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Juvenile Lost River and Shortnose Sucker Year-Class Formation, Survival, and Growth in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California—2018 Monitoring Report

Open-File Report 2020–1064

U.S. Department of the Interior
U.S. Geological Survey

Cover: Juvenile sucker on wet net mesh before release into Upper Klamath Lake, Oregon. Photograph by Ryan J. Bart, U.S. Geological Survey, September 19, 2019.

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Conversion Factors

International System of Units to U.S. Customary Units

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square millimeter (mm^2)	0.00155	square inch (in^2)
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	2.471	acre
hectare (ha)	0.003861	square mile (mi^2)
square hectometer (hm^2)	2.471	acre
square kilometer (km^2)	247.105	acre
	Volume	
liter (L)	1.057	quart (qt)
	Mass	
mg (milligram)	0.00003527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as: °F = (1.8 × °C) + 32

Datum

Vertical coordinate information is referenced to the Bureau of Reclamation Vertical Datum.
Elevation, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Note to USGS users: Use of hectare (ha) as an alternative name for square hectometer (hm^2) is restricted to the measurement of small land or water areas.

Abbreviations

CPUE	catch per unit effort
DNA	deoxyribonucleic acid
SL	standard length
FWS	U.S. Fish and Wildlife Service
Reclamation	Bureau of Reclamation
MCMC	Markov chain Monte Carlo
SNPs	single nucleotide polymorphisms
PIT	passive integrated transponder
TNC	The Nature Conservancy
SARP	Sucker Assisted Rearing Program
CL	Clear Lake
UKL	Upper Klamath Lake

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Executive Summary

Populations of federally endangered Lost River (*Deltistes luxatus*) and shortnose suckers (*Chasmistes brevirostris*) in Upper Klamath Lake, Oregon, and Clear Lake Reservoir (hereinafter Clear Lake), California, are experiencing long-term decreases in abundance. Upper Klamath Lake populations are decreasing not only because of adult mortality, which is relatively low, but also because they are not being balanced by recruitment of young adult suckers into known adult spawning aggregations.

Long-term monitoring of juvenile sucker populations is conducted to (1) determine if there are annual and species-specific differences in production, survival, and growth; (2) better understand when juvenile sucker mortality is greatest, and (3) help identify potential causes of high juvenile sucker mortality, particularly in Upper Klamath Lake. The U.S. Geological Survey monitoring program, which began in 2015, tracks cohorts through summer months and among years in Upper Klamath and Clear Lakes. Data on juvenile suckers captured in trap nets are used to provide information on annual variability in age-0 sucker apparent production, juvenile sucker apparent survival, apparent growth, species composition, and health.

Juvenile sucker year-class strength and apparent survival were low in 2018 in Upper Klamath Lake. Most juvenile sucker mortality occurs within the first year of life. The Upper Klamath Lake year-class strength indices for Lost River and shortnose suckers in 2018 were the lowest they had been since the start of monitoring in 2015. The annual catch rates of shortnose sucker remained consistently low, whereas Lost River sucker catch rates varied. The capture of only four age-1 and older suckers from Upper Klamath Lake during the 2018 sampling season indicated low annual survival of the 2017 cohort.

Annual production indices of juvenile suckers in Clear Lake are highly variable and potentially affected by seasonal connections to spawning habitat in Willow Creek. A total of seven age-0 shortnose or Klamath largescale suckers (*Catostomus snyderi)* were captured from Clear Lake in 2018, which was a relatively wet year, indicating that a small cohort was formed or that there was a delay in the recruitment of age-0 suckers. The 2018 sampling continued to detect recruitment of juveniles from the 2015 cohort to the lake. Given the dysconnectivity between Willow Creek and Clear Lake during the 2015 spawning season, the continued recruitment of young fish of this cohort to the lake may be attributed to reproduction by resident suckers in Willow Creek. Suckers younger than age-3 in Clear Lake could be identified as either shortnose or Klamath largescale suckers. A stream resident life history, if it were occurring, is consistent with these fish being Klamath largescale suckers. Survival of all distinguishable taxa of juvenile suckers is much higher in Clear Lake than in Upper Klamath Lake, with non-trivial numbers of suckers surviving to join spawning aggregations.

Background

Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*) are jointly listed as endangered under the Endangered Species Act (U.S. Fish and Wildlife Service, 1988). Two of the remaining spawning populations of both Lost River sucker and shortnose sucker exist in Upper Klamath Lake (Klamath County, Oregon) and Clear Lake Reservoir (hereinafter Clear Lake; Modoc County, California) (U.S. Fish and Wildlife Service, 2013). The persistence of Upper Klamath Lake Lost River and shortnose sucker populations are threatened by a prolonged lack of recruitment into adult spawning aggregations (National Research Council, 2004; U.S. Fish and Wildlife Service, 2013). In fact, the last cohorts to join the current spawning population in Upper Klamath Lake were spawned in the early 1990s. The role of recruitment limitation to Clear Lake populations remains uncertain because year-classes seem to recruit intermittently but not infrequently (Hewitt and Hayes, 2013). In Upper Klamath Lake, decreasing catch rates of age-0 juvenile suckers during August and September in most years and a lack of age-1 or older juvenile sucker catches indicate that the lack of recruitment is due to high mortality within the first year or two of life (Burdick and Martin, 2017). In contrast, a more diverse age distribution of juvenile suckers has been documented in Clear Lake, indicating that juvenile sucker survival may be greater in Clear Lake compared to Upper Klamath Lake (Burdick, Hewitt, and others, 2015).

Recovery of Lost River and shortnose sucker populations requires increasing the number of suckers surviving to maturity. A long-term monitoring program exists for adult suckers at spawning areas aimed at tracking recruitment into the spawning populations in Upper Klamath Lake and Clear Lake (Hewitt and others, 2015). This adult sucker monitoring program has not detected substantial recruitment into spawning populations, as would be expected 4–7 years after suckers hatch. Relatively strong cohorts of age-0 suckers were detected in Upper Klamath Lake in 2006 and 2011, but substantial numbers of individuals from these cohorts did not seem to persist past age-2 (Simon and others, 2013; Burdick and Martin, 2017).

Hypothesized causes of juvenile sucker mortality include loss of habitat, poor water quality, disease, parasites, and predation (mostly by birds) (Perkins and others, 2000; Rasmussen, 2011). However, causes of high apparent juvenile mortality are unknown. To help determine the causes and timing of juvenile sucker mortality and to monitor the long-term success of recovery actions, the U.S. Fish and Wildlife Service (FWS) prioritized the assessment and monitoring of juvenile sucker populations in Upper Klamath Lake and Clear Lake (U.S. Fish and Wildlife Service, 2013; recovery actions 6.1 and 6.2).

Over the last two decades, research and monitoring data have been collected on juvenile Lost River and shortnose suckers in Upper Klamath Lake. Juvenile suckers in Upper Klamath Lake were consistently monitored by Simon and others (2013) from 1997 to 2012. The U.S. Geological Survey (USGS) conducted various research projects from 2001 to 2010 and from 2012 to 2015 with the objectives of understanding habitat use, distribution, and health of age-0 and age-1 juvenile suckers. Simon and others (2013) sampled with beach seines, cast nets, and trawls using a consistent study design among years but captured small numbers of suckers relative to USGS, who sampled with trap nets. Locations and sampling gears used were inconsistent across USGS research projects, making these data undesirable for monitoring long-term trends (Burdick and Martin, 2017). Nevertheless, USGS analyzed data from their projects across their 15-year period of record to identify patterns in recruitment, survival, and growth of age-0 suckers in Upper Klamath Lake (Burdick and Martin, 2017). The Simon and others (2013) dataset indicated that the strongest year-classes for both species within the 16 years of their record probably occurred prior to 2001, and in 2011 (Simon and others, 2013). Relatively strong cohorts for both species also were produced in 2006 (Simon and others, 2013; Burdick and Martin, 2017). Because sampling conducted by Simon and others (2013) and USGS occurred primarily in the summer, overwinter and summer-to-fall survival could not be assessed with data collected in either sampling program. USGS also cautioned that inconsistencies among years in the types of gear used, sample locations, and timing of sample collection limited inferences that could be made from their historical data.

The USGS juvenile sucker monitoring program was initiated in 2015 with the intention of generating relative indices of juvenile Lost River and shortnose sucker production, growth, and survival in both Upper Klamath Lake and Clear Lake. This monitoring program aims to track cohorts both within and among years. The sample design used in this monitoring program addresses the issues of inconsistency identified by USGS and uses trap nets, which are more efficient in catching suckers than active sampling gears such as cast nets, seines, and trawls. Data are anticipated to be useful for identification of environmental variables affecting annual production and survival of young suckers. The dataset also will be useful for understanding collective effects of recovery actions on production, survival, and growth of juvenile suckers. Through these monitoring efforts, long-term trends will be identified and assist in the recovery of endemic suckers in the Upper Klamath Basin.

Study Area

Upper Klamath Lake is uniformly shallow, with an average water depth of 2.6 m and a surface area of 305 km^2 at full pool (National Research Council, 2004). A 6.4–9.5-m-deep trench runs along the western shore of the lake. The primary inflows are through the Williamson River on the eastern shore and the smaller Wood River (fig. 1). A small but notable amount of water also upwells through the volcanic soils along the lakeshore as spring inputs and also enters the lake as precipitation. A natural volcanic reef at the outlet of the lake was replaced with a dam in 1921 to provide access to a greater volume of water for agriculture (National Research Council, 2004). The dam allows the lake surface elevation to range from about 1,261.0 m (4,137 ft) to 1,262.8 m (4,143 ft; Bureau of Reclamation vertical datum for the Upper Klamath Basin [U.S. Geological Survey, 2019]). Surface water and groundwater inputs exceed downriver flows from about October to about June each year, causing the lake volume to increase. Agricultural water deliveries, downriver water releases to meet instream flow requirements, and to a lesser extent evaporation, exceed water inputs from around June to October each year causing the lake volume to decrease at a somewhat predictable rate.

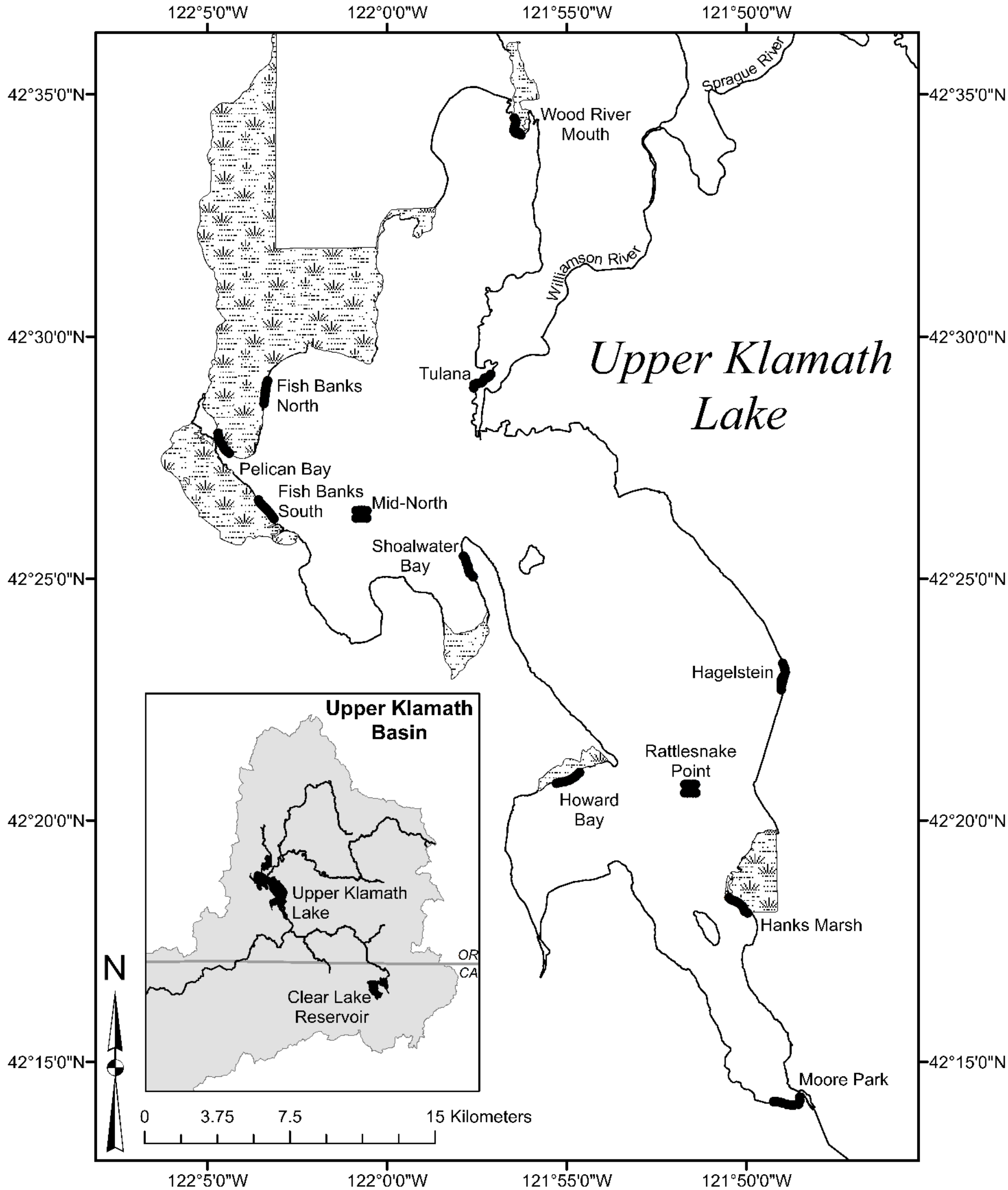

Figure 1. Maps showing locations of sample sites used to capture juvenile suckers in Upper Klamath Lake, Klamath County, Oregon, 2018.

The bottom of Upper Klamath Lake is covered with fine organic detritus composed primarily of decaying diatoms and cyanobacteria. Shoreline wetlands in the northern part of the lake are heavily vegetated with wocus (*Nuphar* sp.), tules (*Schoenoplectus acutus*), and willows (*Salix* spp.). Massive annual blooms of the blue-green cyanobacterium *Aphanizomenon flos-aquae* (AFA) drive summer water-quality dynamics in Upper Klamath Lake (Eldridge, Caldwell Eldridge, and others, 2012). Algal blooms are associated with extremely dynamic dissolved oxygen concentrations that can range from supersaturation to anoxia within diel cycles. Extreme summer water-quality conditions can be as follows: water temperatures greater than 24 °C, dissolved-oxygen less than 2 mg/L, pH greater than or equal to 10, and microcystin toxin concentrations 40–60 parts per billion (Eldridge, Caldwell Eldridge, and others, 2012; Eldridge, Wood, and Echols, 2012).

Clear Lake, located in the upper Lost River watershed, was historically a natural lake covering approximately 6,500 ha (fig. 2). An associated wetland and meadow were located to the east of the lake. The Bureau of Reclamation built a dam on the Lost River near the lake outlet in 1910 to enable better seasonal water regulation. The dam enlarged the lake and inundates the wetland in most years, which expands the lake by about 3,900 ha (Buettner and Scoppettone, 1991). The present-day Clear Lake has two distinct parts that are connected by a wide shallow channel; the shallower former marsh on the eastern side and the deeper historical lake on the western side. Willow Creek, which has the only known spawning area and provides the only substantial inflows, enters into the eastern lobe of the reservoir near the dam. Inflows primarily occur in the winter or spring and the tributaries become intermittent by midsummer. Water is released through the Clear Lake Dam into the Lost River to provide spring and summer irrigation to the Langell Valley in Oregon. At a lake surface elevation of about 1,378.6 m (4,523 ft), the two parts of the lake become disconnected. At lake-surface elevations around 1,378.9 m (4,524 ft), access to Willow Creek is impeded for spawning suckers (National Marine Fisheries Service and U.S. Fish and Wildlife Service, 2013). Water can be delivered downriver below the point of disconnection between the lobes until the lake surface elevation reaches the operational floor at 1,378.3 m (4,522 ft). The eastern lobe almost completely dries out when the lake surface elevation declines to about 1,377.7 m (4,520 ft), which happened in 2014 and 2015. Because of these dynamics, the lake depth can fluctuate by more than 3 m among and within years (Bureau of Reclamation, 2019).

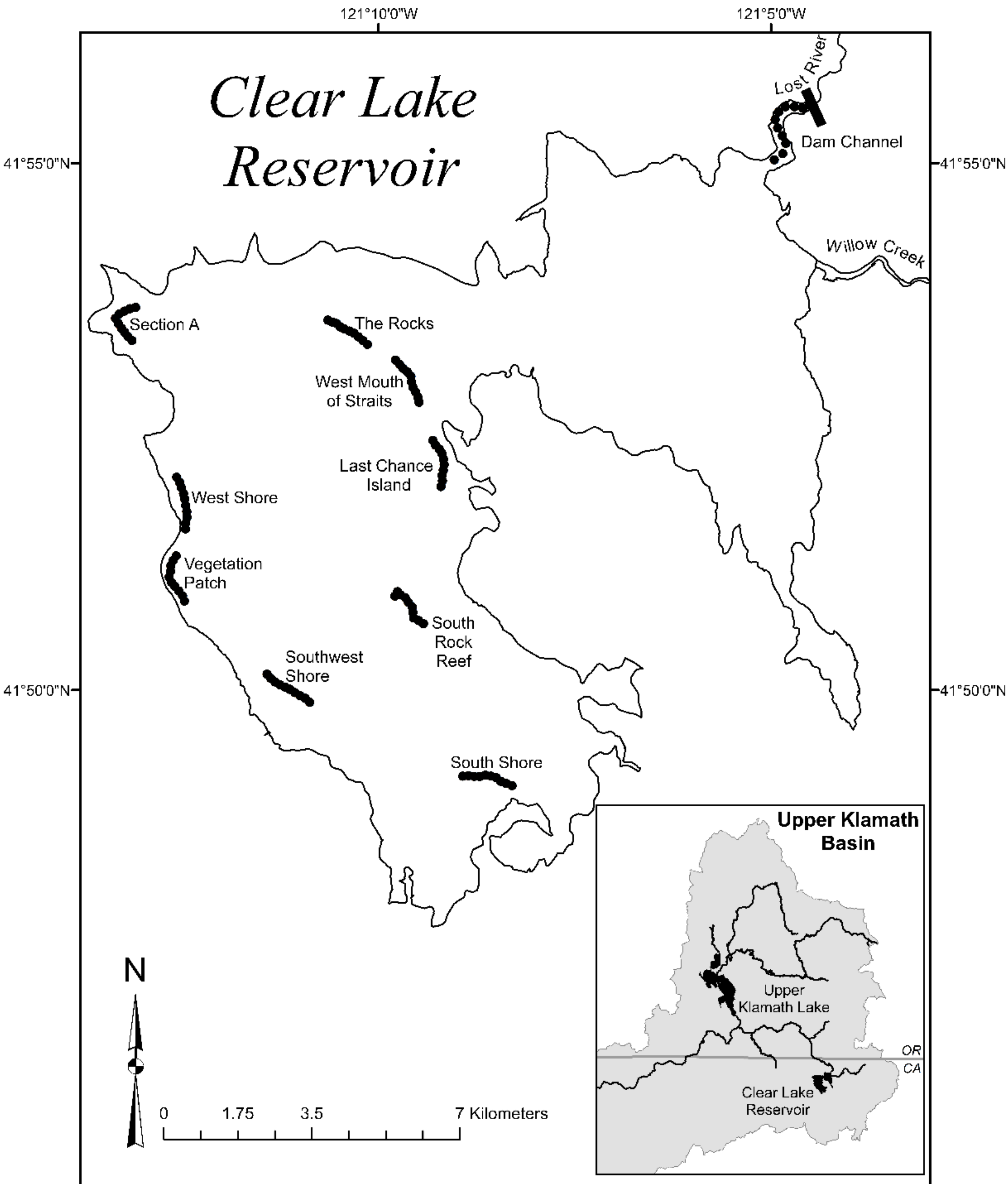

Figure 2. Maps showing locations of sample sites used to capture juvenile suckers in Clear Lake Reservoir, Modoc County, California, 2018.

Clear Lake is in the FWS Clear Lake National Wildlife Refuge, and the upper watershed is almost entirely located within the U.S. Forest Service Modoc and Fremont National Forests. The area around the lake is rocky with sagebrush (*Artemesia* sp.) steppe plant communities and western juniper (*Juniperus occidentalis*), whereas the upper watershed is a ponderosa pine (*Pinus ponderosa*) forest (Buettner and Scoppettone, 1991). The bottom of Clear Lake is covered with claylike sediment and occasional large lava rocks. The lake is turbid, which likely is the result of wind coupled with shallow water and fine sediments. Summer water temperatures have greater diel fluctuations and water quality generally is better than in Upper Klamath Lake, with Clear Lake water temperatures as high as 26 °C, dissolved-oxygen greater than or equal to 5 mg/L, pH around 8.5, and no detectable microcystin toxin (Burdick, Elliott, and others, 2015).

Species

Lost River and shortnose suckers are long-lived lake dwelling catostomids that make springtime spawning migrations to lake shores or tributaries beginning at age 4 through 7 (Hewitt and others, 2015). Upper Klamath Lake populations typically spawn from March to June, whereas Clear Lake populations spawn from February to April (Hewitt and Hayes, 2013; Burdick, Hewitt, and others, 2015). Additionally, Klamath largescale suckers (*Catostomus snyderi),* which are the least lake dependent of the Upper Klamath Basin suckers, also are present in Upper Klamath and Clear Lakes (Moyle, 2002). Spawning migrations start when spawning tributary water temperatures exceed 10 °C in Upper Klamath Lake and approximately 6 °C in Clear Lake. Larvae of Upper Klamath Lake river spawning populations out-migrate at night in May and early June to in-lake rearing habitats within several days of emerging from gravel (Cooperman and Markle, 2003). Clear Lake sucker larvae out-migrate from Willow Creek during April and May (Sutphin and Tyler, 2016). Age-0 juvenile suckers of both taxa are widely distributed throughout Upper Klamath Lake by late July and August and there is no evidence of directed migrations during this time period (Hendrixson and others, 2007; Burdick and others, 2009; Burdick and Hewitt, 2012). Age-1 suckers are much less abundant than age-0 suckers and immature suckers age-2 and older are rarely encountered in Upper Klamath Lake. The oldest Lost River sucker sampled was estimated to be 57 years and the oldest shortnose sucker was estimated to be 33 years (Terwilliger and others, 2010).

Both species historically were abundant enough to support a subsistence fishery; however, decreasing population trends started to become evident by the 1960s (Markle and Cooperman, 2002). Regular recruitment to the spawning populations in Upper Klamath Lake has not been documented since the early 1970s (Scoppettone 1986; Terwilliger and other, 2010). The fishery was eventually closed in 1987 (Janney and others, 2008; Markle and Cooperman, 2002), but poor survival of juvenile suckers persisted in Upper Klamath Lake populations after closure of the fishery. Whereas adult survival typically is high, populations are limited by occasional (sometimes massive) adult fish die-off events and little to no recruitment to the spawning populations (Hewitt and others, 2018).

Methods

Sample Design

We sampled for suckers with trap nets to assess species-specific annual variability in production and growth, and annual seasonal variability in survival of juvenile suckers in Upper Klamath and Clear Lakes. The timing of the sampling periods was chosen based on previous catch data in Upper Klamath Lake. Specifically, we targeted age-1 suckers in early June, the increase of age-0 sucker catches in July, the peak of age-0 sucker catches in August, and the tail end of age-0 sucker catches in September (Burdick and Martin, 2017). A July sampling period was added in July of 2018 to ensure that we did not miss early age-0 suckers. In 2015, sampling was conducted over three 3-week periods simultaneously in Upper Klamath and Clear Lakes. An evaluation of the study design in 2015 indicated that with increased effort concentrated into shorter time periods, we could better describe growth and differences in catch rates between sampling periods. In each sampling month in 2018, sampling events were within 1-week intervals within each lake and lakes were sampled in sequential weeks within each month. Air quality from the 2018 wildfire smoke limited access to Upper Klamath Lake in July and delayed the sampling effort in that month by 1 week compared to timing in previous years.

Given the limitations of our chosen gear type, our analysis of catch data is only relevant to suckers between about 45 and 300 mm standard length (SL). Trap nets likely are size-selective for fish of an intermediate size range, which may have led to underrepresentation of both age-0 less than 45 mm SL and suckers larger than approximately 300 mm SL. Fish small enough to pass through the mesh of our nets, such as small age-0 suckers (less than 45mm SL), have a low catchability in trap nets (Burdick and Martin, 2017). Because adult suckers (greater than 300 mm SL) are captured at high rates in spring and fall trammel net sampling and infrequently in summer trap net sampling, we presume that trap nets select for smaller suckers relative to trammel nets (Hewitt and Hayes, 2013). Burdick and others (2016) did not find a length-based pattern in the proportions of passive integrated transponder- (PIT-) tagged and released suckers that were recaptured, indicating no strong size selectivity within this size range.

To reduce potential sample bias caused by apparently minor spatial heterogeneity in the densities, species, ages, size, or health of suckers, we selected fixed sample sites in a variety of habitats throughout both lakes. Age-0 suckers at least 45 mm SL, the size targeted in our sampling, are not known to be distributed differentially within Upper Klamath Lake based on species or size (Hendrixson and others, 2007; Burdick and Hewitt, 2012). However, age-1 suckers are more likely to be found in shallow (less than 1 m deep) nearshore habitats in the spring and deep water around 2 m deep in the summer (Bottcher and Burdick, 2010). Spatial patterns among age classes of suckers have not been identified in Clear Lake (Burdick and Rasmussen, 2012). Sample areas were either 1-km long sections of shoreline or 300-m^2 offshore areas. Within each area, 10 fixed sites were identified as potentially accessible given a variety of water levels. In 2018, eight sites in each area in Upper Klamath Lake and seven sites in each area in Clear Lake were sampled during each sampling period (tables 1 and 2). To address the concern of inadvertent bias in our fixed-site selection, randomly determined site locations were sampled in 2016 and we found no significant difference between fixed and random sites (Burdick and others, 2016). Therefore, randomly determined sites were excluded from all analyses in this report.

Because of high lake surface elevations in 2018 in Clear Lake, sample sites that were shallow and near shore in 2015 and 2016 often were in more than 3 m of water and far from shore in 2018. Because juvenile sucker catch rates with trap nets decrease at depths greater than 3 m (Burdick and Hewitt, 2012), we decided to change sampling sites slightly in 2018 by going to the 2015 and 2016 locations, then driving directly toward shore from the original site until we were in less than 3 m of water before setting the trap nets.

Table 1. Number of nets fished for juvenile suckers by area and sampling period in Upper Klamath Lake, Oregon, 2018.

Area	Latitude	Longitude	Number of nets set in 2018			
			June 11–15	July 25–August 3	August 13–17	September 10–14
Wood River Mouth	42° 34' 18.84" N	121° 56' 27.44" W	8	8	8	8
Fish Banks North	42° 28' 53.18" N	122° 3' 22.89" W	8	8	8	8
Fish Banks South	42° 26' 25.19" N	122° 3' 20.45" W	8	8	8	8
Pelican Bay	42° 27' 48.44" N	122° 4' 37.62" W	8	8	8	8
Tulana	42° 29' 5.56" N	121° 57' 19.40" W	8	8	0	0
Shoalwater Bay	42° 25' 16.54" N	121° 57' 45.27" W	8	8	8	8
Hagelstein	42° 23' 0.79" N	121° 48' 56.44" W	8	8	8	8
Howard Bay	42° 20' 49.72" N	121° 54' 57.38" W	8	8	8	8
Hanks Marsh	42° 18' 17.85" N	121° 50' 13.72" W	8	8	8	8
Moore Park	42° 14' 6.57" N	121° 48' 46.31" W	8	8	8	8
Mid-North	42° 26' 0.91" N	122° 0' 56.35" W	8	7	8	8
Rattlesnake Point	42° 20' 34.57" N	121° 51' 3.79" W	8	8	8	8
Total nets set			96	95	88	88

Table 2. Number of nets fished for juvenile suckers by area and sampling period in Clear Lake Reservoir, California, 2018.

Area	Latitude	Longitude	Number of nets set in 2018			
			June 4–8	July 16–20	August 6–24	September 17–21
Dam to Willow Creek mouth (Dam Channel)	41° 55' 24.80" N	121° 4' 56.75" W	7	7	7	7
The Rocks	41° 53' 25.75" N	121° 10' 26.15" W	7	7	7	7
West Mouth of Straits	41° 52' 58.76" N	121° 9' 35.24" W	7	7	7	7
Section A	41° 53' 31.72" N	121° 13' 21.14" W	7	7	7	7
West Shore	41° 51' 48.77" N	121° 12' 28.12" W	7	7	7	7
Last Chance Island	41° 52' 11.56" N	121° 9' 10.31" W	7	7	7	7
Vegetation Patch	41° 51' 4.47" N	121° 12' 40.10" W	7	7	7	7
South Rock Reef	41° 50' 47.41" N	121° 9' 34.39" W	7	7	7	7
South Shore	41° 49' 11.02" N	121° 8' 34.03" W	7	7	7	7
Southwest Shore	41° 50' 0.46" N	121° 11' 7.77" W	7	7	7	7
Total nets set			70	70	70	70

Fish Handling and Sampling

Sampling was conducted with rectangular trap nets with mouth dimensions of 0.61×0.91 m, a 10-m-lead, and three internal fykes. Weight, SL, and fork length were recorded for each captured individual. The leading left pectoral fin ray was removed at the proximal joint for aging. Fin rays were not collected from some small suckers (45–60 mm SL) from Upper Klamath Lake because they were presumed to be age-0 fish based on length at date of capture (Burdick and Martin, 2017). We compared the length and number of annuli on fish with fin rays collected to length of suckers without fin rays collected to validate our length-based age assumptions. A small (about 2 mm^2) piece of tissue from the caudal fin was collected for genetic identification to taxa. The numbers of suckers from which age and genetic samples were collected and analyzed are given in table 3. Emaciation, deformities, macro parasites, and petechial skin hemorrhaging were systematically recorded. Other abnormalities and afflictions were noted when they were observed. Suckers were either released at their site of capture or sacrificed for other research.

Table 3. Number of total suckers captured, aged using fin rays, and identified to species using genetics from Clear Lake Reservoir, California, and Upper Klamath Lake, Oregon, 2018**.**

Number of suckers	Clear Lake Reservoir	Upper Klamath Lake
Aged	204	40
Genetic identification	210	38
Total captured	214	40

Aging Juvenile Suckers

To estimate sucker age, fin rays were mounted in epoxy, sectioned, and viewed by two experienced readers under magnification using transmitted light (Quist and others, 2012). The number of annuli was first determined in blind reads, with each reader having no knowledge of the other's annuli count. When both readers agreed on a number of annuli, that number was presumed to be the correct age and was used in analyses. If there was disagreement in the annuli count, the two readers viewed the structure together and came to a consensus or a third reader acted as a tie breaker. All the suckers from Upper Klamath Lake were assigned an age. Five Upper Klamath Lake suckers were assumed to be age-0 because they were less than 60 mm and, therefore, no fin ray was taken. Ten Clear Lake suckers were not aged owing either to no fin ray being collected or the inability to read the fin ray under magnification.

Species Identification

To identify juvenile suckers to taxa, we applied genetic identification methods described by Hoy and Ostberg (2015). Caudal fin tissue was collected and dried from all but 12 juvenile suckers from each lake owing to failure of collection. Deoxyribonucleic acid (DNA) was extracted from the caudal tissues using DNeasy kits (Qiagen, Inc.®, Valencia, California). A total of 18 nuclear DNA TaqMan® assays were used to differentiate the species based on single nucleotide polymorphisms (SNPs) (Hoy and Ostberg, 2015).

We used the program STRUCTURE, version 2.3 (Pritchard and others, 2000; Evanno and others, 2005), to probabilistically assign individual multilocus genotypes to the sampled juvenile suckers based on the posterior distribution of the program output. STRUCTURE uses a Markov chain Monte Carlo (MCMC) simulation approach to identify the posterior probability (q) for the proportion of an individual genotype derived from each of K population clusters. We applied the admixture model with independent allele frequencies, given the high differentiation between Lost River and shortnose suckers. A total of 10 repetitions were run in STRUCTURE, and the model parameters were as follows: (1) markers assumed to be unlinked; (2) 18 nuclear loci; (3) two populations assumed; and (4) 50,000 burn-in steps, followed by 100,000 MCMC iterations. We followed the procedure of Evanno and others (2005) to estimate the most probable number of K population clusters. The most probable number of population clusters was K=2 (that is, Lost River and a combination of indistinguishable shortnose and Klamath largescale suckers). Therefore, admixture proportions between Lost River and non-Lost River suckers were estimated for each individual using the mean posterior probability over the 10 repetitions. For species assignments for Upper Klamath Lake, we categorized suckers having a probability of being Lost River suckers (Prob[LRS]) greater than or equal to (≥) 0.95 Lost River suckers, those with a Prob [LRS] less than or equal to (≤)0.05 non-Lost River suckers, and fish with a Prob[LRS] intermediate of the two values "Intermediate prob[LRS]". We refer to the non-Lost River suckers shortnose suckers in Upper Klamath Lake based on evidence that Klamath largescale suckers are relatively rare in the lake (Burdick and others, 2009). We refer to the non-Lost River suckers in Clear Lake shortnose/Klamath largescale suckers, based on evidence that Klamath largescale suckers comprise most of the suckers in Clear Lake (Smith and others, 2020).

Indices of Juvenile Sucker Year-Class Strength

To describe annual relative (among cohorts, species, and lakes) year-class strength and apparent age-0 sucker production, we calculated (1) the proportion of August nets to catch one or more age-0 sucker (successful age-0 nets), (2) the mean August catch per unit effort (CPUE) for age-0 suckers in successful age-0 nets, and (3) the total August age-0 CPUE as the number of suckers in each taxa divided by the number of nets set.

We assumed that sampling efficiency was similar between years and within year sampling periods. The presence of vegetation, substrate type, and water depth have minor effects on detection probability of juvenile suckers (Burdick and others, 2008). By using the same fixed sites throughout fairly homogenous habitat with little to no vegetation, we ensured that habitat variables were similar at sampled sites between years. Furthermore, water management in Upper Klamath Lake ensures that water depth is similar each August and therefore did not differentially affect capture probability. Water depth decreases at a similar rate in Upper Klamath Lake between the August and September sampling periods and increases again each year. Therefore, a smaller water volume could cause higher fish density and capture probability given the same number of fish. Consequently, September results may indicate higher fish densities and capture probabilities owing to the lower water levels.

Apparent Growth

We examined change in fish length among sampling periods for shortnose/Klamath largescale suckers from the 2016 cohort captured in Clear Lake using a graphical analysis. This analysis is an expansion of the 2016 cohort growth observation from Bart and others (2020) and includes data collected in 2018. Because of low catch rates of all other age classes and taxa in both lakes, there were no other groups of fish with a large enough sample size to warrant an analysis of growth.

Observations on External Afflictions

We summarized the prevalence and intensity of external afflictions on juvenile suckers as a way to roughly compare the apparent health of suckers between years and lakes and potentially identify causes of sucker mortality. We paid special attention to those afflictions that are either common or potentially associated with mortality such as *Lernaea* sp., petechial hemorrhaging, and lamprey wounds (Markle and others, 2014; Burdick, Elliott, and others, 2015). Although deformed opercula were observed in the previous monitoring years, none were observed during this monitoring year; therefore, deformed opercula were not summarized. Afflictions then were quantified and compared to observed afflictions relative to previous years.

Results

Upper Klamath Lake Year-Class Strength and Apparent Survival

Forty suckers were captured in Upper Klamath Lake during the 2018 juvenile monitoring sampling, most of which (90 percent) were age-0 (table 4, fig. 3). Of the 36 age-0 suckers captured in Upper Klamath Lake, 12 were Lost River suckers, 10 were shortnose suckers, 12 were an Intermediate prob[LRS], and 2 had no species identification (table 4, fig. 4). Age-0 suckers from Upper Klamath Lake ranged from 45 to 87 mm SL (fig. 5). Although approximately 2,400 reared juveniles were tagged and released by the FWS in 2018 through SARP (Sucker Assisted Rearing Program), we did not capture any tagged juveniles in Upper Klamath Lake.

Year-class strength varied between species and among years in Upper Klamath Lake. Indices of annual year-class strength, calculated as August CPUE, were largest for the 2016 cohort and smallest for the 2018 cohort, whereas the 2015 and 2017 cohorts were an intermediate between the two (table 5). A greater CPUE in 2016 than other years seemed to be driven by greater catches of Lost River suckers than shortnose suckers, or a combination of the two species (table 5). The cohort strength varied for Lost River suckers and was consistently low for shortnose suckers among years.

Cohort tracking among years indicated that first- and second-year apparent survival of suckers was very low in Upper Klamath Lake, and that no juveniles older than 2 years were captured. The oldest suckers detected during the 2018 sampling period were from the 2016 cohort. These consisted of one shortnose sucker and one Intermediate prob[LRS]. The 2017 cohort was represented by capture of two shortnose suckers (table 6). The 2018 cohort was captured in July and September (table 7). Total numbers of suckers captured in 2017 and 2018 were extremely small, which limits our ability to infer differences in survival rates between cohorts. However, the observation of Upper Klamath Lake catches diminishing to a nearly undetectable abundance by age-1 is an indication of poor survival.

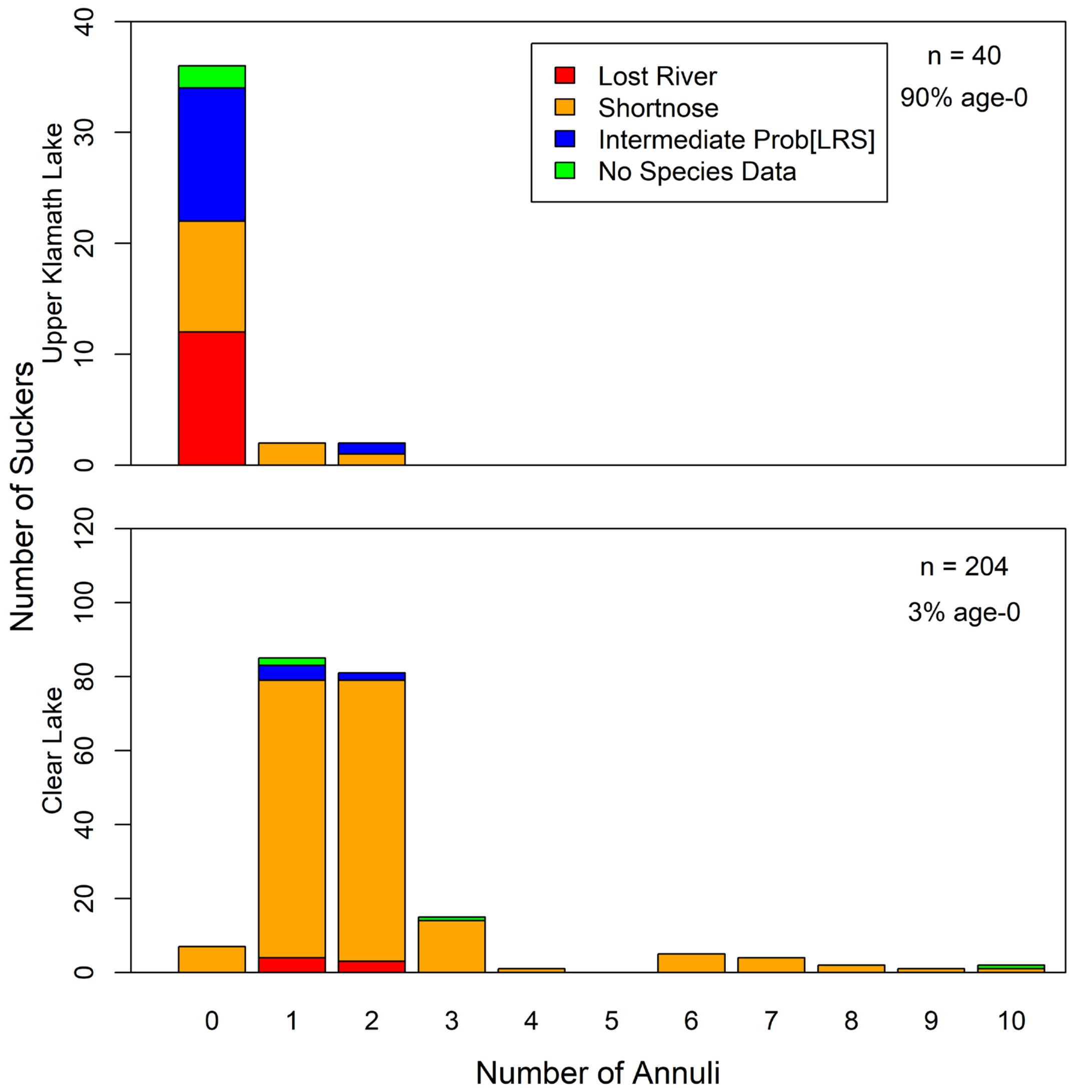

Figure 3. Graphs showing number of annuli on suckers collected from Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2018. Taxa were identified as the probability of STRUCTURE assignment LRS (Prob[LRS]). Fish with Prob[LRS] ≤0.05 are referred to as shortnose suckers, fish with Prob[LRS] ≥0.95 are referred to as Lost River suckers, and fish with 0.05<Prob[LRS] <0.95 are referred to as Intermediate prob[LRS]. Clear Lake shortnose suckers labeled in the graph are shortnose/Klamath largescale suckers. Percentages (%) of the total number (n) of suckers in each graph that had no annuli on fin rays (age-0) are given. ≥, greater than or equal to; <, less than; ≤, less than or equal to.

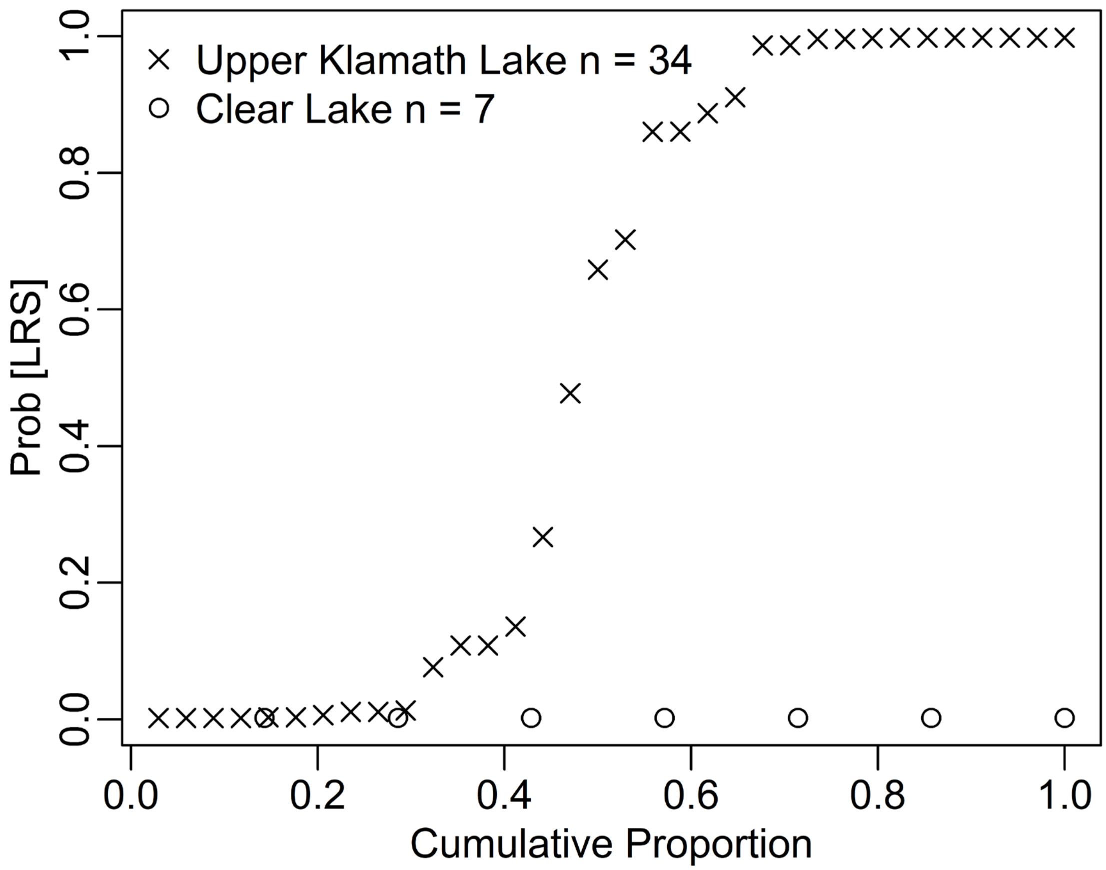

Figure 4. Graph showing probability of taxa assignment as Lost River sucker based on STRUCTURE (Prob [LRS]) at fixed sites in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2018. Numbers of age-0 fish with genetics data from each lake (n) are given**.**

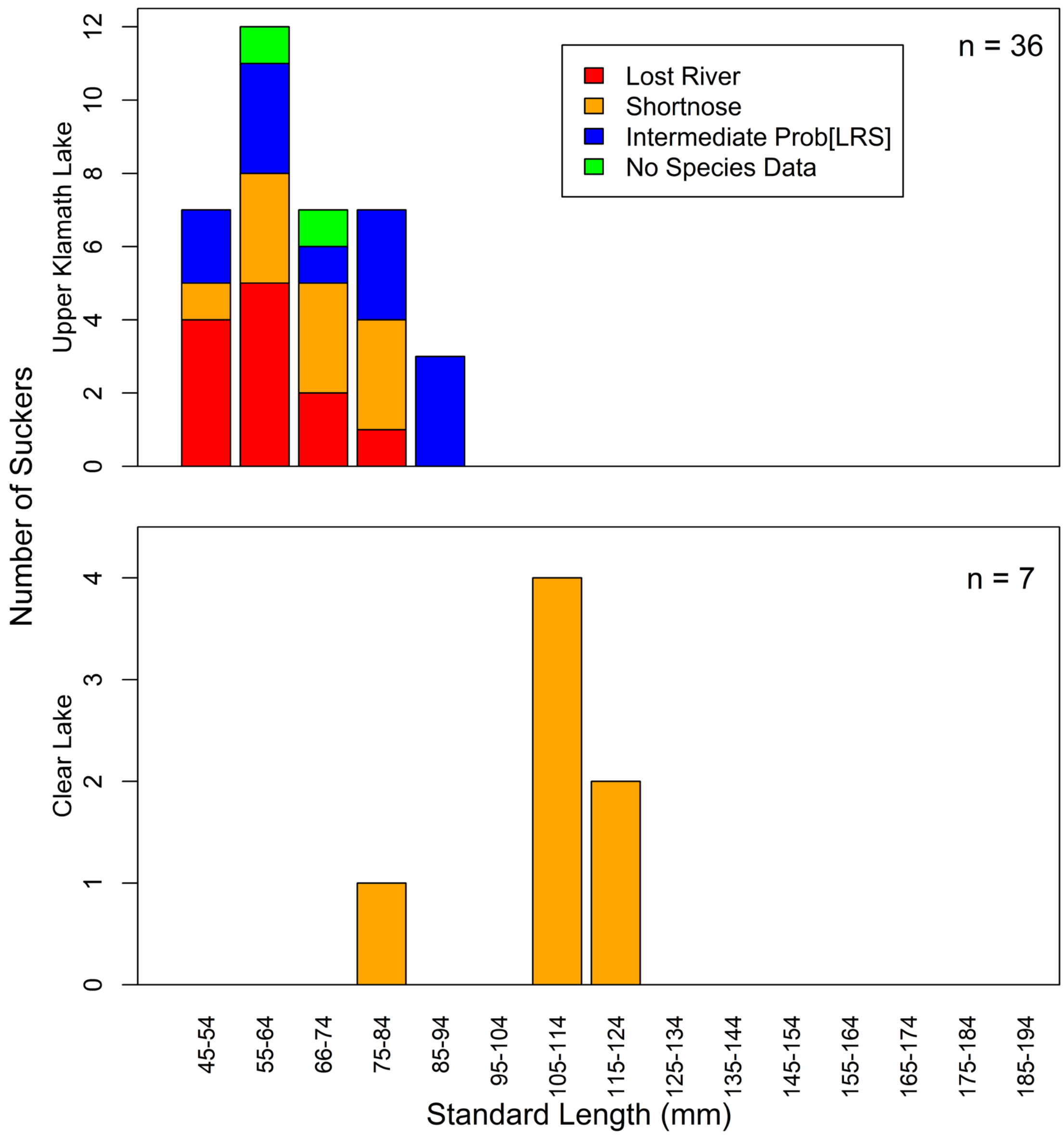

Figure 5. Graphs showing standard lengths of age-0 suckers collected at fixed locations in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2018. Taxa were identified as the probability of STRUCTURE assignment LRS (Prob[LRS]). Fish with Prob[LRS] ≤0.05 are referred to as shortnose suckers, fish with Prob[LRS] ≥0.95 are referred to as Lost River suckers, and fish with 0.05<Prob[LRS] <0.95 are referred to as Intermediate prob[LRS]. Clear Lake shortnose suckers labeled in the graph are shortnose/Klamath largescale suckers. Number of fish in each graph (n) are given. ≥, greater than or equal to; <, less than; ≤, less than or equal to.

Table 4. Catch per net and percentage of age-0 suckers for each taxa captured in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2018.

[Number of total and age-0 suckers captured in each taxa, the catch per net (catch per unit effort, or CPUE), and percentage of each taxa that were age-0 are given. Taxa were identified based on their genetic information from STRUCTURE results. Clear Lake shortnose suckers labeled in the plot are shortnose/Klamath largescale suckers. Intermediate prob[LRS] refers to suckers having a probability of being Lost River suckers intermediate between the values of 0.95 and 0.05]

Taxa	Upper Klamath Lake				Clear Lake			
	Number suckers	Number age-0	Age-0 CPUE	Age-0 (percent)	Number suckers	Number age-0	Age-0 CPUE	Age-0 (percent)
Lost River suckers	12	12	0.03	100	7	0	0.00	0
Shortnose suckers	13	10	0.03	77	197	7	0.03	4
Intermediate prob[LRS]	13	12	0.03	92	6	0	0.00	0
No taxa data	2	2	0.01	100	4	0	0.00	0
All taxa suckers	40	36	0.10	90	214	7	0.03	3

Table 5. Catch statistics for August age-0 suckers from Upper Klamath Lake, Oregon, 2015–18.

[n is the number of suckers. Total capture per unit effort (CPUE) was calculated as the number of fish captured per net set. Intermediate prob[LRS] refers to suckers having a probability of being Lost River suckers intermediate between the values of 0.95 and 0.05]

		August 2015	August 2016	August 2017	August 2018
Number of nets		98	94	96	88
Lost River suckers	n	21	120	7	8
	Total CPUE	0.21	1.28	0.07	0.09
Intermediate prob[LRS]	n	13	59	12	4
	Total CPUE	0.13	0.63	0.13	0.05
Shortnose suckers	n	17	35	14	2
	Total CPUE	0.17	0.37	0.15	0.02
Total suckers	n	51	214	33	14
	Total CPUE	0.52	2.28	0.34	0.16

Table 6. Catch statistics for the 2017 cohort of suckers from Upper Klamath Lake, Oregon.

[Percentage of nets to successfully capture one or more sucker in each taxa, mean and standard deviation (SD) catch per net (catch per unit effort, or CPUE) in nets that successfully captured one or more sucker, and total suckers captured in all nets set (Total CPUE) are given for each seasonal sampling period. Total CPUE was calculated as the number of fish captured per net set. (NA) is used instead of standard deviations that are not applicable due to low sample sizes. Intermediate prob[LRS] refers to suckers having a probability of being Lost River suckers intermediate between the values of 0.95 and 0.05]

		August 7–11, 2017	September 18–22, 2017	June 11–15, 2018	July 25–August 3, 2018	August 6–24, 2018	September 9–14, 2018
Number of nets		96	88	96	87	88	88
Lost River suckers	Percentage	6	1	0	0	0	0
	Mean (SD)	1.16 (0.41)	1.00 (NA)	0.00 (NA)	0.00 (NA)	0.00 (NA)	0.00 (NA)
	Total CPUE	0.07	0.01	0.00	0.00	0.00	0.00
Intermediate prob[LRS]	Percentage	13	0	0	0	0	0
	Mean (SD)	1.00 (NA)	0.00 (NA)	0.00 (NA)	0.00 (NA)	0.00 (NA)	0.00 (NA)
	Total CPUE	0.13	0.00	0.00	0.00	0.00	0.00
Shortnose suckers	Percentage	11	0	2	0	0	0
	Mean (SD)	1.27 (0.46)	0.00 (NA)	1.00 (NA)	0.00 (NA)	0.00 (NA)	0.00 (NA)
	Total CPUE	0.15	0.00	0.02	0.00	0.00	0.00
Total suckers	Percentage	30	1	2	0	0	0
	Mean (SD)	1.14 (0.35)	1.00 (NA)	1.00 (NA)	0.00 (NA)	0.00 (NA)	0.00 (NA)
	Total CPUE	0.34	0.01	0.02	0.00	0.00	0.00

Table 7. Catch statistics for the 2018 cohort of suckers from Upper Klamath Lake, Oregon.

[Percentage of nets to successfully capture one or more sucker in each taxa, mean and standard deviation (SD) catch per net (catch per unit effort, or CPUE) in nets that successfully captured one or more sucker, and total suckers captured in all nets set (Total CPUE) are given for each seasonal sampling period. Total CPUE was calculated as the number of fish captured per net set. (NA) is used instead of standard deviations that are not applicable due to low sample sizes. Intermediate prob[LRS] refers to suckers having a probability of being Lost River suckers intermediate between the values of 0.95 and 0.05]

		July 25–August 3, 2018	August 6–24, 2018	September 9–14, 2018
Number of nets		87	88	88
Lost River suckers	Percentage	3	6	0
	Mean (SD)	1.33 (0.57)	1.60 (0.89)	0.00 (NA)
	Total CPUE	0.05	0.09	0.00
Intermediate prob[LRS]	Percentage	3	3	8
	Mean (SD)	1.00 (NA)	1.33 (0.58)	1.25 (0.50)
	Total CPUE	0.03	0.05	0.06
Shortnose suckers	Percentage	1	2	5
	Mean (SD)	1.00 (NA)	1.00 (NA)	1.00 (NA)
	Total CPUE	0.01	0.02	0.08
Total suckers	Percentage	8	11	15
	Mean (SD)	1.14 (0.37)	1.40 (0.70)	1.07 (0.28)
	Total CPUE	0.09	0.16	0.16

Clear Lake Year-Class Strength and Survival

There were 214 suckers captured in Clear Lake during the 2018 juvenile monitoring sampling, 3 percent of which were age-0 (table 4, fig. 3). Age-0 fish from Clear Lake were larger than Upper Klamath Lake young-of-year (fig. 5). Indices of year-class strength among cohorts show 2016 as the largest cohort, followed by the 2017 and 2018 cohorts (table 8). Based on August age-0 catches, in 2015 we concluded that there was no 2015 sucker cohort in Clear Lake. However, the cohort was captured in following years, indicating that age-0 suckers in 2015 did not recruit to Clear Lake until after our sampling was complete that year.

Most suckers in Clear Lake were shortnose/Klamath largescale suckers (fig. 3), including all 7 of the age-0 suckers (fig. 4). Only 7 Lost River suckers were captured in Clear Lake, of which 4 individuals were from the 2017 cohort and 3 were from the 2016 cohort. All age-0 suckers captured during the 2018 season were identified as shortnose/Klamath largescale suckers.

Tracking Clear Lake cohorts among years indicated that survival was better in Upper Klamath Lake than in Clear Lake. In Clear Lake, there was an age-4 shortnose/Klamath largescale sucker captured from the 2014 cohort (fig. 3). The 2015 cohort was represented by 14 shortnose/Klamath largescale suckers and one sucker with no species identification (fig. 3). The 2016 cohort continued to be captured through September of 2018. The August CPUE did not decrease from 2016 to 2018 for the 2016 cohort (table 9).

Table 8. Catch statistics August age-0 suckers from Clear Lake Reservoir, California, 2015–18.

[n is the number of suckers. Total catch per unit effort or CPUE was calculated as number of suckers captured divided by the number of nets set. Intermediate prob[LRS] refers to suckers having a probability of being Lost River suckers intermediate between the values of 0.95 and 0.05]

		August 2015	August 2016	August 2017	August 2018
Number of nets		70	70	70	70
Lost River suckers	n	0	2	4	0
	Total CPUE	0.00	0.03	0.06	0.00
Intermediate prob[LRS]	n	0	1	0	0
	Total CPUE	0.00	0.01	0.00	0.00
Shortnose/Klamath Largescale suckers	n	0	21	3	3
	Total CPUE	0.00	0.30	0.04	0.10
Total suckers	n	0	24	7	3
	Total CPUE	0.00	0.34	0.10	0.04

Table 9. Catch statistics for the 2016–18 cohorts of shortnose/Klamath largescale suckers from Clear Lake Reservoir, California.

[Percentage of nets to successfully capture one or more shortnose/Klamath largescale sucker in each taxa, mean and standard deviation (SD) catch per net (catch per unit effort, or CPUE) in nets that successfully captured one or more sucker, and total suckers captured in all nets set (Total CPUE) are given for each seasonal sampling period. CPUE was calculated as the number of fish per net set. Total CPUE was calculated as number of suckers captured divided by the number of nets set. (NA) is put in place of standard deviations that are not applicable due to low sample sizes]

Sampling period		August 1–5, 2016	September 12–16, 2016	June 5–9, 2017	August 14–18, 2017	September 18–22, 2017	June 5–9. 2018	July 15–20, 2018	August 7–11, 2018	September 17–24, 2018
Number of nets		70	70	70	70	70	70	70	70	70
2016 cohort	Percentage	16	54	4	37	19	19	31	20	13
	Mean (SD)	1.91 (1.45)	3.05 (4.92)	1.00 (NA)	1.76 (1.21)	1.69 (1.11)	1.31 (0.75)	1.23 (0.43)	1.50 (0.76)	1.22 (0.44)
	Total CPUE	0.30	1.66	0.04	0.66	0.20	0.24	0.39	0.30	0.16
2017 cohort	Percentage				4	6	13	33	27	16
	Mean (SD)				1.00 (NA)	1.00 (NA)	1.33 (0.50)	1.22 (0.52)	1.05 (0.22)	1.36 (0.67)
	Total CPUE				0.04	0.06	0.17	0.40	0.29	0.21
2018 cohort	Percentage						3	1	4	0
	Mean (SD)						1.00 (NA)	2.00 (NA)	1.00 (NA)	0.00 (NA)
	Total CPUE						0.03	0.03	0.04	0.00

Length and Apparent Growth of Clear Lake Shortnose/Klamath Largescale Suckers

Standard length of the 2016 cohort of shortnose/Klamath largescale suckers increased most rapidly from August 2016 to August 2017 (fig. 6). Apparent growth seemed less rapid from August 2017 to September 2018 than during the previous time periods. The presence of a few smaller individuals in the 2016 cohort, captured from July to September of 2018, may have resulted in smaller average lengths.

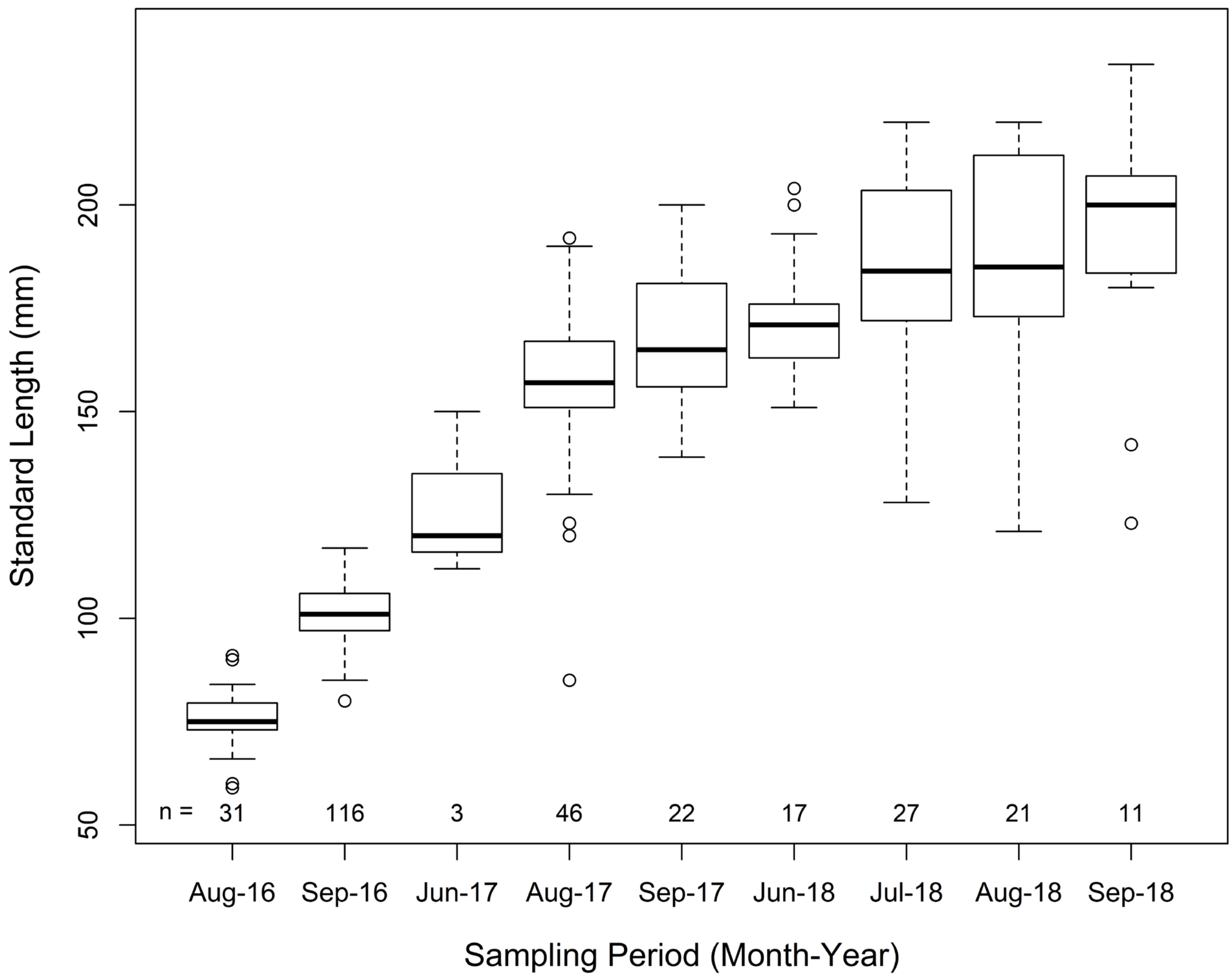

Figure 6. Standard length boxplot of the 2016 cohort of shortnose/Klamath largescale suckers from Clear Lake Reservoir, California. Sample sizes (n) are given at the bottom of the boxplot. Black lines within boxes represent the median of data, boxes represent the 1st and 3rd quartiles, and whiskers represent minimums and maximums determined by (quartile ±1.5 × interquartile range). Circles represent outliers determined by points outside the whisker range. mm, millimeter.

Afflictions

The two primary afflictions observed during the 2018 monitoring season were attached *Lernaea* sp. and petechial hemorrhaging. Other afflictions observed were one lamprey wound on an age-2 shortnose/Klamath largescale sucker in Clear Lake and four observations of missing or blind eyes, two of which with missing eyes were age-2 Lost River suckers. We did not observe any fish with black spot (metacercariae of *Bolbophorus* spp.) or deformed opercula from either lake in 2018.

Lernaea sp. were the most common parasite seen on age-0 suckers in 2018, with all observations from Upper Klamath Lake (table 10). The most *Lernaea* sp. attached to an individual juvenile sucker was seven but most often only one *Lernaea* sp. was attached. *Lernaea* sp. were observed on age-1 and older fish from both lakes but occurred on a higher proportion of Upper Klamath Lake fish (table 11). Although this parasite was a relatively common occurrence in Upper Klamath Lake, there were no obvious signs that *Lernaea* sp. cause mortality of juvenile suckers.

Petechial hemorrhaging on age-0 fish was only observed on Upper Klamath Lake suckers (table 12). The proportion of age-0 suckers with petechial hemorrhaging in 2018 was lower relative to previous years (table 12). The 2018 monitoring on Clear Lake was the first observation of petechial hemorrhaging on age-1 and older fish in the past 3 years (table 13). Although petechial hemorrhaging was observed on Clear Lake suckers in 2018, it was still a relatively rare affliction not commonly observed in Clear Lake.

Table 10. Proportions of age-0 suckers with attached *Lernaea* sp., Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2015–18.

[Sample size of age-0 suckers captured is given in parentheses. **Abbreviations:** CL, Clear Lake Reservoir; UKL, Upper Klamath Lake. (NA) represents proportions that are not applicable due to no age-0 fish caught. Intermediate prob[LRS] refers to suckers having a probability of being Lost River suckers intermediate between the values of 0.95 and 0.05]

Taxonomic group	UKL 2015	CL 2015	UKL 2016	CL 2016	UKL 2017	CL 2017	UKL 2018	CL 2018
Lost River sucker	0.79 (24)	NA	0.47 (136)	0.10 (10)	0.13 (8)	0.25 (4)	0.25 (12)	0.00 (0)
Intermediate prob[LRS]	0.56 (18)	NA	0.33 (67)	0.00 (2)	0.33 (12)	0.00 (1)	0.08 (12)	0.00 (0)
Shortnose sucker	0.25 (28)	NA	0.22 (45)	0.04 (137)	0.21 (14)	0.13 (8)	0.00 (10)	0.00 (7)
Total	0.51 (70)	NA	0.38 (258)	0.04 (186)	0.26 (34)	0.16 (13)	0.11 (36)	0.00 (7)

Table 11. Proportions of age-1 and older suckers with attached *Lernaea* sp., Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2015–18.

[Number of age-1 and older suckers given in parentheses]

Lake	2015	2016	2017	2018
Upper Klamath Lake	0.29 (14)	0.40 (15)	0.14 (14)	0.50 (2)
Clear Lake	0.17 (24)	0.06 (65)	0.05 (131)	0.04 (196)

Table 12. Proportions of age-0 suckers in each of the three taxa that had petechial hemorrhages on the skin in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2015–18.

[Sample size of age-0 suckers captured is given in parentheses. Intermediate prob[LRS] refers to suckers having a probability of being Lost River suckers intermediate between the values of 0.95 and 0.05. **Abbreviations:** CL, Clear Lake Reservoir; UKL, Upper Klamath Lake. (NA) represents proportions that are not applicable due to no age-0 fish caught]

Taxonomic group	UKL 2015	CL 2015	UKL 2016	CL 2016	UKL 2017	CL 2017	UKL 2018	CL 2018
Lost River sucker	0.38 (24)	NA	0.23 (136)	0.00 (10)	0.00 (8)	0.00 (4)	0.25 (12)	0.00 (0)
Intermediate prob[LRS]	0.06 (18)	NA	0.16 (67)	0.00 (2)	0.08 (12)	0.00 (1)	0.00 (12)	0.00 (0)
Shortnose sucker	0.11 (28)	NA	0.13 (45)	0.01 (137)	0.14 (14)	0.00 (8)	0.00 (10)	0.00 (7)
Total	0.19 (70)	NA	0.19 (258)	0.01 (186)	0.09 (34)	0.00 (13)	0.08 (36)	0.00 (7)

Table 13. Proportions of age-1 and older suckers with petechial hemorrhages of the skin in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2015–18.

[Number of age-1 and older suckers is given in parentheses]

Lake	2015	2016	2017	2018
Upper Klamath Lake	0.07 (14)	0.07 (15)	0.07 (14)	0.25 (4)
Clear Lake	0.00 (24)	0.00 (65)	0.00 (131)	0.04 (196)

Discussion

Upper Klamath Lake

The lack of substantial recruitment to the spawning population continues to be the limiting factor for the recovery of shortnose and Lost River suckers in Upper Klamath Lake. Since the early 2000s, the abundance of both species has decreased by more than 40 percent (Hewitt and others, 2018). Nearly all the adult suckers in Upper Klamath Lake are older than the average life span expected for each species and shortnose suckers are approaching the maximum known age for their species (Hewitt and others, 2018). As the adult sucker populations diminish, we continue to catch small numbers of juvenile suckers during our monitoring efforts. Without the balance of recruitment by new individuals to the spawning population, Lost River and shortnose suckers will continue on their downward trend until extirpated from Upper Klamath Lake.

The addition of a July sampling period provided better within-season resolution in catch rate patterns but failed to allow for a more refined estimate of within-season survival. This could be attributed to overall small catches or small cohort size during the 2018 monitoring season. July sampling may allow for better within-year survival estimates in future years, if higher abundances occur.

The scarcity of age-1 and older suckers in Upper Klamath Lake likely is attributable to juvenile mortality. The presumption that mortality rather than reduced selectivity or emigration from sampled areas explains the reduction in catch by age and is corroborated by several other observations. Most of our catch in Clear Lake were age-1 and older suckers, indicating that older, larger fish are vulnerable to our trap nets. A substantial lack of recruitment to the adult populations indicates that juvenile suckers have unsustainably low survival rates (Hewitt and others, 2018).

The first official release of approximately 2,400 SARP-reared suckers was in 2018 and was much lower than the target goal of 3,500 suckers (Childress and others, 2019). We did not detect any individuals from SARP during our monitoring efforts with trap nets based on our scanning of all captures for a PIT tag. Given the large size of Upper Klamath Lake and small number of released fish, the probability of detecting a PIT-tagged sucker was small; even when ignoring mortality post release.

Although it is typical for survival rates to be low in the early life stages of fish (Houde, 1989), near-complete disappearance of entire cohorts within the first 2 years is alarming. High fecundity may be a life-history strategy to overcome high mortality for suckers in the Klamath Basin, but near-complete mortality is unsustainable (Rasmussen and Childress, 2018). Given that the adult population of Lost River and shortnose suckers has decreased by more than 50 percent since the early 2000s (Hewitt and others, 2018), a significant recruitment event must occur soon for both species to recover naturally.

Clear Lake

Clear Lake continues to have much higher juvenile survival relative to Upper Klamath Lake. With higher survival, recruitment of new spawners has been documented for Clear Lake populations (Hewitt and Hayes, 2013); however, cohort success is intermittent. Although cohort success is better in Clear Lake relative to Upper Klamath Lake, the mechanisms behind this success are not completely clear.

Strong cohort formation in Clear Lake may be associated with better water years when access to spawning habitat occurs (Burdick and others, 2018). Clear Lake surface area and water levels can fluctuate greatly between wet and dry years (figs. 7 and 8). During low-water periods (water levels less than 1,378.9 m [4,524 ft] elevation or lower), any adults in the lake basin are expected to be unable to spawn because of lack of access to Willow Creek (D. Hewitt, U.S. Geological Survey, oral commun., 2019). However, once water levels rose again, cohorts from years when Willow Creek was separated from the rest of the lake were detected (for example, the 2015 cohort). Burdick and others (2018) reported an apparent correlation between cohort strength and access to Willow Creek during the spawning season.

The first appearance of the 2015 juvenile cohort in Clear Lake during the 2016 sampling season challenges the Burdick and others (2018) presumption that high springtime lake elevations are required to form strong year-classes in Clear Lake (Bart and others, 2020). The 2015 cohort was captured in Clear Lake in 2017 and 2018, confirming its presence. Given our rigorous aging methods, substantial numbers of suckers in these age classes and repeated detection of the 2015 cohort in three consecutive years, aging error is an unlikely explanation for the apparent presence of the 2015 cohort. Because lake-dwelling suckers did not have access to Willow Creek in 2015 (fig. 8), this cohort likely was produced by adult stream resident fish. High flow events in 2016 and 2017 may have pushed suckers downstream from Willow Creek to Clear Lake, explaining the detection of the 2015 cohort during 2016–18. Nearly all of the 2015 cohort in Clear Lake were identified as shortnose suckers or Klamath largescale suckers based on 18 genetic SNPs indicating an equal likelihood to be either species (Hoy and Ostberg, 2015). These fish could have been either shortnose or Klamath largescale suckers, but less lake-dependent life history is more consistent with Klamath largescale suckers.

Catches of juvenile Lost River suckers in Clear Lake continued to be very low in 2018. Only 7 of 207 suckers captured in Clear Lake in 2018 were identified as Lost River suckers. Lost River suckers have constituted only a small part of juvenile sucker catches in Clear Lake since monitoring began in 2015 (Burdick and others, 2016, 2018; Bart and others, 2020). Lost River suckers also make up small portions of adult sucker catches in Clear Lake, which likely explains the low abundance of juvenile Lost River suckers (Hewitt and Hayes, 2013).

There are several possible explanations for why growth seemed reduced for shortnose/Klamath largescale suckers during summer 2018. The median length of adult shortnose/Klamath largescale suckers captured in Clear Lake is more than 350 mm SL (Hewitt and Hayes, 2013). Therefore, a length asymptote of around 200 mm SL is an unlikely explanation for the apparent reduction in growth. Catostomids, similar to Klamath largescale suckers, have highly variable growth rates depending on environmental conditions (Beamish, 1973), which may have contributed to the range of sizes of the 2016 cohort in 2018. For example, new smaller suckers from the 2016 cohort may have joined the lake populations from Willow Creek between our June and July 2018 sampling periods. Small sample sizes each month also may have limited our ability to detect growth.

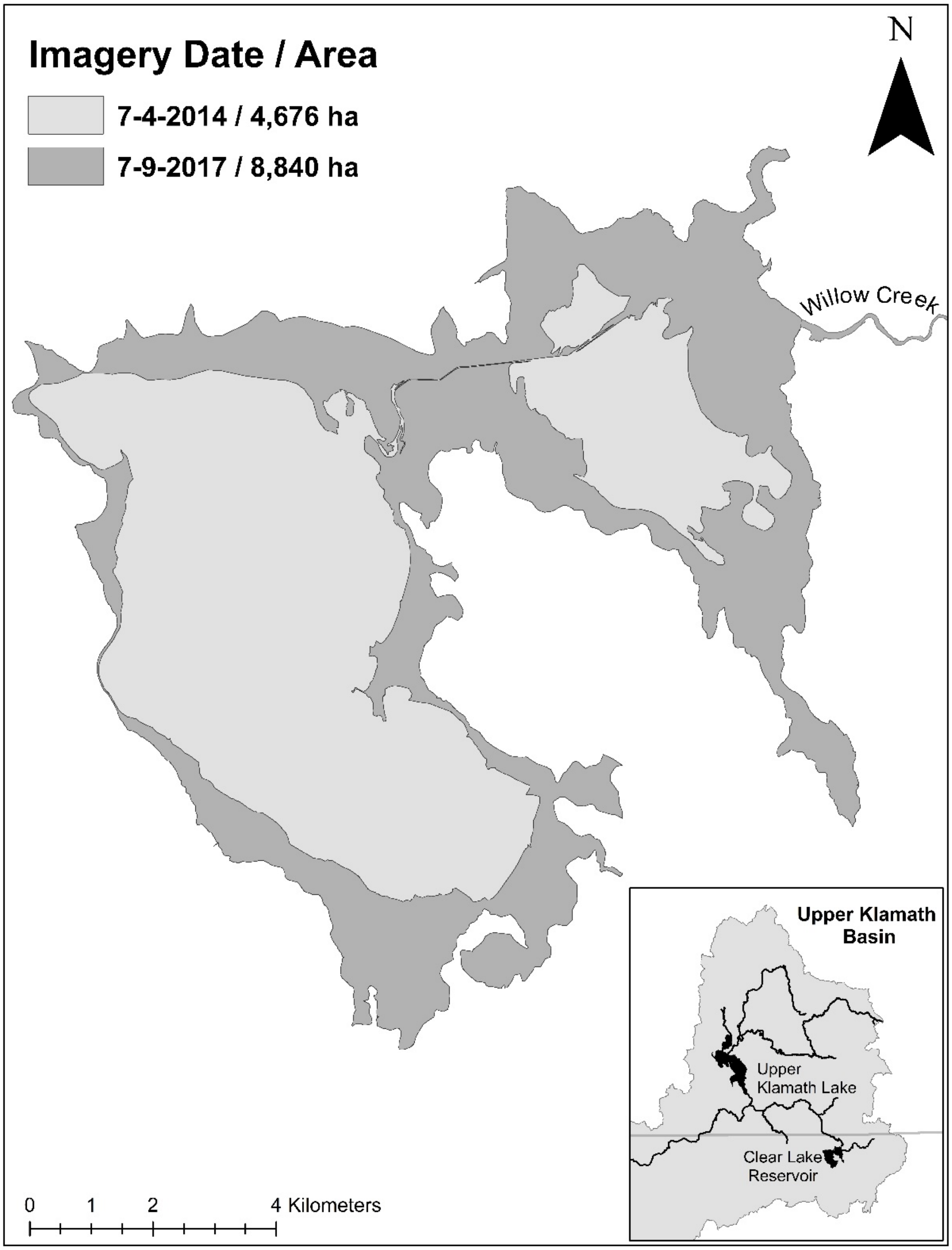

Figure 7. Images showing surface area of Clear Lake Reservoir. Modoc County, California, during low water (July 4, 2014) and high water (July 9, 2017) and location (inset). ha, hectares.

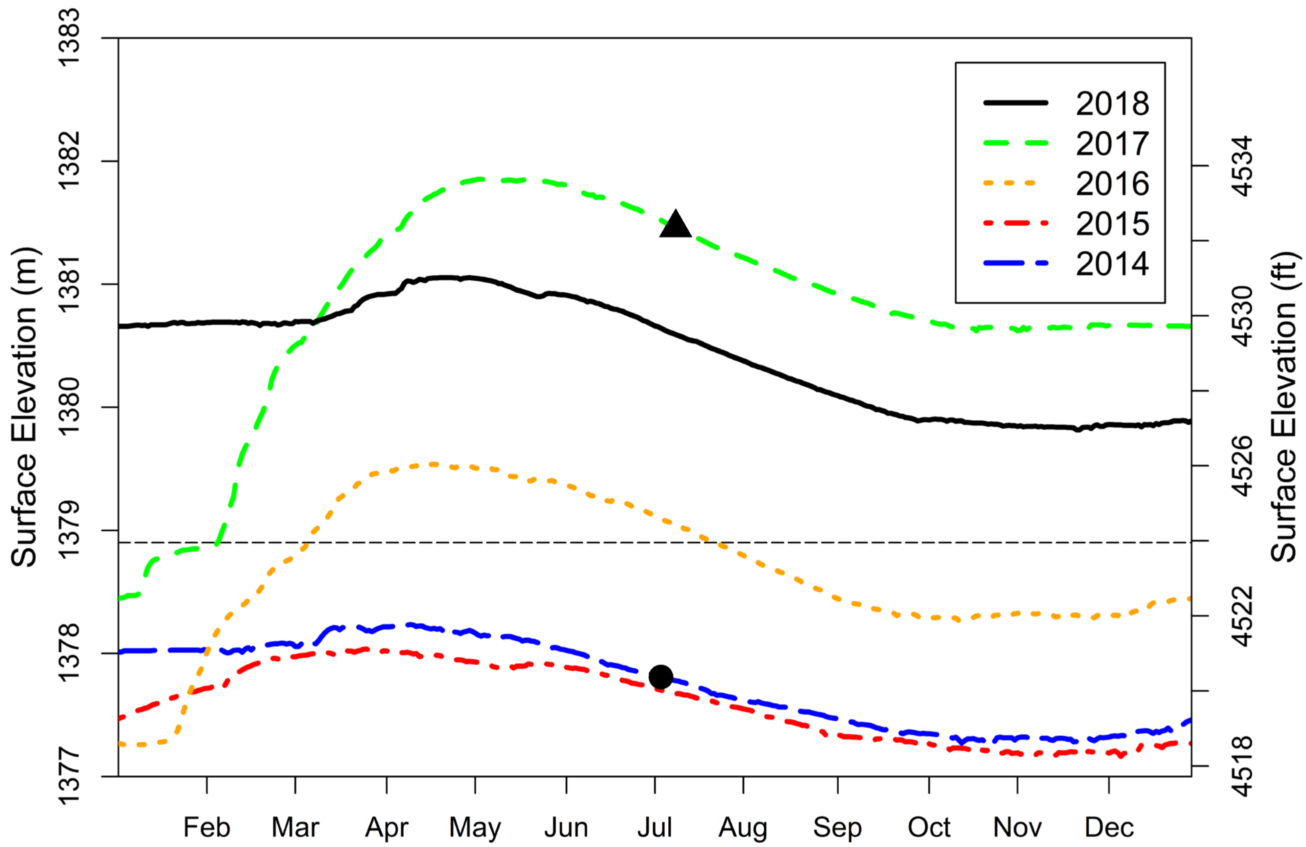

Figure 8. Graph showing lake surface elevations, Clear Lake Reservoir, California, 2015–18. Black horizontal dashed line represents the approximate elevation. Willow Creek is not accessible to spawning adult suckers migrating from Clear Lake (D. Hewitt, U.S. Geological Survey, oral commun., May 2019). Circle is the low-water elevation and triangle is the high-water elevation presented in figure 7. Surface elevations are in feet (ft) and meters (m) above Bureau of Reclamation Vertical Datum.

Afflictions

Lernaea sp. parasitism was the most common affliction of juvenile suckers captured in Upper Klamath Lake. Although this parasite was not observed on age-0 suckers from Clear Lake in 2018, it was reported in Clear Lake during 2015–17. Wounds that form at *Lernaea* sp. attachment sites may provide a pathway for bacterial infection (Berry and others, 1991). Inflammation associated with *Lernaea* sp. attached to juvenile suckers from Upper Klamath Lake most often is limited to a focal area in the skin and skeletal muscle directly surrounding the attachment site, indicating that this parasite is unlikely to cause systemic infections that result in mortality (Burdick, Elliott, and others, 2015). The mechanisms behind the prevalence of *Lernaea* sp. in Upper Klamath Lake compared to Clear Lake are not completely understood. The entire life cycle of *Lernaea* sp. takes 18–25 days at approximately 25–30 °C, which is warmer than the average mid-water column summer water temperatures in Upper Klamath and Clear Lakes (Steckler and Yanong, 2012).

The causes of petechial hemorrhaging, which was almost exclusively found on suckers from Upper Klamath Lake, is unknown. Petechial hemorrhages of the skin have been found to be caused by irritants including abrasion, bacteria, or toxins (Ferguson and others, 2011). Petechial hemorrhages of the skin are a common observation in Upper Klamath Lake and have been documented since monitoring for them began in 2014 (Burdick, Elliott, and others, 2015). The very low prevalence of observed hemorrhages in Clear Lake relative to Upper Klamath Lake indicates that abrasions due to our method of capture are unlikely to be the primary cause of the hemorrhaging. Burdick and others (2018) examined the hemorrhages microscopically and did not observe associated bacterial disease or other parasites. Janik and others (2018) observed petechial hemorrhaging on collected fish from Upper Klamath Lake canals; however, they could not observe it through histology, which made the infection likely confined to the skin.

Lamprey wounds were not observed on age-0 suckers and only one observation was observed on an age-2 fish from Clear Lake. Older suckers potentially are more vulnerable to lamprey because larger suckers have more surface area on which lamprey can attach themselves. All lamprey species found in the Upper Klamath Basin are native (Kostow, 2002), and some are endemic. Given that lamprey have coevolved with suckers in the Upper Klamath Basin, they are unlikely to be the primary cause of annual juvenile sucker year-class failure.

Black spot was hypothesized to be associated with high mortality of juvenile suckers (Markle and others, 2014). In previous years of monitoring, black spot was recorded on a small proportion of fish (Bart and others, 2020) and, during the 2018 monitoring season, no suckers had black spot. In years when black spot was observed, it was more prevalent in Upper Klamath Lake than in Clear Lake (Burdick and others, 2016, 2018; Bart and others, 2020).

Conclusions

We did not detect signs of upcoming recruitment into adult Lost River (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*) populations in Upper Klamath Lake, Oregon. Age-0 suckers of both species continue to be detected in small numbers annually in Upper Klamath Lake, and first-year mortality continues to be high. Most adult suckers in Upper Klamath Lake were hatched in the early 1990s and are approximately 29 years old. There is still time for recruitment to occur for Lost River suckers that have a maximum estimated life span of 57 years and mature in about 7–10 years. Extirpation from Upper Klamath Lake is becoming increasingly likely for shortnose suckers that have a maximum estimated life span of 33 years and mature in 3–5 years of age. We did not capture juvenile PIT-tagged suckers reared and released by U.S. Fish and Wildlife Service to offset natural juvenile mortality and are unable to predict if this action would be effective.

Clear Lake Reservoir (California; hereinafter Clear Lake) shortnose suckers may have life-history traits similar to the non-endangered Klamath largescale sucker (*Catostomus snyderi)* or may in fact be Klamath largescale suckers. The continued detection of the 2015 Clear Lake cohort provides evidence for Willow Creek resident populations of suckers. The stream resident attributes are more associated with Klamath largescale suckers. Although Clear Lake suckers tend to have better survival than Upper Klamath Lake suckers, the lack of juveniles identified as Lost River suckers is concerning.

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