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Assessment of Introduced Prickly Sculpin Populations in Mountain Lakes in Two Areas of Western Washington State

Abstract

Short-distance (i.e., < 100 km) introductions of diminutive fish species are often not well documented but may have important ecological consequences. Prickly sculpin (*Cottus asper*), which are native to lowland habitats of the Pacific Northwest, have been introduced in some mountain lakes of western Washington State. The ecology of six introduced populations of prickly sculpin was investigated through daytime minnow trapping, diet analysis, and age and growth analysis. Results of minnow trapping indicated prickly sculpin were abundant in each lake (Nisqually River lakes, mean = 11.3 individuals/trap; Dry Bed Lakes in Satsop River basin, mean = 1.9 individuals/trap). Prickly sculpin diet in the Nisqually River lakes was composed primarily of micro-crustaceans (92% by number of all prey items; dominated by copepods and cladocerans), chironomids, mollusks, and sculpin In the Dry Bed Lakes, the diet was composed primarily of caddisflies, oligochaetes, and micro-crustaceans. In native lentic habitats, prickly sculpin primarily consume macroinvertebrates with the rare occurrence of micro-crustaceans in the diet. Similar to native populations, prickly sculpin in the mountain lakes reached sizes greater than 150 mm total length; however, their growth rates were slower. In conclusion, prickly sculpin were common in the mountain lakes, consumed a variety of prey types and sizes, and grew to a relatively large size; therefore, this species may have important effects on the ecosystem of these lakes. However, additional assessment of their native and introduced distribution and ecology is needed to better understand their potential as an invasive species.

Keywords: Introduced fish, prickly sculpin, mountain lakes

Introduction

Non-native aquatic species have caused numerous ecological impacts through predation, competition, habitat degradation, hybridization, and disease transmission (Cucherousset and Olden 2011, Lodge et al. 2012). The number of native species translocated to new regions within the United States far exceeds the number of species of foreign origin (Fuller et al. 1999), yet despite receiving little attention, these relatively short-distance movements (i.e., < 100 km) can result in a variety of ecological impacts because geographically proximate river basins are often genetically and ecologically distinct. For example, the intentional translocation of the endangered watercress darter (*Etheostoma nuchale*) to a nearby spring resulted in the population loss of another rare species, the rush darter (*E. phytophilum*) (George et al. 2009). Short-distance introductions can be easily overlooked for species that are difficult to identify, are not a recreationally- or commercially-valuable species, or have a native distribution that is not precisely known. Freshwater sculpin (Cottidae) meet all these criteria and thus their introductions may be under appreciated (Wallace and Zaroban 2013).

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Sculpins are often an important component of cool and cold freshwater lentic and lotic ecosystems of the Northern Hemisphere (Bond 1963, Moyle and Herbold 1987, Herlihy et al. 2006, Adams and Schmetterling 2007). Freshwater sculpins primarily consume benthic macroinvertebrates but in some situations can be a predator of fish eggs (Foote and Brown 1998) or small fishes (Hunter 1959, Moyle 1977, Tabor et al. 2007c). Simultaneously, sculpins are an important forage fish for stream- (Lowry 1966) and lake-dwelling piscivorous fishes (Ricker 1960, Elrod and O'Gorman 1991, Tabor et al. 2007a) and other piscivores (Toweill 1974, Edgehouse et al. 2013). Sculpins may also compete with other fish species (Resetarits 1997, Holmen et al. 2003) and crayfish (Miller et al. 1992), and have other important effects on aquatic ecosystems, primarily through direct predation (Rosenfeld 2000) or indirectly by altering the behavior (e.g., reduction in foraging activity) of their prey (Kuhara et al. 2001).

Prickly sculpin (*Cottus asper*), the largest freshwater sculpin in North America, is common in lacustrine, estuarine, and riverine habitats in lowlands of the Pacific Northwest. They have planktonic larvae, relatively small eggs, and higher fecundity rates than most other freshwater sculpin (Wydoski and Whitney 2003). They spawn during the spring in lakes or lower reaches of rivers (Krejsa 1967, Mason and Machidori 1976, Rickard 1980). Prickly sculpin have a limited ability to disperse to upstream habitats above small barriers because they typically spawn in lowland habitats and are poor swimmers (Mason and Machidori 1976). Generally, prickly sculpin are found at lower elevations compared to other freshwater sculpin species (Mongillo and Hallock 1997).

Introduction of prickly sculpin outside of their native range has occurred (Roberts 1990, Swift et al. 1993, Fuller et al. 1999, Fuller and Neilson 2013) but the effects of these introductions are largely unknown. Prickly sculpin have been reported to be introduced in mountain lakes in two areas in western Washington State; freshwater ecosystems that are considered particularly sensitive to introduced predators (Knapp et al. 2001). Although it is unclear how they were introduced (likely either as bait from anglers or accidentally introduced during trout stockings) and how long they have been in these lakes, individuals were observed by anglers as early as 1990. We hypothesized that because prickly sculpin are large (maximum > 230 mm total length, Tabor et al. 2007b) relative to other sculpin species, they have the potential to consume a broader range of prey (Tabor et al. 2007c) and therefore may cause a variety of ecological impacts in mountain lake ecosystems. In this study, we documented the presence of prickly sculpin in six mountain lakes and report fundamental ecological data (distribution, size, diet, age, and growth) that could be compared to existing information on native populations and help evaluate their potential to inhabit other mountain lakes.

Methods

Study Sites

Four mountain lakes located in the upper Nisqually River Basin (major drainage in the south Puget Sound region) and two mountain lakes in the upper Satsop River Basin (part of the Chehalis River Basin) were surveyed for introduced populations of prickly sculpin (Figure 1). Of the Nisqually River lakes, three of the lakes (Bertha Mae Lake, Cora Lake, and Granite Lake) are in the Gifford-Pinchot National Forest within the Big Creek subbasin and the fourth lake, Lake George, is in Mount Rainier National Park and located in the Tahoma Creek subbasin. The lakes range in elevation from 1,161 to 1,308 m above sea level (Table 1) and historically supported no fish species due to high-gradient outlet streams that represent barriers to fish colonization from downstream. The other two study lakes were the Dry Bed Lakes (hereafter referred to as either Lower or Upper Dry Bed Lake) which are located in the upper Satsop River basin at the upper end of the Dry Bed Creek drainage in the southern edge of the Olympic Mountains. The lakes are located well upstream of the native prickly sculpin distribution in the Satsop River basin (Mongillo and Hallock 1997) and each lake only drains through subsurface flow, thus preventing fish colonization from downstream or between lakes. The elevation of the lakes is around 370 m with

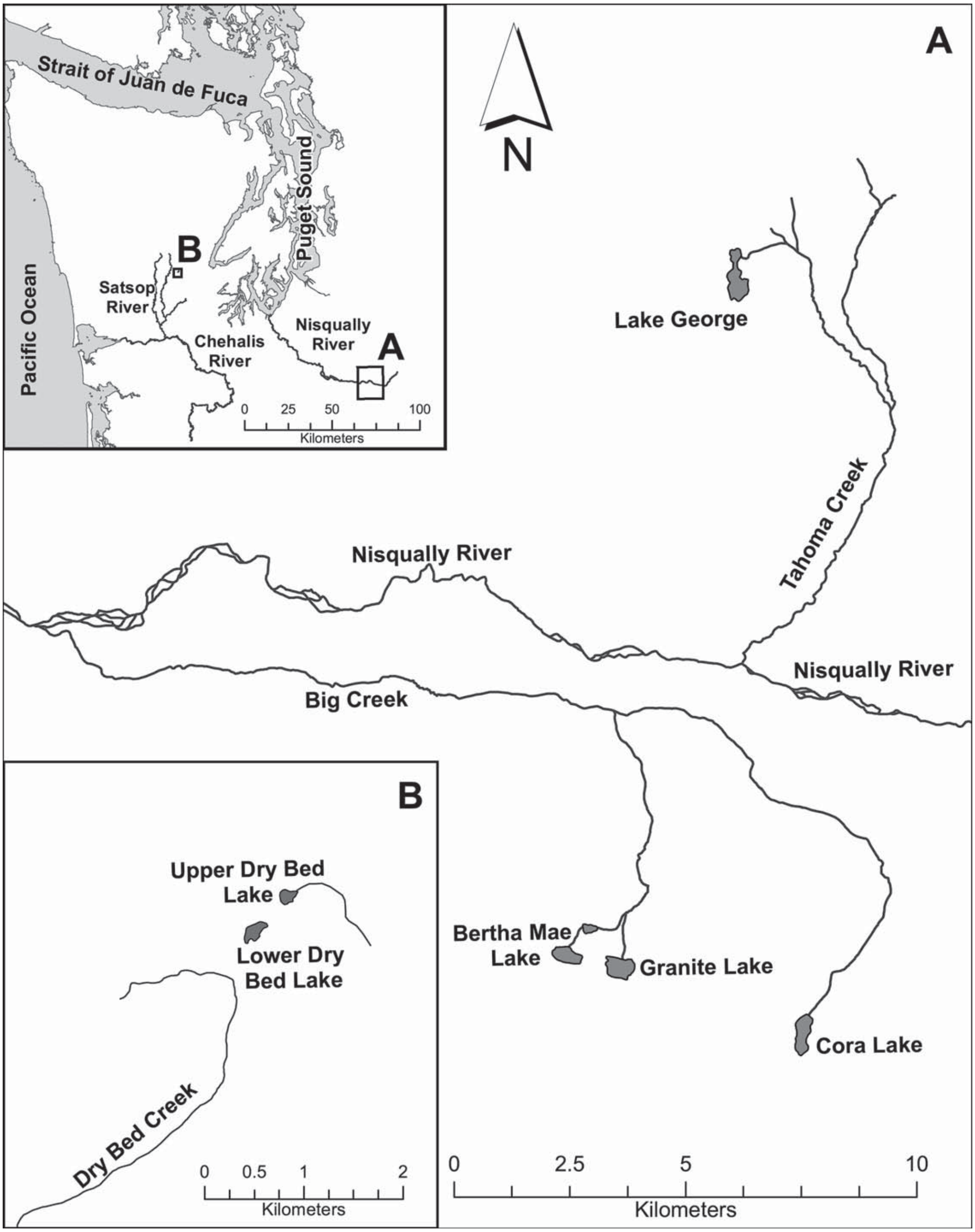

Figure 1. Map of six mountain lakes in western Washington where populations of prickly sculpin were examined for this study. A). Four study lakes in the upper Nisqually River basin; B). Dry Bed Lakes in the upper Satsop River basin)

TABLE 1. Physical characteristics of six mountain lakes in western Washington where prickly sculpin were collected. Secchi depths (all taken while snorkeling) in the Nisqually River lakes were taken on August 21, 2013, while those in the other two lakes were taken on May 20, 2014. ND = No data. Surveyors of Lake George in 2005 recorded a Secchi depth of 11.2 m (Samora et al. 2011).

Basin Lake	Elevation (m)	Area (km^2)	Maximum depth (m)	Secchi depth (m)
Nisqually River				
Bertha Mae Lake	1,236	0.08	34.6	15.0
Cora Lake	1,161	0.10	16.0	9.0
Granite Lake	1,273	0.11	21.1	15.9
Lake George	1,308	0.14	42.5	ND
Satsop River				
Lower Dry Bed Lake	367	0.03	41.8	13.7
Upper Dry Bed Lake	378	0.02	16.8	14.6

the surface elevation varying widely between winter and late summer.

Environmental characteristics of the four Nisqually River study lakes are typical of most high-elevation lakes in the Cascade Mountain Range, ranging from oligotrophic to ultra-oligotrophic conditions and typically ice-covered for 5–6 months from November to May (Lomnicky 1996). Sand and silt represent the dominant substrate type, interspersed with areas of cobble, boulder, and bedrock. Large woody debris is abundant in each mountain lake and extensive macrophyte beds were present in Cora Lake. Detailed water temperature monitoring in Bertha Mae Lake at 2 m depth (July 2009 to January 2011) revealed an annual range from 2 to 21 °C. Environmental characteristics of the two Dry Bed Lakes vary with lake level. In the late spring to fall when the lake level is low, the benthic zone has some structural complexity due to the presence of a few pieces of large woody debris. During other times of the years when the lake level is high in winter and early spring, the nearshore area (0 to approximately 5 m depth) is extremely complex due to numerous inundated shrubs and grasses. Sand, silt, and gravel are the dominant substrate types in both lakes.

Each study lake has been planted periodically with salmonids, including brook trout (*Salvelinus fontinalis*), cutthroat trout (*Oncorhynchus clarkii*), and rainbow trout (*O. mykiss*). Brook trout were observed in Cora Lake and both Dry Bed Lakes. Currently, the presence of trout in the other lakes is unclear. Trout were last planted in Lake George in 1974 and may be extirpated.

Fish Collections and Processing

Baited minnow traps were utilized to document the distribution, diet, age, and growth of the mountain lake populations. Minnow traps were standard Gee-type traps (42 cm long, 19 cm wide, 3.8 cm diameter opening) with 0.6-cm-square wire mesh. Each trap was baited with 5 g of preserved salmon eggs and 20 g of canned sardines placed in a small mesh bag. Since no bait was observed in any of the stomach samples, we assumed the mesh bags prohibited prickly sculpin from feeding on bait. Total effort for each lake consisted of nine traps set on one date (Nisqually River lakes—September 2012; Dry Bed Lakes—30 June 2014); three minnow traps (separated by ≥ 15 m) were set at each of three depths: 1, 5, and 10 m. Traps were set during the day for three hours. Water surface temperatures were similar during sampling periods across lakes (15–18 °C).

After minnow traps were retrieved, all fish were enumerated and the total length (TL) measured to the nearest mm. For age and diet analysis, fish were sampled from each of four size classes: 1) 50–74 mm, 2) 75–99 mm, 3) 100–124 mm, and 4) ≥ 125 mm TL that corresponded to earlier sampling in Lake Washington (Tabor et al. 2007c). For diet analysis, fish were also sampled by depth (1, 5, and 10 m). Some additional prickly sculpin were collected in the Nisqually River lakes by snorkelers with dip nets in water 0.5 to 1 m deep to increase the sample size for diet analysis, especially for fish in the 50–74 mm TL size range which were infrequently collected in the minnow traps. In the Dry Bed Lakes, supplemental minnow trapping during dusk and early night hours on 20 May and 09 June 2014 was also conducted to increase our sample size for diet and age and growth analysis. Fish used for diet analysis were anesthetized with MS-222 and stomach contents removed using gastric lavage as described in Foster (1977). We used gastric lavage because this technique has been shown to remove 100% of the stomach contents of sculpin (Light et al. 1983) and each fish could be processed quickly. On a few occasions, sculpin were captured that had recently-consumed sculpin (skin still completely intact) in their stomachs. These ingested sculpin were likely consumed in the trap and therefore added to the catch data and not included in the diet analysis.

Because the laboratory used to process the samples and lake accessibility was different between the two areas (the more remote Nisqually River lakes were done in 2012 and the more accessible Dry Bed Lakes were done in 2014), we used slightly different techniques to collect and analyze the diet samples. All diet data were converted to percentages to minimize bias between methodologies. For the Nisqually River lakes, diet samples were combined in the field by size category and depth to minimize the amount of ethanol carried to and from each lake and to facilitate laboratory processing. For the Dry Bed Lakes, the diet sample of each fish was frozen and processed individually. To determine the frequency of occurrence of major prey types (fish, micro-crustaceans, mollusks, aquatic insects, and other) in the Nisqually River lakes' samples, stomach contents of each fish were visually inspected in the field. The coloration of micro-crustaceans were mostly bright red and could be easily observed in the field; however, small, rare prey items could have been overlooked and thus these data provide a conservative estimate of frequency of occurrence.

In the laboratory, stomach contents for all lakes were separated into major prey taxa. Aquatic insects, mollusks, and some crustaceans (cladocerans and amphipods) were identified to the family level while terrestrial insects, other crustaceans (copepods and ostracods), and other invertebrate prey items (water mites, spiders, etc.) were identified to the class level. For the Nisqually River lakes samples, prey items that were mostly intact and the length (nearest 0.5 mm if < 5 mm and nearest 1 mm if > 5 mm) could be measured were identified and enumerated. Highly digested and fragmented material from older feeding episodes was not used. Published length-weight regressions were used to calculate dry weight. For the Dry Bed Lakes, each prey group was enumerated and the wet weight (nearest 0.0001 g) measured after blotting for 10 seconds.

To document prickly sculpin age and growth, we sacrificed 30–40 fish (8–10 fish from each size category) from each mountain lake. Fish were from diet sampling as well as preliminary sampling in 2009 (Nisqually River lakes) and 2014 (Dry Bed Lakes). Fish were euthanized with a lethal concentration of MS-222 and then brought back to the lab where their otoliths were removed. To age prickly sculpin, we used the burnt-section technique of MacLellan (1997).

Data Analysis

Comparisons of fish length between depths within each lake were made with a Kruskal-Wallis test and a multiple comparisons procedure (Conover 1999). The multiple comparisons procedure is simply a parametric procedure (Fisher's least significance difference) computed on the ranks rather than the data (Conover 1999). To quantify diet composition, we calculated percent composition by weight ($\%W_i$), percent composition by number ($\%N_i$) and percent frequency of occurrence ($\%O_i$) as follows:

$$\%W_i = \frac{100W_i}{\sum_{i=1}^{n} W_i},$$

$$\%N_i = \frac{100N_i}{\sum_{i=1}^{n} N_i},$$

$$\%O_i = \frac{100O_i}{\sum_{i=1}^{n} O_i},$$

where n is the total number of prey categories found in a given sample, and W_i, N_i, and O_i, are the total weight, number, or occurrence of prey type i in a category (Liao et al. 2001). To compare the diet between lakes and size classes, we calculated overlap index values using the equation of Horn (1966):

$$C = 2\sum_{i=1}^{s} X_i Y_i \,/\, (\sum_{i=1}^{s} X_i^2 + \sum_{i=1}^{s} Y_i^2),$$

where C is the index value, s is the number of food categories; X_i is the proportion of the total diet by size class or lake X contributed by food category i; and Y_i is the proportion of the total diet by size class or lake Y contributed by food category i. Index values can range from 0 (no overlap) to 1 (complete overlap). An overlap index level of 0.6 or more was used to indicate a significant overlap in diet (Zaret and Rand 1971, Johnson 1981).

To compare ages to native populations, we plotted existing age data from Oregon streams (Bond 1963) and Lake Washington (Rickard 1980), as well as data we collected from Lake Sammamish in 2002 and 2009. Data from all sites, including native populations, were fitted to a power regression model ($Y = aX^b$), where Y is total length (mm) and X is age in years.

Results

Population Characteristics

Prickly sculpin was the only species collected in the mountain lakes. In total, 397 individuals representing a mean catch-per-unit-effort (CPUE) of 11.3 individuals/trap were collected in the Nisqually River mountain lakes, and sculpin were present in all minnow traps with the exception of Cora Lake at 10 m depth (Figure 2). CPUE varied from a mean of 20.9 fish/trap in Granite Lake to 4.6 fish/trap in Cora Lake (6.6 fish/trap excluding 10 m traps). In total, only 34 individuals were collected in the Dry Bed Lakes (Lower Dry Bed Lake, 2.4 fish/trap; Upper Dry Bed Lake, 1.4 fish/trap). Prickly sculpin were collected from each depth of the two lakes; however, they were only present in 55.6% (five of nine) of the traps in each lake.

Median size in the Nisqually River mountain lakes ranged from 93.5 mm TL in Lake George to 104 mm TL in Bertha Mae Lake with an overall median size of 98 mm TL (range = 59–215 mm TL). In general, prickly sculpin size increased with sampled depth (Figure 3). For each lake, individuals caught in the 1 m traps were significantly smaller than those in the 5 m or 10 m traps, whereas differences between 5 m and 10 m were

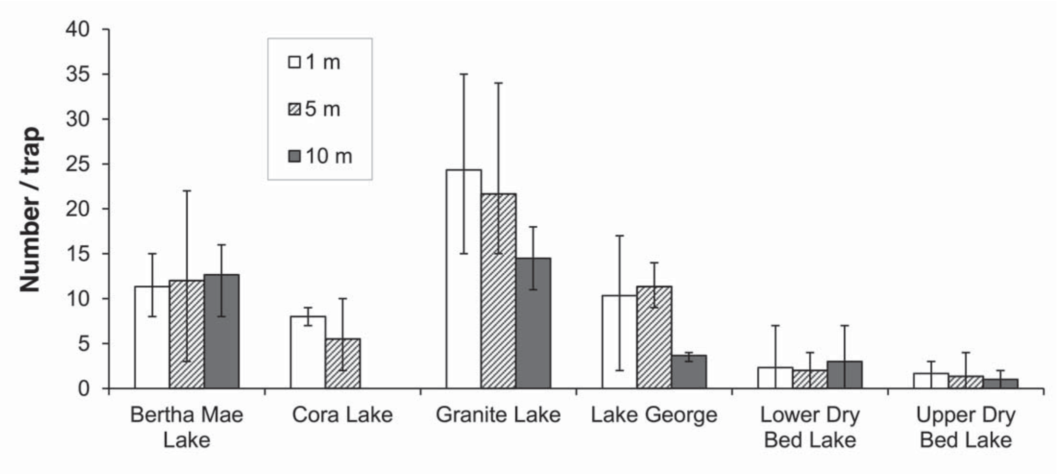

Figure 2. Catch (mean number/trap; ± range) of prickly sculpin in baited minnow traps at three depths in six mountain lakes in western Washington (Nisqually River lakes, September 2012 [Bertha Mae, Cora, Granite, and George lakes]; Dry Bed Lakes, 30 June 2014). Traps were set for three hours during the day. No prickly sculpin were collected in the 10 m traps in Cora Lake.

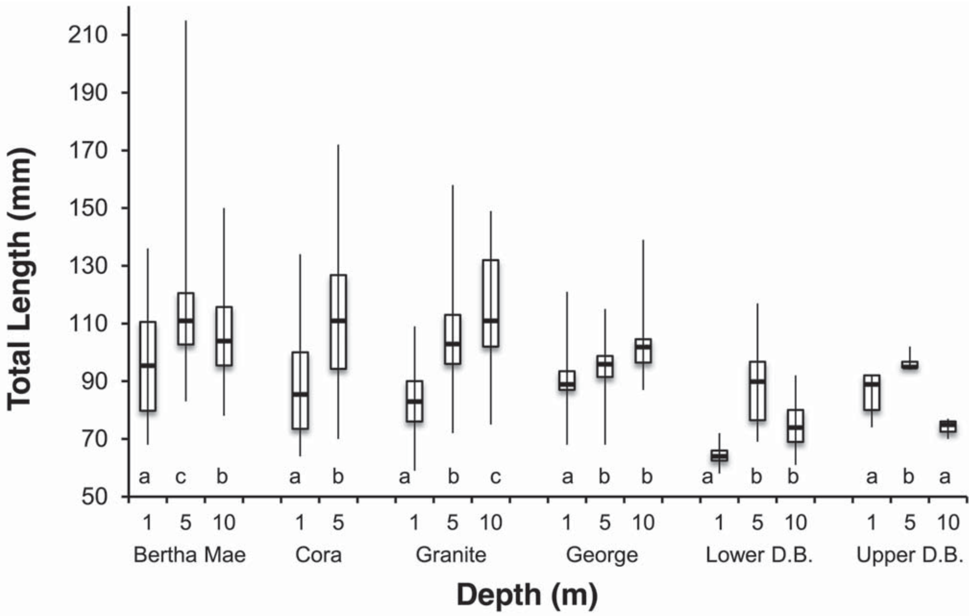

Figure 3. Total length box plots (range, 25 and 75% quartiles, and median) of prickly sculpin collected at three depths with baited minnow traps in six mountain lakes in western Washington (Nisqually River lakes, September 2012 [Bertha Mae, Cora, Granite, and George lakes]; Dry Bed Lakes, 30 June 2014). D. B. = Dry Bed Lake. Bars (within each lake) with different letters are significantly different (Kruskal-Wallis test and multiple comparisons test).

more variable (Kruskal-Wallis tests and multiple comparisons tests; Figure 3). In the Dry Bed Lakes, all prickly sculpin collected in daytime minnow traps were < 120 mm TL. Larger prickly sculpin used for diet and age and growth analyses were collected during supplemental dusk/nighttime minnow trapping.

Diet Composition

Prickly sculpin diet in the Nisqually River mountain lakes was composed primarily of four prey categories: micro-crustaceans, aquatic insects, mollusks, and sculpin (Figure 4). For the Nisqually River mountain lakes combined, 92% of the prey items were micro-crustaceans (dominated by copepods and cladocerans); a pattern most apparent for the 50–74 mm TL size range (range of four lakes: %W = 59–87 and %N = 91–98). Observations of the diet in the field indicated that most prickly sculpin 50–99 mm TL consumed micro-crustaceans (mean of four lakes, %O = 81; range, %O = 64–94). Close to half of all prickly sculpin in the > 100 mm TL size classes consumed micro-crustaceans, but it usually composed a minor part of the diet (range of four lakes: %W = 0.1–19.1).

Ninety-one percent of the aquatic insects by number in the Nisqually River lakes were chironomids, which represented 6.0% of all the prey items. By weight, chironomids were the dominant prey item in two of the four size classes in Bertha Mae Lake and Granite Lake, whereas in the other two lakes, chironomids composed less than 20% of the diet (%N and %W) of each size class (Figure 4). Other aquatic insects, which included caddisflies (primarily Leptoceridae), alderflies (*Sialis* sp.), and biting midge larvae (Ceratopogonidae), usually composed a minor part of the diet. Consumption of mollusks was primarily observed in Lake George, where 85 sphaeriid clams were present in the stomach samples (%O = 37) and composed 25% of the overall diet by weight. Sculpin was a rare prey item in each mountain lake (%N, range 0.02–0.14; %O, range 2–10) and only present in prickly sculpin > 100 mm TL (size range, 104–149 mm TL), but was often the dominant prey item by weight (Figure 4).

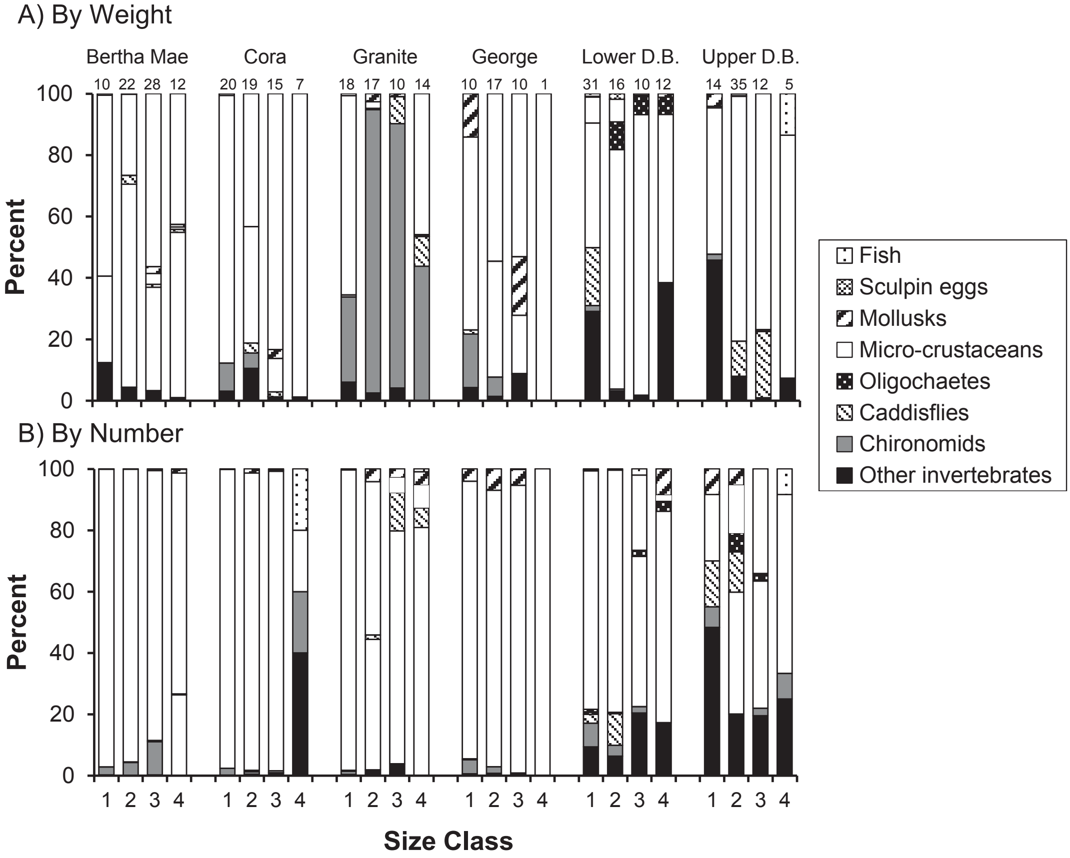

Figure 4. Diet composition (percent by weight and by number) of prickly sculpin in six mountain lakes in western Washington (Nisqually River lakes, September 2012 [Bertha Mae, Cora, Granite, and George lakes]; Dry Bed Lakes, May–June, 2014). Number of fish sampled is given above each bar of the top panel. Size class: 1 = 50–74, 2 = 75–99, 3 = 100–124, 4 = ≥ 125 mm TL (total length). D. B. = Dry Bed Lake. Sculpin eggs were not enumerated because they typically are consumed as a cluster. Micro-crustaceans include copepods, cladocerans, and ostracods. The other invertebrate category includes: amphipods (most prevalent in the Dry Bed Lakes), crayfish (primarily from sculpin ≥ 125 mm TL in Upper Dry Bed Lake), mayflies, alderflies (*Sialis* sp.; Nisqually River lakes only), other aquatic dipterans (primarily crane fly larvae [Tipulidae] and biting midge larvae [Ceratopogonidae]), water mites, and terrestrial invertebrates.

Prickly sculpin diet (by weight) in the Dry Bed Lakes consisted primarily of large macroinvertebrates including caddisflies (emerging adults and larvae), oligochaetes, and crayfish (Figure 4). Overall, %O for caddisflies was higher than any other prey type (Lower Dry Bed Lake, %O = 47.1; Upper Dry Bed Lake, %O = 43.9). Also, %N for caddisflies was higher than any other prey type for the two largest size classes in both lakes. Consumption of micro-crustaceans was common (Lower Dry Bed Lake, %O = 44.1; Upper Dry Bed Lake, %O = 27.3), but made up a small percentage of the diet (by weight) except for fish 50–99 mm TL in Lower Dry Bed Lake (Figure 4). Consumption of fish was rare and included only two small sculpin and one juvenile trout. Additionally, one sculpin (113 mm TL) had consumed large numbers of sculpin eggs.

Diet Overlap Between Lakes

Overlap index values (*C*) between Nisqually River mountain lakes were all greater than 0.80 for the smallest and largest size classes. For the two intermediate size classes, overlap index values varied considerably, largely because of differences in the consumption of chironomids, mollusks, and sculpin. The overlap index value between the two Dry Bed Lakes for the largest size class was 0.78, whereas it was < 0.3 for the other three size classes. Within each size class, little overlap was observed between the Nisqually River lakes and the Dry Bed Lakes (*n* = 30; mean = 0.02; range = 0–0.11).

Age and Growth

Growth of prickly sculpin in the Nisqually River mountain lakes was substantially slower than that recorded from lowland areas (Figure 5). Maximum longevity documented in native habitats is 7 years; however, fish over 175 mm have not been analyzed (Bond 1963, Rickard 1980). The maximum age observed was 21 years (213 mm TL) in Bertha Mae Lake, 12 years (172 mm TL) in Cora Lake, 14 years (194 mm TL) in Granite Lake, 12 years (139 mm TL) in Lake George, and 7 years in the Dry Bed Lakes (123–157 mm TL). Among the mountain lakes, sculpin growth appeared to be related to elevation. They appeared to grow the slowest in Lake George (the highest lake), the fastest in Lower Dry Bed Lake (the lowest lake), and intermediate in the other lakes (Figure 5).

Discussion

Our study is the first to provide basic ecological information on introduced prickly sculpin populations in mountain lakes of the Pacific Northwest, United States. Biotic (e.g., prey availability and predators) and abiotic (e.g., temperature and light) conditions in the mountain lakes are quite different than in lowland native habitats but they appear to have readily adapted to their new environments. Adaptations to the mountain lakes include consumption of large numbers of micro-crustaceans and increased longevity. These results suggest that prickly sculpin demonstrate a shift in their Grinnellian niche across space (*sensu* Wiens and Graham 2005) and our findings contribute to the limited literature examining niche conservatism of species in both their native and non-native ranges (e.g., Pintor et al. 2008, Larson et al. 2010). This

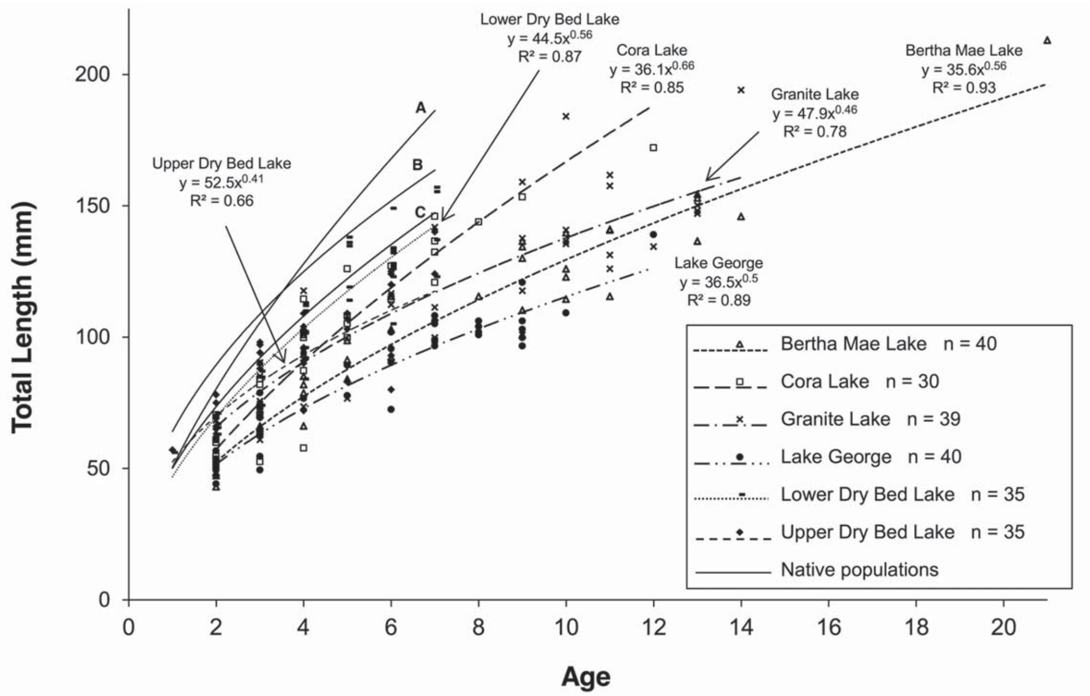

Figure 5. Age of prickly sculpin in six mountain lakes in western Washington (dotted lines) and compared to native populations (solid lines). A). Lake Washington (Rickard 1980). B). Lake Sammamish (R. Tabor and H. Berge, unpublished data). C). Oregon streams (Bond (1963). Age was determined through otolith analysis. The number of fish examined from the mountain lakes is given in the legend. The result of a power regression analysis is also given for each mountain lake.

line of inquiry has implications for determining whether prickly sculpin will be capable of adapting to new environmental conditions in their native range, and similarly, if they are able to successfully invade new habitats and regions.

Prickly sculpin appeared to be common in each mountain lake. Although minnow trap catch of sculpin can vary widely (Foote and Brown 1998), our relatively high CPUE of prickly sculpin compared to Lake Washington (Rickard 1980) and short duration sets (3 hours) would suggest prickly sculpin are common in benthic areas of each mountain lake. Preliminary daytime and/or nighttime snorkeling surveys in each lake also indicated prickly sculpin are common in shallow water along the shoreline, but additional sampling is needed to estimate the density and total population size in each mountain lake.

Although the mountain lakes are oligotrophic, they may be able to support large populations of prickly sculpin because of good habitat conditions and few competitors and predators. Each lake appeared to have high levels of structural complexity (large woody debris, large substrates, and inundated riparian vegetation) that creates favorable conditions for sculpin to forage, nest, and seek refuge. Unlike most lowland habitats, the mountain lakes did not appear to have many competitors or predators. Except for a few trout, prickly sculpin was the only fish species observed in the nearshore area of the mountain lakes and was the only species collected in the minnow traps. The only lakes where we observed much fish activity was Cora Lake and the Dry Bed Lakes, where trout were observed feeding at the surface. Additionally, piscivorous birds were not observed at any of the mountain lakes.

Prickly sculpin have been described as an opportunistic predator (Bond 1963, Tabor et al. 2007c). Our results appear to be consistent with this characterization. Diets of prickly sculpin from native populations consist primarily of benthic macroinvertebrates with fish occasionally being consumed (Clemens et al. 1939, Northcote 1954, Bond 1963, Bonar et al. 2005, Tabor et al. 2007c). Introduced prickly sculpin in the mountain lakes also preyed on benthic macroinvertebrates and fish; however, they also consumed large numbers of micro-crustaceans (e.g., copepods, cladocerans, and ostracods). Consumption of micro-crustaceans by prickly sculpin has been primarily observed in larval and juvenile sculpin but rare in sculpin over 50 mm (Clemens et al. 1939, Northcote 1954, Bond 1963, Tabor et al. 2007c). Additionally, clams of the family Sphaeriidae which are small, sessile invertebrates made up a substantial portion of the diet of prickly sculpin from Lake George and were present in the diet of sculpin from the other mountain lakes. In Lake Washington and other lakes, they are rare in the diet of prickly sculpin (Tabor et al. 2007c) but are often a common benthic invertebrate (Thut 1969). The invertebrate community of the mountain lakes is not well known but is likely different than that in lowland lakes and other habitats (Hoffman 1994, Füreder et al. 2006). Prickly sculpin have been able to switch to other, perhaps less-preferred, prey types, particularly in the Nisqually River mountain lakes.

The ages of prickly sculpin in this study are among the oldest recorded for freshwater sculpin. We found prickly sculpin that were at least 12 years old in each Nisqually River mountain lake and the oldest sculpin was 21 years. Previous studies report a maximum age of prickly sculpin within their native distribution to be 7 years; however, sculpin greater than 175 mm TL were not examined (Bond 1963, Patten 1971, Rickard 1980). Therefore, their maximum age within their native range might be 10 or more years for fish greater than 200 mm TL (Bond 1963). In the mountain lakes, cold water temperatures, low prey availability, and intense intraspecific competition may create conditions where fish grow slowly and live substantially longer than expected. Increased longevity of fish introduced into mountain lakes has also been observed for brook trout (Reimers 1979), rainbow trout (Donald and Alger 1986), and the European minnow (*Phoxinus phoxinus,* Museth et al. 2002). Similarly, increased longevity in colder, more northerly latitudes has been demonstrated in several fish species (Blanck and Lamouroux 2007) including some freshwater sculpin (Fox 1978, McDonald et al. 1982) within their native range.

Because our sampling for each mountain lake was primarily limited to one to three days, this study only provides a snapshot of the relative abundance and diet of prickly sculpin. Additional sampling is needed to better understand their overall ecology in these mountain lakes. A bioenergetics approach would also help to better understand their ability to persist in a cold environment with suboptimal forage and help predict their status in other mountain lakes if they were introduced (Moss 2001). Niche modeling exercises would also be beneficial to predict their potential distribution (Vander Zanden and Olden 2008).

In conclusion, there are well-established populations of prickly sculpin in at least six mountain lakes in western Washington State and they provide an example of a short-distance introduction that could have important ecological consequences but could easily be overlooked. Because prickly sculpin were common in the mountain lakes, consumed a variety of prey types and sizes, and grew to a relatively large size, they may have important effects on the ecosystem of these lakes. Prickly sculpin are also present in other western Washington lakes that appear to be upstream of their native distribution (Mongillo and Hallock 1997, Tabor et al. 2007b). Additional assessment of their native and introduced distribution and ecology is needed to better understand their potential as an invasive species. Short-distance introductions of diminutive species often receive little attention because the ecology and natural distribution is not well understood. This may be particularly true for sculpins in the Pacific Northwest because they are represented by several species and can be difficult to identify to species; thus introduced species may be missed.

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Literature Cited

Adams, S. B., and D. A. Schmetterling. 2007. Freshwater sculpins: phylogenetics to ecology. Transactions of the American Fisheries Society 136:1736-1741.

Blanck, A., and N. Lamouroux. 2007. Large-scale intraspecific variation in life-history traits of European freshwater fish. Journal of Biogeography 34:862-875.

Bonar, S. A., B. D. Bolding, M. Divens, and W. Meyer. 2005. Effects of introduced fishes on wild juvenile coho salmon in three shallow Pacific Northwest lakes. Transactions of the American Fisheries Society 134:641-652.

Bond, C. E. 1963. Distribution and ecology of freshwater sculpins, genus *Cottus*, in Oregon. Ph.D. Dissertation, University of Michigan, Ann Arbor.

Clemens, W. A., D. S. Rawson, and J. L. McHugh. 1939. A biological survey of Okanagan Lake, British Columbia. Bulletin of the Fisheries Research Board of Canada 56.

Conover, W. J. 1999. Practical Nonparametric Statistics. John Wiley and Sons, New York.

Cucherousset, J., and J. D. Olden. 2011. Ecological impacts of non-native freshwater fishes. Fisheries 36:215-230.

Donald, D. B., and D. J. Alger. 1986. Dynamics of unexploited and lightly exploited populations of rainbow trout (*Salmo gairdneri*) from coastal, montane, and subalpine lakes in western Canada. Canadian Journal of Fisheries and Aquatic Sciences 43:1733-1741.

Edgehouse, M., T. J. Brown, A. J. Colon, W. C. Cromwell, B. S. Schwimmer, M. A. Skinner, and D. M. Walton. 2013. Diet of a population of western terrestrial garter snake, *Thamnophis elegans*, along the Grande Ronde River, southeastern Washington. Northwest Science 87:349-353.

Elrod, J. H., and R. O'Gorman. 1991. Diet of juvenile lake trout in southern Lake Ontario in relation to abundance and size of prey fishes, 1979-1987. Transactions of the American Fisheries Society 120:290-302.

Foote, C. J., and G. S. Brown. 1998. Ecological relationship between freshwater sculpins (genus *Cottus*) and beach-spawning sockeye salmon (*Oncorhynchus nerka*) in Iliamna Lake, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 55:1524-1533.

Foster, J. R. 1977. Pulsed gastric lavage: an efficient method of removing the stomach contents of live fish. Progressive Fish-Culturist 39:166-169.

Fox, P. J. 1978. Preliminary observations on different reproduction strategies in the bullhead (*Cottus gobio* L.) in northern and southern England. Journal of Fish Biology 12:5-11.

Fuller, P., and M. Neilson. 2013. Cottus asper. Nonindigenous Aquatic Species Database, U. S. Geological Survey, Gainesville, FL. Available online at http://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=501 (accessed 27 May 2013).

Fuller, P. L., L. G. Nico, and J. D. Williams. 1999. Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society Special Publication 27, Bethesda, MD.

Füreder, L., R. Ettinger, A. Boggero, B. Thaler, and H. Thies. 2006. Macroinvertebrate diversity in alpine lakes: effects of altitude and catchment properties. Hydrobiologia 562:123-144.

George, A. L., B. R. Kuhajda, J. D. Williams, M. A. Cantrell, P. L. Rakes, and J. R. Shute. 2009. Guidelines for propagation and translocation for freshwater fish conservation. Fisheries 34:529-545.

Herlihy, A. T., R. M. Hughes, and J. C. Sifneos. 2006. Landscape clusters based on fish assemblages in the conterminous USA and their relationship to existing landscape classifications. American Fisheries Society Symposium 48:87-112.

Hoffman, R. L., Jr. 1994. Distribution of nearshore macroinvertebrates in lakes of the northern Cascade Mountains, Washington, USA. M.S. Thesis, Oregon State University, Corvallis.

Holmen, J., E. M. Olsen, and L. A. Vøllestad. 2003. Interspecific competition between stream-dwelling brown trout and Alpine bullhead. Journal of Fish Biology 62:1312-1325.

Horn, H. S. 1966. Measurement of "overlap" in comparative ecological studies. American Naturalist 100:419-424.

Hunter, J. G. 1959. Survival and production of pink and chum salmon in a coastal stream. Journal of the Fisheries Research Board of Canada 16:835-886.

Johnson, J. H. 1981. Food interrelationships of coexisting brook trout, brown trout and yearling rainbow trout in tributaries of the Salmon River, New York. New York Fish and Game Journal 28:88-99.

Knapp, R. A., K. R. Matthews, and O. Sarnelle. 2001. Resistance and resilience of alpine lake fauna to fish introductions. Ecological Monographs 71:401-421.

Krejsa, R. J. 1967. The systematics of the prickly sculpin, *Cottus asper* Richardson, a polytypic species, part II. studies on their life history, with especial reference to migration. Pacific Science 21:414-422.

Kuhara, N., S. Nakano, and H. Miyasaka. 2001. Alterations in the grazing activities of cased caddisfly larvae in response to variations in predation risk and resource level. Ecological Research 16:705-714.

Larson, E. R., J. D. Olden, and N. Usio. 2010. Decoupled conservatism of Grinnellian and Eltonian niches in an invasive arthropod. Ecosphere 1(6):16.

Liao, H., C. L. Pierce, and J. G. Larscheid. 2001. Empirical assessment of indices of prey importance in the diets of predacious fish. Transactions of the American Fisheries Society 130:583-591.

Light, R. W., P. H. Alder, and D. E. Arnold. 1983. Evaluation of gastric lavage for stomach analyses. North American Journal of Fisheries Management 3:81-85.

Lodge, D. M., A. Deines, F. Gherardi, D. C. J. Yeo, T. Arcella, A. K. Baldridge, M. A. Barnes, W. L. Chadderton, J. L. Feder, C. A. Gantz, G. W. Howard, C. L. Jerde, B. W. Peters, J. A. Peters, L. W. Sargent, C. R. Turner, M. E. Wittmann, and Y. Zeng. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. Annual Review in Ecology, Evolution, and Systematics 43:449-472.

Lomnicky, G. A. 1996. Lake classification in the glacially influenced landscape of the North Cascade Mountains, Washington, USA. Ph.D. Dissertation, Oregon State University, Corvallis.

Lowry, G. R. 1966. Production and food of cutthroat trout in three Oregon coastal streams. Journal of Wildlife Management 30:754-767.

MacLellan, S. E. 1997. How to age rockfish (*Sebastes*) using *S. alutus* as an example—the otolith burnt section technique. Canadian Technical Report of Fisheries and Aquatic Sciences 2146.

Mason, J. C., and S. Machidori. 1976. Populations of sympatric sculpins, *Cottus aleuticus* and *Cottus asper*, in four adjacent salmon-producing coastal streams on Vancouver Island, B.C. Fishery Bulletin 74:131-141.

McDonald, M. E., B. E. Cuker, and S. C. Mozley. 1982. Distribution, production, and age structure of slimy sculpin in an Arctic lake. Environmental Biology of Fishes 7:171-176.

Miller, J. E., J. F. Savino, and R. K. Neely. 1992. Competition for food between crayfish (*Orconectes virilis*) and the slimy sculpin (*Cottus cognatus*). Journal of Freshwater Ecology 7:127-136.

Mongillo, P. E., and M. Hallock. 1997. Distribution and habitat of native nongame stream fishes of the Olympic Peninsula. Technical Report FRD 97-05, Washington Department of Fish and Wildlife, Olympia.

Moss, J. H. N. 2001. Development and application of a bioenergetics model for Lake Washington prickly sculpin (*Cottus asper*). M.S. Thesis, University of Washington, Seattle.

Moyle, P. B. 1977. In defense of sculpins. Fisheries 2(1):20-23.

Moyle, P. B., and B. Herbold. 1987. Life-history patterns and community structure in stream fishes of western North America: comparisons with eastern North America and Europe. *In* W. J. Matthews and D. C. Heins (editors), Community and Evolutionary Ecology of North American Stream Fishes, University of Oklahoma Press, Norman. Pp. 25-32.

Museth, J., R. Borgstrøm, J. E. Brittain, I. Herberg, and C. Naalsund. 2002. Introduction of the European minnow into a subalpine lake: habitat use and long-term changes in population dynamics. Journal of Fish Biology 60:1308-1321.

Northcote, T. G. 1954. Observations on the comparative ecology of two species of fish, *Cottus asper* and *Cottus rhotheus*, in British Columbia. Copeia 1954:25-28.

Patten, B. G. 1971. Spawning and fecundity of seven species of northwest American *Cottus*. American Midland Naturalist 85:493-506.

Pintor, L. M., A. Sih, and M. L. Bauer. 2008. Differences in aggression, activity and boldness between native and introduced populations of an invasive crayfish. Oikos 117:1629-1636.

Reimers, N. 1979. A history of a stunted brook trout population in an alpine lake: a lifespan of 24 years. California Fish and Game 65:196-215.

Resetarits, W. J., Jr. 1997. Interspecific competition and qualitative competitive asymmetry between two benthic stream fish. Oikos 78:429-439.

Rickard, N. A. 1980. Life history and population characteristics of the prickly sculpin (*Cottus asper* Richardson) in Lake Washington. M.S. Thesis, University of Washington, Seattle.

Ricker, W. E. 1960. A population of dwarf coastrange sculpins (*Cottus aleuticus*). Journal of the Fisheries Research Board of Canada 17:929-932.

Roberts, W. 1990. The prickly sculpin (*Cottus asper*) recorded from Alberta (with a key to the sculpins found in Alberta). Alberta Naturalist 20(1):24-26.

Rosenfeld, J. 2000. Effects of fish predation in erosional and depositional habitats in a temperate stream. Canadian Journal of Fisheries and Aquatic Sciences 57:1369-1379.

Samora, B. A., R. A. Lofgren, and M. Bateman. 2011. Mountain lakes records. Unpublished report on file at Mount Rainier National Park, Ashford, Washington.

Swift, C. C., T. R. Haglund, M. Ruiz, and R. N. Fisher. 1993. The status and distribution of the freshwater fishes of southern California. Bulletin of the Southern California Academy of Science 92:101-167.

Tabor, R. A., B. A. Footen, K. L. Fresh, M. T. Celedonia, F. Mejia, D. L. Low, and L. Park. 2007a. Smallmouth bass and largemouth bass predation on juvenile Chinook salmon and other salmonids in the Lake Washington basin. North American Journal of Fisheries Management 27:1174-1188.

Tabor, R. A., K. L. Fresh, D. K. Paige, E. J. Warner, and R. J. Peters. 2007b. Distribution and habitat use of cottids in the Lake Washington basin. American Fisheries Society Symposium 53:135-150.

Tabor, R. A., E. J. Warner, K. L. Fresh, B. A. Footen, and J. R. Chan. 2007c. Ontogenetic diet shifts of prickly sculpin in the Lake Washington basin, Washington. Transactions of the American Fisheries Society 136:1801-1813.

Thut, R. N. 1969. A study of the profundal bottom fauna of Lake Washington. Ecological Monographs 39:79-100.

Toweill, D. E. 1974. Winter food habits of river otters in western Oregon. Journal of Wildlife Management 38:107-111.

Vander Zanden, M. J., and J. D. Olden. 2008. A management framework for preventing the secondary spread of aquatic invasive species. Canadian Journal of Fisheries and Aquatic Science 65:1512-1522.

Wallace, R. L., and D. W. Zaroban. 2013. Native Fishes of Idaho. American Fisheries Society, Bethesda, Maryland.

Wiens, J. J., and C. H. Graham. 2005. Niche conservatism: integrating evolution, ecology, and conservation biology. Annual Review of Ecology, Evolution, and Systematics 36:519-539.

Wydoski, R. S., and R. R. Whitney. 2003. Inland Fishes of Washington. University of Washington Press, Seattle.

Zaret, T. M., and A. S. Rand. 1971. Competition in tropical stream fishes: support for the competitive exclusion principle. Ecology 52:336-342.

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