6).

At each study site, Wood River sculpin abundance was determined with depletion electrofishing, using one or more backpack electrofishers with pulsed DC. Block nets were installed at the upper and lower ends of the sites to meet the population estimate modeling assumption that the sculpin populations were closed. Depletion sites were 70–120 m in length (depending on habitat types and ability to place block nets). Maximum-likelihood abundance and variance estimates were calculated with the MicroFish software package (Van Deventer and Platts 1989). Because electrofishing is known to be size selective (Sullivan 1956; Reynolds 1996), Wood River sculpin were separated into two length categories, <60 mm TL and ≥60 mm TL. Abundance estimates were made separately for these two size groups and summed for an overall estimate. Capture efficiency for sculpin <20 mm was low relative to larger fish, thus estimates for fish <60 mm were probably underestimated. Captured Wood River sculpin were overdosed with tricaine methanosulfonate (MS-222) at 250 mg/L and transported directly to a freezer for storage. If an adequate sample was not obtained from within the depletion reach, electrofishing continued in an upstream direction until a sufficient number of fish were captured and retained. Our goal was to retain 60-100 fish from each location for demographics analyses.

In addition to Wood River sculpin density, several other physical and physiochemical stream attributes were measured to assess their effect on Wood River sculpin demographic characteristics. Selection of which stream characteristics to measure was based on their ecological importance, and on previous research into factors generally related to fish growth as well as age and length at maturity. We generally focused on variables we felt reflected stream size (e.g., stream order, width, depth), fish growing conditions (e.g., elevation, water temperature, conductivity), or microhabitat characteristics (substrate, depth, stream shading, unstable banks).

At each collection site, we determined elevation (in meters) from U.S. Geological Survey (USGS) 1:24,000 scale topographic maps using Universal Transverse Mercator (UTM) coordinates obtained at the lower end of the reach electrofished. Stream order (Strahler 1964) was determined from a 1:100,000 scale stream hydrography layer. Gradient (%) was determined using the software package All Topo Maps Version 2.1 for Windows (iGage Mapping Corporation, Salt Lake City, Utah); stream length (in meters) was traced between the two contour lines that bounded the study site (average traced distance was about 1 km), and gradient was calculated as the elevational increment between the contours divided by the traced distance. Conductivity (µS/cm) was measured with a calibrated hand-held conductivity meter accurate to ± 2%.

Ten equally spaced transects were established throughout the sample site from which the remaining measurements took place. Stream width (m) was calculated from the average of all transect readings. Across the transects, depth was measured at ¼, ½, and ¾ distance across the channel, and the sum of the measurements was divided by four to account for zero depths at the stream margins (Platts et al. 1983). Percent substrate composition, unstable banks, and stream shading were occularly estimated at the transects and averaged for an overall mean for each study site. Because both cobbles and boulders provide refuges that are commonly used by stream-dwelling sculpin for spawning and rearing (Zarbock 1951; Natsumeda 1998, 2001), we pooled them into a combined percent composition value.

Laboratory Processing and Analysis

Sacrificed fish were thawed in the laboratory, blotted dry, and measured for total length (TL, nearest mm) and weight (nearest g). Sagittal otoliths were removed and stored dry in vials. To age fish, annuli were counted on otoliths that were viewed primarily dry or submersed in water, with a dissecting microscope using reflected or transmitted light. Annuli were counted as the translucent zones when using reflected light (Patten 1971). Readers had no knowledge of fish length during readings and read otoliths at separate time periods. The same two readers aged all fish, and agreement between first readings was deemed satisfactory; for our 10 study sites, the mean index of average error (Beamish and Fournier 1981) between readers was 10.2%. Discrepancies between readers were resolved with additional readings, and for those that could not be resolved (*n* = 17), results for that fish were discarded. All fish were considered one year old when they reached their first January.

Gender was determined by laboratory examination of the gonads. Ovaries were visually distinguishable from testes for Wood River sculpin about 40 mm and larger (in general, fish below this size were not sexed). To evaluate sex ratio at each site, we calculated 95% confidence intervals (CIs) around the percentage of the population that was female, following Fleiss (1981); CIs not overlapping 50% indicated a statistically significant departure from a 50:50 ratio.

Maturity was determined only from the late winter samples collected on February 28, 2004, just before the presumed spawning period (Bailey 1952; Gasser et al. 1981). Males were classified as immature if testes were opaque and threadlike and mature if they were thicker, fleshy, and cream-colored. Females were classified as immature if the ovaries were small and granular, and mature if they contained large, well-developed eggs. To estimate fecundity, eggs were removed and counted from 50 gravid females. A curvilinear power function was developed to predict fecundity (F) from fish length (TL).

We characterized the length and age at maturity (termed the maturity transition point, or MTP; see Meyer et al. 2003) for Wood River sculpin from the two late winter sample sites. For estimating length at maturity, we used one of two methods. If there was no overlap between the largest immature and smallest mature fish, we selected the midpoint between the length of these two fish as the MTP. If there was overlap, we related fish length to maturity using logistic regression, using a binary dependent variable (0 = immature, 1 = mature), and selected the MTP as the fish length at which the probability of being mature was equal to 0.5. Separate estimates were developed for males and females because length at maturity selection forces may be different between sexes (Roff 1992). These guidelines were not appropriate for age at maturity characterization because there was no age overlap in immature and mature fish for males or females. Instead, we simply reported the percent of each sex that was mature at each age.

Following Robson and Chapman (1961), we estimated total annual survival rate (*S*) and 95% CIs using catch curves. Based on the results of the catch curves, it appeared that only age-2 and older Wood River sculpin were fully recruited to the electrofishing gear and thus useable for survival estimates. We assumed that capture efficiency was equivalent for sculpin age-2 and older. For comparison and to test this assumption we also estimated *S* only using fish age-3 and older. Growth was assessed by calculating mean length at age (and 95% CIs) following DeVries and Frie (1996).

We assessed whether any stream characteristics that we measured were correlated to Wood River sculpin survival and growth estimates obtained from summer sampling sites (*n* = 10 sites total). We first plotted all potential independent variables against survival and growth to assess whether any relationships appeared nonlinear and to look for data abnormalities, but neither nonlinearity nor abnormalities were apparent. Because areal density of Wood River sculpin was not independent of width, we standardized sculpin density using a linear estimate (number/m). Multicollinearity between independent variables was assessed with correlation analysis; depth was highly correlated (r >0.70) with four other variables and thus was removed from consideration, but no other elevated correlations were encountered. We then assessed the relationship between each independent variable and growth and survival (separately) using correlations and multiple linear regression. Because our growth data was obtained throughout the summer, we used Julian date of the sample in all the models to account for this known variation instead of back-calculating growth to a standardized date, which tends to underestimate length at age (Campana 1990). To assess whether stream attributes affected growth of young Wood River sculpin differently than older fish, we analyzed growth of both age-1 and age-3 fish against stream characteristics.

RESULTS

Of the 716 Wood River sculpin whose age could be estimated, most were projected to be age-1 (16%), age-2 (33%), age-3 (30%), or age-4 (12%). Only 11 fish (<2%) were estimated to be age-6 and older. The oldest Wood River sculpin was estimated to be age-8 at Soldier Creek. Five of the 10 study sites contained no fish that were estimated to be older than age-4.

Estimated total annual survival rate (S) was very consistent across all sites (Figure 5), averaging 66% and ranging from a low of 56% (± 6%) at Iron Mine Creek to a high of 70% (± 6%) at Warm Springs Creek. Had we only used age-3 and older sculpin to estimate survival, S would have been only slightly lower on average (mean 60%, range 53 to 74%). Estimated total annual survival at the study sites (from summer sampling only) was positively correlated with stream order and width and negatively correlated with gradient (Table 7). Conductivity, percent stream shading, and sculpin density had the weakest correlations to sculpin S. The inclusion of width, gradient, and stream order in a multiple linear regression model accounted for 63% of the variation in S.

Growth was most rapid from age-0 to age-3 and began to level off afterwards (Figure 6). On average, Wood River sculpin reached 60 mm by age-2 and 90 mm at around age-4 (Table 8); the largest Wood River sculpin captured was 121 mm. Not surprisingly, growth within each age tended to increase as the summer progressed, at least for ages 1 through 5 (Figure 7). Most fish (74%) were between 50 and 90 mm TL, and less than 4% were >100 mm (Figure 8). Comparing growth of male and female sculpin from the two sites sampled in the winter (when sex could be most definitively determined), males were larger than females for all five meaningful comparisons (i.e. samples sizes >1 for both sexes), but in only two of the five comparisons did the 95% CIs not overlap (Table 9).

For age-1 Wood River sculpin, percent fines were positively correlated, and gradient and percent gravel were negatively correlated to mean length at age (Table 2); percent stream shading and sculpin density were not strongly correlated to age-1 mean length at age. With the inclusion of Julian day to account for seasonal variation in length at age, percent fines and percent gravel substrate accounted for 57% of the variation in age-1 mean length at age. For age-3 fish, stream order, conductivity, and percent fines were all weakly negatively correlated to mean length at age, with correlations even lower for the remaining comparisons (Table 2). With the inclusion of Julian day, stream order and percent gravel accounted for 55% of the variation in age-3 mean length at age.

Sex ratio was near 50:50 for most populations. The proportion of the population that was female averaged 51% (± 4%) and ranged from a low of 39% (± 14%) at East Fork Big Wood River to a high of 71% (± 15%) at Iron Mine Creek. Ninety-five percent CIs around the estimate of the proportion of the population that was female did not include 50% at only two locations (Iron Mine Creek and the lower Friedman Creek site). Total length (mm) and weight (g) were highly correlated ($g = 0.00001 \cdot TL^{3.071}$, n = 733, r^2 = 0.98) and fit a curvilinear (i.e. power function) regression.

The length-fecundity relationship for Wood River sculpin was somewhat curvilinear and there was much scatter to the data (Figure 9), although there was much more scatter in the age-fecundity relationship, which appeared to be linear. Fecundity ranged from a low of 38 eggs in a 58 mm age-2 fish to a high of 314 eggs in an 86 mm age-4 fish. Mean fecundity by age for Warm Springs Creek was 132 for age-2 fish (n = 10), 141 for age-3 (n = 13), 194 for age-4 (n = 5), and 268 for age-5 (n = 1). In comparison, mean fecundity for Trail Creek was 110 for age-3 fish (n = 17), 169 for age-4 (n = 1), and 140 for age-5 (n = 1).

Where winter sampling occurred (Warm Springs and Trail creeks) and maturity could be more definitively determined, almost all Wood River sculpin age-3 and older were mature, regardless of gender (Figure 10). No age-1 sculpin were mature, and no age-2 male sculpin were mature, but 57% of age-2 female sculpin were mature. For females, there was no overlap between the largest immature and smallest mature fish for either Warm Springs Creek (53 and 58 mm) or Trail Creek (53 and 57 mm), whereas for males there was overlap between the largest immature and smallest mature fish for both Warm Springs Creek (74 and 62 mm) and Trail Creek (68 and 61 mm; Figure 11). Maturity transition points for Warm Springs Creek and Trail Creek were almost identical for both genders, with females transitioning from immature to mature at 56 mm and 55 mm, respectively, compared to 62 mm for males at both locations (Figure 11). Once the transition occurred, nearly all fish appeared ripe, suggesting that mature fish spawned every year.

DISCUSSION

Our results demonstrate that Wood River sculpin on average live to be about 6 years old, reach sexual maturity in the spring by about 3 years of age and 60 mm in length, have a 50:50 sex ratio, grow to 100 mm by age 5, and rarely exceed 120 mm. Based on these characteristics, Wood River sculpin appear to be demographically similar to other stream-dwelling species of sculpin in Idaho, such as shorthead sculpin *C. confusus*, Piute sculpin *C. beldingi*, mottled sculpin *C. bairdi*, and slimy sculpin *C. cognatus* (Zarbock 1951; Bailey 1952; Patten 1971; Craig and Wells 1976; Gasser et al. 1981). Not surprisingly, Wood River sculpin are taxonomically more closely related to these species than many other species of sculpin in western North America (Bailey and Bond 1963).

The consistency we saw in estimates of *S*, which ranged only from 56 to 70% among the 10 populations we sampled, and with 95% CIs overlapping for all but three populations, could be caused by stream and environmental conditions being relatively similar between all streams during this study. However, most of the stream characteristics we measured at our study sites varied substantially, with examples of 3-fold, 5-fold, 7-fold, 12-fold, and 14-fold differences in percent cobble/boulder substrate, stream order, conductivity, gradient, and stream width, respectively. Wood River sculpin appeared to survive better in larger, lower elevation streams with lower gradient. Similarly, growth for age-1 fish was negatively associated with stream gradient, and was positively associated with finer substrate. Jones (1972) concluded that Piute sculpin grew faster but were less abundant in downstream reaches than in upper reaches of the same stream. For stream-dwelling sculpin, occupancy may be more likely (Meyer et al., companion paper) and abundance may be higher (Inoue and Nakano 2001; Light 2005) where substrate is more coarse and less embedded by fine substrate. Wood River sculpin may experience better growth conditions at lower elevation streams where water temperatures are higher but where habitat conditions support fewer fish.

Longevity appeared to be related to stream size. For the five streams that were <5 m wide, we never encountered fish older than age-4. For the five streams that were >5 m wide, the oldest fish in the population ranged from age-5 to age-8. Our maximum age of 8 years is equivalent to the longevity found in siberian sculpin (*Cottus poecilopus*) by Hesthagen et al. (2004), but is slightly older than other studies on stream-dwelling sculpin of which we are aware, which typically have found a maximum age of 6 or 7 years (Craig and Wells 1976; Gasser et al. 1981; Grossman et al. 2002).

Our results suggest that male Wood River sculpin tended to be slightly larger than females, as has been shown for mottled sculpin and slimy sculpin (Jones 1972; Anderson 1985). Conversely, female Wood River sculpin matured at a slightly smaller size and earlier age than males. We could find no other gender-specific size at maturity data for stream-dwelling sculpin for comparison, but this finding is unusual for some other stream-dwelling fish in western North America such as trout (Meyer et al. 2003, 2006) and suckers (Dauble 1980).

We also found that the transition from immature to mature occurred quickly for both genders. Indeed, no age-1 Wood River sculpin were mature, but by age-3, almost all (98%) were mature. This transition was slightly later in life and slower for Slimy Sculpin, which matured in an Alaska stream at ages 3 and 4 but were not entirely mature until age-6 (Craig and Wells 1976). Female mottled sculpin in Montana transitioned from immature to mature at about 65 mm (Bailey 1952), compared to our finding of a transition at about 56 mm. Our results suggest that, for both males and females, once fish reach maturity, they spawn every year. Similarly, shorthead sculpin also appear to spawn annually in Idaho (Gasser et al. 1981). We caution that these maturity findings stem from only two stream locations. Clearly, more data is needed from a variety of study sites to assess whether these findings hold true elsewhere and to more fully assess what factors affect size and age at maturity and other reproductive demographics for Wood River sculpin.

Taken together, it appears that Wood River sculpin population dynamics are similar to most other stream-dwelling sculpin in western North America. Survival is high, almost all fish are mature by age-3, and longevity is usually age-5 and older, offering multiple chances for reproduction for each cohort. Nevertheless, considerably more work may be needed to fully describe Wood River sculpin life history characteristics and requirements, and to explain what factors may influence the variation observed in these parameters. Such findings would only serve to better protect and preserve this endemic species.

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Table 6. Stream attributes for study sites in the Wood River basin, Idaho. Stream numbers correspond to those in Figure 1 (see Part I). NA is for data that was not available.

	Streamname	Sample date	UTM coordinates East	UTM coordinates North	UTM coordinates Zone	Stream order (1: 100,000)	Elevation (m)	Gradient (%)	Conductivity (µS/cm)	Width (m)	Depth (m)	Percent: Fines	Percent: Gravel	Percent: Cobble/ boulder	Percent: Stream shading	Percent: Unstable banks	Wood River Sculpin density (no./m)
1	Trail Creek	7/30/2003[a]	715875	4844638	11	4	1871	1.2	342	6.8	0.21	1	44	34	10	0	8.5
2	Warm Springs Creek	7/31/2003[a]	702601	4834873	11	4	1896	0.4	165	9.5	0.22	1	28	64	12	0	2.3
3	Soldier Creek	7/8/2003	677008	4814530	11	3	1695	1.5	49	5.3	0.15	0	33	55	38	0	3.1
4	East Fork Big Wood River	8/6/2003	718051	4833027	11	4	1775	1.8	293	9.9	0.15	2	52	34	34	1	1.3
5	Friedman Creek, lower	8/13/2003	266125	4821885	12	3	1829	1.8	159	4.2	0.16	18	43	30	16	1	3.6
6	Friedman Creek, upper	8/13/2003	267929	4824027	12	2	1916	2.2	159	3.4	0.09	3	50	38	5	3	4.4
7	Big Wood River	9/16/2003	714026	4829359	11	5	1678	0.7	172	23.3	0.37	5	27	63	3	2	NA
8	Iron Mine Creek	9/10/2003	279322	4824078	12	2	1887	2.8	217	3.2	0.08	7	47	18	26	0	2.3
9	Muldoon Creek	9/16/2003	258542	4820336	12	3	1706	0.8	202	4.2	0.16	7	42	45	17	48	1.5
10	Westernhome Gulch	9/25/2003	688282	4861416	11	1	2278	5.1	191	1.7	0.05	2	54	19	2	0	1.4

[a] Also sampled on 2/28/2004

Table 7. Correlation coefficients (r) between several stream attributes and survival and growth of Wood River sculpin at study sites in the Wood River basin, Idaho.

Stream variable	Survival	Growth Age-1	Growth Age-3
Stream order	0.74	0.34	-0.36
Elevation (m)	-0.39	-0.43	0.09
Gradient (%)	-0.66	-0.47	0.12
Conductivity (µS/cm)	0.13	-0.41	-0.33
Width (m)	0.55	0.39	-0.19
Percent fines	-0.24	0.45	-0.32
Percent gravel	-0.43	-0.56	-0.21
Percent shading	-0.16	0.00	0.00
Sculpin density (#/m)	0.19	-0.09	-0.20

Table 8. Characterization of Wood River sculpin mean length at age for all study sites combined in the Wood River basin, Idaho.

Age	Overall mean length at age (mm)		
	Minimum	Average	Maximum
0	13	23	28
1	32	46	54
2	57	60	63
3	69	74	79
4	77	87	99
5	90	96	104
6	101	104	107

Table 9. Mean length at age for male and female Wood River sculpin from two study sites sampled in February 2004 in the Wood River basin, Idaho.

	Warm Springs Creek						Trail Creek					
	Males			Females			Males			Females		
Age	Mean	± 95% CI	*n*	Mean	± 95% CI	*n*	Mean	± 95% CI	n	Mean	± 95% CI	*n*
2	67.0	6.0	5	64.8	5.3	12	52.5	2.0	11	48.6	1.7	9
3	73.5	2.2	15	73.2	2.4	13	71.2	3.3	13	65.7	2.5	17
4	85.4	3.5	16	83.4	5.7	5	81.6	5.8	8	86.0	-	1
5	98.3	7.2	4	102.0	-	1	94.0	-	1	83.0	-	1
6	113.0	-	1									

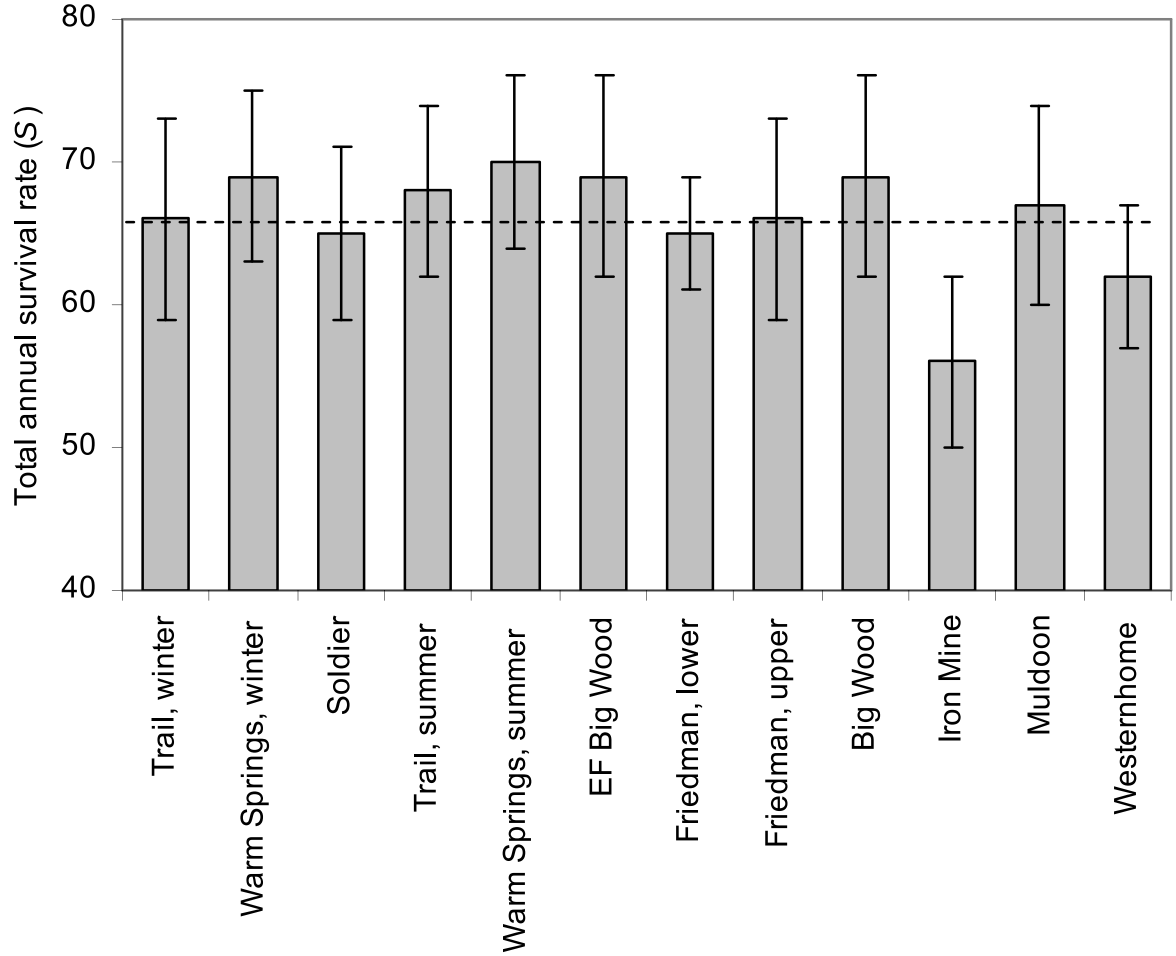

Figure 5. Estimates of total annual survival rate (*S*) for Wood River sculpin based on catch curves of age-2 and older fish from streams in the Wood River basin, Idaho. Dashed line represents the mean survival rate for all sites.

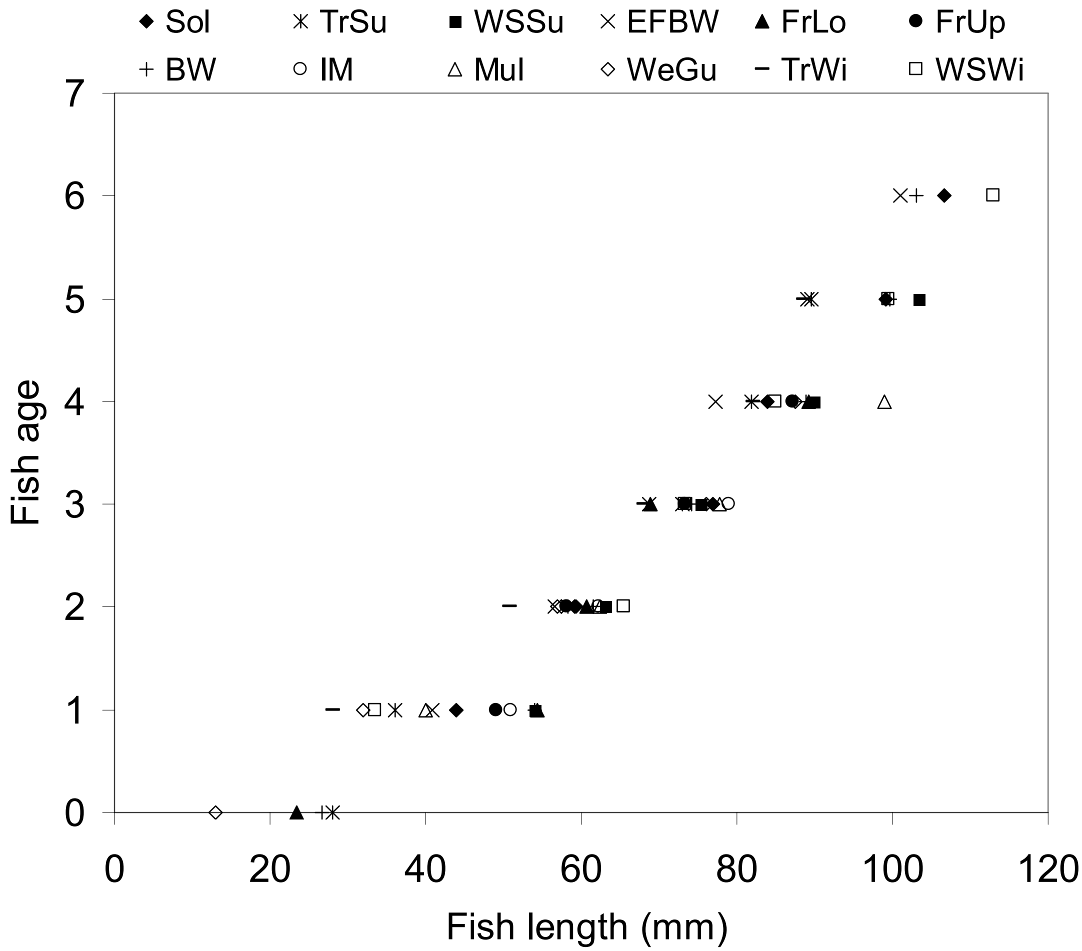

Figure 6. Mean length at age for Wood River sculpin in the Wood River basin, Idaho. Sol is Soldier Creek, TrSu is Trail Creek in summer, WSSu is Warm Springs in summer, EFBW is East Fork Big Wood River, FrLo is lower Friedman Creek, FrUp is upper Friedman Creek, BW is Big Wood River, IM is Iron Mine Creek, Mul is Muldoon Creek, WeGu is Westernhome Gulch, TrWi is Trail Creek in winter, and WSWi is Warm Springs Creek in winter.

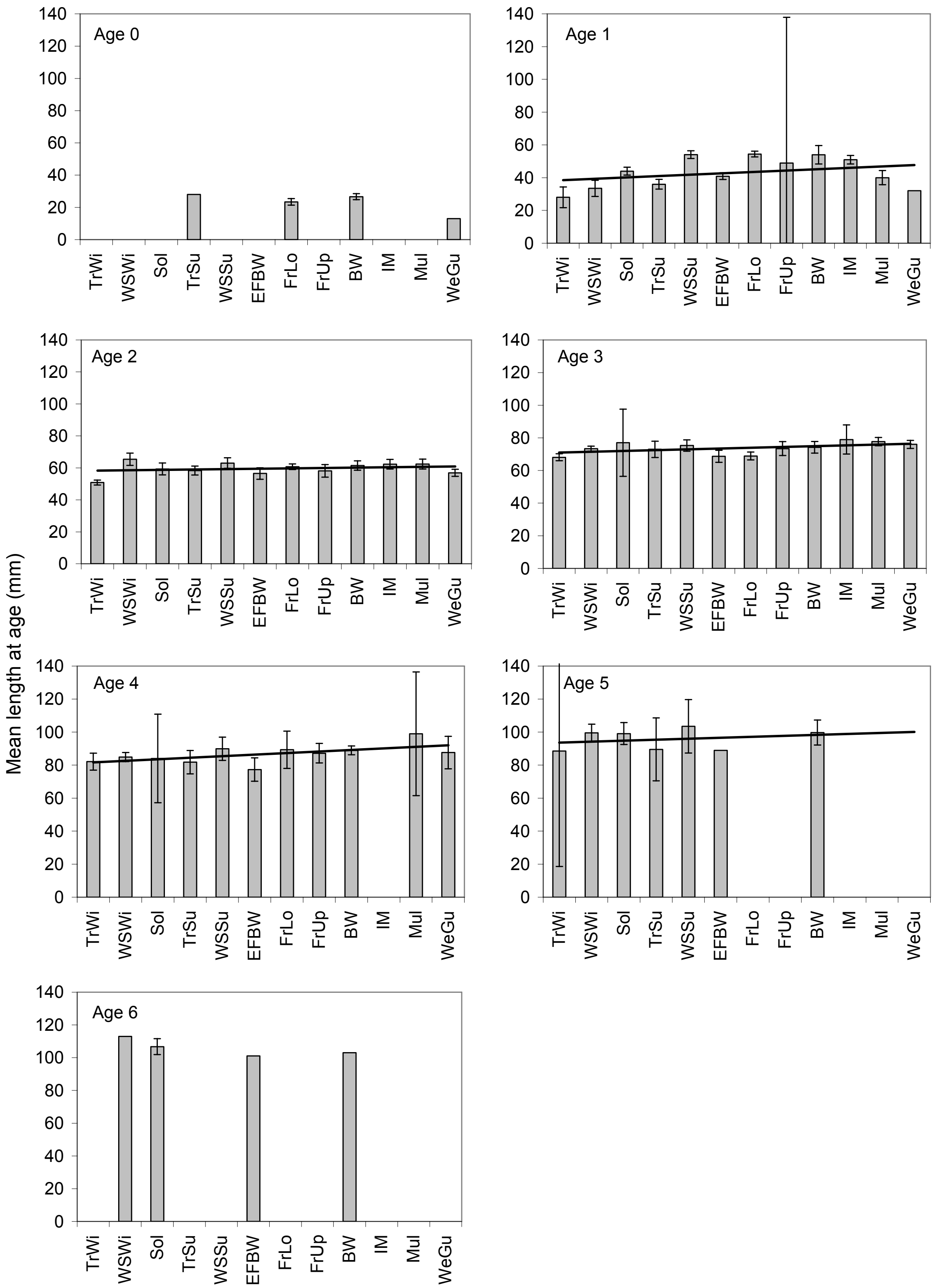

Figure 7. Wood River sculpin mean lengths by age (and 95% confidence intervals) for all sites in the Wood River basin, Idaho. Sites are arranged in chronological order of calendar sample date, and where adequate data was available, horizontal lines depict trends in growth related to time of year. See Figure 2 for study site abbreviations.

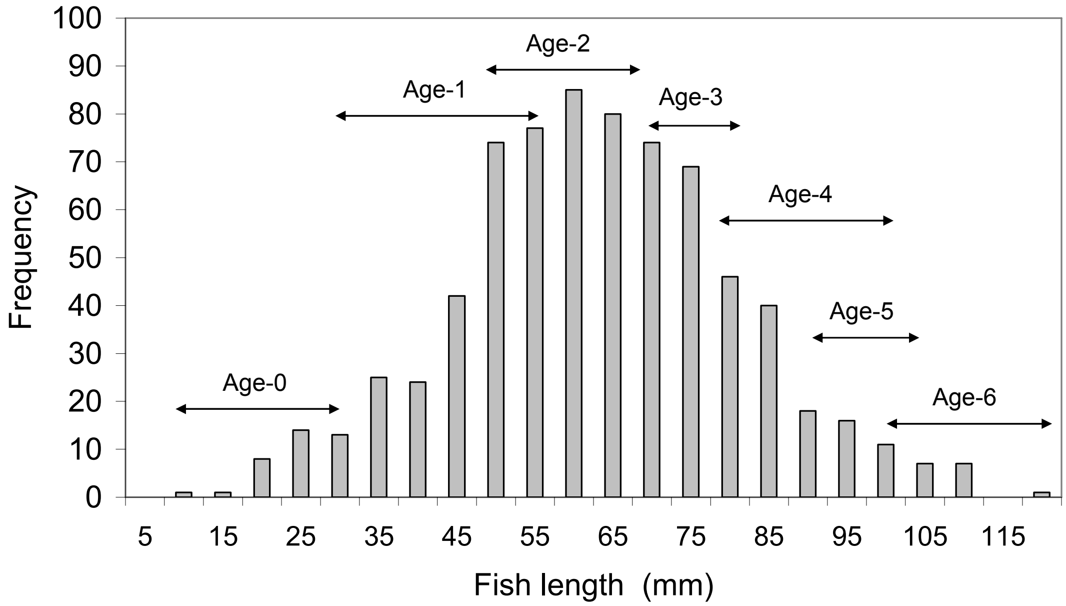

Figure 8. Length frequency and corresponding range of ages for all Wood River sculpin captured (n = 713) in the Wood River basin, Idaho.

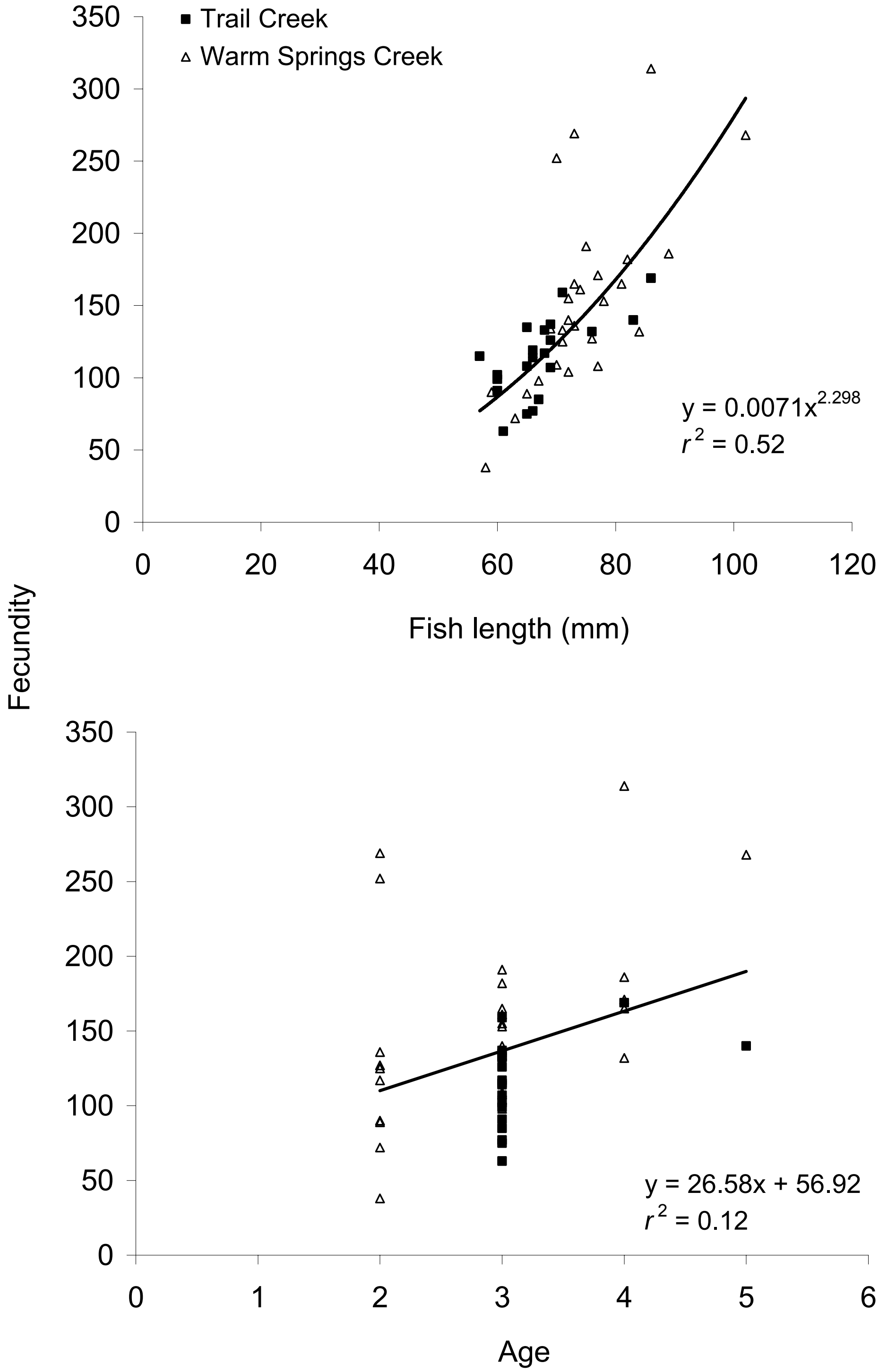

Figure 9. Relationships between fecundity and the length and age of Wood River sculpin in the Wood River basin, Idaho.

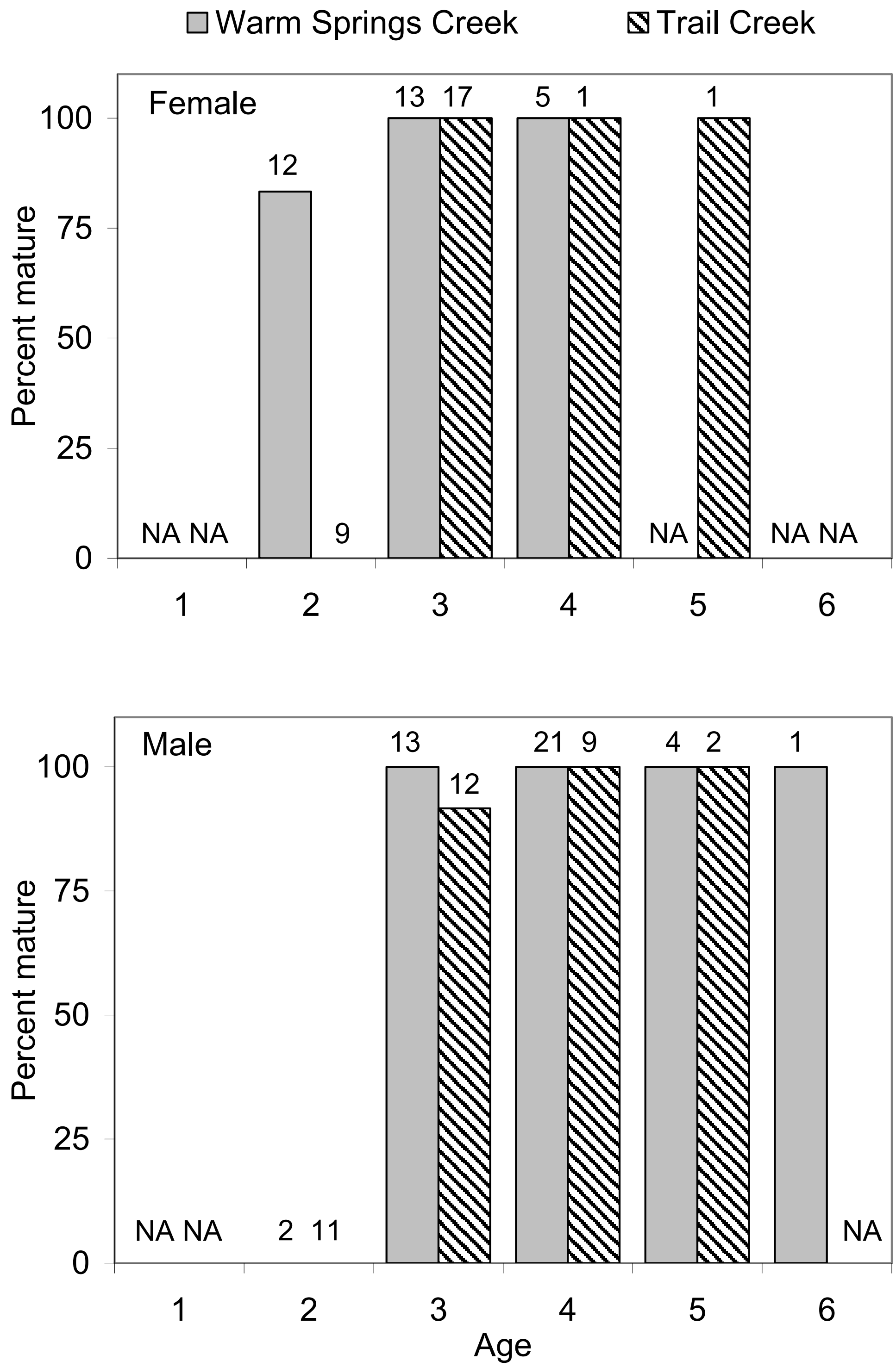

Figure 10. Proportions of male and female Wood River sculpin mature at age in the Wood River basin, Idaho. Numbers above bars are sample sizes; NA is where no data was available.

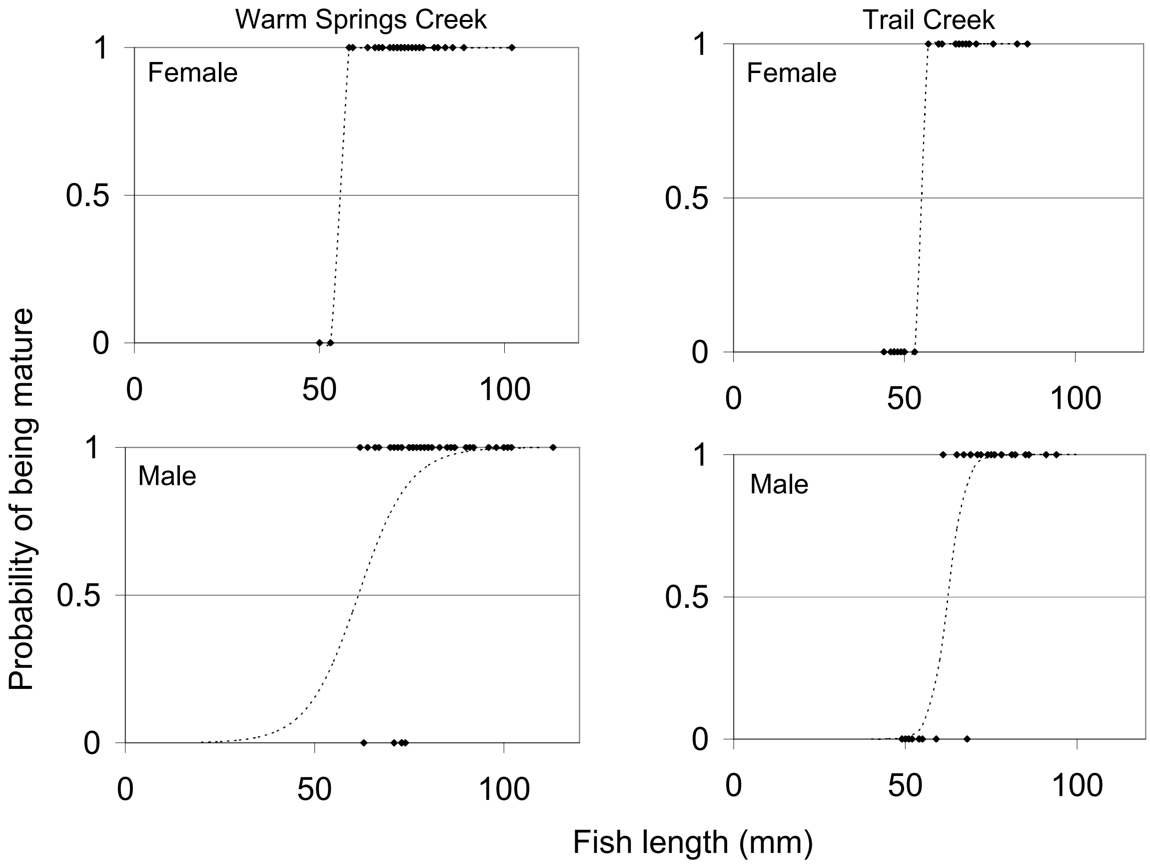

Figure 11. Logistic regression models fit to fish length vs. maturity data, which depict the maturity transition points for Wood River sculpin in Idaho.

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