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Biological Review, Occupancy and Abundance, and Sampling Considerations for Umpqua Chub Status and Trend Monitoring

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Biological Review, Occupancy and Abundance, and Sampling Considerations for Umpqua Chub Status and Trend Monitoring

Oregon Department of Fish and Wildlife – Native Fish Investigations Program

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Summary

Umpqua Chub *Oregonichthys kalawatseti* is a small cyprinid that is endemic to the streams of the Umpqua River drainage, Oregon, and they are considered distinct from the congeneric Oregon Chub *O. crameri* found within the Willamette River drainage. Fishery scientists and managers typically divide Umpqua Chub into six ecological populations: Smith River, Elk Creek, Calapooya Creek, Olalla Creek, Cow Creek, and South Umpqua River. Contemporary genetic data suggest that Umpqua Chub may comprise four evolutionary populations: Smith River, Elk Creek, Calapooya Creek-Olalla Creek, and Cow Creek-South Umpqua River. Additionally, Umpqua Chub have been recently re-detected in the North Umpqua River.

The general biology of Umpqua Chub has been described by small sample sizes of Umpqua Chub from limited portions of their distribution. Umpqua Chub have a maximum length of about 65 mm FL. Umpqua Chub are typically found in habitats with slow water velocities, and the presence of infauna and sand in their diets may suggest association with, or selection for, benthic habitat and prey species. Given the paucity of data on the general biology of Umpqua Chub, further study may be warranted.

Surveys conducted in 1987, 1998, and 2006-2007 suggest that Umpqua Chub distribution was variable among sample periods, and likely among populations or sampling strata. However, overall patterns are indicative of a decrease in the distribution of Umpqua Chub during the last three decades. Conversely, the distribution of nonnative Smallmouth Bass *Micropterus dolomieu* has increased during the same time period. The apparent decrease in Umpqua Chub distribution and concurrent increase in the distribution of Smallmouth Bass has prompted concern from fishery scientist and managers involved in Umpqua Chub conservation and management.

Methods used to document the distribution and relative abundance of Umpqua Chub and other fishes in the Umpqua River drainage have been variable from 1987 through 2007, which makes direct and statistically-valid comparisons among previously collected data sets suspect. Consequently, we evaluated the efficacy of a variety of analytical techniques for estimating Umpqua Chub detection probability, occupancy, and abundance using data collected from 2015 through 2017. These analyses provide insight into sampling-related and site-level environmental factors that influence Umpqua Chub and Smallmouth Bass detection, presence, and abundance. Additionally, we evaluated the power of two monitoring strategies for detecting trend in the status of Umpqua Chub.

We conclude that monitoring Umpqua Chub using double-pass snorkeling and multistate occupancy models may provide a reasonable compromise between sampling efficiency and power to detect trend over time. We also recommend that the spatial distribution of sample sites should be increased over sampling efforts conducted in 2015-2017. We recommend that fishery and resource managers convene to discuss inter-organizational capacity to conduct surveys and desired level of power to detect trend. This information will provide a starting point for defining an appropriate monitoring plan that allocates sampling effort among sampling sites and strata and that can be maintained through time to benefit both trend monitoring and attainment of new information.

Biological Review of Umpqua Chub

Umpqua Chub *Oregonichthys kalawatseti* is a small cyprinid (< 65 mm FL) that is endemic to the streams of the Umpqua River drainage, Oregon (Figure 1). Umpqua Chub are considered distinct from the congeneric Oregon Chub *O. crameri* found within the Willamette River drainage (Markle et al. 1991). Fishery scientists and managers typically divide Umpqua Chub into six ecological populations: Smith River, Elk Creek, Calapooya Creek, Olalla Creek, Cow Creek, and South Umpqua River. However, contemporary genetic data suggest that Umpqua Chub may comprise four evolutionary populations: Smith River, Elk Creek, Calapooya Creek-Olalla Creek, and Cow Creek-South Umpqua River. Additionally, Umpqua Chub have been recently re-detected in the North Umpqua River (Penaluna and Ellenburg 2019). Descriptive information on the general biology of Umpqua Chub is available, but is generally limited to observations from a small number of individuals from geographically restricted areas. Survey data suggest a potential decline in Umpqua Chub distribution since the mid-1980s. A concurrent increase in the distribution of nonnative Smallmouth Bass *Micropterus dolomieu* within the Umpqua River drainage has prompted concern that Smallmouth Bass may displace Umpqua Chub through some combination of ecological interactions (e.g., predation, competition, etc.).

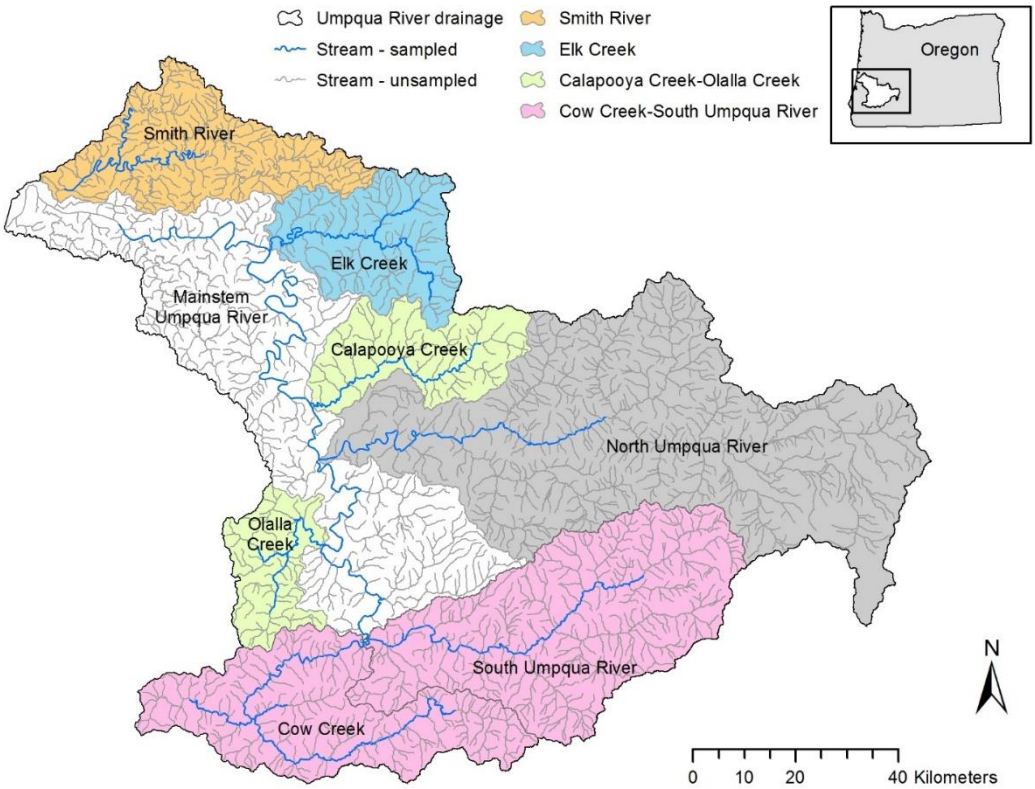

Figure 1. Umpqua River drainage located in southwestern Oregon. The Smith River, Elk Creek, Calapooya Creek-Olalla Creek, and Cow Creek-South Umpqua River evolutionary populations are represented by distinctly colored polygons (see O'Malley et al. 2013). The Smith River, Elk Creek, Calapooya Creek, Olalla Creek, Cow Creek, and South Umpqua River ecological populations are labeled on the map (see O'Malley et al. 2013). The Mainstem Umpqua River and North Umpqua River sampling strata are labeled on the map (see 'Future Sampling Considerations'; this document). The general extent of streams that have been sampled for Umpqua Chub at any point during 1987 through 2017 are shown in blue, the extent of streams that have not been sampled during this time period are shown in gray.

Here we summarize published and gray literature related to the biology of Umpqua Chub. We outline diagnostic differences between Umpqua Chub and Oregon Chub, population genetics and phylogenetics of Umpqua Chub, the general biology of Umpqua Chub (e.g., size, growth, reproduction, and food habits), habitat associations and general distribution of Umpqua Chub, and conservation, research, and monitoring needs for Umpqua Chub. This summary is largely drawn from Pearsons (1989), Markle et al. (1991), Simon and Markle (1999), Simon (2007a, 2007b, 2008), Markle et al. (2011), and O'Malley et al. (2013). We also present summaries and graphics based on review of data from Simon (2007a, 2007b, 2008). The terms 'isolate' and 'nominal population' have been used to refer to isolated clusters of Umpqua Chub (Simon 2008; Markle et al. 2011) and putative populations of Umpqua Chub (Markle et al. 2011), respectively; however, we use the terms population, ecological population, and evolutionary population throughout this document (*sensu* Waples and Gaggiotti 2006). We reference geographic distribution of Umpqua Chub based on Hydrologic Unit Codes (HUC; USGS 2020) at the subbasin (8-digit HUC) and watershed (10-digit HUC) scales. We delineate the Umpqua River drainage as the combination of the Umpqua (17100303; 8-digit HUC), North Umpqua (17100301), and South Umpqua (17100302) subbasins. To our knowledge the evolutionary and ecological populations referenced in the available literature are not delineated by distinct geographic features. For the purposes of this document, we delineate these evolutionary and ecological populations based on combinations of 10-digit HUCs (Table 1; Figure 1).

Diagnostic Differences between Umpqua Chub and Oregon Chub

Umpqua Chub is a cyprinid endemic to the rivers and streams of the Umpqua River drainage, Oregon. Umpqua Chub are distinct from the congeneric Oregon Chub based on allopatric distributions, subtle differences in morphology, behavioral differences, and the presence of one unique muscle lactate dehydrogenase (LDH-A) allele in Umpqua Chub relative to Oregon Chub (Markle et al. 1991). Markle (2019) hypothesized that *Oregonichthys* evolved as part of coastal Miocene Epoch fauna that was isolated in the ancestral Umpqua River by Grande Ronde Basalt flows, and that they colonized the Willamette River through a stream capture event in the headwaters of the Umpqua River drainage. Alternatively, the Umpqua River may have been a tributary to the Willamette River and a stream capture event during the late Cenozoic Era (Baldwin 1981; cited by Markle et al. 1991) may have geographically isolated these two drainages (Diller 1915; cited by Markle et al. 1991) leading to the allopatric distribution and speciation of Umpqua Chub and Oregon Chub (Markle et al. 1991). However, Markle (2019) believes that a Miocene-origin for *Oregonichthys* is more likely given the geological history of the region and large-scale patterns of fish faunal diversity.

Measurable morphometric, meristic, and enzymatic differences between Umpqua Chub and Oregon Chub are minor. Individual morphometric and meristic characteristics generally overlap between the two species; however, two separate discriminant function analyses showed that individuals of these species could be correctly classified based on combinations of morphometric measurements (95% correct classification) and on combinations of meristic measurements (98% correct classification) (Markle et al. 1991). Morphometric comparisons show that Umpqua Chub have a shorter caudal peduncle than Oregon Chub (Markle et al. 1991). The most prominent morphological difference between these two species is the presence and distribution of breast scales; scales are well distributed on the breast of Oregon Chub, but are less well distributed or absent on the breast of Umpqua Chub (see Figure 2 *in* Markle et al. 1991). Additionally, the mouth position of Umpqua Chub is more subterminal relative to Oregon Chub.

To our knowledge contemporary genetic and genomic methods have not been used to evaluate differences between Umpqua Chub and Oregon Chub; however, enzyme electrophoresis has

Table 1. Hydrologic Unit Codes (HUC) and 10-digit HUC names for evolutionary populations and ecological populations. Evolutionary and ecological populations are defined in O'Malley et al. (2013). For the purpose of this document, we use the terms evolutionary population and sampling strata interchangeably depending on context. Boundary delineation based on combinations of 10-digit HUCs (watersheds) represent our interpretation of O'Malley et al. (2013) for use in this document. Evolutionary and ecological populations for the Mainstem Umpqua River and North Umpqua River have not been previously defined, but are defined in this document as sampling strata (see 'Future Sampling Consideration'; this document).

Evolutionary population (sampling strata)	Ecological population	10-digit HUC	10-digit HUC name
Smith River	Smith River	1710030306	Upper Smith River
		1710030307	Lower Smith River
Elk Creek	Elk Creek	1710030303	Elk Creek
Calapooya Creek-Olalla Creek	Calapooya Creek	1710030301	Calapooya Creek
	Olalla Creek	1710030212	Olalla Creek-Lookingglass Creek
Cow Creek-South Umpqua River	Cow Creek	1710030208	West Fork Cow Creek
		1710030206	Upper Cow Creek
		1710030207	Middle Cow Creek
		1710030209	Lower Cow Creek
		1710030202	Jackson Creek
		1710030203	Dumont Creek-South Umpqua River
		1710030204	Elk Creek
		1710030205	Days Creek-South Umpqua River
	South Umpqua River	1710030201	Upper South Umpqua River
Mainstem Umpqua River	*Not defined*	1710030210	Myrtle Creek
		1710030211	Clark Branch-South Umpqua River
		1710030213	Deer Creek-South Umpqua River
		1710030302	Upper Umpqua River
		1710030304	Umpqua River-Sawyers Rapids
		1710030305	Mill Creek
		1710030308	Lower Umpqua River
North Umpqua River	*Not defined*	1710030109	Rock Creek
		1710030110	Little River
		1710030111	Lower North Umpqua River
		1710030101	Diamond Lake
		1710030102	Headwaters North Umpqua River
		1710030103	Clearwater River
		1710030104	Fish Creek
		1710030105	Upper North Umpqua River
		1710030106	Canton Creek
		1710030107	Steamboat Creek
		1710030108	Middle North Umpqua River

been used to evaluate protein polymorphism between Umpqua Chub and Oregon Chub. Among 21 enzymes assayed for these two species, one unique LDH-A allele was observed for Umpqua Chub and one rare LDH-A allele was observed for Oregon Chub. These observations were used to infer evolutionary differences between these species (Markle et al. 1991).

Population Genetics and Phylogenetics of Umpqua Chub

Population genetic diversity, genetic structure, and population fragmentation were evaluated for Umpqua Chub based on a sample of 25 individuals collected from each of the six ecological populations and genotyped at 10 microsatellite loci; individuals were collected from one sample site per ecological population (O'Malley et al. 2013). O'Malley et al. (2013) conducted analyses following 1) an ecological population paradigm and 2) an evolutionary population paradigm (*sensu* Waples and Gaggiotti 2006). Under the ecological population paradigm, analyses were performed based on *a priori* assignment of individuals to ecological populations (Smith River, Elk Creek, Calapooya Creek, Olalla Creek, Cow Creek, and South Umpqua River). Under the evolutionary population paradigm, Bayesian clustering was used to group Umpqua Chub *de novo* into evolutionary populations prior to subsequent analyses.

Umpqua Chub exhibit relatively high and consistent levels of genetic diversity among ecological populations (Table 2) (O'Malley et al. 2013). Genetic differentiation is significant among all pairs of ecological populations based on F_{ST} and estimates of genic and genotypic differentiation; additionally, Cavalli-Sforza and Edwards chord distances (Cavalli-Sforza and Edwards 1967) support genetic differentiation among the six ecological populations (O'Malley et al. 2013). Overall, genetic differentiation among ecological populations of Umpqua Chub follows a pattern of isolation by distance (i.e., genetic differentiation increases with geographic distance). However, this pattern is strongly influenced by the Smith River ecological population such that isolation by distance is not supported if the Smith River population is removed from the analysis; additionally, the pairwise comparison between the Smith River and Elk Creek populations is an outlier in this analysis (O'Malley et al. 2013). Taken together, these analyses suggest that measurable genetic differences exist among the *a priori* defined, or hypothesized, Umpqua Chub populations. Additionally, genetic differentiation of these populations is at least partly influenced by geographic separation, but that other factors likely influence genetic differentiation among ecological populations. *De novo* assignment of individuals into groups using Bayesian clustering suggests that there are four evolutionary populations of Umpqua Chub: Smith River, Elk Creek, Calapooya Creek-Olalla Creek, and Cow Creek-South Umpqua River (Figure 1).

Genetic divergence among Umpqua Chub populations may be greatest between the Smith River population and other populations. This population is the most genetically distinct population among ecological populations and was the first group to separate out among evolutionary populations (see Figure 5c *in* O'Malley et al. 2013). O'Malley et al. (2013) estimated that the Smith River population diverged (measured as splitting time; *see* Hey and Nielsen 2007) from other Umpqua Chub populations about 188 years before present (from the time of their sample collection), and estimated that the other evolutionary populations diverged about 41-89 years before present. Although the precision of the estimated divergence time for the Smith River population was relatively low (i.e., 20-396 years before present), O'Malley et al. (2013) suggest that these estimates should be sufficient to eliminate isolating mechanisms such as Holocene sea level rise and support a more recent divergence time among Umpqua Chub populations.

Based on patterns of genetic diversity, genetic differentiation, estimated divergence times, and spatial genetic patterns, O'Malley et al. (2013) hypothesize that "Umpqua Chub populations formed by peripheral isolation from a larger population, the remnant of which is the mid-drainage

Table 2. Genetic diversity of six ecological populations of Umpqua Chub measured as the mean number of alleles per locus (*A*), expected heterozygosity (H_e), and observed heterozygosity (H_o). Reproduced with permission from O'Malley et al. (2013).

Ecological population	*A*	H_e	H_o
Smith River	6.9	0.564	0.576
Elk Creek	8.1	0.546	0.572
Calapooya Creek	9.4	0.567	0.580
Olalla Creek	9.5	0.570	0.590
Cow Creek	6.2	0.578	0.535
South Umpqua River	8.4	0.603	0.606

Calapooya-Olalla population." Furthermore, the Smith River evolutionary population may have been isolated about four times longer than other populations (O'Malley et al. 2013). Construction of Cunningham Dam may have isolated the Elk Creek evolutionary population and establishment of Smallmouth Bass and subsequent ecological interactions with Umpqua Chub may have fragmented the Calapooya Creek-Olalla Creek and the Cow Creek-South Umpqua River evolutionary populations (O'Malley et al. 2013); however, further work is warranted to elucidate historic and contemporary factors associated with fragmentation among Umpqua Chub populations.

General Biology of Umpqua Chub

Umpqua Chub have a maximum length of about 65 mm FL (Markle et al. 2011). Age and growth of Umpqua Chub has been characterized from 25 Umpqua Chub collected from each of six ecological populations (Smith River, Elk Creek, Calapooya Creek, Olalla Creek, Cow Creek, and South Umpqua River) (Markle et al. 2011; O'Malley et al. 2013). Umpqua Chub from this collection varied in length from 23-65 mm FL and varied in age from 1-7 years. Among populations, Umpqua Chub growth rate is rapid during their first 2 years and slows thereafter, resulting in substantial overlap in length-at-age for Umpqua Chub older than age-2 (Markle et al. 2011; O'Malley et al. 2013). The von Bertalanffy growth curve presented in Markle et al. (2011) took the form of:

$$L_t = 60.07\left(1 - e^{-0.70(t+0.28}\right),$$

where L_t = FL at time *t* in years. Based on this growth curve, Umpqua Chub mean FL at age is: age-0 = 11 mm; age-1 = 36 mm; age-2 = 48; age-3 = 54 mm; age-4 = 57; age-5 = 59 mm; age-6 = 59 mm; age-7 = 60 mm.

Putative differences in size, age, and growth rate among populations of Umpqua Chub have not been sufficiently examined or documented to draw broad conclusions. Markle et al. (2011) provide summaries showing that Umpqua Chub from the Smith River are smaller, younger, and have a slower mean growth rate than other populations, and that Umpqua Chub from the South Umpqua River are larger, older, and have a faster mean growth rate than other populations. However, age-0 and age-1 fish are underrepresented within the sample of Umpqua Chub examined (see Figures 2 and 3 *in* Markle et al. 2011). In fact, the only population where age-0 and age-1 Umpqua Chub were collected was the Smith River population, the sample collected from the South Umpqua River comprised "a large proportion of fish older than 3 years", and individuals were collected from only one sample site per population (Markle et al. 2011; O'Malley et al. 2013). Markle et al. (2011) acknowledge limitations of their data to make definitive comparisons among populations; however, we believe it is important to highlight that data are currently insufficient to draw conclusions about size, age, and growth rate differences among populations. For example, age-

0 Umpqua Chub comprised large proportions of the total sample of Umpqua Chub in Elk Creek (26%), Calapooya Creek (54%), and South Umpqua River (42%) during sampling in 2006-2007 (Simon 2008).

Little is known about the reproductive biology of Umpqua Chub. Umpqua Chub generation time has been speculated to be about 3-4 years (Markle et al. 2011; O'Malley et al. 2013) based on estimated growth rates of Umpqua Chub and comparisons with the congeneric Oregon Chub (Scheerer and McDonald 2003; Scheerer et al. 2005; DeHaan et al. 2012). Fecundity of two female Umpqua Chub has been calculated at 322 eggs for a 45 mm SL Umpqua Chub and at 231 eggs for a 47 mm SL Umpqua Chub; mean egg diameter varied from 0.9-1.1 mm for these two Umpqua Chub (Pearsons 1989; Markle et al. 1991).

Putative spawning behavior has been observed for captive Umpqua Chub held in 72-l aquaria and exposed to a solution of luteinizing hormone-release hormone ethylamide intended to induce spawning (Pearsons 1989; Markle et al. 1991). Pearsons (1989) and Markle et al. (1991) assumed that individual fish expressing agonistic behavior were males and individual fish that were passive and had fuller bodies were females. Spawning activity typically involved one female and one or more males, and began when a dominant male would swim into the flank of the female. The female will typically swim up and down away from the male, with the male following and nudging the female with its head. Putative spawning would occur with the female taking a head down position with a straight body on a flat rock, and with the male moving next to the female and nudging the female (Markle et al. 1991). No egg laying was noted during observations, but these activities were assumed to be related to spawning (Pearsons 1989; Markle et al. 1991).

Information about the food habits of Umpqua Chub are available for a limited number of individuals (N = 20) collected from the Calapooya River (Pearsons 1989; Markle et al. 1991). Infaunal chironomids were present in the diets of 85% of the Umpqua Chub and sand grains were present in the diets of 70% of the Umpqua Chub. Other diet items commonly observed included epifaunal dytiscids (present 55% of the Umpqua Chub), and ephemeroptera (present in 55% of the Umpqua Chub) (Pearsons 1989).

Umpqua Chub Habitat Use, Distribution, and Potential Interactions with Smallmouth Bass

Limited data are available on habitat use by Umpqua Chub. Umpqua Chub are typically found in habitats with slow water velocities (Pearsons 1989), such as run, slough, and pool habitats (Markle et al. 1991). When found in habitats with moderate to high water velocities, Umpqua Chub have been observed along stream banks or behind structure that may reduce water velocity (Markle et al. 1991). Umpqua Chub have been observed associated with both erosional and depositional substrates, and associated with aquatic and riparian vegetation (Pearsons 1989; Markle et al 1991); Umpqua Chub catch rates using baited minnow traps were greater in areas with aquatic and overhanging riparian vegetation compared to areas with other types of cover in one section of Elk Creek (Markle et al. 2011). The presence of infauna and sand in the diets of Umpqua Chub (Pearsons 1989; Markle et al. 1991) may suggest association with, or selection for benthic habitat.

The distribution of Umpqua Chub has been periodically evaluated since the mid-1980s to describe general characteristics of this species and its habitat, and to evaluate suspected changes in its distribution. The suspected changes in the distribution of Umpqua Chub have been associated with an increase in the distribution of Smallmouth Bass within the Umpqua River drainage. The distribution of Umpqua Chub and Smallmouth Bass has been described based on three datasets; these data sets were collected in 1987 (Markle et al. 1991), 1998 (Simon and Markle 1999), and

2006-2007 (Simon 2007a, 2007b, 2008; O'Malley 2013). The distribution of sample sites and the sampling intensity were nearly identical in 1987 and 1998, with the exception that 38 sample sites were visited in 1987 and only 37 of those sites were sampled in 1998[1]. These sample sites were primarily located in areas where Umpqua Chub had been observed at some time during the past based on historical records from the Oregon State University fish collection database. Compared to efforts in 1987 and 1998, the sampling intensity was increased substantially to 141 sample sites in 2006-2007 and the spatial distribution of sample sites was greater; with the exception that sampling did not occur in the North Umpqua River in 2006-2007.

Sampling protocols and sampling gears used in 1987, 1998, and 2006-2007 were variable. Neither Markle et al. (1991) nor Simon and Markle (1999) provide information on sample site dimensions for sites sampled in 1987 and 1998. Sample sites "typically" comprised two, adjacent, 100-m reaches in 2006 (Simon 2007a), and were 200-m in 2007 (Simon 2007b); however, Simon (2008) notes that sites sampled in 2006-2007 varied in length from 50-400 m. Sites were sampled using some combination of seines, dip nets, snorkeling, and electrofishing in 1987 (Markle et al. 1991), and some combination of seines, dip nets, push nets, hook-and-line, and visual observation in 1998 (Simon and Markle 1999). Sample sites were sampled using some combination of snorkeling, shoreline visual surveys, and beach seine hauls in 2006-2007 (Simon 2007a, 2007b)[2]; specifically, snorkeling was conducted at 95 sites, shoreline visual surveys were conducted at 16 sites, a combination of snorkeling and shoreline visual surveys were conducted at 18 sites, beach seine hauls were conducted at 11 sites, and a combination of beach seine hauls and shoreline visual surveys were conducted at 1 site (Simon 2008)[3]. We urge caution when making comparisons among these three datasets given the known and potential unknown differences in sampling methodology; however, for purposes of this review we summarize the interpretations of others.

Results from surveys conducted in 1987, 1998, and 2006-2007 suggest that Umpqua Chub distribution was variable among sample periods, and likely among populations or sampling strata. Umpqua Chub were detected at 13 of the 38 sample sites in 1987[4], but only at 6 of the 37 sample sites in 1998 (Figure 2). Umpqua Chub were present in some high-order stream reaches of the mainstem Umpqua River in 1987 where they were not detected in 1998. In 2006-2007, the percent of sample sites where Umpqua Chub were detected varied from 9-50% among sampling strata (Table 3). Umpqua Chub were rarely detected in the mainstem Umpqua River in 2007 (Figure 3), and the frequency of sample sites where Umpqua Chub were detected was inversely related to stream order (see Figure 2 *in* O'Malley et al. 2013).

The known distribution of nonnative Smallmouth Bass in the Umpqua River drainage is converse to that of Umpqua Chub in many ways. Smallmouth Bass were detected at 7 of the 38 sample sites in 1987 and 19 of the 37 sample sites in 1998 (Figure 2). In 2006-2007, the percent of sample

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[1] The methods section *in* Markle et al. (1991) states that 39 sample sites were visited in the Umpqua River drainage in 1987; however, the results section *in* Markle et al. (1991) and Simon and Markle (1999) suggest that 38 sample sites were visited in the Umpqua River drainage in 1987.

[2] Our records suggest that kick nets, dip nets, and minnow traps were used at some sample sites. These sampling methods are not mentioned in Simon (2007a, 2007b, 2008); however, we use count data from these sampling gears for summaries presented in this document (e.g., Table 3; Figure 3)

[3] O'Malley et al. (2013) state that snorkel surveys were conducted at 113 sites, beach seine hauls were conducted at 12 sites, and shoreline visual surveys were conducted at 16 sites.

[4] Markle et al. (1991) state that Umpqua Chub were detected at 13 of the 38 sample sites visited in 1987; however, Simon and Markle (1999) state that Umpqua Chub were detected at 12 of the 38 sample sites visited in 1987.

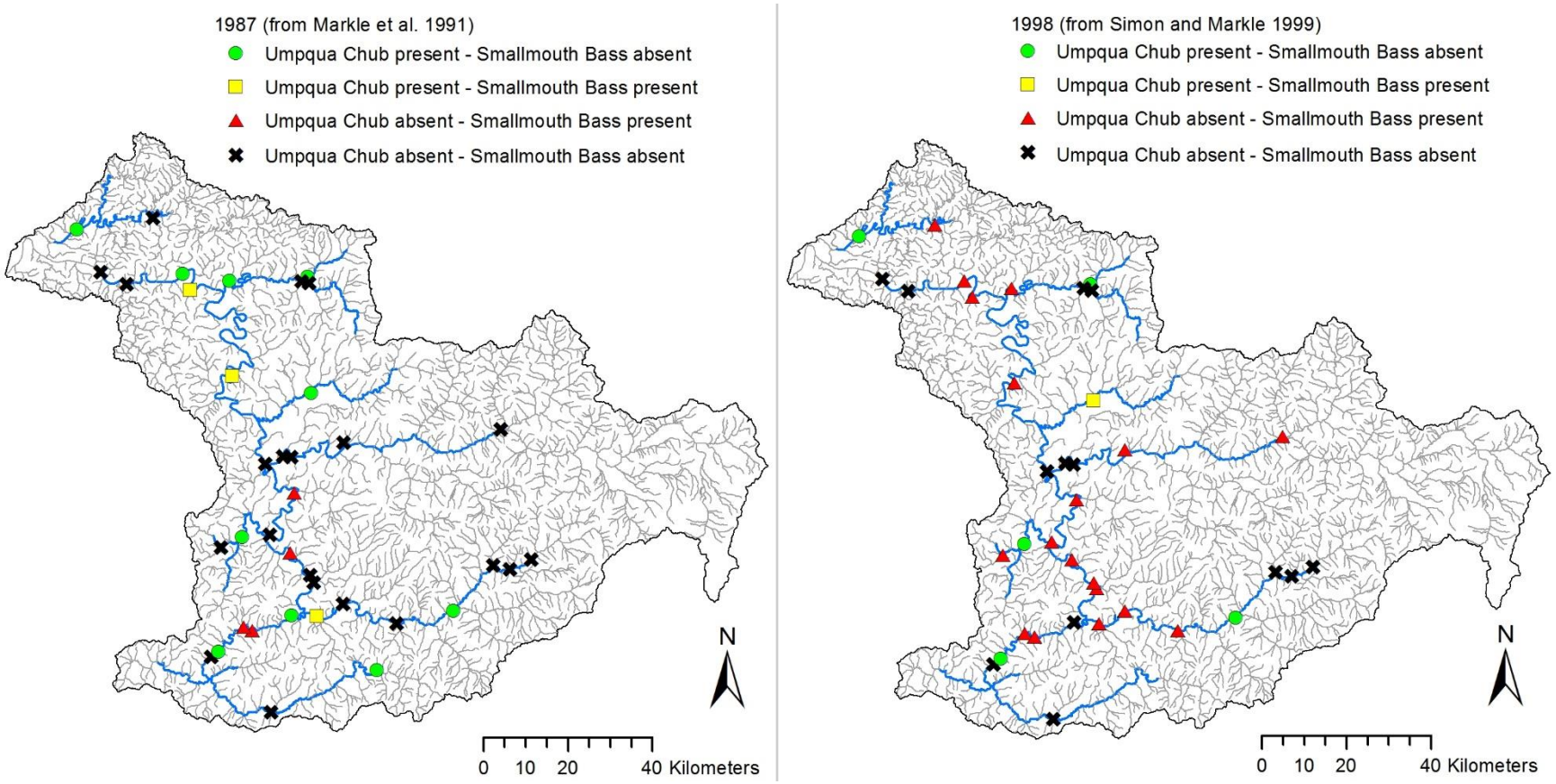


Figure 2. Sample sites in the Umpqua River drainage where Umpqua Chub and Smallmouth Bass were present or absent during surveys conducted in 1987 (Markle et al. 1991; left panel) and in 1998 (Simon and Markle 1999; right panel). The general extent of streams that have been sampled for Umpqua Chub at any point during 1987 through 2017 are shown in blue, the extent of streams that have not been sampled during this time period are shown in gray. Some points were offset on the map to allow visualization of overlapping or close-proximity sample sites.

Table 3. The number of sample sites surveyed during 2006 and 2007 (*N*) and the percent of samples sites where Umpqua Chub and Smallmouth Bass were present (≥ 1 individual) and sympatric for each ecological population (or sampling strata denoted by an '*') and all populations combined. Reproduced from Simon (2007a, 2007b) and available data.

Ecological population	*N*	Umpqua Chub present (%)	Smallmouth Bass present (%)	Sympatric (%)
Smith River	15	33	0	0
Elk Creek	20	50	30	0
Calapooya Creek	13	38	46	15
Olalla Creek	15	13	20	0
Cow Creek	27	44	48	22
South Umpqua River	29	31	83	28
Mainstem Umpqua River*	22	9	95	9
All populations and strata	141	33	52	13

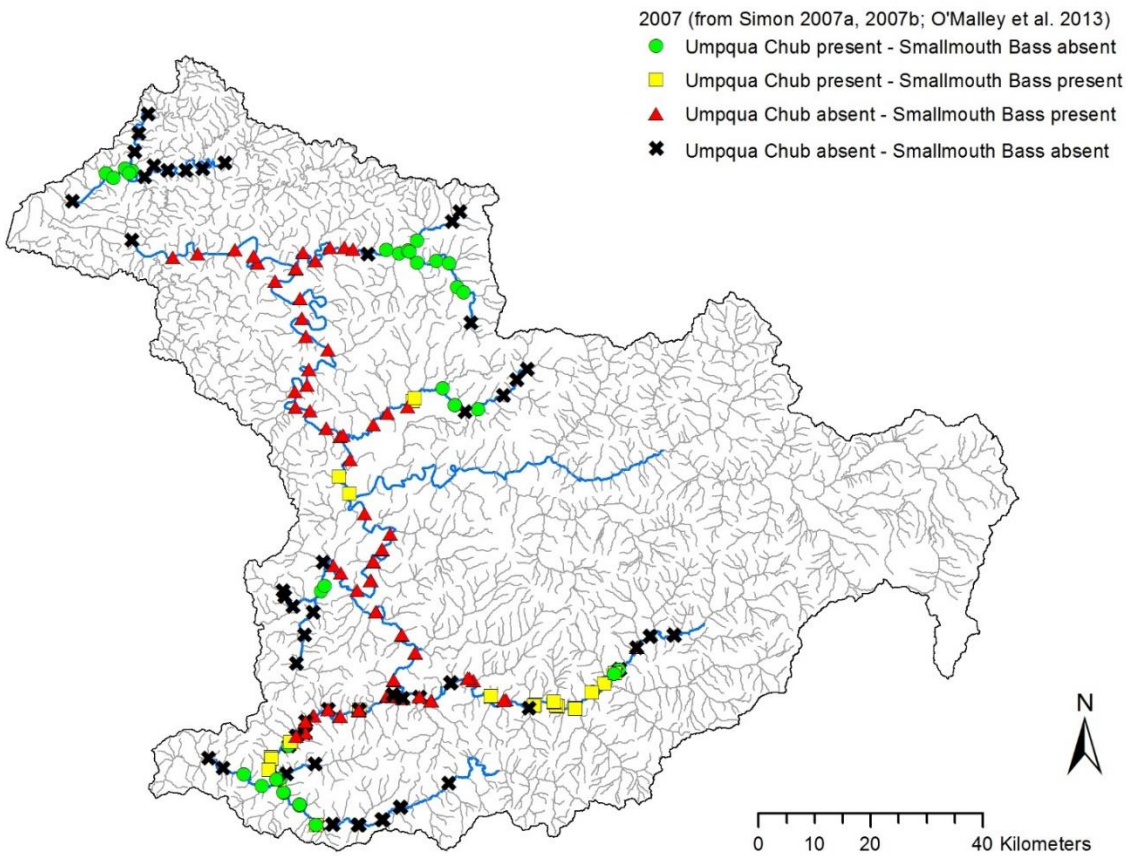


Figure 3. Sample sites in the Umpqua River drainage where Umpqua Chub and Smallmouth Bass were present or absent during surveys conducted during 2006-2007 (Simon et al. 2007a, 2007b; O'Malley et al. 2013). The general extent of streams that have been sampled for Umpqua Chub at any point during 1987 through 2017 are shown in blue, the extent of streams that have not been sampled during this time period are shown in gray.

sites where Smallmouth Bass were detected varied from 0-95% among sampling strata (Table 3). Smallmouth Bass were present throughout the mainstem Umpqua River in 2006-2007 (Figure 3), and the frequency of sample sites where Smallmouth Bass were detected was positively related to stream order (see Figure 2 *in* O'Malley et al. 2013). In 2006-2007, Smallmouth Bass were associated with all ecological populations and sampling strata evaluated, with the exception of the Smith River population. Interestingly, Smallmouth Bass were detected in the Smith River with only limited sampling (i.e., 2 sample sites) during 1998; additional surveys in the Smith River strata are warranted to evaluate the presence of Smallmouth Bass (see 'Future Sampling Considerations'; this document). Within the geographic extent of individual ecological populations, Umpqua Chub were typically observed in high elevation stream reaches, Smallmouth Bass were typically observed in low elevation stream reaches, and a zone of sympatry was observed at mid-elevation stream reaches for some Umpqua Chub populations (Figure 3). However, the extent of sympatry between Smallmouth Bass and Umpqua Chub was relatively small overall (13% of all sample sites were sympatric) and variable among ecological populations (range: 0-28% of sample sites among sampling strata) (Table 3).

Overall, observations from 1987, 1998, and 2006-2007 have prompted some fishery scientists and managers to speculate that "Smallmouth Bass may have replaced Umpqua Chub in mainstem [river] sections and restricted them to lower order tributaries [within the Umpqua River drainage]" (Simon and Markle 1999; Simon 2008). Furthermore, Simon and Markle (1999) and Simon (2008) suggest that Umpqua Chub populations have been fragmented and isolated over time, and that this fragmentation may have demographic and genetic effects. We concur that observations from available data are indicative of a reduction in the spatial extent of Umpqua Chub and an increase in the spatial extent of Smallmouth Bass; however, we urge caution when interpreting these data and call for additional research. Methodological differences among samples collected during 1987 1998, and 2006-2007 are substantial, and although these differences likely do not account for all of the variability observed among sample periods, they should be considered carefully. Sampling gears used varied considerably among sample sites within sample periods, and among sample periods; with unknown effects on detection probabilities for target species. The sampling intensity and spatial distribution of sample sites varied considerably between the combined 1987 and 1998 sample period and the 2006-2007 sample period, and observations from 2006-2007 suggest that spatially explicit or spatially implicit analyses may be more appropriate for evaluating Umpqua Chub distribution than simple calculations of the number of sites where target species were observed.

Umpqua Chub Conservation, Research, and Monitoring Needs

The Umpqua Chub is listed as "vulnerable" by the International Union for Conservation of Nature (IUCN 2020). Additionally, the Umpqua Chub is listed as a "Species of Concern" by the U.S. Fish and Wildlife Service (USFWS 2020), "Oregon-Sensitive" by the Bureau of Land Management-Forests Service Interagency Special Status Sensitive Species Program (FS/BLM 2020), and "sensitive critical" on the Oregon Department of Fish and Wildlife – Sensitive Species List (ODFW 2020a); the Umpqua Chub is also a strategy species under the Oregon Conservation Strategy (ODFW 2020b). Markle et al. (2011) recommended future research should include: documenting the existence and spatial extent of each population at regular intervals, obtaining unbiased estimates of abundance and age structure, refining sampling methods for monitoring abundance and trends, and a rigorous evaluation of the threats to each population. Simon and Markle (1999) and Markle et al. (2011) note that previous surveys lack context related to natural variability in population abundance as a function of time. Data gaps identified in the Oregon Conservation Strategy include lack of abundance and trend data and information regarding population dynamics (ODFW 2020b). The IUCN identifies a need for more information related to interactions between

Umpqua Chub and nonnative fishes (NatureServe 2013). Common themes related to research and monitoring needs include 1) a lack of methods for detecting trend in distribution and abundance, 2) a lack of sufficient data for documenting trend in distribution and abundance, and 3) a lack of data related to ecological interactions between Umpqua Chub and nonnative species (particularly Smallmouth Bass).

Umpqua Chub distribution surveys conducted in 1987 (Markel et al. 1991), 1998 (Simon and Markle 1999), and 2006-2007 (Simon 2007a, 2007b, 2008; O'Malley et al. 2013) provide a template for developing future surveys and survey methodologies. However, given the potential limitations associated with comparisons across these disjunct datasets, we suggest that future sampling efforts aimed at evaluating status and trend of Umpqua Chub follow a pre-planned sampling protocol designed for that purpose. Field surveys should be conducted at a sufficient intensity (i.e., number of sample sites), frequency (e.g., number of intervals such as years), and spatial extent to adequately represent target species and to provide acceptable levels of power to detect trend. Fishery scientists and managers should consider potential natural fluctuations in occupancy or abundance of Umpqua Chub and other species of interest when developing field surveys. For example, Oregon Chub, a closely related congener to Umpqua Chub, can exhibit interannual variability in population abundance of up to an order of magnitude (Scheerer 2007). Indeed, Simon and Markle (1999) noted that "we know nothing about interannual variation in abundance of Umpqua Chub", and failing to account for natural and potentially high levels of interannual variation in distribution and abundance may lead to spurious conclusions.

Research aimed at evaluating sampling gears (including snorkeling) to efficiently survey Umpqua Chub and other species of interest is warranted. Choice of sampling gears may be dependent on the type of habitat surveyed, the species surveyed, or study-specific objectives (Bonar et al. 2009). Consideration of permit requirements and fish care and handling may also be important when choosing appropriate sampling gears (Jennings et al. 2012). Snorkeling was the primary sampling gear used during surveys in 1987, 1998, and 2006-2007; however, other sampling gears were also used (e.g., beach seines, dip nets, kick nets, visual surveys, minnow traps, electrofishing, etc.). Using multiple sampling gears is not a limitation of previous surveys *per se*; however, detection probability, sampling efficiency, and catchability may vary among sampling gears (Pregler et al. 2015; MacKenzie et al. 2018). Additionally, detection probability, sampling efficiency, and catchability may vary among fish species, fish size groups, fish life-history stages, seasons, and other factors for any single gear type (Thurow et al. 2006; MacKenzie et al. 2018). Consequently, combining data among sampling gears, sample sites, and sample periods from previous survey efforts may be problematic. The role of imperfect detections and methods for incorporating detection probability into analytical techniques aimed at quantifying the status of species has received substantial attention over the last two decades (MacKenzie et al. 2002; MacKenzie et al. 2018). Future efforts should consider explicitly addressing the role of detection probability when identifying appropriate sampling gears and survey methodologies.

Additional research should be conducted on potential ecological interactions between Umpqua Chub, Smallmouth Bass, and other species as appropriate. Concerns related to the establishment and spread of Smallmouth Bass in the Umpqua River drainage are warranted. In general, Smallmouth Bass feed on a variety of taxa including insects, crayfish, and fish, and food habits vary with Smallmouth Bass size (Scott and Crossman 1973). In the Umpqua River drainage, teleost fishes were present in 26% of the diets of Smallmouth Bass sampled from Elk Creek and they made up 32% of prey energy [i.e., prey mass (g) x energy density (J/g)] consumed by Smallmouth Bass (Schultz et al. 2017). Consequently, Smallmouth Bass represent a novel, potential predator of Umpqua Chub and other fishes in the Umpqua River drainage. The observed changes in distribution of Umpqua Chub and Smallmouth Bass noted by Simon and Markle

(1999), Simon (2007a, 2007b, 2008), and O'Malley et al. (2013) are indicative of some negative interaction between these species; however, it is unknown whether these changes are a result of competition, predation, or some other factor or factors affecting multiple species within the Umpqua River drainage. Field-based or laboratory-based experiments and observational studies could be conducted to evaluate ecological interactions between Umpqua Chub and Smallmouth Bass (e.g., competition and predation). Field-based studies aimed at understanding the ecology of Umpqua Chub within the context of the entire fish assemblage, the physical characteristics of the Umpqua River drainage, or both may reveal more complex interactions.

Population genetic and phylogenetic data show that Umpqua Chub have relatively high levels of genetic diversity within populations, but that there is evidence for relatively recent divergence and fragmentation among populations (O'Malley et al. 2013). Consequently, conservation efforts may aim to better understand factors influencing fragmentation and their potential effects on adaptive capacity of Umpqua Chub. These efforts could take the form of genetic monitoring at some regular interval or an updated, hypothesis-driven genetic assessment (see Schwartz et al. 2007). Currently available genetic data are based on samples collected from one sample site from each ecological population (O'Malley et al. 2013). These data have provided valuable information regarding Umpqua Chub; however, incorporating greater spatial representation of samples may allow for a fine-scaled assessment of factors driving evolutionary processes in Umpqua Chub. Furthermore, using contemporary genetic and genomic methods to evaluate phylogenetic differences between Umpqua Chub and Oregon Chub may allow for a better understanding of the evolutionary history of the species.

The general biology of Umpqua Chub (e.g., size, growth, reproduction, and food habits) has been described in some detail (Pearsons 1989; Markle et al. 1991; Markle et al. 2011; O'Malley et al. 2013); however, much of this information comes from small sample sizes of individuals collected from a limited number of locations, observational data, or inference from the congeneric Oregon Chub. Understanding Umpqua Chub age-structure, growth, reproductive biology, movement or migration, and life-history may help elucidate population dynamics. Additionally, developing a greater understanding of Umpqua Chub habitat requirements or preferences may help guide habitat conservation and enhancement. Although recent efforts have primarily focused on documenting the distribution of Umpqua Chub, fishery scientists and managers may consider expanding on available data related to the general biology of this species through carefully designed field studies or laboratory evaluations.

Analysis of Contemporary Data on Umpqua Chub Occupancy and Abundance (2015-2017)

Previous surveys for Umpqua Chub have noted a potential decline in the distribution of Umpqua Chub (Simon and Markle 1999; Simon 2008; O'Malley et al. 2013). This potential decline has occurred concurrently with observed increases in the distribution of nonnative Smallmouth Bass within the Umpqua River drainage (Simon and Markle 1999; Simon 2008; O'Malley et al. 2013). Additionally, fragmentation of Umpqua Chub populations within portions of the Umpqua River drainage may have occurred as recently as 41-89 years before present (O'Malley et al. 2013), a time period that is coincident with the establishment of Smallmouth Bass and other anthropogenic perturbations.

Although available data suggest a decline in the distribution of Umpqua Chub, limitations of currently available data warrant development or refinement of monitoring techniques. Consequently, fishery managers identified a need for methods to assess status and trend of Umpqua Chub. Therefore, field surveys were conducted using a variety of sampling strategies during 2015-2017. The resulting data and multiple analytical techniques were used to evaluate detection probability, occupancy, and abundance of Umpqua Chub. These analyses provide insight into sampling-related and site-level environmental factors that influence Umpqua Chub and Smallmouth Bass detection, presence, and abundance. Additionally, we evaluated the power of two monitoring strategies for detecting trend in the status of Umpqua Chub.

Field Survey Methods

Fish and habitat within Cow Creek and South Umpqua River watersheds (Table 1; Figure 4) were surveyed in 2015, 2016, and 2017; similar methods were used among years with some exceptions. We refer to this area as the Cow Creek-South Umpqua River sampling stratum.

<u>Survey method used in 2015</u>

In 2015 we conducted surveys at 28 sample sites within Cow Creek-South Umpqua River sampling stratum (Table 4; Figure 4). Each sample site was located from pre-assigned geographic coordinates using a hand-held global positioning system (GPS) unit; the geographic coordinate was flagged and treated as the downstream boundary of the sample site. We measured the wetted width of the stream at three locations near the downstream site boundary, averaged these wetted widths, and multiplied the average wetted width by six to determine the sample site length; consequently, the sample site length was scaled to stream width. We measured the site length upstream along the stream thalweg, identified a habitat-unit break (e.g., pool-riffle transition), flagged this habitat-unit break as the upstream site boundary, and recorded the total site length and average wetted width.

Snorkel surveys were conducted by a two-person survey crew at most of the sample sites (N = 17). The survey crew started at the downstream site boundary, sampled in an upstream direction, and each person counted all Umpqua Chub and Smallmouth Bass observed within about 2-m from the stream bank (one snorkeler per stream bank). Additional surveyors were added to the survey crew to count fish along the middle portion of the stream channel at some of the larger more complex sample sites (one additional surveyor at 8 sample sites; two additional surveyors at 2 sample sites), and a one-person survey crew was used at one sample site (Table 4). Counts were repeated on two consecutive days (hereafter "double-pass snorkel survey") with the same surveyor surveying the same stream bank or location on each day. The survey crew recorded the survey start and end times to calculate survey duration, and, in general, attempted to exert equal

Table 4. Geographic coordinates for sample sites surveyed in 2015, 2016, and 2017 in the Cow Creek-South Umpqua River sampling stratum. The number of snorkelers that surveyed sample sites varied from 1-4 during primary surveys and from 2-3 during secondary surveys in 2015. An 'X' denotes sites that were sampled following either a snorkel only protocol or a snorkel and trap protocol during 2016 and 2017. Coordinates were not recorded for sample site 15.

			2015 (*N* snorkelers)		2016		2017	
Site	Latitude	Longitude	Primary	Secondary	Snorkel only	Snorkel and trap	Snorkel only	Snorkel and trap
1	42.9839	-122.8648	2		X			X
2	42.9665	-122.8871	2	2	X			X
2A	42.9658	-122.8868	1		X			
3	42.9616	-122.8891	2				X	
4	42.9529	-122.9053	3		X			X
5	42.9557	-122.9091	3			X		
6	42.9375	-122.9362	2		X			
7	42.9320	-122.9457	2		X			
8	42.9271	-122.9514	2	2		X		
9	42.9300	-122.9820	2			X		
10	42.9377	-123.0124	2		X			
11	42.9293	-123.0590	2					
15			2					
16	42.7733	-123.5703	2		X			
17	42.8121	-123.5972	4		X			
18	42.8126	-123.6028	3		X			
19	42.8171	-123.6093	2			X		
20	42.8195	-123.6176	3		X			
21	42.8264	-123.6194	3			X		
22	42.8321	-123.6180	2			X		
23	42.8386	-123.6210	2					
24	42.8530	-123.6070	2	3		X		
25	42.8666	-123.5762	3	3	X			
26	42.8836	-123.5585	3	3		X		
27	42.8045	-123.6114	3		X			
28	42.8018	-123.6344	4			X		
29	42.9327	-122.9920	2			X		
31	42.9492	-123.1736	2					

effort by surveying the same areas over a similar amount of time on both sampling occasions. Additionally, at five sample sites an independent secondary survey was conducted about 30 minutes after completion of the primary survey by a two- or three-person, inexperienced survey crew (Table 4) to assess differences in snorkel counts between experienced and inexperienced survey crews.

Habitat data were compiled for each sample site. Sample site length and average width were measured prior to snorkel surveys (see above). Sample site depth, percent aquatic vegetation, percent algae, and percent substrate composition were quantified following completion of snorkel surveys. Depth was measured at five locations along each shoreline snorkel transect, and mid-channel snorkel transect when applicable. Percent aquatic vegetation and percent algae were visually assessed based on the areal coverage of aquatic vegetation and algae, respectively, relative to the wetted surface area. Percent substrate composition was visually assessed relative to the wetted surface area for each of the following substrate types: silt and sand (particle size < 2 mm), gravel (2-64 mm), cobble (65-256 mm), boulder (> 256 mm), and bedrock. Derived habitat data included wetted surface area (sample site length multiplied by average wetted width), average depth (average of all depth measurements for each sample site), and dominant substrate type (most prevalent substrate type by sample site). We acknowledge that visually-assessed habitat characteristics may be prone to limited precision and repeatability (e.g., Anlauf-Dunn and Jones 2012). However, they provide a rapid way of assessing habitat characteristics that may influence fish detection, occupancy, and abundance, and results from visual assessments may be suitable for typical fishery applications (Wang et al. 1996; Strickland and Davies 2020). Water temperature was recorded immediately prior to each sampling occasion and snorkel survey duration was recorded immediately following each sampling occasion.

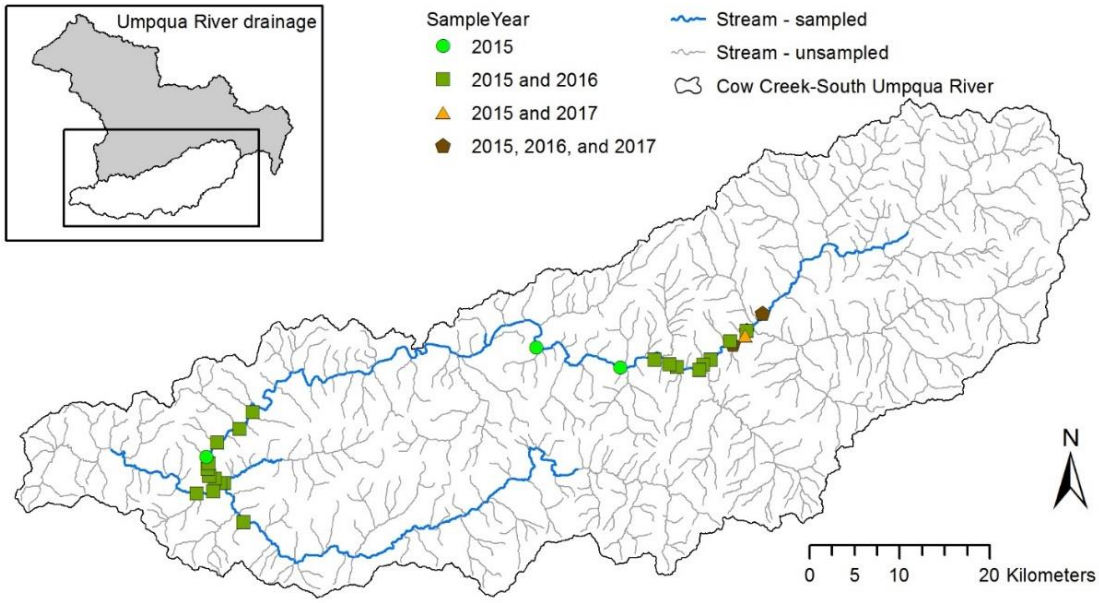


Figure 4. Sample sites surveyed during 2015-2017 in the Cow Creek-South Umpqua River sampling stratum in the southern portion of the Umpqua River drainage. Not all sample sites were surveyed during all years. The general extent of streams that have been sampled for Umpqua Chub at any point during 1987 through 2017 are shown in blue, the extent of streams that have not been sampled during this time period are shown in gray.

Survey methods used in 2016 and 2017

In 2016 we conducted surveys using the two following protocols: 1) snorkel only protocol and 2) snorkel and trap protocol. The snorkel only protocol was implemented at 13 of the 28 sample sites that were surveyed in 2015 (Table 4; Figure 4). These 13 sample sites were surveyed on multiple occasions spanning the time period of July 7 through September 1, 2016; 11 sample sites were surveyed on 5 occasions and 2 sample sites were surveyed on 6 sample occasions. Each survey occasion consisted of one single-pass snorkel survey following the protocol used in 2015 (see above).

The snorkel and trap protocol was implemented at 10 of the 28 sample sites that were surveyed in 2015 (Table 4; Figure 4); sampling occurred over a 4-d period, and block nets were not used. For each sample site, we conducted a single-pass snorkel survey on day 1 following the protocol used in 2015 (see above). Following the single-pass snorkel survey on day 1, we distributed 56 minnow traps (6.4 mm mesh) within the sample site and allowed them to soak overnight. Minnow traps were baited and placed on the stream substrate within about 2-m from the stream bank with approximately equal spacing between traps; traps were distributed along each stream bank. Minnow trap spacing was determined by dividing the site length by 28 (half of the 56 minnow traps). On day 2, minnow traps were recovered, captured Umpqua Chub were counted, marked with a partial upper caudal fin clip, and returned to the water near the location of capture, and minnow traps were re-distributed near their original locations. This procedure was repeated on day 3 with the exceptions that 1) we noted whether Umpqua Chub had been previously captured based on the presence of a partial upper caudal fin clip and 2) we marked all Umpqua Chub with a partial lower caudal fin clip. On day 4, minnow traps were recovered, the number of Umpqua Chub was recorded, capture histories for individual Umpqua Chub were noted based on caudal fin clip pattern, and fish were returned to the water near their location of capture. Minnow trap capture data were treated as capture-recapture data in subsequent analyses.

In 2017 we conducted surveys using the snorkel only protocol at 1 of the 28 sample sites that were surveyed in 2015 (Table 4; Figure 4); this site was surveyed on one sample occasion. Additionally, we conducted surveys using the snorkel and trap protocol at 3 of the 28 sample sites that were surveyed in 2015 (Table 4; Figure 4).

Data Analytic Methods

Detection probability and abundance – N-mixture model

We used an N-mixture model to estimate detection probability and abundance of Umpqua Chub and Smallmouth Bass at each site sampled in 2015. An N-mixture model uses data from spatially replicated sample sites that have been sampled on multiple occasions during a period of assumed closure (i.e., no births, deaths, immigration, or emigration) (Royle 2004; Kéry and Schaub 2012). The N-mixture model estimates abundance using count data without the need for individual identification (e.g., without the need for marking or tagging individuals), and corrects abundance estimates based on detection probabilities. Variation in detection probability of Umpqua Chub and Smallmouth Bass was modeled assuming a binomial distribution, and the variation in abundance among sites was modeled assuming a negative binomial distribution.

We evaluated the effect of covariates on detection probability and abundance of Umpqua Chub and Smallmouth Bass. Covariates evaluated in the detection probability sub-model included sample site length, average wetted width, wetted surface area, average depth, percent aquatic vegetation, percent algae, percent of each substrate type, snorkel survey duration, and snorkel

team (experienced or inexperienced). Covariates evaluated in the abundance sub-model included sample site length, average wetted width, wetted surface area, average depth, percent aquatic vegetation, percent algae, and percent of each substrate type. Covariates were evaluated by systematically fitting alternative sub-models with and without each covariate and by calculating Akaike's Information Criteria adjusted for small sample size (AIC_C; Burnham and Anderson 2002). The model with the lowest AIC_C value was considered the best approximating model. The same covariate was not included simultaneously in both the capture probability and abundance sub-models during the model selection procedure in order to avoid model convergence and parameter identifiability problems. We calculated 95% confidence limits for abundance estimates using the asymptotic variance for lambda, which represents the density of occurrences within a time interval (see Royle 2004). All models were fit using R package UNMARKED (Fiske and Chandler 2011). Goodness-of-fit of the best approximating models were evaluated using a bootstrap goodness-of-fit test implemented in R statistical software (R Development Core Team; available at https://www.r-project.org/) with the package AICcmodavg (M.J. Mazerolle; available at https://cran.r-project.org/web/packages/AICcmodavg/index.html). We also calculated a quasi-coefficient of variation to determine the probability that the N-mixture estimate was biased for the top-ranked model (Duarte et al. 2018).

Abundance, presence, and absence – multistate occupancy model

We applied multistate occupancy models (MacKenzie et al. 2006; 2018) to data collected during 2015 to estimate the probability that Smallmouth Bass and Umpqua Chub were in one of three states: absent, present, or abundant. For each species, a sample site was classified as absent if the species was not observed, present if the species was observed, and abundant if the number of individuals counted was in the upper 80th percentile of the number of individuals counted among sample sites (e.g., Peterson and Barajas 2018); the abundant state was conditional on species presence. The multistate occupancy models also adjust the occupancy estimates for incomplete detection by estimating the probability of detection using the counts obtained during the repeated snorkel surveys. We evaluated the influence of the following covariates on detection probability and occupancy probability of Umpqua Chub and Smallmouth Bass: sample site length, average wetted width, wetted surface area, average depth, percent aquatic vegetation, percent algae, percent of each substrate type, snorkel survey duration, and snorkel team (experienced or inexperienced). The best approximating model for each species was determined as the model with the lowest AIC_C value. We also calculated 95% confidence limits for the parameter estimates in the best approximating model. All multistate occupancy models were fit using program MARK (White and Burnham 1999) (G. White; available at http://www.phidot.org/software/mark/).

We evaluated the goodness-of-fit of the best approximating multistate occupancy model for each species using a parametric bootstrap. Occupancy data were simulated with R statistical software using the parameters from the best approximating model for each species and the simulated data were fit using program MARK. Goodness-of-fit was determined by comparing the distribution of 1,000 randomly generated dispersion parameters ($\hat{c}$) to the observed parameter (Williams et al. 2002). We assumed occupancy model fit was adequate if the observed dispersion parameter was contained within the 95th percentiles of the bootstrapped value.

Potential interactions between Umpqua Chub and Smallmouth Bass - multi-species occupancy model

We applied a multi-species occupancy model (MacKenzie et al. 2006; 2018) to data collected in 2015 to evaluate potential interactions between Umpqua Chub and Smallmouth Bass. The multi-species occupancy model allowed us to account for incomplete detection of both species and the

potential for the occupancy of one species to affect our ability to detect the other species. We used the conditional binomial version of the multi-species occupancy model (MacKenzie et al. 2006; 2018) to estimate the following eight parameters:

Ψ_S	the occupancy probability for Smallmouth Bass,
Ψ_{US}	the occupancy probability for Umpqua Chub, given Smallmouth Bass were present,
$\Psi_U - \Psi_{US}$	the occupancy probability for Umpqua Chub, given Smallmouth Bass were absent,
p^S	the detection probability for Smallmouth Bass, given Umpqua Chub were absent,
p^U	the detection probability for Umpqua Chub, given Smallmouth Bass were absent,
r^S	the detection probability for Smallmouth Bass, given both species were present,
r^{US}	the detection probability for Umpqua Chub, given both species were present and Smallmouth Bass were detected, and
r^{Us}	the detection probability for Umpqua Chub, given both species were present and Smallmouth Bass were not detected.

The relative support for hypotheses regarding the effect of Smallmouth Bass on the occupancy probability and detection probability of Umpqua Chub were evaluated by fitting models with parameters estimated separately and comparing AIC_c values to similar models with parameters set equal to one another. For example, the relative fit of a model that estimated the probability of Umpqua Chub occupancy as a function of Smallmouth Bass presence was compared to a model where the probability of Umpqua Chub occupancy did not depend on Smallmouth Bass presence. As with the multistate occupancy models described above, we evaluated the relationship between covariates and detection and occupancy probabilities. We also evaluated support for the following hypotheses: 1) Umpqua Chub occupancy depends on the presence of Smallmouth Bass, 2) detection of Smallmouth Bass depends on the presence of Umpqua Chub, and 3) detection of Umpqua Chub depends on the presence of Smallmouth Bass. The relative support for the covariates and each hypothesis were evaluated by calculating ΔAIC_c values among candidate models (Burnham and Anderson 2002). We considered models with $\Delta AIC_c \leq 2$ to have a substantial level of support, ΔAIC_c between 2 and 4 to have some level of empirical support, ΔAIC_c between 4 and 7 to have less support, and $\Delta AIC_c > 7$ to have little or essentially no support. We calculated 95% confidence limits for parameter estimates for the best approximating model.

We calculated a species interaction factor (*SIF*) to quantify the relationship between occupancy probability of Umpqua Chub and Smallmouth Bass. The SIF was calculated as:

$$SIF = \frac{\Psi_S \Psi_{US}}{\Psi_S(\Psi_S + (1-\Psi_S)\Psi_{US})},$$

where the parameters are described above. An *SIF* of one indicates that the two species occur independently, a value less than one indicates that Umpqua Chub are less likely to occur in the presence of Smallmouth Bass, and a value greater than one indicates that Umpqua Chub are more likely to co-occur with Smallmouth Bass (MacKenzie et al. 2006; 2018). We evaluated the

goodness-of-fit of the best approximating multi-species occupancy model using a parametric bootstrap as above (see multistate occupancy model).

Trapping efficiency, snorkeling efficiency, and abundance – integrated Bayesian model

We developed an integrated Bayesian model to estimate trapping efficiency, snorkeling efficiency, and abundance of Umpqua Chub using data collected in 2016 and 2017. Trapping efficiency and snorkeling efficiency were defined as the detection probability of the respective sampling methods. The modeling procedure: 1) estimated trapping efficiency and abundance using capture-recapture data at each sample site where minnow trapping was conducted, 2) used those abundance estimates to estimate snorkeling efficiency based on snorkeling counts from sample sites where the snorkel and trapping protocol was used, and 3) used those snorkeling efficiency estimates to estimate abundance for each sample site and day where only snorkel surveys were conducted. In this way, the model produced calibrated abundance estimates of Umpqua Chub based on single-pass snorkel surveys by calibrating snorkel count data to abundance estimates from capture-recapture minnow trap surveys.

The model estimated trapping efficiency using the Huggins estimator and assumed that Umpqua Chub trapping capture and recapture probabilities at each trapping site were unique, but came from a common distribution that was logit-normally distributed. Using the estimated capture probabilities, the abundance of Umpqua Chub in the trapping sites was estimated as:

$$M_{t,j} \sim dbin\left(\hat{r}_j, \hat{N}_j\right),$$

where $M_{t,j}$ is the number of marked Umpqua Chub, $\hat{r}_j$ is the probability of being captured at least once, and $\hat{N}_j$ is the abundance in site *j*. Estimated abundance was generated from a uniform distribution as:

$$\hat{N}_j \sim dunif\left(M_{t,j}, 1000\right),$$

with $\hat{N}_j$ rounded to the nearest whole number. The remaining parameters are defined above. Snorkeling efficiency in the trapping sites was modeled using a binomial distribution with estimated abundance from the trapping data, $\hat{N}_j$, as the binomial index:

$$c_j \sim dbin\left(\hat{p}_j, \hat{N}_j\right),$$

where c_j is the number of Umpqua Chub counted during snorkel surveys and $\hat{p}_j$ is the estimated snorkeling efficiency in site *j*. Snorkeling efficiency was modeled using a logit linear model. We evaluated the effect of the covariates average depth, average stream width, stream length, substrate type, wetted surface area, percent vegetation, percent algae, snorkeling duration, the presence of Smallmouth Bass, and snorkel team on snorkeling efficiency. The best-fitting model was obtained by systematically including each covariate in the model and examining the 95% credible intervals. Parameter estimates with 95% credible intervals that did not contain zero were retained and those that did were removed. The best-fitting model was used to estimate snorkeling efficiency in snorkeling-only sites. Abundance in these sites was estimated as:

$$c_i \sim dbin(\hat{p}_i, N_i),$$

where $\hat{p}_i$ is snorkeling efficiency estimated using the best-fitting logit-linear model, c_i is the number of fish counted during snorkeling in the non-trapping site *i*. The abundance in these sites (*N*) was

generated from a uniform distribution rounded to the nearest whole number as described above. All model fitting was conducted using R package R2WinBUGS (Sturtz et al. 2005) (U. Ligges; available at https://cran.r-project.org/web/packages/R2WinBUGS/index.html) using 150,000 iterations with 100,000 burn-in iterations and no thinning.

Sampling efforts in 2015 suggested that the presence or abundance of Umpqua Chub may be temporally variable at the site level. Consequently, we applied snorkeling efficiency estimates to count data from the 13 sample sites that were sampled by snorkeling on multiple occasions during 2016. We plotted abundance of Umpqua Chub by date for each sample site to provide a qualitative assessment of temporal variability in Umpqua Chub abundance.

Power to detect trend among optimal sample designs

We conducted simulations to identify optimal sample designs, and we calculated power to detect trend in Umpqua Chub abundance and power to detect trend in Umpqua Chub multistate occupancy. Additionally, we compared between the power to detect trend in Umpqua Chub abundance and the power to detect trend in Umpqua Chub multistate occupancy.

To identify the optimal sample design and power to detect trend in abundance of Umpqua Chub, we partitioned the sources of variation in the calibrated abundance estimates of Umpqua Chub at all sites from the integrated Bayesian model using a random effects (Model II) ANOVA (Snedecor and Cochran 1991). Here, we partitioned variation in abundance among sites, among months within sites, and the residual, which represented variation among sampling occasions within month. We then used these variance estimates to evaluate alternative sample designs that apportioned samples among sites, among months within sites, and replicate samples within a month using the following equation from Snedecor and Cochran (1991):

$$s_T^2 = \frac{s_s^2}{n_s} + \frac{s_m^2}{(n_s \cdot n_m)} + \frac{s_r^2}{(n_s \cdot n_m \cdot n_{rep})},$$

where s_T^2 is the total estimated variance for a given design, s_s^2 is the among site variation, n_s is the number of sites sampled, s_m^2 is the predictable month to month variation at a site, n_m is the number of months sampled, s_r^2 is the residual variance, and n_{rep} is the number of replicate samples at a site within a month. We wanted to evaluate the efficiency of designs that held the total number of samples $(n_s \cdot n_m \cdot n_{rep})$ constant at values from 10 to 100 by increments of 10. We fixed the maximum number of months to sample at three (i.e., July, August, and September) because these were the only months sampled in this study. We considered a design to be optimal when total variance was minimized. Using this design, we evaluated the power to detect two levels of change (2.5% and 5.0%) in fish abundance per year over a 10-year period. This was accomplished by simulating fish changes in abundance and incorporating variance in abundance among sites, among months, and within sites (residual) using the variance estimates from the random effects ANOVA and assuming a normal distribution. We ran 500 replicate simulations and calculated power as the proportion of simulations that resulted in a significant ($\alpha = 0.05$ and $\alpha = 0.10$) time-trend in abundance from a linear mixed model fit to the simulated data using a one-sided test. All modeling was conducted using *lmer* function in R package lme4 (Bates et al. 2015) (B. Bolker; available at https://cran.r-project.org/web/packages/lme4/index.html).

To identify the optimal sample design and power to detect trend in multistate occupancy of Umpqua Chub, we converted annual decreases in abundance (see above) into changes in occupancy, we used the estimated abundance at each sample site from 2016, decreased abundance by 2.5% per year for 10 years, and calculated the number of sites that had abundant

Table 5. Parameter estimates from the best approximating N-mixture models for estimating Umpqua Chub and Smallmouth Bass detection probabilities and abundance based on data collected in 2015 from 28 sample sites in the Cow Creek-South Umpqua River sampling stratum.

					95% CL	
Species	Sub-model	Parameter	Estimate	SE	Lower	Upper
Umpqua Chub	Detection probability	Intercept	-3.075	0.662	-4.373	-1.777
		Snorkel team experience	0.348	0.149	0.056	0.640
	Abundance	Intercept	3.194	0.819	1.588	4.799
		Wetted surface area	0.001	0.000	0.001	0.001
		Negative binomial dispersion	-1.440	0.280	-1.989	-0.891
Smallmouth Bass	Detection probability	Intercept	-3.480	1.250	-5.930	-1.030
	Abundance	Intercept	2.594	1.662	-0.663	5.850
		Wetted surface area	0.001	0.000	0.001	0.001
		Negative binomial dispersion	-1.680	0.368	-2.401	-0.959

populations using the 80th percentile in abundance from 2016 (i.e., the same threshold used in the occupancy models). This equated to a 1% decrease in occupancy per year and the abundance state decrease of 2.6% per year. Using the 5% decrease in abundance per year, the corresponding decrease in occupancy and abundant states were 1.5% and 12% per year. We then simulated changes in occupancy assuming an initial Umpqua Chub occupancy probability of 85% and abundant state probability of 20%, which were similar to the observed values. We also assumed a detection probability that varied uniformly from 0.6 – 0.9, which was similar to the ranges we observed. Similar to the abundance evaluation, we evaluated the power of designs that held the total number of samples (i.e., number of sites x number of visits per site) constant at values from 10 to 100 by increments of 10. The minimum number of visits was fixed at two because at least two visits were needed to calculate detection probabilities. All simulations were conducted using R package RMark (Laake 2013) (J. Laake; available at https://cran.r-project.org/web/packages/RMark/index.html) run for 500 iterations. For each iteration, detection of a significant decrease in occupancy and abundant states were assumed when the year parameter was significant at $\alpha = 0.05$ and $\alpha = 0.10$. We considered a design to be optimal when the power to detect changes in occupancy over the 10-year period was greatest.

Results

Detection probability and abundance – N-mixture model

The best approximating N-mixture model for Umpqua Chub modeled detection probability as a function of snorkel team experience and modeled abundance as a function of wetted surface area and as a function of a negative binomial dispersion parameter (Table 5); the negative binomial dispersion parameter was included to account for unexplained variance among sample sites. Detection probability of Umpqua Chub was 6.1% for the experienced survey crew and 4.4% for the inexperienced survey crew. Abundance estimates for Umpqua Chub varied from 0-1,697 fish among sample sites (Table 6; Figure 5). The mean count (see Duarte et al. 2018) for Umpqua Chub was 7.1 and the quasi-coefficient of variation for the Umpqua Chub model was 1.57, which corresponds to a probability of > 50% that the N-mixture model abundance estimates are biased (see Figure 5 *in* Duarte et al. 2018).

Table 6. Wetted surface area of sample site, snorkel counts from snorkel surveys on two consecutive days, and N-mixture abundance estimates with lower 95% confidence limits (L95CL) and upper 95% confidence limits (U95CL) for Umpqua Chub and Smallmouth Bass sampled at 28 sample sites in the Cow Creek-South Umpqua River sampling stratum during 2015.

		Umpqua Chub					Smallmouth Bass				
		Snorkel count		N-mixture abundance			Snorkel count		N-mixture abundance		
Site	Area (m^2)	Day 1	Day 2	Estimate	L95CL	U95CL	Day 1	Day 2	Estimate	L95CL	U95CL
1	2,538	80	72	1,697	1,453	1,983	13	11	431	298	628
2	5,385	60	67	1,218	1,049	1,417	7	10	326	229	465
2A	318	2	7	87	47	168	0	0	0	0	20
3	2,989	0	0	0	0	18	0	3	37	13	124
4	5,017	3	0	19	7	61	6	20	491	346	700
5	4,515	2	7	68	36	129	46	26	1,191	949	1,497
6	1,672	0	1	3	1	46	24	14	598	438	820
7	6,146	3	7	105	58	195	0	6	88	41	200
8	7,726	38	47	722	595	879	3	10	350	250	494
9	3,478	0	0	0	0	18	9	5	220	131	372
10	1,279	1	1	13	4	64	5	1	82	38	187
11	2,065	0	0	0	0	18	0	5	70	30	171
15	702	0	0	0	0	17	0	0	0	0	21
16	2,692	3	1	37	14	101	0	0	0	0	24
17	1,990	0	1	3	1	46	6	3	133	70	258
18	2,613	16	33	392	300	515	1	0	3	1	66
19	2,826	14	11	273	186	402	0	0	0	0	24
20	5,267	12	27	313	231	425	0	0	0	0	24
21	3,442	8	33	322	240	435	0	0	0	0	24
22	2,346	4	13	183	116	293	0	0	0	0	23
23	727	0	0	0	0	17	0	0	0	0	21
24	1,129	18	9	371	285	486	0	0	0	0	15
25	3,211	49	48	1,012	875	1,171	1	0	13	3	65
26	2,268	13	26	431	346	539	2	2	35	14	99
27	3,763	10	20	331	234	471	0	0	0	0	24
28	1,174	44	60	1,131	938	1,366	0	0	0	0	22
29	2,913	19	12	341	242	482	2	2	53	20	148
31	1,421	0	0	0	0	18	17	26	670	500	902

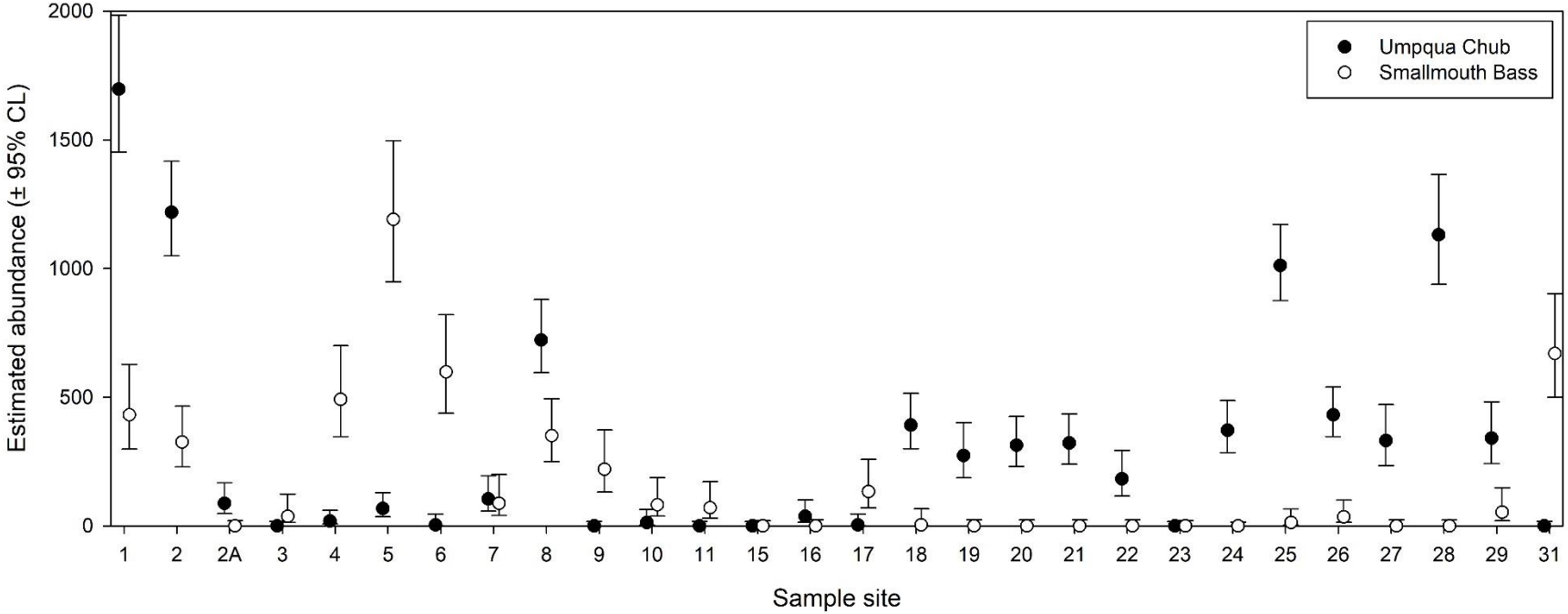


Figure 5. Estimated abundance (± 95% CL) of Umpqua Chub (filled symbols) and Smallmouth Bass (open symbols) among 28 sites sampled by snorkeling during 2015 in the Cow Creek-South Umpqua River sampling stratum. Abundance estimates were generated using an N-mixture model.

The best approximating N-mixture model for Smallmouth Bass modeled detection probability as a constant 3.0% (i.e., intercept only model) and modeled abundance as a function of wetted surface area and as a function of a negative binomial dispersion parameter (Table 5). Abundance estimates for Smallmouth Bass varied from 0-1,191 fish among sample sites (Table 6; Figure 5). The mean count for Smallmouth Bass was 5.5 and the quasi-coefficient of variation for the Smallmouth Bass model was 0.87, which corresponds to a probability of > 50% that the N-mixture model abundance estimates are biased (see Figure 5 *in* Duarte et al. 2018).

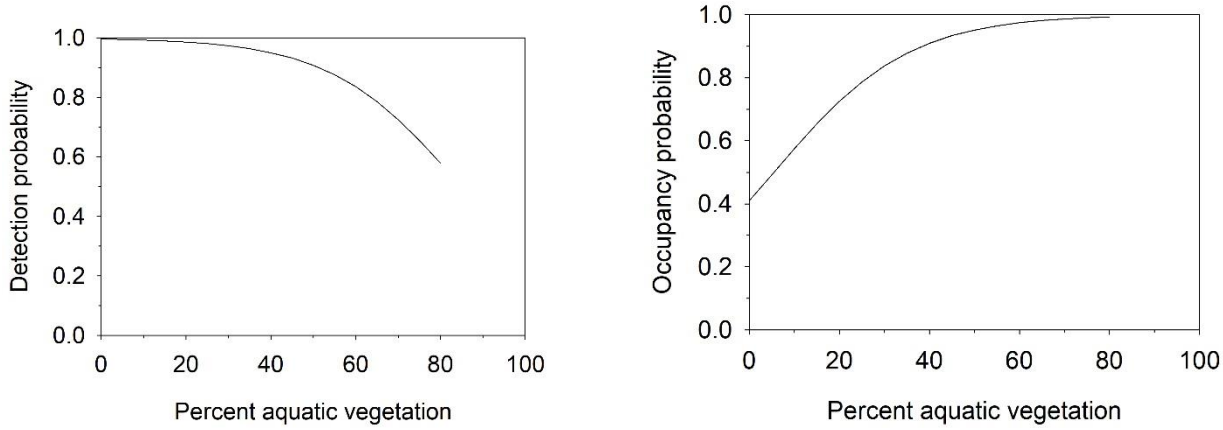
Abundance, presence, and absence – multistate occupancy model

Bootstrap goodness-of-fit evaluations of the Umpqua Chub and Smallmouth Bass multistate occupancy models indicated that the best approximating multistate occupancy model for both species adequately fit the data. The best approximating multistate occupancy model for Umpqua Chub modeled detection probability as a function of aquatic vegetation, modeled occupancy probability as a function of aquatic vegetation, and modeled the conditional probability that Umpqua Chub were abundant as a function of aquatic vegetation and cobble substrate (Table 7). Umpqua Chub detection probability decreased as aquatic vegetation increased (Figure 6). Umpqua Chub occupancy probability increased as aquatic vegetation increased (Figure 6). The probability that Umpqua Chub were abundant also increased with increases in aquatic vegetation; however, the response to aquatic vegetation differed between cobble and non-cobble substrates (Figure 6).

The best approximating multistate occupancy model for Smallmouth Bass modeled detection probability as a constant 77.6% (i.e., intercept only model), modeled occupancy probability as a function of average depth, and modeled the conditional probability that Smallmouth Bass were abundant as a function of average depth (Table 7). Consequently, both the probability that Smallmouth Bass were present and the probability that Smallmouth Bass were abundant increased with average depth (Figure 7).

Table 7. Parameter estimates from the best approximating multistate occupancy models for estimating Umpqua Chub and Smallmouth Bass detection probabilities and multistate occupancy probability based on data collected in 2015 from 28 sample sites in the Cow Creek-South Umpqua River sampling stratum.

					95% CL	
Species	Sub-model	Parameter	Estimate	SE	Lower	Upper
Umpqua Chub	Detection probability	Intercept	5.582	2.215	1.240	9.924
		% aquatic vegetation	-0.066	0.033	-0.130	-0.001
	Occupancy probability	Intercept	-0.367	0.845	-2.022	1.289
		% aquatic vegetation	0.067	0.033	0.002	0.131
	Abundance probability	Intercept	-1.872	0.760	-3.361	-0.383
		Cobble substrate	2.565	1.441	-0.260	5.390
Smallmouth Bass	Detection probability	Intercept	1.240	0.489	0.282	2.199
	Occupancy probability	Intercept	-3.507	2.042	-7.508	0.495
		Average depth	7.189	3.594	0.146	14.233
	Abundance probability	Intercept	-3.015	1.745	-6.435	0.405
		Average depth	2.868	1.817	-0.695	6.430



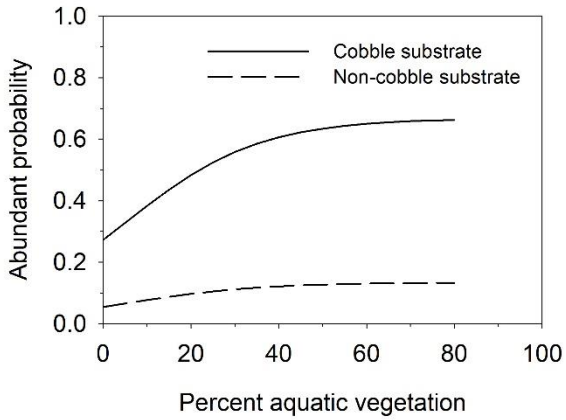


Figure 6. Umpqua Chub detection probability (top-left panel), occupancy probability (top-right panel), and conditional probability that Umpqua Chub were abundant in cobble and non-cobble dominated habitats (bottom-left panel) as a function of percent aquatic vegetation modeled using a multistate occupancy model using data from 28 sites sampled in 2015 in the Cow Creek-South Umpqua River sampling stratum.

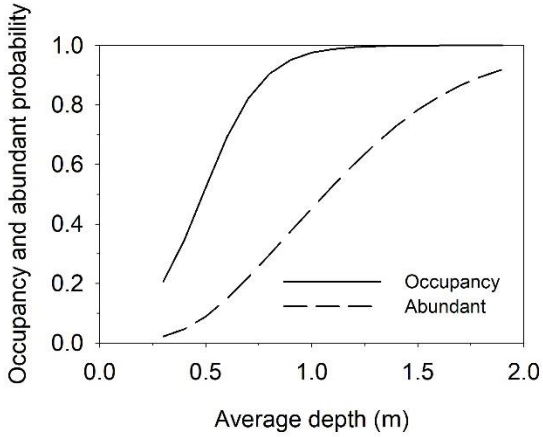


Figure 7. Smallmouth Bass occupancy probability and conditional probability of abundant as a function of average depth modeled using a multistate occupancy model using data from 28 sites sampled in 2015 in the Cow Creek-South Umpqua River sampling stratum.

Table 8. Parameter estimates from the best approximating multi-species occupancy model for estimating Umpqua Chub and Smallmouth Bass detection probabilities and occupancy probability based on data collected in 2015 from 28 sample sites in the Cow Creek-South Umpqua River sampling stratum.

					95% CL	
Species	Sub-model	Parameter	Estimate	SE	Lower	Upper
Umpqua Chub	Detection probability	Intercept	2.686	0.609	1.493	3.879
	Occupancy probability	Intercept	1.771	0.710	0.380	3.163
		% aquatic vegetation	1.405	0.691	0.050	3.152
Smallmouth Bass	Detection probability	Intercept	1.561	0.470	0.641	2.482
	Occupancy probability	Intercept	0.879	0.440	0.017	1.985
		Average depth	1.868	0.956	-0.006	3.947

Potential interactions between Umpqua Chub and Smallmouth Bass - multi-species occupancy model

Goodness-of-fit evaluations indicate that the best approximating multi-species occupancy model adequately fit the data. The best approximating multi-species occupancy model modeled Umpqua Chub and Smallmouth Bass detection probabilities as constants, modeled Umpqua Chub occupancy probability as a function of percent aquatic vegetation, and modeled Smallmouth Bass occupancy probability as a function of average depth (Table 8). There was little or no empirical support that Umpqua Chub occupancy probability differed when Smallmouth Bass were present or absent (ΔAIC_c = 7.06). There also was little support that Umpqua Chub detection probability differed when Smallmouth Bass were present or absent (ΔAIC_c = 4.44). Taken together, there was no evidence that Smallmouth Bass affected the occupancy or detection of Umpqua Chub (ΔAIC_c = 11.01) at the site level. In the best approximating model that estimated Umpqua Chub occupancy as a function of Smallmouth Bass presence, the parameter estimate was small and imprecise (estimate= 0.36; 95% CI= -1.70–2.42). The *SIF* of this model also indicated no evidence of an interaction between these two species ($\widehat{SIF}$=0.97; 95% CI: 0.81–1.13).

Trapping efficiency, snorkeling efficiency, and abundance – integrated Bayesian model

The best approximating model for estimating trapping efficiency for Umpqua Chub was a function of a recapture effect and random effects for capture and recapture (Table 9). The recapture effect was negative indicating that capture probabilities for marked fish were lower than those for unmarked fish. If not accounted for, this effect would result in overestimated abundance. Umpqua Chub trapping efficiency estimates were relatively high (i.e., generally > 50%), but varied substantially among sites (Figure 8). Abundance estimates among trapping sites varied from 22–463 Umpqua Chub based on the Huggins estimator (Figure 9).

Table 9. Trapping efficiency parameter estimates from an integrated Bayesian model based on data collected during 2016-2017 in the Cow Creek-South Umpqua River sampling stratum.

			95% CL	
Parameter	Estimate	SD	Lower	Upper
Intercept	0.508	0.422	-0.360	1.319
Recapture	-1.579	0.540	-2.607	-0.459
Random capture effect	1.472	0.398	0.894	2.432
Random recapture effect	1.944	0.481	1.248	3.108

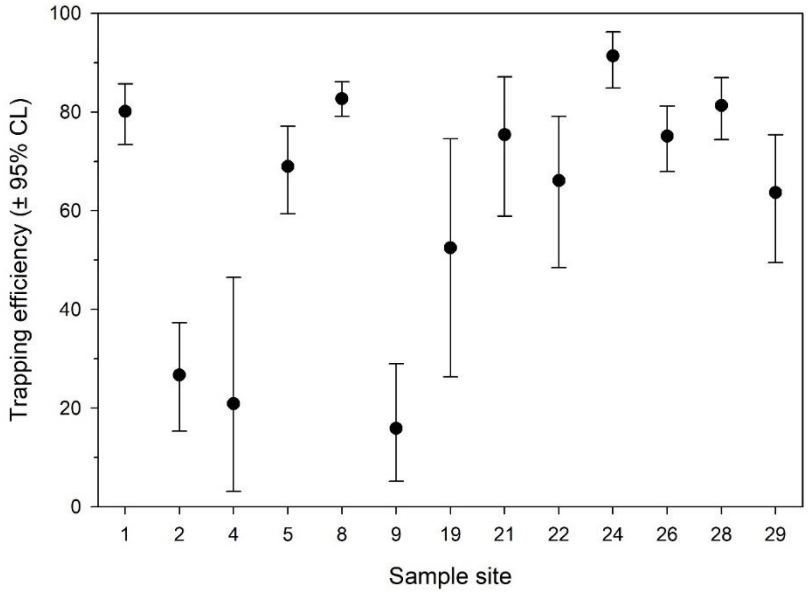


Figure 8. Trapping efficiency estimates (± 95% CL) for 13 sites sampled during 2016-2017 in the Cow Creek-South Umpqua River sampling stratum. Trapping efficiency estimates are for Umpqua Chub sampled using baited minnow traps and a Huggins closed capture-recapture model implemented over 3 sampling occasions.

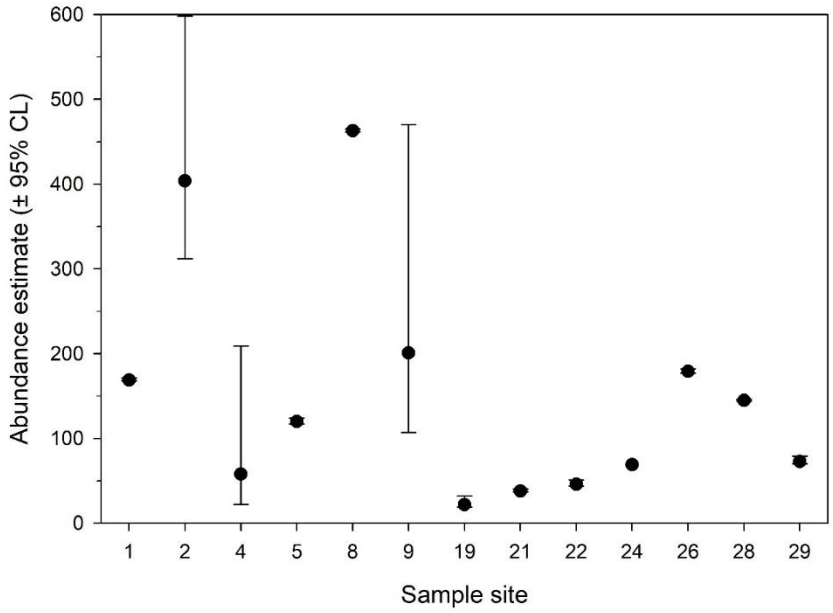


Figure 9. Estimated abundance (± 95% CL) for Umpqua Chub sampled among 13 sites during 2016-2017 in the Cow Creek-South Umpqua River sampling stratum. Umpqua Chub were sampled using baited minnow traps, sampling occurred over 3 sample occasions, and a Huggins closed capture-recapture model was used to estimate abundance.

Table 10. Snorkeling efficiency parameter estimates from an integrated Bayesian model based on data collected during 2016-2017 in the Cow Creek-South Umpqua River sampling stratum.

			95% CL	
Parameter	Estimate	SD	Lower	Upper
Intercept	-0.792	0.591	-2.380	-0.062
Snorkel duration	-0.016	0.006	-0.028	-0.004
Bedrock dominant substrate	1.178	0.586	0.013	2.306
Random effect	1.320	0.389	0.759	2.262

The best approximating model for estimating snorkeling efficiency for Umpqua Chub was a function of snorkeling duration, bedrock substrate, and a random effect that was included to account for unexplained variance in snorkel counts among sample sites (Table 10). Estimated snorkeling efficiency declined with increasing snorkeling duration and was higher for sample sites with bedrock dominated substrates (Figure 10). Calibrated abundance estimates varied considerably among sample sites and among sampling occasions within sample sites for sites where snorkel surveys were conducted multiple times during the summer of 2016 (Figure 11).

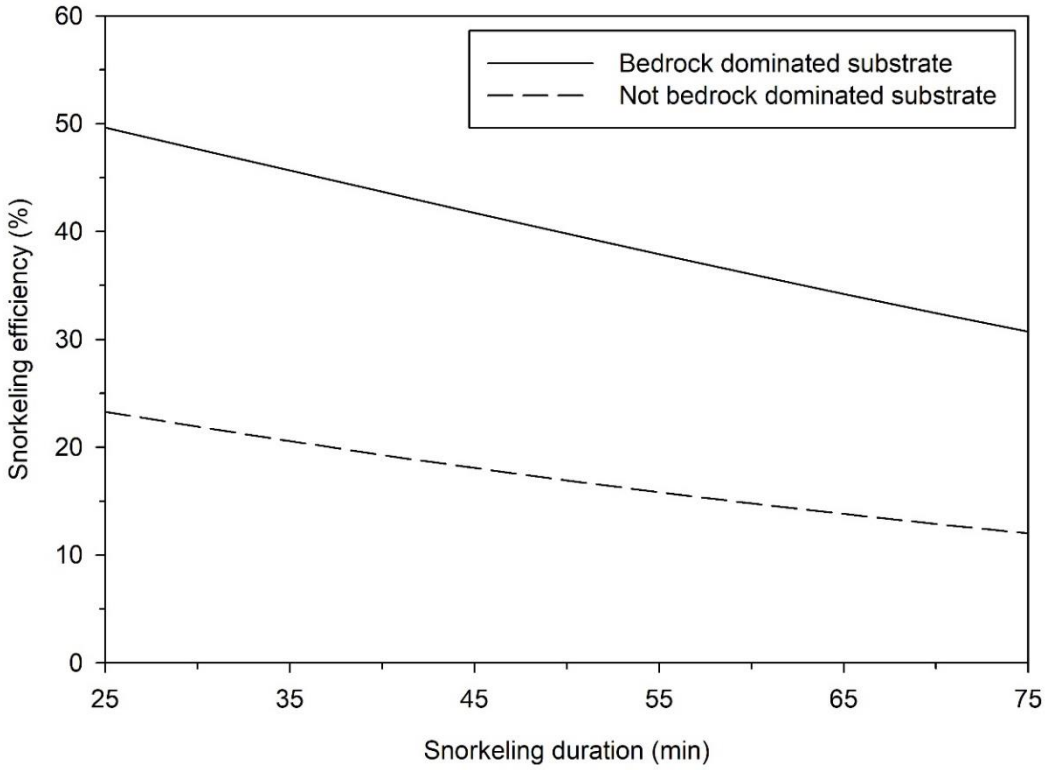


Figure 10. Snorkeling efficiency estimates as a function of snorkel duration in sample sites dominated by bedrock and not dominated by bedrock. Snorkeling efficiency estimates are for Umpqua Chub based on data collected during 2016-2017 in the Cow Creek-South Umpqua River sampling stratum. Snorkeling efficiency estimates are based on single-pass snorkeling and an integrated Bayesian model that used minnow trap capture-recapture data to calibrate abundance from snorkel counts.

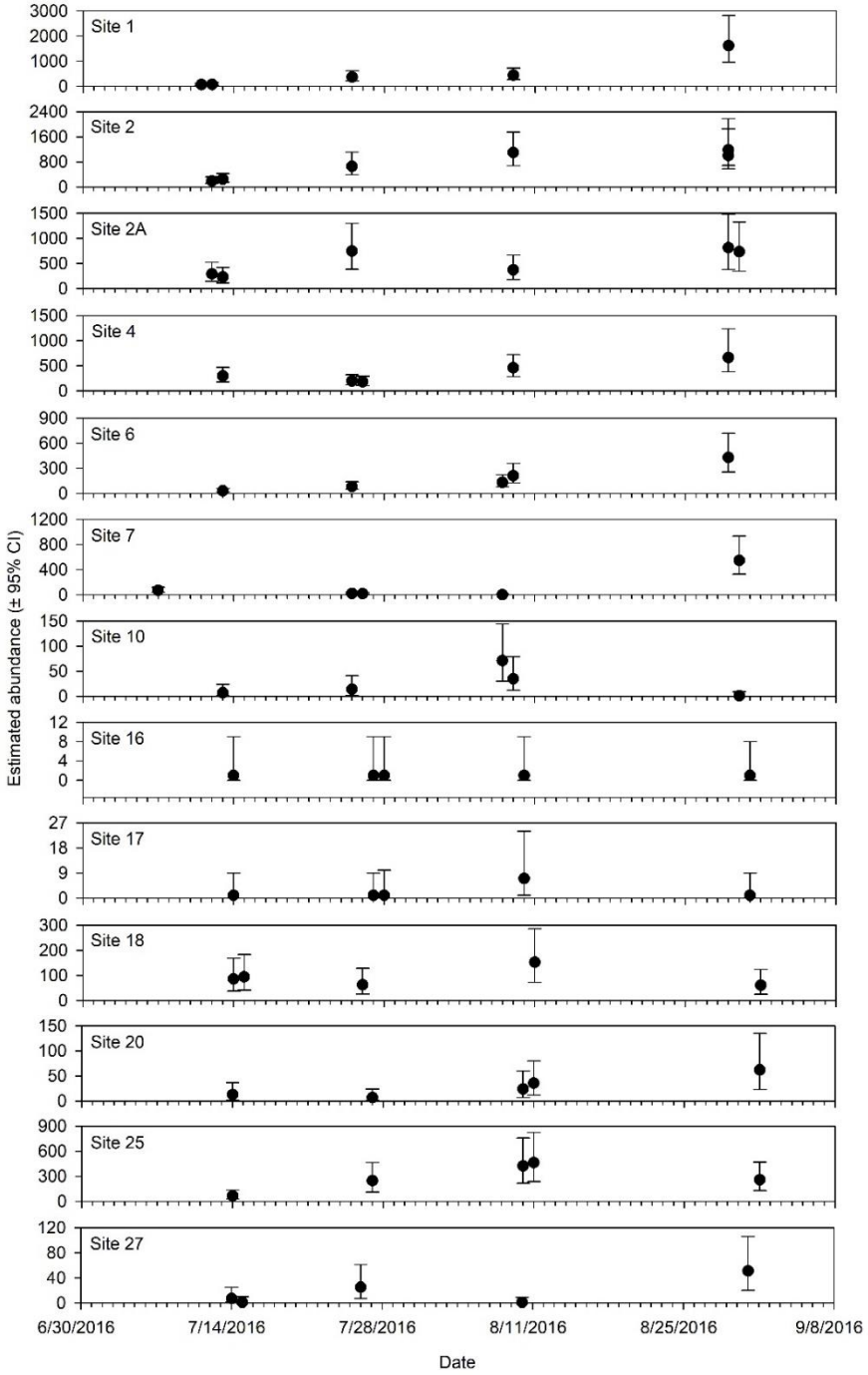


Figure 11. Estimated abundance (± 95% CL) for Umpqua Chub sampled among 13 sites during 2016 in the Cow Creek-South Umpqua River sampling stratum. Each sample site was snorkeled multiple times during 2016. Abundance estimates are based on single-pass snorkeling and an integrated Bayesian model that used minnow trap capture-recapture data to calibrate abundance from snorkel counts.

Power to detect trend among optimal sample designs

Partitioning variation in calibrated abundance estimates indicated that 40.73% of the variation was residual (i.e., variation from sampling occasion to sampling occasion within month), 30.63% was variation within sites (i.e., among months from sampling occasion to sampling occasion), and 28.64% was variation among sites. The optimal sample design for detecting changes in Umpqua Chub abundance allocates half of the sampling occasions to different locations (additional sites) and half of sampling occasions to resampling each site, with at least one month between each visit (additional site visits). The power to detect changes in abundance over a 10-year period for the optimal sample designs suggests that relatively small changes (i.e., 2.5% decrease per year; 20% decline from years 1–10) will be difficult to detect statistically with power > 0.80 with small to moderate sample sizes (< 80 samples per year), even at $\alpha = 0.10$. However, larger changes in abundance (5% per year, 37% decline from years 1–10) would require a fewer number of samples (50) to achieve reasonable power (Table 11; Figure 12).

The optimal sample design for detecting changes in multistate occupancy over a 10-year period for Umpqua Chub includes two sampling occasions at as many sites as feasible (Table 12). The power to detect changes in the abundant state was greater than occupancy only, likely due to the larger decreases in the proportion of abundant states that were associated with the decreases in abundance. When fewer total samples were allocated to sampling, the power of designs that monitored changes in abundance and changes in multistate occupancy were very similar (Table 11; Table 12; Figure 12). However, at moderate to high number of samples, the optimal multistate occupancy designs had lower power to detect trends equivalent to the abundance designs.

Discussion

Previous surveys of Umpqua Chub have noted a potential decline in the distribution of Umpqua Chub and a concurrent increase in the distribution of Smallmouth Bass (Simon and Markle 1999; Simon 2008; O'Malley et al. 2013). However, these surveys were implemented using a variety of sampling gears, which were not always well documented, and over a variety of spatial scales. Consequently, limitations exist related to making estimates of status or trend using these datasets. Concerns related to potential declines in Umpqua Chub prompted interest in developing sampling strategies suitable for evaluating status and trend. Therefore, we used data collected during 2015-2017 and multiple analytical techniques to evaluate detection, occupancy, and abundance of Umpqua Chub and Smallmouth Bass based on snorkel surveys and minnow trap surveys. Identifying appropriate sampling and analytic strategies will allow fishery scientists and managers to evaluate Umpqua Chub status and trend in the future.

Fishery managers are often interested in estimating abundance of target species and populations. Previous efforts to estimate abundance of Umpqua Chub using capture-recapture methods were hindered by low recapture rates of marked individuals (Markle et al. 2011). We estimated site-level abundance using multiple analytical frameworks. First, we used count data from double-pass snorkel surveys and an N-mixture model to estimate abundance of Umpqua Chub and of Smallmouth Bass. Second, we used capture-recapture data from minnow trapping and a Huggins closed capture-recapture estimator to estimate abundance of Umpqua Chub; this was part of an integrated Bayesian model that also used trapping efficiency estimates to calibrate abundance based on single-pass snorkeling. Third, we estimated the probability that Umpqua Chub and Smallmouth Bass were absent, present, or abundant using double-pass snorkel surveys and multistate occupancy models.

Table 11. Power to detect a 2.5% and 5.0% decrease in abundance of Umpqua Chub at two alpha-levels using calibrated abundance estimates for a total number of sample sites varying from 5-50. Under the optimal sampling design for detecting trend in calibrated abundance of Umpqua Chub, each sample site should be visited two times; once during each of two separate months.
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Sites sampled	Months sampled per site	Replicate samples within months	Total samples	Total variance	Power at α = 0.05		Power at α = 0.10	
					2.5% decrease	5.0% decrease	2.5% decrease	5.0% decrease
5	2	1	10	10,078	0.12	0.31	0.20	0.43
10	2	1	20	5,039	0.18	0.49	0.30	0.61
15	2	1	30	3,359	0.30	0.62	0.38	0.81
20	2	1	40	2,519	0.30	0.76	0.42	0.86
25	2	1	50	2,016	0.35	0.86	0.51	0.92
30	2	1	60	1,680	0.50	0.92	0.57	0.98
35	2	1	70	1,440	0.51	0.93	0.66	0.99
40	2	1	80	1,260	0.55	0.93	0.74	0.98
45	2	1	90	1,120	0.58	0.97	0.76	1.00
50	2	1	100	1,008	0.62	0.98	0.80	1.00

Table 12. Power to detect a 2.5% and 5.0% decrease in abundance of Umpqua Chub at two alpha-levels for a total number of sample sites varying from 5-50. Under the optimal sampling design for detecting trend in occupancy of Umpqua Chub, each sample site should be visited two times; the two visits can occur over a short time period (e.g., on consecutive days, within the same day with a break between visits, etc.).

			Power at α = 0.05				Power at α = 0.10			
			2.5% abundance decrease		5.0% abundance decrease		2.5% abundance decrease		5.0% abundance decrease	
Sites sampled	Visits per site	Total samples	1% decrease occupancy	2.6% decrease abundant state	1.5% decrease occupancy	12% decrease abundant state	1% decrease occupancy	2.6% decrease abundant state	1.5% decrease occupancy	12% decrease abundant state
5	2	10	0.10	0.10	0.17	0.26	0.24	0.26	0.30	0.43
10	2	20	0.12	0.13	0.21	0.33	0.27	0.24	0.37	0.51
15	2	30	0.16	0.17	0.24	0.40	0.24	0.28	0.37	0.62
20	2	40	0.18	0.08	0.22	0.45	0.28	0.18	0.33	0.67
25	2	50	0.20	0.12	0.33	0.51	0.30	0.22	0.47	0.67
30	2	60	0.25	0.23	0.31	0.65	0.43	0.18	0.46	0.74
35	2	70	0.23	0.17	0.43	0.72	0.38	0.29	0.59	0.81
40	2	80	0.27	0.19	0.43	0.67	0.40	0.35	0.58	0.80
45	2	90	0.35	0.18	0.58	0.76	0.47	0.25	0.68	0.87
50	2	100	0.42	0.19	0.55	0.84	0.50	0.29	0.67	0.91

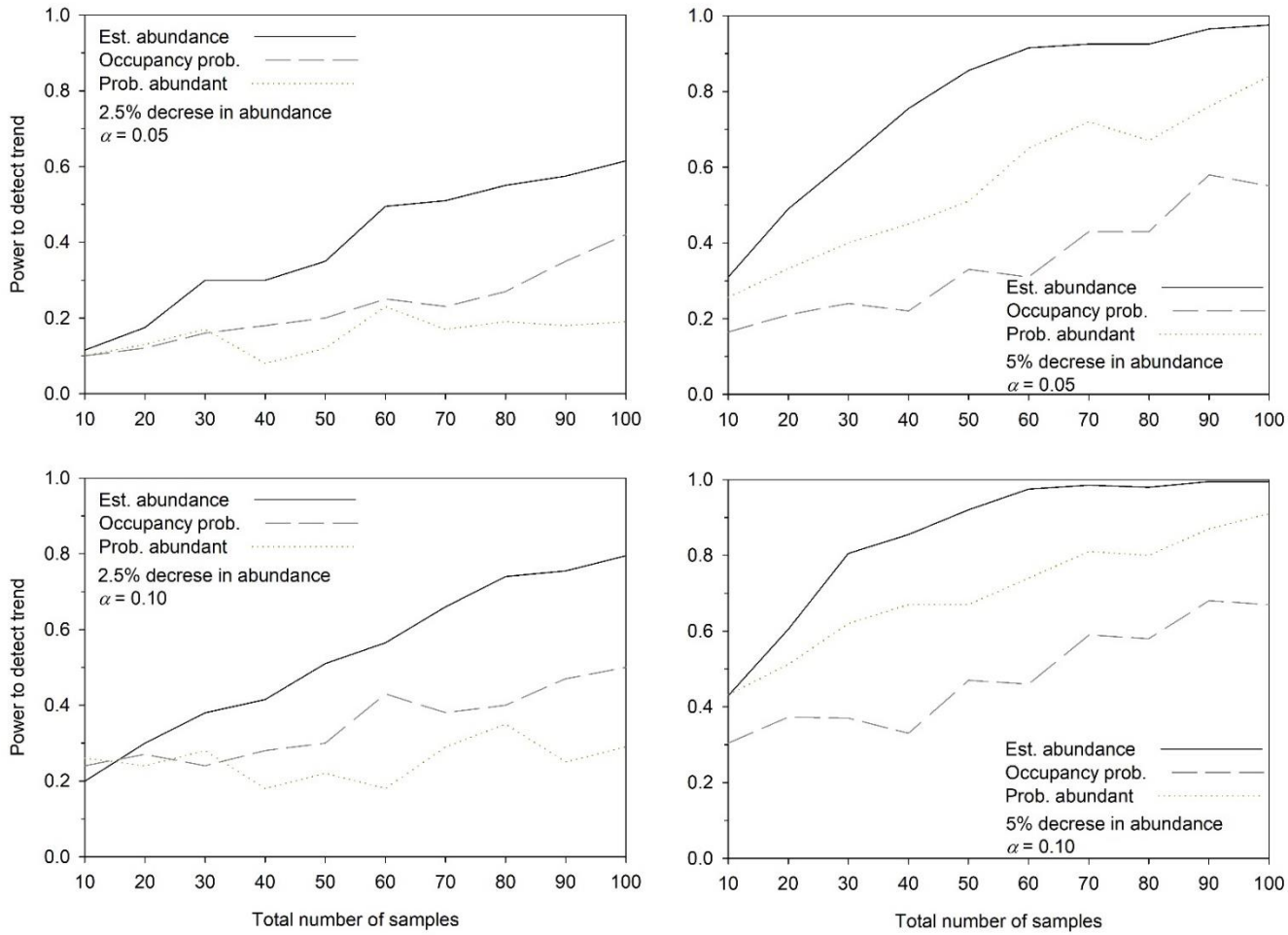

Figure 12. Power to detect a 2.5% decrease (left panels) or a 5.0% decrease (right panels) in abundance and occupancy over a 10-y period for Umpqua Chub as a function of the total number of samples collected per year at alpha levels of 0.05 (top panels) and 0.10 (bottom panels).

The N-mixture model can generate abundance estimates with relatively little effort (e.g., double-pass snorkel surveys at multiple sample sites). N-mixture models have been used to estimate abundance of a variety of taxa (e.g., Belant et al. 2016; Ficetola et al. 2018; Som et al. 2018; Kidwai et al. 2019). However, N-mixture models may be biased when assumptions are not met or when detection probabilities are low (Duarte et al. 2018). In this study the N-mixture model estimates were biased by > 50%; consequently, we do not believe that this is an appropriate analytical framework for estimating abundance of Umpqua Chub or Smallmouth Bass in the study system evaluated here.

Umpqua Chub abundance estimates from the Huggins closed capture-recapture estimator were relatively precise, with some exceptions (Figure 9). Therefore, capture-recapture sampling with minnow traps may be an effective method for estimating abundance of Umpqua Chub. However, this method required 3 sampling occasions occurring over a 4-d period to sample each site as implemented here, which could considerably limit the number of sites that can be sampled. Deriving snorkeling efficiencies from a Huggins estimator and applying them to single-pass snorkeling also resulted in relatively precise calibrated abundance estimates of Umpqua Chub. Application of this technique for monitoring the status and trend of Umpqua Chub would likely require some level of continued calibration (i.e., capture-recapture abundance estimates via trapping would need to be made at some snorkeling sample sites). Therefore, using calibrated abundance estimates to monitor status and trend represents a compromise between time-intensive sampling such as capture-recapture sampling at all sample sites and less time-intensive sampling such as single-pass snorkeling at all sample sites.

We were able to estimate the probability that Umpqua Chub and Smallmouth Bass were absent, present, or abundant using double-pass snorkel surveys and multistate occupancy models. Although these models do not estimate abundance on a continuous scale, occupancy models have been used to evaluate temporal trends in site occupancy or distribution for a variety of taxa (e.g., Zielinski et al. 2013; Banner et al. 2019; Green et al. 2019). Additionally, the time requirement necessary for collecting occupancy data may be less than that for more traditional methods that are used to estimate abundance (e.g., capture-recapture surveys). Therefore, if understanding or documenting status and trend of Umpqua Chub and other species is of interest to fishery managers, a sampling strategy that employs double-pass snorkel surveys and occupancy modeling may offer a reasonable compromise between sampling efficiency and data resolution.

Given that snorkeling was effective at providing data for both calibrated abundance estimates and multistate occupancy estimates for Umpqua Chub, we compared the power of these two analytical methods for detecting trend over time. Both methods provide similar and relatively low power to detect trend over a 10-year period when the number of samples per year is low (e.g., less than about 20-30 samples per year; Figure 12). However, as the number of samples per year increases, calibrated abundance estimates have greater power to detect trend (Figure 12). These data indicate that, all else being equal, monitoring based on calibrated abundance may be better for detecting trend when compared to occupancy modeling; however, occupancy modeling has certain advantages. First, detection probability can be calculated for each sample site with occupancy modeling, whereas snorkeling efficiency was estimated for calibrated abundance estimates based on results from a subset of sample sites where capture-recapture surveys were conducted in this study. This may be problematic given the observed variability in trapping efficiency (i.e., detection probability) among sample sites during minnow trapping (Figure 8) and the relatively large random effect observed in the integrated Bayesian model for snorkeling efficiency (Table 10). Sampling a larger number of sites with a snorkel and trap protocol may help identify factors associated with this random variability, but this would come at a cost of additional

sampling effort. Second, the optimal sampling design for both the calibrated abundance estimates and the multistate occupancy estimates require sampling each site twice. The calibrated abundance sampling design requires that each site is sampled in two separate months, whereas the multistate occupancy model simply requires that each site is visited twice. The two visits per site under the occupancy model could be conducted within the same day with a short break between site visits. Logistically, this may reduce travel time to sample sites (e.g., only drive to a remote site one day as compared to one day in each of two months) and could result in a shorter sampling season (e.g., intensive sampling within a one-month period as opposed to spreading sampling out over multiple months). Consequently, fishery scientists and managers may use these data to evaluate multiple factors such as data resolution, data precision, and logistics when identifying appropriate monitoring methods for assessing status and trend of Umpqua Chub and other species.

Although we did not explicitly evaluate the advantages and limitations of different sampling gears, certain patterns emerged during occupancy and abundance modeling that may help guide future sampling. Detection probability was variably affected by covariates among sampling strategies and analytical techniques. Detection probability of Umpqua Chub was influenced by team experience during snorkeling (N-mixture model), suggesting that sufficient time should be spent training snorkeling crews prior to initiating surveys. Detection probability of Umpqua Chub was negatively influenced by the percent of aquatic vegetation within sample sites during snorkeling (multistate occupancy model; Figure 6), and snorkeling efficiency was positively associated with the amount of bedrock substrate within sample sites (integrated Bayesian model; Figure 10). These results suggest that concealment habitat may obscure Umpqua Chub from detection during snorkeling; therefore, snorkelers should consider habitat complexity when determining the appropriate amount of effort to expend during surveys. Snorkeling efficiency was negatively associated with snorkeling duration (integrated Bayesian model; Figure 10). This result is somewhat counterintuitive, but may represent a situation where snorkelers become fatigued or complacent with respect to counting Umpqua Chub as survey time increases. Alternatively, this may be a result of Umpqua Chub being able to behaviorally avoid, or be concealed from, surveyors in sample sites that take longer to sample, such as large sample sites. However, this likely would have been expressed as an effect of other covariates specifically related to sample site size such as sample site length, width, or depth. Increasing sample sizes through future sampling efforts my help elucidate what factor or factors are driving snorkeling efficiency. Capture-recapture data using minnow traps suggest that Umpqua Chub exhibit trap-shy behavior; if left unaccounted for this could result in artificially inflated abundance estimates from capture-recapture surveys. Taken together, these results highlight a number of factors influencing detection probability and sampling efficiency for Umpqua Chub, and the importance of recording data related to biotic, abiotic, and sampling conditions when performing surveys. These data also highlight our concerns related to comparisons among disjunct data sets (see 'Biological Review of Umpqua Chub'; this document).

Abundance of both Umpqua Chub and Smallmouth Bass was positively associated with sample site surface area when estimated with N-mixture models. This observation makes intuitive sense, but we acknowledge that the N-mixture model estimates were substantially biased in this study. Umpqua Chub occupancy and abundance was positively associated with the percent of aquatic vegetation based on occupancy models. These results support previous studies, which have noted that Umpqua Chub catch rates were higher in areas with aquatic or overhanging vegetation compared to areas with other cover types (Markle et al. 2011). Umpqua Chub were abundant in sample sites dominated by cobble substrate compared to sample sites dominated by other substrates (Figure 6). Positive associations between Umpqua Chub occupancy and abundance with percent aquatic vegetation and cobble substrate suggest that Umpqua Chub may be

selecting for habitat complexity in general. Smallmouth Bass were associated with increasing average depths of sample sites. Further research is warranted prior to protecting or enhancing habitats specifically for Umpqua Chub; however, data presented here can provide a foundation for developing testable hypotheses related to Umpqua Chub habitat selection.

During 2016, Umpqua Chub abundance was variable among sampling occasion within sample sites (Figure 11). This observation shows that time of sampling could greatly affect site-specific and population-wide abundance estimates, and potentially affect site-specific occupancy estimates. Data are currently unavailable to explain this variability, but it may be influenced by a variety of factors such as immigration, emigration, and mortality; additionally, these factors may be dependent on life-history stage or age. Future research on movement patterns and life-history for Umpqua Chub is warrant; indeed Markle et al. (2011) called for research to evaluate movement and dispersal ability of Umpqua Chub.

We found no evidence that Umpqua Chub detection probability or occupancy differed when Smallmouth Bass were present or absent at the site level. This finding is contrary to the assumption that Smallmouth Bass are responsible for the apparent decline in Umpqua Chub abundance and distribution (Simon and Markle 1999; Simon 2008; O'Malley et al. 2013). There are a number of plausible explanations for why we did not observe an effect of Smallmouth Bass on Umpqua Chub detection and occupancy. First, the grain, or resolution, of our sampling may have been too coarse to evaluate interactions between Smallmouth Bass and Umpqua Chub. Our primary sampling unit (the sample site) was six-times the average wetted width of the stream and therefore each sample site typically incorporated multiple habitat units (e.g., some combination of slow-water and fast-water habitat units). Consequently, our sampling strategy may not detect interactions between Smallmouth Bass and Umpqua Chub if they occur at the habitat unit scale (e.g., exclusion of Umpqua Chub from specific habitat unit types). Second, the spatial extent of our sampling may have been too fine. Sampling during 2015-2017 occurred in portions of the Cow Creek-South Umpqua River sampling stratum (Figure 4), and specifically in portions of that sampling strata that were generally occupied by Umpqua Chub or Umpqua Chub and Smallmouth Bass in 2006-2007 (Figure 3). If patterns observed in 2006-2007 were representative of the species assemblage at that time, and if the species assemblage has not changed substantially since 2006-2007, then our sampling in 2015-2017 would have included very few areas where Umpqua Chub would be absent. While this may not explicitly reduce our ability to detect an effect of Smallmouth Bass on Umpqua Chub, if displacement of Umpqua Chub by Smallmouth Bass is progressing over time as suggested by others (Simon 2008; O'Malley et al. 2013) then displacement may not yet have occurred in the areas sampled in 2015-2017. Regardless, surveying a larger spatial extent that includes a sufficient number of sample sites where Umpqua Chub are absent may allow fishery scientists to determine if spatial, temporal, or site-specific habitat covariates are associated with patterns of Smallmouth Bass and Umpqua Chub occupancy. Third, our sample size may be insufficient to detect an effect of Smallmouth Bass. Similar to above, sampling a larger number of sites may increase power to detect whether Smallmouth Bass have an effect on Umpqua Chub detection probability or occupancy. Fourth, Smallmouth Bass may not influence the distribution of Umpqua Chub. This hypothesis is unlikely given the patterns observed during previous surveys (Markle et al. 1991; Simon and Markle 1999; Simon 2008) and Umpqua Chub population fragmentation patterns (O'Malley et al. 2013); consequently, we suggest that future research should be designed specifically to address various ecological interactions and spatial relationships between Umpqua Chub and Smallmouth Bass.

Fishery scientists and managers have expressed a need for methods suitable for evaluating status and trend of Umpqua Chub. We evaluated a variety of analytical frameworks for estimating detection, occupancy, and abundance using data collected during 2015-2017 in the Cow Creek-

South Umpqua River sampling stratum. We found that N-mixture model abundance estimates were biased and we suggest that this modeling framework is not suitable for monitoring purposes. Capture-recapture models using minnow traps produced relatively precise abundance estimates for Umpqua Chub; using these estimates to calibrate snorkel counts resulted in relatively precise abundance estimates based on single-pass snorkel surveys. Multistate occupancy models may be a reasonable alternative to abundance estimates for monitoring trend of Umpqua Chub. Although multistate occupancy models have less power to detect trend in abundance for a given number of samples, logistical constraints may make it easier to collect a larger number of samples following a multistate occupancy strategy. Umpqua Chub and Smallmouth Bass detection, occupancy, and abundance were influenced by a number of factors related to sampling gear, field crew experience, and environmental conditions; consequently, comparisons among data sets that do not adequately document or address these factors could result in spurious conclusions and should be approached with caution. Modeling results suggest that Umpqua Chub occupancy may be positively associated with aquatic vegetation and particular substrate types; however, we argue that additional research on the life-history requirements, habitat selections, and movement patterns of Umpqua Chub are needed prior to implementation of habitat protection or enhancement for this species. Finally, our results do not provide evidence for negative interactions between Smallmouth Bass and Umpqua Chub; however, a number of limitations related to the scale (grain and extent) at which data were collected are noted and we suggest that future research should be conducted to evaluate ecological interactions between these species.

Future Sampling Considerations

There are advantages and limitations to all sample designs and sample gears that should be considered when developing a sampling or monitoring strategy. We evaluated multiple sampling strategies and analytical techniques for monitoring status and detecting trend for Umpqua Chub based on data collected in 2015-2017 [see 'Analysis of Contemporary Data on Umpqua Chub Occupancy and Abundance (2015-2017)'; this document]. Based on our analyses, we consider that monitoring Umpqua Chub using double-pass snorkeling and multistate occupancy models may provide a reasonable compromise between sampling efficiency and power to detect trend over time. We also believe that the spatial distribution of sample sites should be increased over sampling efforts conducted in 2015-2017. Increased spatial distribution of sample sites 1) should be more representative of Umpqua Chub status throughout their historical distribution and 2) will increase the area over which we can make inference regarding associations among Umpqua Chub occupancy, habitat use, and interactions with Smallmouth Bass. The following methods and rationale were used to select sample sites in the Umpqua River basin to sample Umpqua Chub under a multistate occupancy framework. Our assumption is that sampling will occur over multiple years to provide information on Umpqua Chub trend.

Sample Site Classification and Distribution

Potential sample sites were spatially stratified to ensure a thorough distribution of sites throughout the Umpqua River drainage and for each year surveys are conducted based on the four distinct evolutionary populations identified in O'Malley et al. (2013), and to sampling strata in the North Umpqua River and Mainstem Umpqua River. The resulting six sampling strata were: 1) Smith River; 2) Elk Creek; 3) Olalla Creek-Calapooya Creek; 4) Cow Creek-South Umpqua River; 5) North Umpqua River; and 6) Mainstem Umpqua River (including the South Umpqua River downstream from the Cow Creek confluence) (Figure 13).

Sample sites were classified into two types: Sentinel Sites and Exploratory Sites. Sentinel Sites were selected from the list of 141 sites sampled by Oregon State University (OSU) personnel in 2006-2007 (Simon 2007a, 2007b, 2008). These sites were generally located along stream reaches with public access, so access for the duration of the long-term monitoring should be reasonably certain. For each stratum, up to 15 Sentinel Sites were randomly selected from the list of potential OSU sites (Figure 13; Appendix 1), with the exception that there were only 15 OSU sites sampled in the Smith River, so all 15 were selected as Sentinel Sites. Additionally, OSU did not sample the North Umpqua River in 2006-2007 so we used the 5 sites sampled in 1987 by OSU (Simon and Markle 1999).

Exploratory Sites were selected from a sampling frame developed with ArcMap 10.4 (Esri Inc., Redlands, California) and based on portions of the Umpqua River drainage stream network that met each of the following criteria:

- Strahler Stream Order ≥ 2 based on the National Hydrography Dataset (NHD) Plus layer (USGS 2020).
- Stream slope of ≤ 1.3% from the NHD Plus layer (USGS 2020).
- Mean August stream temperature (2002-2011) of ≥ 16°C from the NorWeST stream temperature layer (USFS 2020).

The sampling frame was developed by populating the stream network with potential sample sites spaced at 200-m increments along the network. A generalized random-tessellation stratified

sampling design (Stevens and Olsen 2004) was then used to select Exploratory Sites in each stratum. Exploratory Sites should be sampled without replacement over the course of the monitoring period. A total of 100 sample sites per stratum were selected (Appendix 2), which should provide enough sample sites for the foreseeable future.

Rationale for stream network criteria

Stream Order: The stream order criterion was guided by previous sampling by OSU in 2006-2007. Out of all 141 OSU sites, only 3 were in second order streams. No Umpqua Chub were observed at these sites, but we included all second order streams in the sampling frame as part of the exploratory effort to determine if Umpqua Chub occur in these lower order streams.

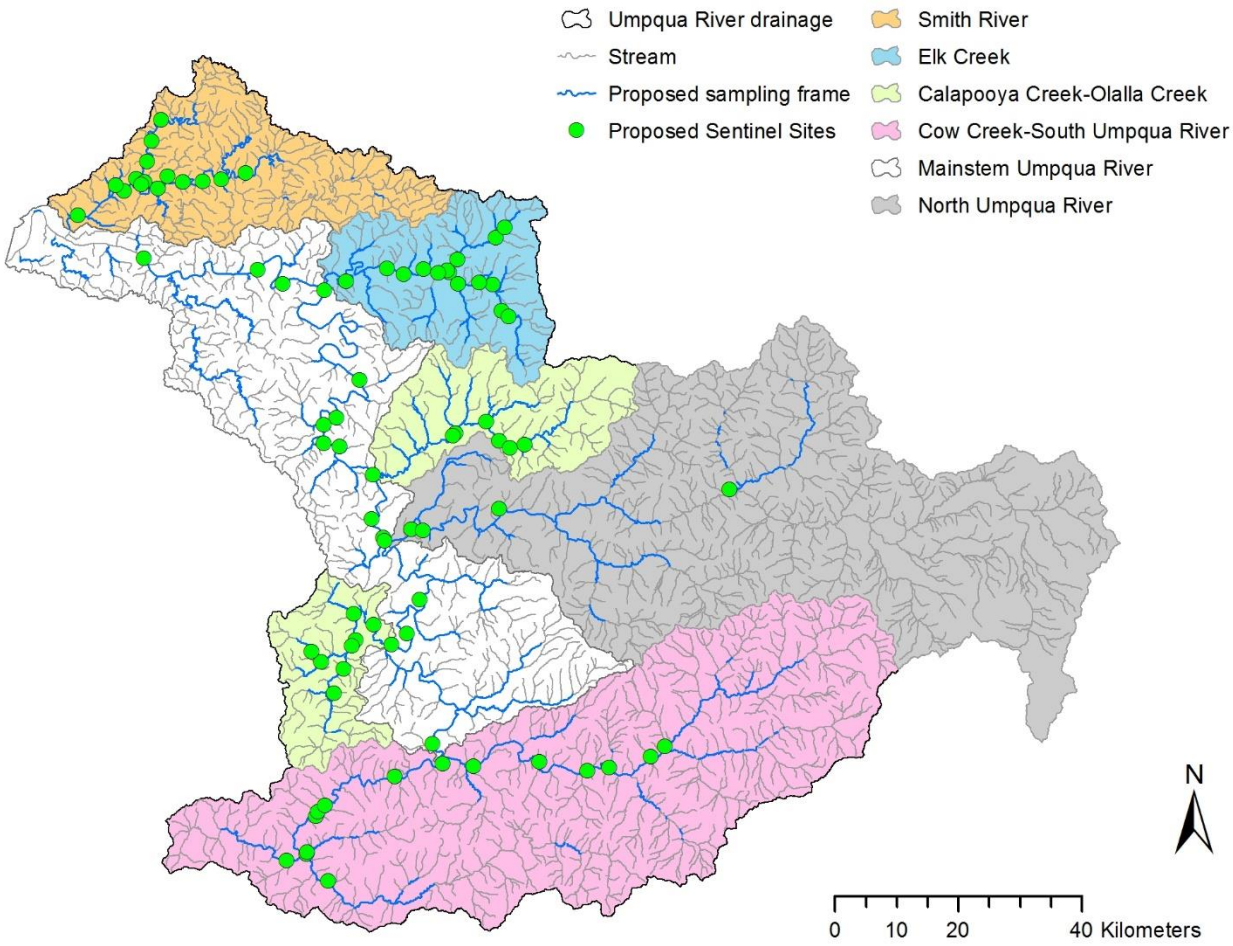

Figure 13. Smith River, Elk Creek, Calapooya Creek-Olalla Creek, Cow Creek-South Umpqua River, Mainstem Umpqua River, and North Umpqua River sampling strata in the Umpqua River drainage and location of Sentinel Sites selected to monitor status and trend of Umpqua Chub. The sampling frame used to select Exploratory Sites (Appendix 2) is shown in blue; other stream segments are shown in gray.

Stream slope: Oregon Chub, an Umpqua Chub congener, live in moderate- to no-flow environments (Pearsons 1989) typical in low gradient streams. The greatest stream slope where Umpqua Chub were found in the 2006-2007 OSU surveys was 1.3%; therefore, we set this as the upper limit of stream slope in the sampling frame.

Temperature: Although little is known about Umpqua Chub spawning requirements, we assumed they are similar to Oregon Chub. Oregon Chub require stream temperature ≥ 16°C to spawn (Pearsons 1989), and spawning can occur as late as August (Scheerer and McDonald 2003). Therefore, we assumed that streams with temperatures < 16°C in August would be too cold for Umpqua Chub to complete their life cycle. Therefore, only streams with mean August temperature ≥16°C were included in the sampling frame.

Allocating Sampling Effort

It is difficult for us to provide definitive direction regarding the desired level and frequency of sampling effort (e.g., number of sample sites to visit per year) without additional input from fishery and natural resource managers that are involved with Umpqua Chub conservation and management. At a minimum, knowing the level of effort that could be dedicated, and the frequency at which that effort could be dedicated, would provide a basis for developing a monitoring plan that appropriately allocates sampling effort between Sentinel Sites and Exploratory Sites and among strata. Although we could recommend sampling effort based on power to detect trend [see 'Analysis of Contemporary Data on Umpqua Chub Occupancy and Abundance (2015-2017)'; this document], it would be impractical for us to recommend a sampling strategy that exceeds the capacity of those directly involved in data collection. Consequently, we recommend that fishery and resource managers convene to discuss inter-organizational capacity to conduct surveys and desired level of power to detect trend. This information could provide a starting point for defining an appropriate monitoring plan that allocates sampling effort among Sentinel Sites and Exploratory Sites to benefit both trend monitoring and attainment of new information. At the time of writing this report, the methodologies provided herein were used for surveys conducted in 2019 and 2020; data and anecdotal information from these surveys may help inform discussions associated with future sampling capacity and limitations.

Survey Protocol

The following is an example of simplified protocol for double-pass snorkel surveys for Umpqua Chub multistate occupancy modeling. Our intent is to provide an outline of the minimum data collection necessary to model Umpqua Chub and Smallmouth Bass multistate occupancy as implemented herein. Development of a comprehensive protocol aimed at addressing other issues of interest to a diverse group of stakeholders is beyond the scope of this document. We recommend that fishery and resource managers convene to discuss inter-organizational data needs that may go beyond what is necessary for Umpqua Chub and Smallmouth Bass multistate occupancy models; e.g., information on other taxa, within species size data, etc. Additionally, snorkeling may not be efficient under certain conditions (e.g., limited visibility due to water turbidity). Using an alternative sampling method under conditions that are not conducive to snorkeling may be an option; however, we did not evaluate detection probabilities for different gear types associated with Umpqua Chub and Smallmouth Bass multistate occupancy models. Consequently, further research would be needed to identify situations where alternative sampling gears should be used and how data collected using alternative sampling gears could be incorporated into the recommended multistate occupancy models. We provide a subjective cutoff

value associated with when surveyors may wish to avoid sampling a site based on water clarity in the following protocol, and suggest further research should be considered if data generated from alternative sampling gears may be collected.

The following simplified protocol is similar to the protocol implemented in 2015-2017, and in 2019-2020. The two passes should be conducted on consecutive days, or on the same day with a brief break between passes. Generally, sample sites should be surveyed by two snorkelers; one on each side of the stream. The snorkelers should switch stream sides between passes and should avoid sharing information related to the locations and numbers of fish observed on the previous pass. A subjective cutoff value associated with when surveyors may wish to avoid sampling a site based on water clarity is provided. See Appendix 3 for an example survey form used to record data from double-pass snorkel surveys.

<u>Simplified snorkel survey protocol</u>

Pass-1

1. Navigate to sample site based on pre-defined geographic coordinates.
    a. The pre-defined coordinates represent the approximate downstream boundary of the sample site.
    b. The downstream site boundary should be established at a habitat-unit break (e.g., pool—riffle transition) in close proximity to the geographic coordinates.

2. Record the stream name, sample site number, coordinates of the downstream site boundary, date, crew members, and sampling pass number (i.e., pass-1).

3. Measure the sample site wetted width with a range finder; record this measurement.

4. Measure and record the sample site length and record the coordinates of the upstream boundary of the sample site.
    a. The sample site length should be about 6-times the wetted width (e.g., if the width is 30 m then the length should be about 180 m).
    b. The upstream boundary of the sample site should be established at a habitat-unit break.

5. Measure and record water temperature.

6. Measure and record water clarity with Secchi disk. Position disk perpendicularly on substrate and facing downstream. While facing the disk, gradually snorkel downstream until disk is no longer visible. Measure and record the distance to disk. Repeat for each snorkeler.
    a. Surveyors may choose to avoid sampling a site if the average Secchi distances is less than 5-m; contact your supervisor or project lead as appropriate.

7. For each snorkeler, record the start time and stream bank on a survey wristband.
    a. Stream bank is left or right and is determined looking downstream.
    b. Transfer these data to the survey form at the end of the survey pass.

8. Conduct snorkel survey, starting at the downstream end of the site, trying to stay within 5-m of the bank. Count each Umpqua Chub and Smallmouth Bass that is encountered. This information will be entered into the first block of the survey form, along with the

Observers name and their survey unit (i.e., left or right bank as determined by looking downstream). For sites on narrow streams (< 7-m wide), one surveyor will conduct the survey observing fish on both banks. For sites on wide streams where surveyors feel they cannot render prompt assistance to the other observer due to wide stream widths, one side may be surveyed. Choose two contiguous units that are each 6-times the stream width on one side of the stream. Record habitat from Step 10 below separately for each unit.

9. Record finish time at the upstream end of sample site.

10. For each right bank and left bank *survey unit*, determine the following on the swim/walk back down to the put-in/take-out:
    a. Record the substrate composition for sand, gravel, cobble, boulder, bedrock and wood. These should add up to 100%.
    b. Determine and record the cover for vegetation in the water, up to 100%.
    c. Determine and record the cover of algae on the substrate, up to 100%. The vegetation and algae are independent of each other.
    d. Determine and record the percentage of bank with overhanging cover (e.g., tree branches, shrubs, etc.).
    e. Record riparian habitat category: Old Growth (OG); Timber Plantation (TP); Hardwood (H); Shrub (S); Open Agricultural (OA); Agricultural w/ narrow timbered buffer (AT); Open-Grassland (OG), Urban (U), other (Other).
    f. Note: For smaller streams where only one observer counted fish on both banks, characterize the habitat of the entire site (left and right sides combined).

11. Transfer all data to the survey form.

12. Sketch site as needed to show where survey occurred.

13. Ensure that all required data have been entered on the survey form.

Pass-2

****Snorkelers switch sides from previous pass****

1. Record the stream name, sample site number, date, crew members, and sampling pass number (i.e., pass-2).

2. Measure and record water temperature.

3. For each snorkeler, record the start time and stream bank on a survey wristband.
    a. Transfer these data to the survey form at the end of the survey pass.

4. Conduct snorkel survey and record data similar to pass-1.

5. Record finish time at the upstream end of sample site.

References

Anlauf-Dunn, K.J., and K.K. Jones 2012. Stream habitat conditions in western Oregon, 2006-2010. OPSW-ODFW-2012-5, Oregon Department of Fish and Wildlife, Salem, OR.

Baldwin, E.M. 1981. Geology of Oregon, 3rd edition. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Banner, K.M., K.M. Irvine, T.J. Rodhouse, D. Donner, and A.R. Litt. 2019. Statistical power of dynamic occupancy models to identify change: Informing the North American Bat Monitoring Program. Ecological Indicators 105:166-176.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67:1-48.

Belant, J.L., F. Bled, C.M. Wilton, R. Fyumagwa, S.B. Mwampeta, and D.E. Beyer, Jr. 2016. Estimating lion abundance using N-mixture models for social species. Scientific Reports 6:35920.

Bonar, S.A., S. Contreras-Balderas, and A.C. Iles. 2009. An introduction to standardized sampling. Pages 1-12 *in* S.A. Bonar, W.A. Hubert, and D.W. Willis, editors. Standard methods for sampling North American freshwater fishes. American Fisheries Society, Bethesda, Maryland.

Burnham, K.P., and D.R. Anderson. 2002. Model selection and multimodel inference: A practical information-theoretic approach, 2nd edition. Springer, New York, New York.

Cavalli-Sforza, L.L., and A.W.F. Edwards. 1967. Phylogenetic analysis: Models and estimation procedures. Evolution 21:550-570.

DeHaan, P.W., P.D. Scheerer, R. Rhew, and W.R. Ardren. 2012. Analyses of genetic variation in populations of Oregon Chub, a threatened floodplain minnow in a highly altered environment. Transactions of the American Fisheries Society 141:533-549.

Diller, J.S. 1915. Guidebook of the western U.S., Part D. U.S. Geological Survey Bulletin 614:1-142.

Duarte, A., M.J. Adams, and J.T. Peterson. 2018. Fitting N-mixture models to count data with unmodeled heterogeneity: Bias, diagnostics, and alternative approaches. Ecological Modeling 374:51-59.

Fiske, I., and R. Chandler. 2011. unmarked: An R package for fitting hierarchical models of wildlife occurrence and abundance. Journal of Statistical Software 43:1-23.

Ficetoal, G.F., B. Barzaghi, A. Melotto, M. Muraro, E. Lunghi, C. Canedoli, E.L. Parrino, V. Nanni, L. Silva-Rocha, A. Urso, M.A. Carretero, D. Salvi, S. Scali, G. Scari, R. Pennati, F. Andreone, and R. Manenti. 2018. N-mixture models reliably estimate the abundance of small vertebreates. Scientific Reports 8:10357.

FS/BLM (U.S. Forest Service/U.S. Bureau of Land Management). 2020. Interagency Special Status Sensitive Species Program [online database]. U.S. Forest Service Region 6, Portland, Oregon. Available: https://www.fs.fed.us/r6/sfpnw/issssp/.

Green, A.W., D.J. Pavlacky, Jr., and T.L. George. 2019. A dynamic multi-scale occupancy model to estimate temporal dynamics and hierarchical habitat use for nomadic species. Ecology and Evolution 9:793-803.

Hey, J., and R. Nielsen. 2007. Integration within the Felsenstein equation for improved Markov chain Monte Carlo methods in population genetics. Proceedings of the National Academy of Sciences of the United States of America 104:2785-2790.

IUCN (International Union for Conservation of Nature). 2020. The IUCN Red List of Threatened Species [online database]. International Union for Conservation of Nature , Washington D.C. Available: https://www.iucnredlist.org/.

Jennings, C.A., B.L. Sloss, B.A. Lasee, G.J. Burtle, and G.R. Moyer. 2012. Care, handling, and examination of sampled organisms. Pages 163-221 *in* A.V. Zale, D.L. Parrish, and T.M. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Kéry, M., and Schaub, M. 2012. Bayesian population analysis using WinBugs: A hierarchical approach. Academic Press, San Diego, California.

Kidwai, Z., J. Jimenez, C.J. Louw, H.P. Nel, and J.P. Marshal. 2019. Using N-mixture models to estimate abundance and temporal trends of black rhinoceros (*Diceros bicornis* L.) populations from aerial counts. Global Ecology and Conservation 19:e00687.

Laake, J.L. 2013. RMark: An R interface for analysis of capture-recapture data with MARK. Alaska Fisheries Science Center Report 2013-01, National Oceanic and Atmospheric Administration, Seattle, Washington.

MacKenzie, D.I., J.D., Nichols, G.B. Lachman, S. Droege, J.A. Royle, and C.A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, J.E. Hines. 2006. Occupancy estimation and modeling: Inferring patterns and dynamics of species occurrence. Elsevier, Boston, Massachusetts .

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, J.E. Hines. 2018. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence, 2nd edition. Academic Press, San Diego, California.

Markle, D.F. 2019. Drainage evolution and freshwater fish zoogeography in coastal Oregon and Washington. Northwestern Naturalist 100:71-89.

Markle, D.F., K. O'Malley, M. Terwilliger, P. Baki, H. Truemper, and D. Simon. 2011. Umpqua Chub population estimate. Final Report to US Fish and Wildlife Service, grant # E-2-54, Roseburg, Oregon.

Markle, D.F., T. Pearsons, and D. Bills. 1991. Natural history of *Oregonichthys kalawatseti* (Pisces: Cyprinidae), with a description of a new species from the Umpqua River of Oregon. Copeia 1991:277-293.

ODFW (Oregon Department of Fish and Wildlife). 2020a. Sensitive Species [online database]. Oregon Department of Fish and Wildlife, Salem, OR. Available: https://www.dfw.state.or.us/wildlife/diversity/species/sensitive_species.asp.

ODFW (Oregon Department of Fish and Wildlife). 2020b. The Oregon Conservation Strategy [online database]. Oregon Department of Fish and Wildlife, Salem, OR. Available: https://www.oregonconservationstrategy.org/.

O'Malley, K.G., D.F. Markle, and W.R. Ardren. 2013. Timing of population fragmentation in a vulnerable minnow, the Umpqua Chub, and the role of nonnative predators. Transactions of the American Fisheries Society 142:447-457.

Pearsons, T.N. 1989. Ecology and decline of a rare western minnow: the Oregon Chub (*Oregonichthys crameri*). Master's thesis, Oregon State University, Corvallis, Oregon.

Penaluna, B. E., and L. Ellenburg. 2019. Reoccurrence of the Umpqua Chub (Oregonichthys kalawatseti) in the North Umpqua after Almost a century. Northwest Naturalist 100:208-210.

Peterson, J.T., and M.F. Barajas. 2018. An evaluation of three fish surveys in the Bay-Delta, 1995-2015. San Francisco Estuary and Watershed Science 16:4.

Pregler, K.C., J.C. Vokoun, T. Jensen, and N. Hagstrom. 2015. Using multimethod occupancy estimation models to quantify gear differences in detection probabilities: Is backpack electrofishing missing occurrences for a species of concern? Transactions of the American Fisheries Society 144:89-95.

Royle, J.A. 2004. N-mixture models for estimating population size from spatially replicated counts. Biometrics 60:108-115

Scheerer, P.D. 2007. Improved status of the endangered Oregon Chub in the Willamette River, Oregon. Pages 91-102 *in* M.J. Brouder, and J. A Scheurer, editors. American Fisheries Society Symposium 53, Bethesda, MD.

Scheerer, P., S. Jacobs, and M. Terwilliger. 2005. Monitoring of Hospital Pond (2005): Willamette basin Oregon Chub investigations, Monitoring and Management. Oregon Department of Fish and Wildlife – Annual Progress Report, Salem, OR.

Scheerer, P.D. and P.J. McDonald. 2003. Age, growth, and timing of spawning of an endangered minnow, the Oregon Chub (*Oregonichthys crameri*), in the Willamette Basin, Oregon. Northwestern Naturalist 84:68-79.

Schultz, L.D., M.P. Heck, B.M. Kowalski, C.A. Eagle-Smith, K. Coates, J.B. Dunham. 2017. Bioenergetics models to estimate numbers of larval lampreys consumed by Smallmouth Bass in Elk Creek, Oregon. North American Journal of Fisheries Management 37:714-723.

Schwarz, M.K., G. Luikart, and R.W. Waples. 2007. Genetic monitoring as a promising tool for conservation and management. Trends in Ecology and Evolution 22:25-33

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Bulletin 184, Ottawa.

Simon, D.C. 2007a. Distributional surveys of Umpqua Chub *Oregonichthys kalawatseti* and Smallmouth Bass *Micropterus dolomieu* in the Cow Creek Basin and South Umpqua River, Oregon. Final report to Pacific Northwest Ecosystems Studies Unit, Cooperative Agreement No. HAA003D00, Roseburg, Oregon.

Simon, D.C. 2007b. Preliminary report on 2007 field sampling activities investigating the distribution and abundance of Umpqua Chub, Umpqua Basin, Oregon. Progress report to US Bureau of Land Management, Roseburg, Oregon, and US Fish and Wildlife Service, Portland, Oregon.

Simon, D.C. 2008. Distributional surveys of Umpqua chub *Oregonichthys kalawatseti* and smallmouth bass *Micropterus dolomeiu* [in] the Umpqua Basin, Oregon. Final report submitted to Pacific Northwest Cooperative Ecosystems Studies Unit, Cooperative Agreement No. HAA003D00, Roseburg, Oregon.

Simon, D.C., and D.F. Markle. 1999. Evidence of a relationship between Smallmouth Bass (*Micropterus dolomieu*) and decline of Umpqua Chub (*Oregonichthys kalawatseti*) in the Umpqua Basin, Oregon. Northwestern Naturalist 80:110-113.

Snedecor, G.W., and W.G. Cochran. 1991. Statistical methods. Iowa State University Press, Ames.

Som, N.A., R.W. Perry, E.C. Jones, K.D. Juilio, P. Petros, W.D. Pinnix, and D.L. Rupert. 2018. N-mix for fish: Estimating riverine salmonid habitat selection via N-mixture models. Canadian Journal of Fisheries and Aquatic Science 75:1048-1058.

Stevens, D.L., and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262-278.

Strickland, M.J., and M. Davies. 2020. Evaluating an ocular estimation method that describes individual substrate size classes in stream habitats. Oregon Department of Fish and Wildlife – Progress Report, Salem, OR.

Sturtz, S., U. Ligges, and A. Gelman. 2005. R2WinBUGS: A package for running WinBUGS from R. Journal of Statistical Software 12:1-16.

Thurow, R.F., J.T. Peterson, and J.W. Guzevich. 2006. Utility of day and night snorkel counts for estimating Bull Trout abundance in first- to third-order streams. North American Journal of Fisheries Management 26:217-232.

USFS (U.S. Forest Service). 2020. NorWeST Stream Temp [online database]. U.S. Forest Service, Rocky Mountain Research Station, Fort Collins, CO. Available: https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html.

USFWS (U.S. Fish and Wildlife Service). 2020. Federally listed, proposed, candidate, delisted species and species of concern under the jurisdiction of the Fish and Wildlife Service which may occur within Oregon. Available: https://www.fws.gov/oregonfwo/Documents/OregonSpeciesStateList.pdf.

USGS (U.S. Geological Survey). 2020. National Hydrography [online database]. U.S. Geological Survey. Available: https://www.usgs.gov/core-science-systems/ngp/national-hydrography.

Wang, L., T.D. Simons, and J. Lyons. 1996. Accuracy and precision of selected stream habitat estimates. North American Journal of Fisheries Management 16:340-347.

Waples, R.S., and O. Gaggiotti. 2006. What is a population? An empirical evaluation of some genetic methods for identifying the number of gene pools and their degree of connectivity. Molecular Ecology 15:1419-1439.

White, G.C., and K.P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46:120-139.

Williams, B.K., J.D. Nichols, and M.J. Conroy. 2002. Analysis and management of animal populations: Modeling, estimation, and decision making. Academic Press, San Diego, California.

Zielinski, W.J., J.A. Baldwin, R.L. Truex, J.M. Tucker, and P.A. Flebbe. 2013. Estimating trend in occupancy for the southern sierra Fisher *Martes pennanti* population. Journal of Fish and Wildlife Management 4:3-19.

Appendix 1. Downstream site coordinates (NAD83), site name, and sampling strata for Sentinel Sites. Fifteen sites per strata were selected from Oregon State University sample sites surveyed in 2006 and 2007, with the exception of North Umpqua River strata where the five Oregon State University sample sites surveyed in 1987 were selected.

Sampling strata	Site name	Latitude	Longitude
Smith River	128	43.792226	-123.9479
Smith River	127	43.774435	-123.9721
Smith River	130	43.787694	-123.9313
Smith River	135	43.784116	-123.9377
Smith River	126	43.782735	-123.9893
Smith River	131	43.818199	-123.9258
Smith River	136	43.788897	-123.8532
Smith River	134	43.796529	-123.8840
Smith River	125	43.737973	-124.0637
Smith River	138	43.792809	-123.7766
Smith River	129	43.778975	-123.9034
Smith River	133	43.879159	-123.8985
Smith River	139	43.802266	-123.7273
Smith River	137	43.790404	-123.8133
Smith River	132	43.848384	-123.9178
Elk Creek	122	43.604137	-123.2104
Elk Creek	121	43.642379	-123.2289
Elk Creek	114	43.660292	-123.3163
Elk Creek	118	43.662356	-123.3199
Elk Creek	119	43.642922	-123.2989
Elk Creek	123	43.595700	-123.1965
Elk Creek	110	43.678832	-123.2999
Elk Creek	112	43.664256	-123.3680
Elk Creek	120	43.645464	-123.2558
Elk Creek	111	43.658646	-123.3389
Elk Creek	113	43.710201	-123.2227
Elk Creek	109	43.725859	-123.2055
Elk Creek	117	43.646353	-123.5239
Elk Creek	116	43.664907	-123.4412
Elk Creek	115	43.656818	-123.4083
Calapooya Creek-Olalla Creek	92	43.425401	-123.3031
Calapooya Creek-Olalla Creek	105	43.123294	-123.4999
Calapooya Creek-Olalla Creek	76	43.421362	-123.3072
Calapooya Creek-Olalla Creek	141	43.442009	-123.2416
Calapooya Creek-Olalla Creek	104	43.114350	-123.5075
Calapooya Creek-Olalla Creek	90	43.408871	-123.1642
Calapooya Creek-Olalla Creek	87	43.414692	-123.2155
Calapooya Creek-Olalla Creek	83	43.090800	-123.5690
Calapooya Creek-Olalla Creek	107	43.045146	-123.5432
Calapooya Creek-Olalla Creek	79	43.161604	-123.5036
Calapooya Creek-Olalla Creek	106	43.081235	-123.5243
Calapooya Creek-Olalla Creek	77	43.117099	-123.4279
Calapooya Creek-Olalla Creek	82	43.105835	-123.5876
Calapooya Creek-Olalla Creek	93	43.404658	-123.1935
Calapooya Creek-Olalla Creek	78	43.145247	-123.4639

Appendix 1. Continued on next page.

Appendix 1. Continued from previous page.

Sampling strata	Site name	Latitude	Longitude
Cow Creek-South Umpqua River	40	42.933505	-123.0384
Cow Creek-South Umpqua River	6	42.866349	-123.5766
Cow Creek-South Umpqua River	18	42.872538	-123.5725
Cow Creek-South Umpqua River	31	42.969023	-122.8840
Cow Creek-South Umpqua River	13	42.801175	-123.6344
Cow Creek-South Umpqua River	25	42.810313	-123.5951
Cow Creek-South Umpqua River	22	42.813284	-123.5933
Cow Creek-South Umpqua River	9	42.771564	-123.5512
Cow Creek-South Umpqua River	45	42.953925	-122.9124
Cow Creek-South Umpqua River	2	42.924383	-123.4214
Cow Creek-South Umpqua River	48	42.940160	-123.2640
Cow Creek-South Umpqua River	39	42.938183	-122.9956
Cow Creek-South Umpqua River	5	42.881546	-123.5592
Cow Creek-South Umpqua River	43	42.946577	-123.1335
Cow Creek-South Umpqua River	50	42.943389	-123.3258
Mainstem Umpqua River	61	43.299396	-123.4696
Mainstem Umpqua River	60	43.272380	-123.4463
Mainstem Umpqua River	70	43.502407	-123.4951
Mainstem Umpqua River	99	43.632988	-123.5677
Mainstem Umpqua River	66	43.409571	-123.5663
Mainstem Umpqua River	68	43.446593	-123.5411
Mainstem Umpqua River	96	43.662029	-123.7011
Mainstem Umpqua River	64	43.405077	-123.5342
Mainstem Umpqua River	75	43.641976	-123.6513
Mainstem Umpqua River	63	43.363797	-123.4671
Mainstem Umpqua River	57	43.182408	-123.3730
Mainstem Umpqua River	67	43.436344	-123.5671
Mainstem Umpqua River	140	43.676879	-123.9307
Mainstem Umpqua River	54	42.972635	-123.3466
Mainstem Umpqua River	55	43.132987	-123.3977
North Umpqua River	201	43.315000	-123.2150
North Umpqua River	202	43.343333	-122.7550
North Umpqua River	203	43.285000	-123.3900
North Umpqua River	204	43.268333	-123.4433
North Umpqua River	205	43.283333	-123.3667

Appendix 2. Downstream site coordinates (NAD83), site name, and sampling order within strata for 100 Exploratory Sites per sampling strata. Site coordinates were selected using a generalized random-tessellation stratified design (Stevens and Olsen 2004).

Sampling strata	Sampling order	Site name	Latitude	Longitude
Smith River	1	SM-001	43.721444	-124.08051
Smith River	2	SM-002	43.768474	-124.00213
Smith River	3	SM-003	43.877991	-123.89421
Smith River	4	SM-004	43.875493	-123.83201
Smith River	5	SM-005	43.768079	-123.90434
Smith River	6	SM-006	43.749196	-124.02675
Smith River	7	SM-007	43.854776	-123.72691
Smith River	8	SM-008	43.880488	-123.84940
Smith River	9	SM-009	43.752177	-123.88274
Smith River	10	SM-010	43.801413	-123.93463
Smith River	11	SM-011	43.802351	-123.79474
Smith River	12	SM-012	43.798120	-123.81126
Smith River	13	SM-013	43.780839	-123.93433
Smith River	14	SM-014	43.829945	-123.91977
Smith River	15	SM-015	43.843525	-123.74026
Smith River	16	SM-016	43.818401	-123.67799
Smith River	17	SM-017	43.734860	-124.08078
Smith River	18	SM-018	43.765651	-123.99398
Smith River	19	SM-019	43.879446	-123.90941
Smith River	20	SM-020	43.876885	-123.82775
Smith River	21	SM-021	43.758877	-123.89786
Smith River	22	SM-022	43.740299	-124.03887
Smith River	23	SM-023	43.795282	-123.76632
Smith River	24	SM-024	43.873567	-123.85882
Smith River	25	SM-025	43.780362	-123.94958
Smith River	26	SM-026	43.788356	-123.95715
Smith River	27	SM-027	43.847516	-123.72380
Smith River	28	SM-028	43.792880	-123.83999
Smith River	29	SM-029	43.773690	-123.98660
Smith River	30	SM-030	43.841550	-123.91825
Smith River	31	SM-031	43.827315	-123.76519
Smith River	32	SM-032	43.810274	-123.70663
Smith River	33	SM-033	43.782835	-123.89089
Smith River	34	SM-034	43.725297	-124.01855
Smith River	35	SM-035	43.852749	-123.91747
Smith River	36	SM-036	43.891654	-123.83280
Smith River	37	SM-037	43.782885	-123.91341
Smith River	38	SM-038	43.778978	-123.76784
Smith River	39	SM-039	43.807419	-123.77140
Smith River	40	SM-040	43.878276	-123.86558
Smith River	41	SM-041	43.777537	-123.96572
Smith River	42	SM-042	43.804475	-123.93308
Smith River	43	SM-043	43.842690	-123.73120
Smith River	44	SM-044	43.796416	-123.51349
Smith River	45	SM-045	43.781616	-123.98169
Smith River	46	SM-046	43.803301	-123.97858
Smith River	47	SM-047	43.801910	-123.72068
Smith River	48	SM-048	43.825803	-123.68455
Smith River	49	SM-049	43.781322	-123.89716
Smith River	50	SM-050	43.735819	-124.04412

Appendix 2. Continued on next page.

Appendix 2. Continued from previous page.

Sampling strata	Sampling order	Site name	Latitude	Longitude
Smith River	51	SM-051	43.852170	-123.91099
Smith River	52	SM-052	43.901512	-123.83197
Smith River	53	SM-053	43.783617	-123.92138
Smith River	54	SM-054	43.787784	-123.83638
Smith River	55	SM-055	43.810543	-123.77429
Smith River	56	SM-056	43.789514	-123.83584
Smith River	57	SM-057	43.784326	-123.93902
Smith River	58	SM-058	43.796755	-123.88813
Smith River	59	SM-059	43.841224	-123.73795
Smith River	60	SM-060	43.824829	-123.66257
Smith River	61	SM-061	43.772859	-123.99422
Smith River	62	SM-062	43.791126	-124.00757
Smith River	63	SM-063	43.804637	-123.75175
Smith River	64	SM-064	43.826250	-123.69414
Smith River	65	SM-065	43.762109	-123.98599
Smith River	66	SM-066	43.824910	-123.91700
Smith River	67	SM-067	43.832870	-123.75534
Smith River	68	SM-068	43.814284	-123.70177
Smith River	69	SM-069	43.766102	-123.90187
Smith River	70	SM-070	43.788075	-123.77499
Smith River	71	SM-071	43.803070	-123.76133
Smith River	72	SM-072	43.873402	-123.87850
Smith River	73	SM-073	43.771114	-123.93275
Smith River	74	SM-074	43.789069	-123.88900
Smith River	75	SM-075	43.836673	-123.74965
Smith River	76	SM-076	43.832036	-123.66481
Smith River	77	SM-077	43.785965	-123.97730
Smith River	78	SM-078	43.797223	-123.97710
Smith River	79	SM-079	43.803630	-123.72404
Smith River	80	SM-080	43.827398	-123.67620
Smith River	81	SM-081	43.772602	-123.90105
Smith River	82	SM-082	43.733279	-124.03363
Smith River	83	SM-083	43.853392	-123.71765
Smith River	84	SM-084	43.874182	-123.84602
Smith River	85	SM-085	43.772957	-123.92122
Smith River	86	SM-086	43.787619	-123.87178
Smith River	87	SM-087	43.818010	-123.77337
Smith River	88	SM-088	43.793596	-123.81587
Smith River	89	SM-089	43.741701	-123.89169
Smith River	90	SM-090	43.792829	-123.95342
Smith River	91	SM-091	43.795692	-123.77671
Smith River	92	SM-092	43.788374	-123.85984
Smith River	93	SM-093	43.738136	-124.06159
Smith River	94	SM-094	43.756010	-124.01868
Smith River	95	SM-095	43.862799	-123.91122
Smith River	96	SM-096	43.882312	-123.85859
Smith River	97	SM-097	43.771956	-124.00155
Smith River	98	SM-098	43.874681	-123.89510
Smith River	99	SM-099	43.797862	-123.74956
Smith River	100	SM-100	43.774431	-123.46569

Appendix 2. Continued on next page.

Appendix 2. Continued from previous page.

Sampling strata	Sampling order	Site name	Latitude	Longitude
Elk Creek	1	EL-001	43.743950	-123.18279
Elk Creek	2	EL-002	43.683147	-123.38519
Elk Creek	3	EL-003	43.659875	-123.49539
Elk Creek	4	EL-004	43.596253	-123.27529
Elk Creek	5	EL-005	43.724875	-123.22256
Elk Creek	6	EL-006	43.723108	-123.30216
Elk Creek	7	EL-007	43.667367	-123.45346
Elk Creek	8	EL-008	43.616506	-123.21213
Elk Creek	9	EL-009	43.680326	-123.29936
Elk Creek	10	EL-010	43.646192	-123.23601
Elk Creek	11	EL-011	43.669579	-123.51375
Elk Creek	12	EL-012	43.604805	-123.34534
Elk Creek	13	EL-013	43.655642	-123.31597
Elk Creek	14	EL-014	43.649529	-123.20918
Elk Creek	15	EL-015	43.649857	-123.54086
Elk Creek	16	EL-016	43.604161	-123.46541
Elk Creek	17	EL-017	43.731792	-123.20075
Elk Creek	18	EL-018	43.686273	-123.35734
Elk Creek	19	EL-019	43.650442	-123.47600
Elk Creek	20	EL-020	43.592350	-123.26474
Elk Creek	21	EL-021	43.705095	-123.23422
Elk Creek	22	EL-022	43.698177	-123.28370
Elk Creek	23	EL-023	43.667152	-123.49846
Elk Creek	24	EL-024	43.566721	-123.17864
Elk Creek	25	EL-025	43.660983	-123.34816
Elk Creek	26	EL-026	43.653822	-123.23744
Elk Creek	27	EL-027	43.686642	-123.50827
Elk Creek	28	EL-028	43.592657	-123.35599
Elk Creek	29	EL-029	43.624821	-123.28812
Elk Creek	30	EL-030	43.660477	-123.43058
Elk Creek	31	EL-031	43.654634	-123.53977
Elk Creek	32	EL-032	43.597219	-123.45453
Elk Creek	33	EL-033	43.714978	-123.21838
Elk Creek	34	EL-034	43.665382	-123.36912
Elk Creek	35	EL-035	43.694918	-123.48586
Elk Creek	36	EL-036	43.595136	-123.18245
Elk Creek	37	EL-037	43.687350	-123.29800
Elk Creek	38	EL-038	43.702281	-123.24690
Elk Creek	39	EL-039	43.665119	-123.44210
Elk Creek	40	EL-040	43.577549	-123.27817
Elk Creek	41	EL-041	43.659861	-123.39182
Elk Creek	42	EL-042	43.641728	-123.22571
Elk Creek	43	EL-043	43.635165	-123.56447
Elk Creek	44	EL-044	43.596201	-123.36344
Elk Creek	45	EL-045	43.638458	-123.29054
Elk Creek	46	EL-046	43.658549	-123.41702
Elk Creek	47	EL-047	43.657837	-123.50677
Elk Creek	48	EL-048	43.531703	-123.17143
Elk Creek	49	EL-049	43.706083	-123.22858
Elk Creek	50	EL-050	43.717829	-123.29701

Appendix 2. Continued on next page.

Appendix 2. Continued from previous page.

Sampling strata	Sampling order	Site name	Latitude	Longitude
Elk Creek	51	EL-051	43.692734	-123.49675
Elk Creek	52	EL-052	43.595415	-123.19551
Elk Creek	53	EL-053	43.690488	-123.30024
Elk Creek	54	EL-054	43.641709	-123.27972
Elk Creek	55	EL-055	43.664880	-123.39754
Elk Creek	56	EL-056	43.621762	-123.28683
Elk Creek	57	EL-057	43.646707	-123.29867
Elk Creek	58	EL-058	43.640655	-123.21317
Elk Creek	59	EL-059	43.657901	-123.54568
Elk Creek	60	EL-060	43.617444	-123.47854
Elk Creek	61	EL-061	43.667913	-123.36566
Elk Creek	62	EL-062	43.630745	-123.48168
Elk Creek	63	EL-063	43.648405	-123.51307
Elk Creek	64	EL-064	43.596815	-123.17722
Elk Creek	65	EL-065	43.659318	-123.33911
Elk Creek	66	EL-066	43.702114	-123.47051
Elk Creek	67	EL-067	43.643753	-123.53631
Elk Creek	68	EL-068	43.594077	-123.45216
Elk Creek	69	EL-069	43.711424	-123.28549
Elk Creek	70	EL-070	43.696801	-123.28502
Elk Creek	71	EL-071	43.674049	-123.50039
Elk Creek	72	EL-072	43.552053	-123.17972
Elk Creek	73	EL-073	43.656087	-123.37914
Elk Creek	74	EL-074	43.629721	-123.22107
Elk Creek	75	EL-075	43.649824	-123.56364
Elk Creek	76	EL-076	43.540601	-123.18002
Elk Creek	77	EL-077	43.639487	-123.28853
Elk Creek	78	EL-078	43.657137	-123.40438
Elk Creek	79	EL-079	43.647836	-123.51542
Elk Creek	80	EL-080	43.586737	-123.17270
Elk Creek	81	EL-081	43.738723	-123.22503
Elk Creek	82	EL-082	43.719211	-123.30615
Elk Creek	83	EL-083	43.667171	-123.46230
Elk Creek	84	EL-084	43.611834	-123.21031
Elk Creek	85	EL-085	43.667804	-123.31189
Elk Creek	86	EL-086	43.644072	-123.26260
Elk Creek	87	EL-087	43.662694	-123.51416
Elk Creek	88	EL-088	43.592880	-123.37961
Elk Creek	89	EL-089	43.632770	-123.35142
Elk Creek	90	EL-090	43.651079	-123.24868
Elk Creek	91	EL-091	43.674786	-123.51592
Elk Creek	92	EL-092	43.622814	-123.34727
Elk Creek	93	EL-093	43.727435	-123.20402
Elk Creek	94	EL-094	43.679716	-123.38638
Elk Creek	95	EL-095	43.655176	-123.48531
Elk Creek	96	EL-096	43.602147	-123.20817
Elk Creek	97	EL-097	43.680638	-123.35303
Elk Creek	98	EL-098	43.638154	-123.47812
Elk Creek	99	EL-099	43.606884	-123.28229
Elk Creek	100	EL-100	43.582589	-123.17353

Appendix 2. Continued on next page.

Appendix 2. Continued from previous page.

Sampling strata	Sampling order	Site name	Latitude	Longitude
Calapooya Creek-Olalla Creek	1	CO-001	43.051531	-123.54801
Calapooya Creek-Olalla Creek	2	CO-002	43.483296	-123.31386
Calapooya Creek-Olalla Creek	3	CO-003	43.118701	-123.60680
Calapooya Creek-Olalla Creek	4	CO-004	43.409946	-123.20182
Calapooya Creek-Olalla Creek	5	CO-005	43.066831	-123.54672
Calapooya Creek-Olalla Creek	6	CO-006	43.404677	-123.36167
Calapooya Creek-Olalla Creek	7	CO-007	43.173582	-123.53083
Calapooya Creek-Olalla Creek	8	CO-008	43.477643	-123.23601
Calapooya Creek-Olalla Creek	9	CO-009	43.003259	-123.55809
Calapooya Creek-Olalla Creek	10	CO-010	43.413480	-123.35724
Calapooya Creek-Olalla Creek	11	CO-011	43.164576	-123.48442
Calapooya Creek-Olalla Creek	12	CO-012	43.492059	-123.27172
Calapooya Creek-Olalla Creek	13	CO-013	43.384762	-123.39425
Calapooya Creek-Olalla Creek	14	CO-014	43.118100	-123.49626
Calapooya Creek-Olalla Creek	15	CO-015	43.421983	-123.22397
Calapooya Creek-Olalla Creek	16	CO-016	43.426643	-123.12507
Calapooya Creek-Olalla Creek	17	CO-017	43.044760	-123.54307
Calapooya Creek-Olalla Creek	18	CO-018	43.447317	-123.32225
Calapooya Creek-Olalla Creek	19	CO-019	43.112597	-123.58929
Calapooya Creek-Olalla Creek	20	CO-020	43.464178	-123.14458
Calapooya Creek-Olalla Creek	21	CO-021	43.060963	-123.55379
Calapooya Creek-Olalla Creek	22	CO-022	43.403510	-123.36310
Calapooya Creek-Olalla Creek	23	CO-023	43.365533	-123.43749
Calapooya Creek-Olalla Creek	24	CO-024	43.459364	-123.23164
Calapooya Creek-Olalla Creek	25	CO-025	42.998438	-123.56024
Calapooya Creek-Olalla Creek	26	CO-026	43.095397	-123.57897
Calapooya Creek-Olalla Creek	27	CO-027	43.117991	-123.43632
Calapooya Creek-Olalla Creek	28	CO-028	43.399063	-123.16813
Calapooya Creek-Olalla Creek	29	CO-029	43.503742	-123.32133
Calapooya Creek-Olalla Creek	30	CO-030	43.103197	-123.52169
Calapooya Creek-Olalla Creek	31	CO-031	43.435647	-123.23776
Calapooya Creek-Olalla Creek	32	CO-032	43.433814	-123.10793
Calapooya Creek-Olalla Creek	33	CO-033	43.034872	-123.55056
Calapooya Creek-Olalla Creek	34	CO-034	43.441348	-123.31674
Calapooya Creek-Olalla Creek	35	CO-035	43.175473	-123.53605
Calapooya Creek-Olalla Creek	36	CO-036	43.469555	-123.18714
Calapooya Creek-Olalla Creek	37	CO-037	43.072818	-123.53568
Calapooya Creek-Olalla Creek	38	CO-038	43.402720	-123.36691
Calapooya Creek-Olalla Creek	39	CO-039	43.369204	-123.41066
Calapooya Creek-Olalla Creek	40	CO-040	43.450415	-123.22815
Calapooya Creek-Olalla Creek	41	CO-041	43.418673	-123.39151
Calapooya Creek-Olalla Creek	42	CO-042	43.094886	-123.56335
Calapooya Creek-Olalla Creek	43	CO-043	43.143357	-123.47469
Calapooya Creek-Olalla Creek	44	CO-044	43.408155	-123.17840
Calapooya Creek-Olalla Creek	45	CO-045	43.496123	-123.31936
Calapooya Creek-Olalla Creek	46	CO-046	43.157031	-123.49814
Calapooya Creek-Olalla Creek	47	CO-047	43.445595	-123.24307
Calapooya Creek-Olalla Creek	48	CO-048	43.417306	-123.15392
Calapooya Creek-Olalla Creek	49	CO-049	43.047479	-123.56850
Calapooya Creek-Olalla Creek	50	CO-050	43.429172	-123.30451

Appendix 2. Continued on next page.

Appendix 2. Continued from previous page.

Sampling strata	Sampling order	Site name	Latitude	Longitude
Calapooya Creek-Olalla Creek	51	CO-051	43.166140	-123.48858
Calapooya Creek-Olalla Creek	52	CO-052	43.464899	-123.19007
Calapooya Creek-Olalla Creek	53	CO-053	43.074812	-123.60321
Calapooya Creek-Olalla Creek	54	CO-054	43.435273	-123.36422
Calapooya Creek-Olalla Creek	55	CO-055	43.362661	-123.45456
Calapooya Creek-Olalla Creek	56	CO-056	43.481905	-123.27817
Calapooya Creek-Olalla Creek	57	CO-057	43.402237	-123.41587
Calapooya Creek-Olalla Creek	58	CO-058	43.115850	-123.50439
Calapooya Creek-Olalla Creek	59	CO-059	43.146864	-123.47810
Calapooya Creek-Olalla Creek	60	CO-060	43.422886	-123.13449
Calapooya Creek-Olalla Creek	61	CO-061	43.462359	-123.38062
Calapooya Creek-Olalla Creek	62	CO-062	43.133247	-123.50146
Calapooya Creek-Olalla Creek	63	CO-063	43.438395	-123.28190
Calapooya Creek-Olalla Creek	64	CO-064	43.451880	-123.08065
Calapooya Creek-Olalla Creek	65	CO-065	43.490321	-123.31502
Calapooya Creek-Olalla Creek	66	CO-066	43.098364	-123.52031
Calapooya Creek-Olalla Creek	67	CO-067	43.414791	-123.21434
Calapooya Creek-Olalla Creek	68	CO-068	43.424286	-123.11563
Calapooya Creek-Olalla Creek	69	CO-069	43.088786	-123.57118
Calapooya Creek-Olalla Creek	70	CO-070	43.402525	-123.37407
Calapooya Creek-Olalla Creek	71	CO-071	43.366905	-123.40704
Calapooya Creek-Olalla Creek	72	CO-072	43.448990	-123.23256
Calapooya Creek-Olalla Creek	73	CO-073	43.397498	-123.40701
Calapooya Creek-Olalla Creek	74	CO-074	43.102296	-123.54570
Calapooya Creek-Olalla Creek	75	CO-075	43.159771	-123.48240
Calapooya Creek-Olalla Creek	76	CO-076	43.420871	-123.14404
Calapooya Creek-Olalla Creek	77	CO-077	43.450748	-123.37059
Calapooya Creek-Olalla Creek	78	CO-078	43.150146	-123.49964
Calapooya Creek-Olalla Creek	79	CO-079	43.443092	-123.25507
Calapooya Creek-Olalla Creek	80	CO-080	43.466184	-123.07517
Calapooya Creek-Olalla Creek	81	CO-081	43.079804	-123.52550
Calapooya Creek-Olalla Creek	82	CO-082	43.416360	-123.32790
Calapooya Creek-Olalla Creek	83	CO-083	43.165727	-123.51305
Calapooya Creek-Olalla Creek	84	CO-084	43.461426	-123.20079
Calapooya Creek-Olalla Creek	85	CO-085	43.076129	-123.59173
Calapooya Creek-Olalla Creek	86	CO-086	43.447187	-123.37018
Calapooya Creek-Olalla Creek	87	CO-087	43.365984	-123.45063
Calapooya Creek-Olalla Creek	88	CO-088	43.456566	-123.27835
Calapooya Creek-Olalla Creek	89	CO-089	43.016908	-123.54923
Calapooya Creek-Olalla Creek	90	CO-090	43.428909	-123.36050
Calapooya Creek-Olalla Creek	91	CO-091	43.118527	-123.44530
Calapooya Creek-Olalla Creek	92	CO-092	43.408981	-123.16506
Calapooya Creek-Olalla Creek	93	CO-093	43.018672	-123.54876
Calapooya Creek-Olalla Creek	94	CO-094	43.432496	-123.30636
Calapooya Creek-Olalla Creek	95	CO-095	43.186538	-123.55024
Calapooya Creek-Olalla Creek	96	CO-096	43.469954	-123.16819
Calapooya Creek-Olalla Creek	97	CO-097	43.454314	-123.32450
Calapooya Creek-Olalla Creek	98	CO-098	43.100718	-123.58447
Calapooya Creek-Olalla Creek	99	CO-099	43.440591	-123.28845
Calapooya Creek-Olalla Creek	100	CO-100	43.448287	-123.08071

Appendix 2. Continued on next page.

Appendix 2. Continued from previous page.

Sampling strata	Sampling order	Site name	Latitude	Longitude
Cow Creek-South Umpqua River	1	CS-001	42.754595	-123.36457
Cow Creek-South Umpqua River	2	CS-002	42.932367	-123.12771
Cow Creek-South Umpqua River	3	CS-003	42.925139	-123.41512
Cow Creek-South Umpqua River	4	CS-004	42.848135	-122.85476
Cow Creek-South Umpqua River	5	CS-005	42.742160	-123.41793
Cow Creek-South Umpqua River	6	CS-006	42.927850	-122.95003
Cow Creek-South Umpqua River	7	CS-007	42.844345	-123.74968
Cow Creek-South Umpqua River	8	CS-008	43.069004	-122.66439
Cow Creek-South Umpqua River	9	CS-009	42.836400	-123.50698
Cow Creek-South Umpqua River	10	CS-010	42.947358	-123.32389
Cow Creek-South Umpqua River	11	CS-011	42.779787	-123.57500
Cow Creek-South Umpqua River	12	CS-012	42.965330	-122.88559
Cow Creek-South Umpqua River	13	CS-013	42.983945	-123.11319
Cow Creek-South Umpqua River	14	CS-014	42.902707	-123.25135
Cow Creek-South Umpqua River	15	CS-015	42.808483	-123.66200
Cow Creek-South Umpqua River	16	CS-016	43.041004	-122.78764
Cow Creek-South Umpqua River	17	CS-017	42.757057	-123.36118
Cow Creek-South Umpqua River	18	CS-018	42.940054	-123.12997
Cow Creek-South Umpqua River	19	CS-019	42.935090	-123.38707
Cow Creek-South Umpqua River	20	CS-020	43.059341	-122.71580
Cow Creek-South Umpqua River	21	CS-021	42.739636	-123.40273
Cow Creek-South Umpqua River	22	CS-022	42.928997	-122.98043
Cow Creek-South Umpqua River	23	CS-023	42.824102	-123.57266
Cow Creek-South Umpqua River	24	CS-024	43.097019	-122.75211
Cow Creek-South Umpqua River	25	CS-025	42.818035	-123.05933
Cow Creek-South Umpqua River	26	CS-026	42.950534	-123.30234
Cow Creek-South Umpqua River	27	CS-027	42.836006	-123.54013
Cow Creek-South Umpqua River	28	CS-028	43.003085	-122.83496
Cow Creek-South Umpqua River	29	CS-029	42.968989	-123.22357
Cow Creek-South Umpqua River	30	CS-030	42.939858	-123.26525
Cow Creek-South Umpqua River	31	CS-031	42.801584	-123.62048
Cow Creek-South Umpqua River	32	CS-032	43.008554	-122.82776
Cow Creek-South Umpqua River	33	CS-033	42.741024	-123.48661
Cow Creek-South Umpqua River	34	CS-034	42.939401	-123.03187
Cow Creek-South Umpqua River	35	CS-035	42.898630	-123.54341
Cow Creek-South Umpqua River	36	CS-036	43.040821	-122.75612
Cow Creek-South Umpqua River	37	CS-037	42.744062	-123.43140
Cow Creek-South Umpqua River	38	CS-038	42.902151	-122.93061
Cow Creek-South Umpqua River	39	CS-039	42.786481	-123.58231
Cow Creek-South Umpqua River	40	CS-040	42.960836	-122.85569
Cow Creek-South Umpqua River	41	CS-041	42.889689	-122.91904
Cow Creek-South Umpqua River	42	CS-042	42.960578	-123.23239
Cow Creek-South Umpqua River	43	CS-043	42.888765	-123.53860
Cow Creek-South Umpqua River	44	CS-044	42.956013	-122.83396
Cow Creek-South Umpqua River	45	CS-045	42.975017	-123.19651
Cow Creek-South Umpqua River	46	CS-046	42.919231	-123.47418
Cow Creek-South Umpqua River	47	CS-047	42.823379	-123.61996
Cow Creek-South Umpqua River	48	CS-048	43.029253	-122.81263
Cow Creek-South Umpqua River	49	CS-049	42.743866	-123.46014
Cow Creek-South Umpqua River	50	CS-050	42.938700	-122.99937

Appendix 2. Continued on next page.

Appendix 2. Continued from previous page.

Sampling strata	Sampling order	Site name	Latitude	Longitude
Cow Creek-South Umpqua River	51	CS-051	42.826092	-123.71286
Cow Creek-South Umpqua River	52	CS-052	43.084565	-122.63267
Cow Creek-South Umpqua River	53	CS-053	42.750452	-123.44462
Cow Creek-South Umpqua River	54	CS-054	42.952725	-123.32158
Cow Creek-South Umpqua River	55	CS-055	42.815056	-123.60721
Cow Creek-South Umpqua River	56	CS-056	42.985135	-122.85671
Cow Creek-South Umpqua River	57	CS-057	42.993869	-123.08522
Cow Creek-South Umpqua River	58	CS-058	42.929839	-123.27842
Cow Creek-South Umpqua River	59	CS-059	42.880396	-123.56249
Cow Creek-South Umpqua River	60	CS-060	43.065858	-122.77862
Cow Creek-South Umpqua River	61	CS-061	42.934382	-123.07192
Cow Creek-South Umpqua River	62	CS-062	42.893007	-123.53411
Cow Creek-South Umpqua River	63	CS-063	42.773512	-123.55741
Cow Creek-South Umpqua River	64	CS-064	42.964207	-122.71516
Cow Creek-South Umpqua River	65	CS-065	42.947899	-123.16962
Cow Creek-South Umpqua River	66	CS-066	42.917927	-123.27251
Cow Creek-South Umpqua River	67	CS-067	42.823366	-123.68599
Cow Creek-South Umpqua River	68	CS-068	43.052831	-122.77376
Cow Creek-South Umpqua River	69	CS-069	42.753416	-123.40837
Cow Creek-South Umpqua River	70	CS-070	42.911526	-122.93792
Cow Creek-South Umpqua River	71	CS-071	42.792388	-123.58656
Cow Creek-South Umpqua River	72	CS-072	42.974887	-122.87255
Cow Creek-South Umpqua River	73	CS-073	42.990871	-123.09518
Cow Creek-South Umpqua River	74	CS-074	42.941249	-123.27850
Cow Creek-South Umpqua River	75	CS-075	42.872530	-123.57106
Cow Creek-South Umpqua River	76	CS-076	42.957093	-122.78557
Cow Creek-South Umpqua River	77	CS-077	42.970483	-123.16916
Cow Creek-South Umpqua River	78	CS-078	42.924829	-123.49714
Cow Creek-South Umpqua River	79	CS-079	42.773391	-123.55500
Cow Creek-South Umpqua River	80	CS-080	42.988692	-122.66366
Cow Creek-South Umpqua River	81	CS-081	42.738489	-123.50780
Cow Creek-South Umpqua River	82	CS-082	42.942153	-122.93280
Cow Creek-South Umpqua River	83	CS-083	42.845805	-123.75111
Cow Creek-South Umpqua River	84	CS-084	43.082379	-122.64294
Cow Creek-South Umpqua River	85	CS-085	42.844449	-123.46114
Cow Creek-South Umpqua River	86	CS-086	42.942945	-123.32849
Cow Creek-South Umpqua River	87	CS-087	42.807721	-123.60349
Cow Creek-South Umpqua River	88	CS-088	43.000392	-122.84045
Cow Creek-South Umpqua River	89	CS-089	42.824705	-123.07629
Cow Creek-South Umpqua River	90	CS-090	42.941084	-123.36755
Cow Creek-South Umpqua River	91	CS-091	42.850188	-123.61202
Cow Creek-South Umpqua River	92	CS-092	42.954078	-122.90656
Cow Creek-South Umpqua River	93	CS-093	42.750757	-123.52550
Cow Creek-South Umpqua River	94	CS-094	42.934055	-123.03845
Cow Creek-South Umpqua River	95	CS-095	42.923286	-123.43185
Cow Creek-South Umpqua River	96	CS-096	43.054728	-122.72228
Cow Creek-South Umpqua River	97	CS-097	42.940026	-123.10796
Cow Creek-South Umpqua River	98	CS-098	42.906310	-123.52949
Cow Creek-South Umpqua River	99	CS-099	42.882676	-122.90380
Cow Creek-South Umpqua River	100	CS-100	42.962645	-122.75291

Appendix 2. Continued on next page.

Appendix 2. Continued from previous page.

Sampling strata	Sampling order	Site name	Latitude	Longitude
Mainstem Umpqua River	1	MA-001	43.481067	-123.47926
Mainstem Umpqua River	2	MA-002	43.445141	-123.70273
Mainstem Umpqua River	3	MA-003	42.964207	-123.34011
Mainstem Umpqua River	4	MA-004	43.679888	-123.67138
Mainstem Umpqua River	5	MA-005	43.211858	-123.29751
Mainstem Umpqua River	6	MA-006	43.408065	-123.58914
Mainstem Umpqua River	7	MA-007	43.111161	-123.41198
Mainstem Umpqua River	8	MA-008	43.648091	-123.87770
Mainstem Umpqua River	9	MA-009	43.369869	-123.50869
Mainstem Umpqua River	10	MA-010	43.529996	-123.57589
Mainstem Umpqua River	11	MA-011	43.015332	-123.29607
Mainstem Umpqua River	12	MA-012	43.648540	-124.04305
Mainstem Umpqua River	13	MA-013	43.210800	-123.39866
Mainstem Umpqua River	14	MA-014	43.610171	-123.77793
Mainstem Umpqua River	15	MA-015	43.023610	-123.23596
Mainstem Umpqua River	16	MA-016	43.034733	-123.17374
Mainstem Umpqua River	17	MA-017	43.498730	-123.49217
Mainstem Umpqua River	18	MA-018	43.501949	-123.73999
Mainstem Umpqua River	19	MA-019	43.135880	-123.30462
Mainstem Umpqua River	20	MA-020	43.660206	-123.73712
Mainstem Umpqua River	21	MA-021	43.197049	-123.24412
Mainstem Umpqua River	22	MA-022	43.405690	-123.53795
Mainstem Umpqua River	23	MA-023	43.082462	-123.40984
Mainstem Umpqua River	24	MA-024	43.616793	-123.84465
Mainstem Umpqua River	25	MA-025	43.308993	-123.45659
Mainstem Umpqua River	26	MA-026	43.585370	-123.55783
Mainstem Umpqua River	27	MA-027	43.051405	-123.32994
Mainstem Umpqua River	28	MA-028	43.679633	-124.08590
Mainstem Umpqua River	29	MA-029	43.244439	-123.46450
Mainstem Umpqua River	30	MA-030	43.536613	-123.82562
Mainstem Umpqua River	31	MA-031	43.671209	-123.65084
Mainstem Umpqua River	32	MA-032	43.048167	-123.21658
Mainstem Umpqua River	33	MA-033	43.553777	-123.50344
Mainstem Umpqua River	34	MA-034	43.501208	-123.79291
Mainstem Umpqua River	35	MA-035	43.081566	-123.36833
Mainstem Umpqua River	36	MA-036	43.652089	-123.81601
Mainstem Umpqua River	37	MA-037	43.218250	-123.35236
Mainstem Umpqua River	38	MA-038	43.447132	-123.54102
Mainstem Umpqua River	39	MA-039	43.129531	-123.38950
Mainstem Umpqua River	40	MA-040	43.653187	-123.90692
Mainstem Umpqua River	41	MA-041	43.245387	-123.41245
Mainstem Umpqua River	42	MA-042	43.596019	-123.54459
Mainstem Umpqua River	43	MA-043	43.063944	-123.34816
Mainstem Umpqua River	44	MA-044	43.677283	-123.99413
Mainstem Umpqua River	45	MA-045	43.239202	-123.48586
Mainstem Umpqua River	46	MA-046	43.562969	-123.71702
Mainstem Umpqua River	47	MA-047	43.669349	-123.64012
Mainstem Umpqua River	48	MA-048	43.035320	-123.14566
Mainstem Umpqua River	49	MA-049	43.576526	-123.51769
Mainstem Umpqua River	50	MA-050	43.469942	-123.53114

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Appendix 2. Continued from previous page.

Sampling strata	Sampling order	Site name	Latitude	Longitude
Mainstem Umpqua River	51	MA-051	43.168147	-123.24094
Mainstem Umpqua River	52	MA-052	43.616371	-123.82347
Mainstem Umpqua River	53	MA-053	43.191486	-123.36103
Mainstem Umpqua River	54	MA-054	43.614149	-123.60988
Mainstem Umpqua River	55	MA-055	43.162881	-123.39540
Mainstem Umpqua River	56	MA-056	43.670021	-123.92481
Mainstem Umpqua River	57	MA-057	43.265385	-123.44871
Mainstem Umpqua River	58	MA-058	43.612384	-123.81270
Mainstem Umpqua River	59	MA-059	43.041925	-123.23101
Mainstem Umpqua River	60	MA-060	43.211420	-123.21810
Mainstem Umpqua River	61	MA-061	43.387656	-123.53953
Mainstem Umpqua River	62	MA-062	43.596190	-123.73600
Mainstem Umpqua River	63	MA-063	43.620450	-123.57348
Mainstem Umpqua River	64	MA-064	43.077854	-123.19612
Mainstem Umpqua River	65	MA-065	43.231598	-123.47976
Mainstem Umpqua River	66	MA-066	43.527419	-123.82514
Mainstem Umpqua River	67	MA-067	43.022125	-123.29766
Mainstem Umpqua River	68	MA-068	43.025049	-123.21831
Mainstem Umpqua River	69	MA-069	43.209259	-123.32014
Mainstem Umpqua River	70	MA-070	43.437533	-123.56744
Mainstem Umpqua River	71	MA-071	43.081375	-123.41599
Mainstem Umpqua River	72	MA-072	43.656072	-123.85604
Mainstem Umpqua River	73	MA-073	43.259468	-123.42494
Mainstem Umpqua River	74	MA-074	43.510560	-123.74431
Mainstem Umpqua River	75	MA-075	42.999829	-123.30814
Mainstem Umpqua River	76	MA-076	43.744335	-124.14580
Mainstem Umpqua River	77	MA-077	43.343648	-123.58907
Mainstem Umpqua River	78	MA-078	43.603940	-123.74309
Mainstem Umpqua River	79	MA-079	43.638958	-123.66334
Mainstem Umpqua River	80	MA-080	43.042621	-123.06980
Mainstem Umpqua River	81	MA-081	43.579373	-123.52072
Mainstem Umpqua River	82	MA-082	43.446834	-123.60905
Mainstem Umpqua River	83	MA-083	43.109425	-123.43837
Mainstem Umpqua River	84	MA-084	43.624615	-123.86717
Mainstem Umpqua River	85	MA-085	43.370131	-123.47267
Mainstem Umpqua River	86	MA-086	43.525110	-123.53978
Mainstem Umpqua River	87	MA-087	43.163898	-123.41464
Mainstem Umpqua River	88	MA-088	43.666238	-124.09051
Mainstem Umpqua River	89	MA-089	43.375228	-123.50646
Mainstem Umpqua River	90	MA-090	43.540710	-123.53500
Mainstem Umpqua River	91	MA-091	43.032327	-123.32191
Mainstem Umpqua River	92	MA-092	43.687781	-124.07196
Mainstem Umpqua River	93	MA-093	43.562608	-123.52416
Mainstem Umpqua River	94	MA-094	43.478708	-123.73035
Mainstem Umpqua River	95	MA-095	43.168332	-123.36816
Mainstem Umpqua River	96	MA-096	43.665615	-123.69646
Mainstem Umpqua River	97	MA-097	43.358005	-123.58266
Mainstem Umpqua River	98	MA-098	43.614114	-123.84182
Mainstem Umpqua River	99	MA-099	43.671933	-123.62610
Mainstem Umpqua River	100	MA-100	43.078366	-123.19014

Appendix 2. Continued on next page.

Appendix 2. Continued from previous page.

Sampling strata	Sampling order	Site name	Latitude	Longitude
North Umpqua River	1	NU-001	43.289771	-123.32872
North Umpqua River	2	NU-002	43.271723	-123.40722
North Umpqua River	3	NU-003	43.235450	-122.99092
North Umpqua River	4	NU-004	43.383469	-122.94320
North Umpqua River	5	NU-005	43.280714	-123.36320
North Umpqua River	6	NU-006	43.313656	-122.96728
North Umpqua River	7	NU-007	43.245069	-122.88628
North Umpqua River	8	NU-008	43.340588	-122.74684
North Umpqua River	9	NU-009	43.315063	-123.28126
North Umpqua River	10	NU-010	43.297673	-123.10641
North Umpqua River	11	NU-011	43.379917	-123.28356
North Umpqua River	12	NU-012	43.479463	-122.60186
North Umpqua River	13	NU-013	43.307960	-123.21407
North Umpqua River	14	NU-014	43.277384	-123.07804
North Umpqua River	15	NU-015	43.384869	-123.31902
North Umpqua River	16	NU-016	43.381877	-122.62575
North Umpqua River	17	NU-017	43.300726	-123.37922
North Umpqua River	18	NU-018	43.268616	-123.42636
North Umpqua River	19	NU-019	43.232378	-122.96383
North Umpqua River	20	NU-020	43.392088	-122.94135
North Umpqua River	21	NU-021	43.284989	-123.35138
North Umpqua River	22	NU-022	43.321523	-123.04813
North Umpqua River	23	NU-023	43.248574	-122.91562
North Umpqua River	24	NU-024	43.341768	-122.76012
North Umpqua River	25	NU-025	43.301658	-123.26352
North Umpqua River	26	NU-026	43.323163	-123.05248
North Umpqua River	27	NU-027	43.388829	-123.30685
North Umpqua River	28	NU-028	43.486005	-122.60246
North Umpqua River	29	NU-029	43.313693	-123.17105
North Umpqua River	30	NU-030	43.269157	-123.06136
North Umpqua River	31	NU-031	43.336827	-123.32934
North Umpqua River	32	NU-032	43.411332	-122.60948
North Umpqua River	33	NU-033	43.317097	-123.34905
North Umpqua River	34	NU-034	43.252072	-123.02642
North Umpqua River	35	NU-035	43.166601	-123.02956
North Umpqua River	36	NU-036	43.415983	-122.90452
North Umpqua River	37	NU-037	43.296406	-123.29076
North Umpqua River	38	NU-038	43.330426	-123.00166
North Umpqua River	39	NU-039	43.296961	-122.93486
North Umpqua River	40	NU-040	43.355052	-122.70822
North Umpqua River	41	NU-041	43.308490	-123.28187
North Umpqua River	42	NU-042	43.307541	-123.14095
North Umpqua River	43	NU-043	43.383417	-123.30514
North Umpqua River	44	NU-044	43.449011	-122.59156
North Umpqua River	45	NU-045	43.284752	-123.20820
North Umpqua River	46	NU-046	43.239468	-123.01843
North Umpqua River	47	NU-047	43.341228	-123.32635
North Umpqua River	48	NU-048	43.366884	-122.67786
North Umpqua River	49	NU-049	43.315006	-123.36032
North Umpqua River	50	NU-050	43.300714	-122.95115

Appendix 2. Continued on next page.

Appendix 2. Continued from previous page.

Sampling strata	Sampling order	Site name	Latitude	Longitude
North Umpqua River	51	NU-051	43.153110	-123.00547
North Umpqua River	52	NU-052	43.432339	-122.77648
North Umpqua River	53	NU-053	43.303430	-123.30176
North Umpqua River	54	NU-054	43.331915	-123.00263
North Umpqua River	55	NU-055	43.295560	-122.91863
North Umpqua River	56	NU-056	43.384950	-122.76354
North Umpqua River	57	NU-057	43.298102	-123.22169
North Umpqua River	58	NU-058	43.271373	-123.05522
North Umpqua River	59	NU-059	43.386522	-123.31815
North Umpqua River	60	NU-060	43.442909	-122.58712
North Umpqua River	61	NU-061	43.284019	-123.24454
North Umpqua River	62	NU-062	43.224212	-123.01966
North Umpqua River	63	NU-063	43.363214	-122.97894
North Umpqua River	64	NU-064	43.372886	-122.66252
North Umpqua River	65	NU-065	43.312305	-123.19882
North Umpqua River	66	NU-066	43.283919	-123.09006
North Umpqua River	67	NU-067	43.370172	-123.32810
North Umpqua River	68	NU-068	43.391733	-122.61342
North Umpqua River	69	NU-069	43.331509	-123.33777
North Umpqua River	70	NU-070	43.328354	-123.01446
North Umpqua River	71	NU-071	43.245327	-122.92846
North Umpqua River	72	NU-072	43.350604	-122.73413
North Umpqua River	73	NU-073	43.317475	-123.22137
North Umpqua River	74	NU-074	43.307734	-123.13357
North Umpqua River	75	NU-075	43.393622	-123.28451
North Umpqua River	76	NU-076	43.422931	-122.60155
North Umpqua River	77	NU-077	43.279214	-123.20361
North Umpqua River	78	NU-078	43.237772	-123.01190
North Umpqua River	79	NU-079	43.371326	-122.95917
North Umpqua River	80	NU-080	43.356566	-122.69654
North Umpqua River	81	NU-081	43.283855	-123.39072
North Umpqua River	82	NU-082	43.306846	-122.96105
North Umpqua River	83	NU-083	43.234262	-122.87471
North Umpqua River	84	NU-084	43.379229	-122.76140
North Umpqua River	85	NU-085	43.294008	-123.32709
North Umpqua River	86	NU-086	43.291744	-123.10108
North Umpqua River	87	NU-087	43.295572	-122.89500
North Umpqua River	88	NU-088	43.422466	-122.90635
North Umpqua River	89	NU-089	43.318571	-123.25834
North Umpqua River	90	NU-090	43.308697	-123.08790
North Umpqua River	91	NU-091	43.391484	-123.24563
North Umpqua River	92	NU-092	43.491684	-122.60064
North Umpqua River	93	NU-093	43.302413	-123.37565
North Umpqua River	94	NU-094	43.268344	-123.04375
North Umpqua River	95	NU-095	43.235073	-122.94496
North Umpqua River	96	NU-096	43.405052	-122.91352
North Umpqua River	97	NU-097	43.285566	-123.25844
North Umpqua River	98	NU-098	43.214074	-123.01938
North Umpqua River	99	NU-099	43.354867	-122.98483
North Umpqua River	100	NU-100	43.374231	-122.64519

Appendix 3. Example survey form used for conducting surveys for Umpqua Chub and Smallmouth Bass using double-pass snorkeling for multistate occupancy models. The survey form should have a space on its back for sketching a map of the sample site.

Umpqua Chub Survey Form

Date:_____

Stream:_____ Site #:_____ Crew:_____

Access:_____ Water Temp (°C) Start:_____ End:_____

Sampling Pass #:_____

	Observer 1	Observer 2
Time	Start:_____	Start:_____
	End:_____	End:_____

Photo #/Time:_____
(Hddd.ddddd; WGS84)

downstream (start):_____ upstream (end):_____

Length (m):_____ Width (m):_____ Gear Type: Snorkel Minnow Trap Efish

Secchi Distance (m)_____

	Left Bank	Right Bank
Observer Name	1	2
Chub #		
Bass#		

%Substrate Composition for **Site** = **100%**

	Sand	Gravel	Cobble	Boulder	Bedrock	Wood
LB						
RB						

%Cover for **Site**

	Vegetation in water within 5m (up to 100%)	Algae on substrate up to 100%	Over hanging Vegetation Cover up to 100%	Riparian Vegetation Old Growth (OG); Timber Plantation (TP); Hardwood (H); Shrub (S); Open Agricultural (OA); Agricultural w/ narrow timbered buffer (AT); Open-Grassland (OG), Urban (U), other (Other)
LB				OG TP H S OA AT OG U Other
RB				OG TP H S OA AT OG U Other

Mussels Present: Yes No Species:_____ Density/m2:_____

Species:_____ Density/m2:_____

Coordinates:_____ Voucher #_____

%Cover Mussel

Observer	Sand	Gravel	Cobble	Boulder	Bedrock	Wood	Vegetation	Algae
1								
2								

Species Observed and Comments _____

Over

4034 Fairview Industrial Drive SE
Salem, OR 97302